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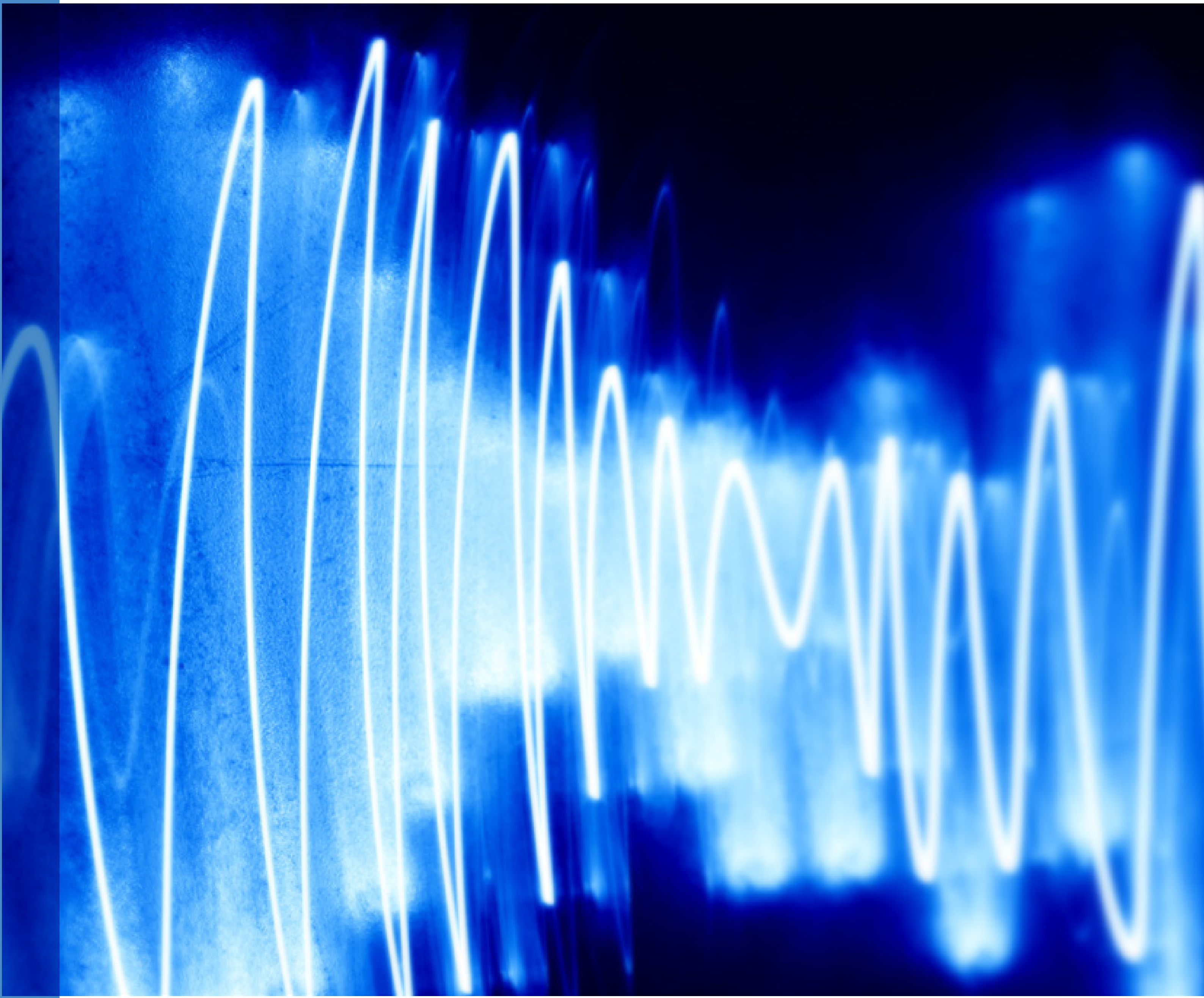

Handbook on National Spectrum Management

Edition of 2015

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FOREWORD

This new revision of the Handbook on National Spectrum Management involved a major update and expansion of the 2005 edition. It was developed by a Correspondence Group established by Working Party 1B in 2011 and then by a Rapporteur Group established by Working Party 1B in 2012 and endorsed by Radiocommunication Study Group 1. Mr Hasan Sharif of the United Arab Emirates served as Rapporteur of the group, assisted by the Counsellor, Mr Philippe Aubineau Mr Ruoting Chang, the Working Party 1B Vice-Chairman from China (People's Republic of), Mr Ilkyoo Lee of Korea (Republic of), Mr Roy Woolsey of the United States of America as well as many other participants at the Working Party 1B meetings were also very active in the preparation of this revision of the Handbook.

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TABLE OF CONTENTS

Page

CHAPTER 1

Spectrum management fundamentals

Table of Contents

Page

1.1 Introduction

Society's increasing use of radio-based technologies, and the tremendous opportunities for social development that these technologies provide, highlight the importance of radio-frequency spectrum and national spectrum management processes. Technological progress has continually opened doors to a variety of new spectrum applications that have spurred greater interest in, and demand for, the limited spectrum resource. Increased demand requires that spectrum be used efficiently and that effective spectrum management processes be implemented. In this framework, modern data handling capabilities and engineering analysis are important to accommodate the variety of potential users seeking access to the spectrum.

Radiocommunications is heavily used in a growing number of services[1] such as national defence, public safety, broadcasting, business and industrial communications, aeronautical and maritime radiocommunications, navigation, and personal communications. Radiocommunication links, as opposed to wireless telecommunications, are necessary in a dynamic or mobile environment, where wireline telecommunication may not be available, or where telecommunications have been disrupted, such as in emergency or natural disaster situations. Radiocommunication systems may operate from satellites or from terrestrial platforms.

If the spectrum is to be used efficiently, its use must be coordinated and regulated through both national regulations and the Radio Regulations of the International Telecommunication Union (ITU). The ability of each country to take full advantage of the spectrum resource depends heavily on spectrum management activities that facilitate the implementation of radio systems and ensure minimum interference. To this end, administrations should, as appropriate, make use of computerized spectrum management systems.

Though the effectiveness of a spectrum management system cannot easily be defined, it is, in general, related to how well the system meets the national needs and how well it is able to safeguard the interests of the public in the accommodation of radio users. National spectrum management consists of the structures, procedures, and regulations whereby an administration controls the use of the radio spectrum within its geographical boundaries. By international agreement, each government has flexibility and autonomy in regulating its use of radio spectrum. Each administration must develop its laws and organization to carry out the duties of spectrum management. Effective management of the spectrum resource encompasses major directives that establish the responsibility of the national authority. This authority regulates the spectrum use as well as all related processes. Although no two administrations would manage the spectrum in exactly the same manner, the basic processes are essential to all national approaches.

1.2 Goals and objectives

For a spectrum management system to be successful, goals and objectives should be defined. The goals, usually set forth in national legislation, should include:

– making the radio spectrum available for government and non-government uses to stimulate social and economic progress; and

– making efficient and effective use of the spectrum.

National spectrum management is closely associated with national law, policy statements, radio regulations and a long-term spectrum plan[2]. National spectrum management must ensure that adequate spectrum is provided over the short term and the long term for public service organizations to fulfil their missions, for public correspondence, for private business telecommunications, and for broadcasting. Many administrations also place high priorities on spectrum usage for research, scientific uses and amateur radio activities.

The national objectives related to the spectrum may include the following:

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[1] The word "service" in this Handbook will cover the radio services described in the radio regulation and any other radio application.

[2] See Report ITU-R SM.2015 – Methods for determining national long-term strategies for spectrum utilization.

– to make available efficient nationwide and worldwide telecommunications services for personal and business use;

– to foster innovation in the development of infrastructures and provision of radiocommunication services;

– to serve national interests, including security and defence;

– to safeguard life and property;

– to support crime prevention and law enforcement;

– to support national and international systems for transportation;

– to foster conservation of natural resources;

– to provide for dissemination of educational, general, and public interest information and entertainment;

– to promote scientific research, resource development, and exploration;

– to promote the dissemination of the cultural heritage and protection of the national and regional folklore; and

– to promote the reduction of the digital divide.

In order to meet these objectives, the spectrum management system must provide an orderly method for allocating and assigning frequency bands, authorizing and recording frequency assignments and establishing regulations and standards. A policy statement or regulation can specify technical factors, establish licensing criteria, and set priorities that will be used to determine who will be authorized to access a frequency band, and for what purpose it will be used. While policy statements also can be a link between the government agenda and spectrum managers, stability of radiocommunication policies is essential for investments. The government may delegate to the spectrum management organization the authority to establish spectrum policy and regulations. The government may alternately choose to have that organization be led by political appointees, delegating to the spectrum manager only the authority to develop means of implementation and to carry out decisions.

Furthermore, a national long-range spectrum plan should provide projection for future spectrum use based on the analysis of long-range national requirements, evolution of technology and spectrum management capabilities. A national allocation table is a key element of such a plan, providing a framework for users to set their own goals[3]. The plan should also specify the steps that the spectrum management organization should take to accommodate future requirements. The plan could also make recommendations for spectrum policy changes in the public interest[4].

1.3 International spectrum aspects

International coordination and notification of radio stations to the ITU is intended to develop radio regulations and associated procedures, and to encourage multilateral coordination to ensure efficient use of spectrum resources on an interference-free basis. Each administration is a constituent part of this inter-governmental organization and plays an important role in these processes (see also Report ITU-R SM.2093). A description of ITU structure and activities is given in Annex 1 to this Chapter.

1.4 Major national spectrum management directives/laws

To conduct spectrum management activities in such a way that encourages efficient use of spectrum resources, major directives and laws should be formulated and made available to the public. The intent of these directives and laws is to establish a legal basis for managing spectrum use and to provide relevant national policy together with specific regulations.

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[3] See Recommendation ITU-R SM.1265 – National alternative allocation methods.

[4] See Recommendation ITU-R SM.1047 – National spectrum management.

1.4.1 Radiocommunication law

Due to the rapid advance of radio technology and the central role that telecommunications plays in a country's economic development, the laws covering the spectrum resource are as important as those that govern land and water use in the country. While the operational environment and requirements for management are different, the radio provisions in the basic law should be clearly delineated. Where radiocommunication use is not yet extensive, the governments must anticipate the increase of radio use and ensure that an adequate legal structure is in place.

It is recommended that the radiocommunication law be a basic document that gives recognition to the radio spectrum as a national resource and the need to govern it in the interest of all citizens. It should therefore establish the right of the government to regulate the use of spectrum, including the enforcement of spectrum management rules. Further, it should establish the right of citizens and governmental bodies to operate radiocommunication equipment. The quality and availability of radiocommunication services may be closely linked to the kind of activity and the level of flexibility granted to the operators. Competition in operating the given radiocommunication services may bring those services to the users at a reduced cost.

Other elements that may be covered within the national radiocommunication law are the requirements for public access to the spectrum management decision process and government responsiveness to public input. The right to access, and any limits to that access, should be established in the law. Therefore, the radiocommunication law may require that the spectrum management authority provide the public with information on its decisions. The law may also provide a process for review of decisions in accordance with established criteria and procedures. This process should be kept as simple as possible.

1.4.2 National frequency allocation table

A national table of frequency allocations provides a basis for an effective spectrum management process.

The International Table of Frequency Allocations (Article **5** of the Radio Regulations (RR)) is agreed by the ITU at world radio conferences for all three ITU Regions. This table should be the basis for a national table. However, the ITU table (covering all three Regions) usually provide for a number of different services in a frequency band. Therefore, an administration may wish to adopt its own national table to facilitate spectrum use within its borders. For example, some countries divide their national table into bands allocated to the government and those allocated to private users. Very often countries incorporate information about present and strategic use of radio applications in allocated frequency bands and conditions of their use into the national table, other ones include such information in separate regulations.

Whatever the national approach, an administration should take into consideration how bands are used in other countries not only for compatibility with neighbouring countries, but also to ensure that equipment for a particular service can be made economically available.

1.4.3 Regulations and procedures

The regulations and procedures promulgated and adopted by the national spectrum management authority should include steps for legal appeal of some decisions (to adopt or amend the regulations and procedures) and should cover areas such as conditions of radio applications use, procedures for obtaining and renewing a licence, technical standards, equipment authorization procedures, channelling plans, and operational requirements. Though these regulations and procedures can be written for each radio-communication service separately, it is more efficient to bring all applicable regulations together in one publication. Annex 2 to this Chapter describes an example outline of a national manual of regulations and procedures for spectrum management.

Each administration needs to evaluate the level of regulation that it believes is necessary to accomplish national goals, while providing protection in accordance with international agreements. A spectrum management organization should be guided by national policies, ensuring that its regulations conform to national objectives as set forth in domestic law and do not conflict with international regulations.

1.5 Organizational structure and processes

1.5.1 Structure and coordination

The national radiocommunication law should delegate the authority and responsibility to manage spectrum use to one or more government bodies. Though a single authority may be ideal, the realities and the level of resources available may dictate other approaches.

In most cases, an administration may favour the appointment of a single department, or agency to manage all radiocommunication use. This approach has the benefit of simplifying the decision-making process and establishing policies that impact all users. The decision authority optimizes its role by accommodating as many of user requirements as possible. A single authority may decrease a part of its workload and increase its effectiveness, if justified, by delegating authority to other groups.

Some administrations may grant management authority to two or more organizations. However, the greater the number of organizations given separate autonomous authority and responsibility, the more difficult the coordination, and the more segregated the allocation of frequencies may become. In some cases, various groups (such as ministries or departments) may not be able to reach agreement among themselves on the use of the spectrum and may require a higher level of authority to make a decision, such as a Prime Minister or a President.

Where more than one authority has been created, the relationship between them should be carefully specified in the regulations. One approach to this separation is dividing the frequency bands among the management authorities. Within the government or the private sector, coordination groups with limited management responsibility may be used to assist the relevant agencies. The group may be used to solve some spectrum issues and to prepare frequency allocations. A representative of the private sector spectrum management structure can be appointed to liaise with these committees to broaden their perspective. However, the coordination group cannot act as an overall spectrum management authority.

Regardless of where the authority and responsibility is placed, the designation and extent of the authority and responsibility should be published and available to the users and potential users of radiocommunication systems.

National telecommunication law may further stipulate who is representing the national interests in the framework of international activities (for example, the spectrum management authority may perform this role). If spectrum use within the country is managed by several authorities, national representation in international negotiations may become complicated. It is recommended therefore, that a single agency or ministry be given the overall authority for coordination of spectrum use and for managing the spectrum internationally.

1.5.2 Decision-making process

The processes developed to nationally allocate spectrum, assign frequencies to licensees, and monitor compliance with license terms are essential tools for implementing national goals and objectives.

Administrative bodies responsible for developing the rules and regulations should follow a predetermined decision-making process to ensure an orderly and timely spectrum management process.

If the national goals contemplate participation by private, non-government parties in the provision of radiocommunications services, then the decision-making processes must provide a certain degree of regulatory openness. This is particularly essential where private sector entities invest in and operate these services.

The independence of the spectrum management authority is crucial in making decisions in the national interest. When the spectrum management authority is limiting spectrum users to a consultative role, there will be less opportunity for biased decisions. However, the participation of users in the decision-making process can help to build confidence that is very important to effective implementation of national objectives.

1.6 Spectrum management functional responsibilities and requirements

The basic national spectrum management responsibilities and requirements (functions) are:

a) Spectrum management planning and regulations;

b) Spectrum management financing, including fees;

c) Allocation and allotment of frequency bands;

d) Frequency assignment and licensing (including non-licence allocations);

e) National liaison and consultation;

f) International and regional cooperation including frequency coordination and notification;

g) Standards[5], specifications, and equipment authorization;

h) Spectrum monitoring;

i) Spectrum enforcement;

j) Spectrum management support functions including;

- administrative and legal;
- computer automation;
- spectrum engineering;
- training.

The spectrum management agency (a self-sustained agency or a part of a national agency) may be structured in different ways according to the law, background, customs, and telecommunication resources of the country concerned. It should encompass all the functions listed above, some of which may be combined or further divided, depending on the size of the organization. The spectrum management organization should publish details about its organization and operational procedures, so that they may be effectively understood by spectrum users. Figure 1.1 outlines the overall national spectrum management system.

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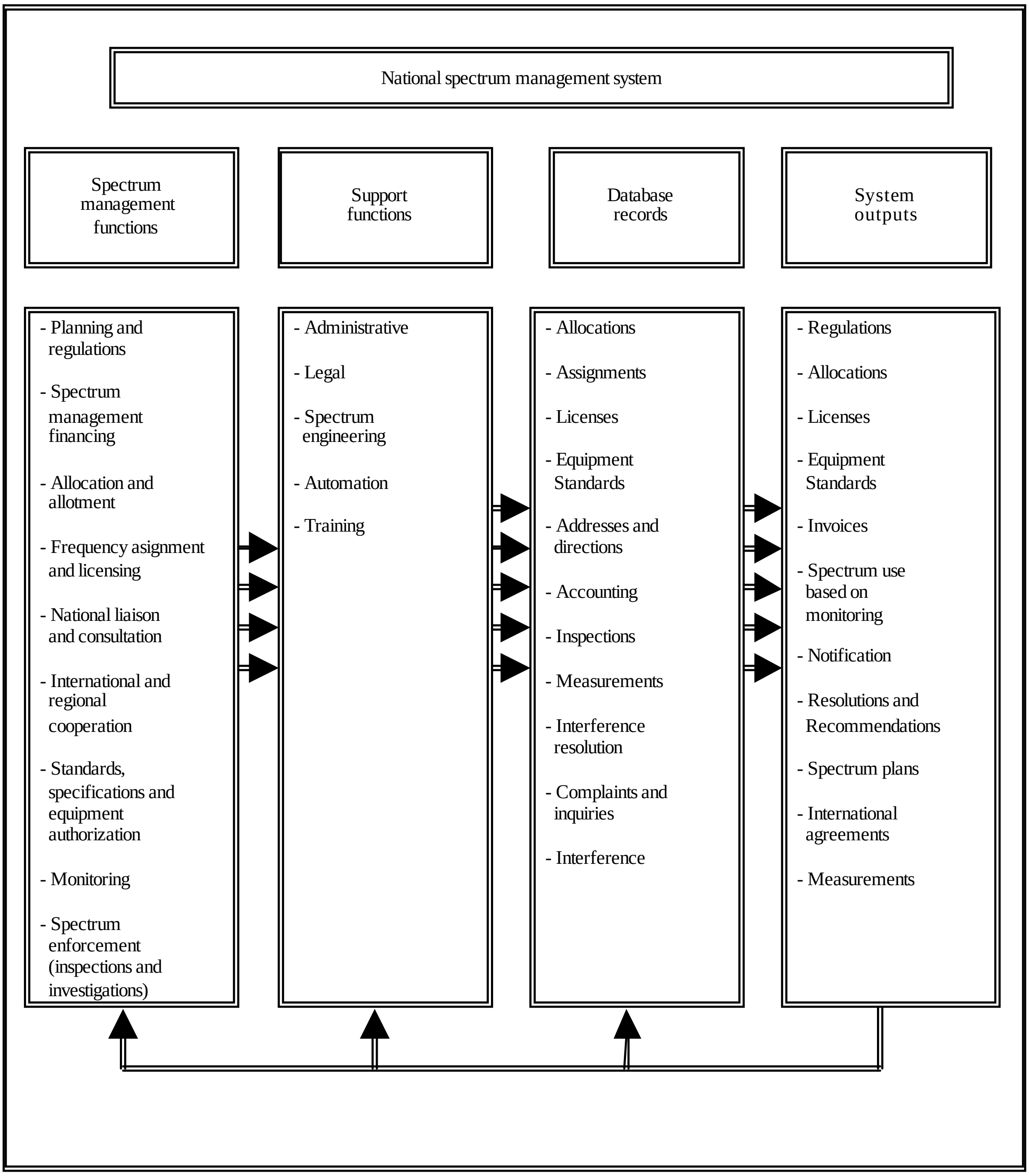
5 The use of the term “standard” refers to ITU-R Recommendations or any other recognized standard.

FIGURE 1.1

National spectrum management system based on functional responsibilities



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1.6.1 Spectrum management planning, regulation and policy making

The spectrum management organization should develop and implement plans, regulations and policies, taking into account advances in technology as well as social, economic and political realities.

The output of the planning and policy-making effort is the allocation of frequency bands to the various radio services, for specific uses. When there are competing interests for spectrum use, the spectrum management organization should determine the use or uses that would best serve the public and government interest, including how to share spectrum. The following factors should be considered when allocating the spectrum:

Public and government needs and benefit considerations

– Requirement of the service for radio frequencies;
– Probable number of people who will receive benefits from the service;
– Relative social and economic importance of the service, including safety of life, protection of property and disaster relief;
– Probability of establishment of the service and the degree of public support which is expected for the service;
– Impact of the new applications on existing investment in the proposed frequency band;
– Government requirements for security, aeronautical, maritime, and science services.

Redeployment as a tool for spectrum management

Technical considerations

– The need for the service to use particular portions of the spectrum with particular propagation characteristics and compatibility with other services within and outside the selected frequency band;
– Amount of spectrum required;
– Signal strength required for reliable service;
– Amount of radio and other electrical interference likely to be encountered;
– Viability of the technology (i.e. whether the technology is proven and available, is at the forefront of development, or is not yet fully developed).

Apparatus limitations

– Upper useful limit of the radio frequency spectrum and, in general, what higher limit can be expected in the future;
– Operating characteristics of transmitters, including practical limitations on output power, ability to stay on frequency and ability to suppress out-of-band and spurious emissions;
– Types of antennas available for service and their practical limitations (i.e. size, cost, and technical characteristics), including best methods of obtaining the most effective use of frequencies; and
– Receivers available and in the process of development, including data indicating their selectivity and practicality for the intended service.

Redeployment among different national organizations responsible for different services may increase the requirement for coordination, leading to an elaboration of detailed sharing conditions and criteria. If national frequency assignments are comprised of relatively small number, e.g. several tens-of-thousands, subdivision of spectrum allocation among the national organizations (e.g. civil and governmental) may have an advantage as opposed to co-band sharing.

1.6.2 Development of a national allocation table

The development of a national allocation table begins with knowledge of the current national frequency assignments and a national plan for future use. It has to be guided by the ITU Allocation Table for the Region to which the particular country belongs. Although a country does not have to follow exactly the ITU Table, it is important to do so for the following reasons:

– Equipment that is available in the Region is available for frequency bands that are in agreement with the allocation table;
– Interference problems with neighbouring countries would be minimized;
– Planning of frequency bands include technical considerations of the equipment in conformity with the Regional Table;
– Services, such as aeronautical, maritime, and certain satellite services require the use of a given band by all countries to provide telecommunications on a global scale.

It is possible for a country to deviate from the international allocations, to a limited degree, to satisfy national requirements. Such use is considered to be in accordance with No. **0.4** of the RR[6], if it does not cause harmful interference and if protection is not required.

As stated earlier, the national allocation table provides a detailed record of how the spectrum is currently being used, including all data on terrestrial and space services and their applications. Users of a given frequency band generally oppose changes to spectrum allocations because it would impact their current operations and because, depending on the type of service, customers for that service may be lost. Any change in the use of the bands is very expensive due to the cost of the new equipment, accommodating customers using the new equipment, developing procedures to maintain equipment and training staff to maintain the equipment in good condition. The user may, however, agree to change the use of given bands if the change is transparent and if others will pay for the cost of new (modern) equipment. Once a record of current use is available, a plan of how all services will be used in the future should be developed. National security services may require large amounts of spectrum that may not be in agreement with the ITU Table of allocation. Every effort should be made to ensure that there are solid justifications for the use of the spectrum and that the spectrum is actually used, and not merely retained for use at a future time.

Other principles to follow in developing a national table of allocation are:
– follow the ITU Table of allocation, as appropriate and as much as possible;
– develop a plan based on current spectrum uses up to the point where this plan impedes future spectrum development;
– allow government and security allocations that are efficient and align with other countries' allocations.

1.6.3 Frequency assignment and licensing

Assigning frequencies represents the central part of daily operations of the spectrum management organization. The frequency assignment unit performs the analysis required to select the most appropriate frequencies for radiocommunication systems and coordinates proposed assignments with existing assignments.

A frequency assignment function, combined with the licensing function, naturally applies national legislation, regulations and related procedures. It exercises control over the operation of stations by:
– examination of licence applications and related documents to determine the licensing eligibility of the applicant from a legal and regulatory point of view and the technical acceptability of the radio equipment proposed;
– assigning radio calls signs to individual stations;
– issuing licences and collecting fees, if appropriate;
– establishing methods for administering system or network licences, as appropriate;
– renewing, suspending, and cancelling licences, as appropriate;

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6 "**0.4** All stations, whatever their purpose, must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other Members or of recognized operating agencies, or of other duly authorized operating agencies which carry on a radio service, and which operate in accordance with provisions of these Regulations (No. 197 of the Constitution)."

– conducting examinations of operator competence and issuing operator certificates, as may be required.

The procedures should specify what information must be supplied in with frequency applications. Depending on the national objectives, this information may pertain to the intent of the spectrum use or merely technical characteristics that will enable the spectrum manager to better coordinate the activities of its constituents. Unnecessary or arduous procedures may discourage radiocommunication development. Some administrations have successfully implemented frequency coordination by a consultancy group.

When there is a potential for causing harmful interference outside the national borders, international coordination is necessary and ITU-R involvement may be required as part of the frequency assignment procedure.

Records of spectrum use requests and approvals should be retained for future reference. Some administrations have chosen to use monitoring as a means to identify unused frequencies. Though this method may conclude that a frequency is unused only because no activity is identified during a monitoring period, it may be the only method of frequency selection in the absence of records.

1.6.4 Relationship between spectrum fees and the spectrum management process

The radio spectrum is a natural resource available for human use, which is limited and easy to be interfered with. It is also a very valuable national asset that is typically controlled by the government. The challenges for the government are to achieve a balance among competing requirements and to develop policies that fulfil the intent of those requirements. Spectrum fees charged for various radio services can be a critical part of the spectrum management process.

The primary objective of the spectrum management fee policy should be to:

– improve the telecommunication infrastructure in the country through the efficient and effective use of the radio spectrum;
– administrative fees that support the spectrum management infrastructure;
– equitable assessment of administrative fees for all users of the radio spectrum and in a manner that encourages spectrum efficiency by providing appropriate incentive;
– assessment of fees according to the amount of spectrum space used for most services, which should include consideration of the number of transmitters in a network;
– economic principles following the relevant ITU-R Recommendations and Reports;
– radio standards equal to, or preferably better than that required in the RR and ITU-R Recommendations;
– relinquishment of spectrum that is not being used efficiently or effectively, applying accepted criteria.

Different types of licence fees can be assessed:

– Application fees – paid when an application for a frequency licence is submitted.
– Construction permit fees – paid to allow the construction or implementation of a new infrastructure or network.
– Spectrum usage or regulatory fees – paid on an annual or regular basis for the use of a calculated portion of the spectrum and to cover national spectrum management expenses.
– Operator certificate fees – associated with examinations to establish competency and for renewal of certificates.
– Administrative fees – to cover the administrative costs of processing a licence, if not covered by the application fee.

Fees or tariffs should be charged for management of the spectrum. These are not considered as a tax on the value of the spectrum. There is a wide diversity of priorities and licence fee objectives vary greatly between the countries (see Chapter 6).

1.6.5 Radio standards specification and equipment authorization

1.6.5.1 General

Article **3** of the RR concerns requirements associated with the technical characteristics of stations with the objective of avoiding interference. Appendices **2** and **3** of the RR give maximum values for frequency tolerance and spurious domain emissions and other technical standards. Administrations have the responsibility to ensure that equipment authorized for use on their territory conforms to these Regulations. This is achieved through the use of "equipment characteristics" (documents which specify the minimum performance standards required for radio transmitters and receivers, or other equipment) and the associated procedures to ensure conformity with these standards.

Equipment standards can be developed by national, regional or international organizations (mainly the ITU-R). A subset of technical standards related to system performance and electromagnetic compatibility should be the major concern of spectrum managers. Application of standards helps to ensure electromagnetic compatibility of a system with its environment. This generally involves limiting transmitted signals to a specified bandwidth or maintaining a specified level of stability in order to prevent harmful interference. In some cases an administration may choose to set standards for receivers, requiring a certain level of immunity to undesired signals.

A great number of compatibility and operational standards already exist within the ITU and the International Special Committee on Radio Interference (CISPR). These can be adopted as national standards, if appropriate, whereas some countries have gone through the process of producing their own standards. Such standards may include, for example, those developed by the European Telecommunications Standards Institute (ETSI) or the U.S. Federal Communications Commission. The use of proven and effective standards makes the national standardization process easier. The drafting of a set of national standards represents a long-term effort, because even reviewing existing international and other standards is a large task.

An essential part of delineating standards is specification of compliance testing requirements and other administrative procedures related to compliance. The testing requirements and administrative procedures related to compliance should only be as demanding as necessary. Procedures, such as equipment manufacturer self-certification, reduce paperwork and costs.

National acceptance of equipment test results from other administrations may be part of an administration's process. Some administrations have found that manufacturer self-certification or the use of private sector testing laboratories is adequate to ensure that radiocommunication equipment meets standards requirements. Self-certification requires the ability of the administration to selectively test equipment and to verify performance. If an administration chooses that approach, it may still want to have its own test laboratory to perform spot checks. The test and measurement group typically provides the following services to the frequency management authority:

– laboratory testing of transmitting and receiving equipment in keeping with prescribed type-approval procedures;
– maintenance and calibration of laboratory test equipment and other equipment used by the inspection and monitoring elements of the organization;
– acceptance evaluation of equipment being purchased for inspection and monitoring purposes; and
– outfitting special-purpose monitoring vehicles, and calibration of equipment to be fitted in such vehicles.

An example procedure for self-certification and conformity assessment

Some administrations consider that national type approval is unnecessary (for some type of equipment) and is a potential barrier to trade, especially as more equipment is intended to be marketed, circulated and operated within a defined region, without regulatory restriction (e.g. public mobile telephones). There is a trend in these administrations to transfer the responsibility for ensuring that equipment conforms to the essential technical requirements (conformity assessment), from the regulator to the manufacturer or supplier. Market surveillance is then applied to identify non-compliant equipment and to impose penalties on negligent manufacturers or suppliers. The licence conditions place a legal requirement on the user to ensure that only compliant equipment is put into service.

Assessment of the conformity of a product with requirements then becomes the responsibility of the manufacturer. The manufacturer makes a declaration of conformity and does not need to obtain an approval certificate from an official body after having passed tests in a legally recognized laboratory. When standards are not available (e.g. for a new or innovative product), or where not appropriate (e.g. for a limited special purpose production), a manufacturer still has a route to market by demonstrating more extensively how the requirements were met. This information must be made available for a certain period of time (usually several years). European Union Member States are obliged to publish their national rules concerning access to the radio-frequency spectrum (Interface Regulations) so that manufacturers are fully aware of national differences in allocation and usage and may build products capable of operating in large markets. Manufacturers are obliged to inform customers of the intended use and the limitations of use of the equipment by including relevant information on the packaging and in the instruction manual. The manufacturer must also inform the EU Member State of its intention to place equipment on the market. That State then has a given period of time to indicate whether it can agree.

In accordance with requirements of the World Trade Organization, many countries have established Mutual Recognition Agreements with other Member States. These Agreements generally assume a comparable level of technical development and compatible conformity assessment approaches. These Agreements establish conditions for mutual acceptance of certificates, marks of conformity, and test reports issued by the conformity assessment bodies of either party to a bilateral Agreement.

1.6.5.2 Equipment authorization

The ITU approves Recommendations with respect to global standards. It collaborates with other Standards Development Organizations (SDOs).

Within an increasingly international context, the ITU finds itself in an environment that includes many other players (see ITU webpage on Standards Developing Organizations and International Organizations: http://www.itu.int/en/ITU-T/C-I/conformity/Pages/organizations.aspx). Standards help to avoid fragmentation of the market for the benefit of both the consumers and the industry. In order to maintain a successful development of global standards, the ITU continues to maintain key principles of consensus, transparency, openness, impartiality, maintenance, public access to deliverables, consistent rules, efficiency, accountability, and coherence.

The ITU pursues, through international collaboration, its objective of developing globally applicable deliverables, meeting the needs of its Member States and mankind as a whole.

1.6.6 Spectrum monitoring and enforcement

This section provides only a short overview of spectrum monitoring and enforcement and depicts the relevance of spectrum monitoring and enforcement in the context of general spectrum management. Detailed information about the organisation of a spectrum monitoring service, measurement procedures and equipment can be found in the ITU Handbook on Spectrum Monitoring.

1.6.6.1 Spectrum monitoring

Theoretical spectrum planning is not sufficient anymore. Knowledge of the actual use of the spectrum is needed before decisions can be made on frequency assignments or allotments.

Monitoring supports the overall spectrum management process in general, including frequency assignment and spectrum planning functions, by practical measurements of channel and band usage so that channel availability statistics may be derived, and the effectiveness of spectrum use can be assessed. With this data, spectrum planning can be verified by comparison between the theoretical planning and actual use. The result of this comparison can be used to adjust planning. Use of the spectrum occurs 24 h/day, 7 days/week, every week of the year, whether locally, regionally, or globally. Likewise, spectrum monitoring should also be available 24 h/day.

Spectrum monitoring comprises:

– monitoring of emissions for compliance with frequency assignment conditions (technical and operational characteristics of the signals);
– frequency band observations and frequency channel occupancy measurements providing information about the actual usage of the spectrum;
– assistance in the investigation of radio interference on a local, regional and global scale;
– detection, localisation and identification of illegal transmitters;
– identification and measurement of interfering signals.

This information may be used to trigger subsequent enforcement activities, e.g. the on-site inspection of a radio station.

Monitoring information is necessary because the spectrum is not always used as intended. This may be due to the complexity of the equipment, interaction with other equipment, a malfunction of equipment, or deliberate misuse. These problems have been further exacerbated due to the proliferation of terrestrial and satellite radio systems and the introduction of unintentional radiators, such as computers, which may cause local interference.

1.6.6.2 Spectrum enforcement

Effective management of the spectrum depends on the spectrum manager's ability to have effectual tools for the enforcement of relevant regulations. Spectrum managers should be granted the authority to enforce spectrum use regulations and set appropriate penalties. For instance, the enforcement staff or other spectrum managers may be granted the authority to, when they identify a source of harmful interference, either require that it be turned off or confiscate the equipment under appropriate legal mechanisms. However, the limits of that authority must be specified.

1.6.6.3 Cooperation between monitoring and spectrum enforcement

Section 1.6.6 says that monitoring information may trigger enforcement activities. Vice versa, the need to identify the source of radio interference may result in a request for monitoring activities. Moreover, techniques used in modern radio systems diminish the possibility to strictly differentiate between some spectrum monitoring and enforcement tasks and measurement methods. However an administration's spectrum management may be organised, there must be a close cooperation between both entities. Hence the complete organisational integration of spectrum monitoring and enforcement entities with fixed manned monitoring stations, remote controlled monitoring stations and vehicles may be considered.

This brings us to further measurement tasks which can be facilitated by measurements:

– assistance on special occasions such as major sporting events and state visits
– radio coverage measurements
– quality of service measurements
– assistance in radio compatibility studies
– conducting technical and scientific studies, e.g. propagation measurements
– EMF measurements to prevent health hazards due to electromagnetic radiation

1.6.6.4 Integration of spectrum monitoring and spectrum management systems

Recommendation ITU-R SM.1537 recommends that administrations which perform both spectrum management and spectrum monitoring should consider using an integrated, automated system with a common relational database which provides the following functionalities:

– Remote access to system resources
– Automatic violation detection
– Frequency assignment and licensing
– Tools to support spectrum engineering
– Automated measurement of signal parameters

– Automated occupancy measurements coupled with optional geo-location measurements
– Scheduling of measurements for immediate or future execution

When considering the procurement of an integrated system, an evaluation has to be made of which of these functions are necessary and how much integration is appropriate for an administration. There is no doubt that the monitoring and enforcement service must have access to the license database, and that spectrum managers can use certain information provided by the monitoring service.

For example, frequency managers should find access to the results of automated occupancy measurements useful for spectrum planning purposes.

Automatic violation detection, which is the process of automatically comparing license and monitoring information to detect transmitters that appear to be unlicensed or operating outside of their licensed parameters, is useful for filtering through all frequencies and identifying those which may have a violation and which require further investigation by the operator. These further investigations should be performed to confirm a violation before any results are stored in the license database.

One of the most important advantages of automated systems is that these systems can perform routine repetitive monitoring measurements. Such automation frees the operator from making such routine and repetitive measurements so the operator is able to analyse measurements that have been automated, and therefore be much more productive. The automated system should process raw measurement data into easy-to-understand reports, including graphical reports, which aid the operator in analysing data and drawing conclusions.

There are a few suppliers who are capable of supplying integrated systems as described in Recommendation ITU-R SM.1537, including the billing function. It must be carefully checked whether the candidate systems fulfil the specifications for all frequency bands, radio services and functions as required. The customer of an integrated system is finally constrained to a single supplier. He should be aware that these systems always have to be adapted to the national peculiarities and serviced over a long period.

1.6.7 International cooperation

1.6.7.1 General

The impact of radiocommunication systems often extends beyond international borders. International activities include ITU activities, activities within other international bodies, and bilateral and multilateral discussions.

ITU World and regional radiocommunication conferences (WRCs and RRCs), together with regular activities in the three ITU Sectors (Radiocommunication, Telecommunication Standardization and Telecommunication Development), require a great deal of resources and preparatory work. This effort includes the preparation of national positions as well as participation in international meetings. Participation in regional meetings may greatly assist individual administrations in their preparations on a more widespread basis.

Coordination of frequency authorizations between Member States and their notification to the Radiocommunication Bureau (BR) is another important activity. Often the unit that provides frequency authorization also performs this function. It also carries out coordination and related actions on request to protect the country's radiocommunication systems from interference or when information on assignments notified by other administrations appears in the Bureau's International Frequency Information Circular (BR IFIC).

Though not directly responsible for the rules and regulations for spectrum use, many other organizations, such as the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the World Meteorological Organization (WMO), the Special Committee of the International Electrotechnical Commission for Interference (CISPR), negotiate the agreements and standards that impact spectrum use. Therefore, administrations must also consider their participation in these organizations.

Information about those and other organizations can be found in the ITU Global Directory (GD) (online at http://www.itu.int/en/membership/Pages/global-directory.aspx) and more specifically on its webpage dedicated to Regional and other International Organizations (CV231), Regional Telecommunication

Organizations (CV269B) and Intergovernmental Organizations Operating Satellite Systems (CV269C) at: http://www.itu.int/online/mm/scripts/mm.list?_search=OTHERORGS&languageid=1&_foto=y.

The following two tables[7] specify the main organizations influencing international wireless regulation, in addition to ITU: the intergovernmental organizations associated with governments and industry. Table 1-1 lists the main intergovernmental regional regulators groups dealing with telecommunications and influencing the international RF spectrum management.

TABLE 1-1

Main regional telecoms regulators

Name	**Regional Intergovernmental Telecoms Regulators**
APT	Asia Pacific Telecommunity, 38 countries
ASMG	Arab States Spectrum Management Group, 23 countries (22, without suspended Syria)
ATU	African Telecommunications Union, 44 countries
CEPT[8]	European Conference of Postal and Telecoms Administrations, 48 countries
CITEL9	Inter-American Commission of Telecoms, 36 countries
EACO	East African Communications Organization Burundi, Kenya, Rwanda, Tanzania, Uganda (like EAC)
FACSMAB	Frequency Assignment Committee Singapore, Malaysia and Brunei
RCC[10]	Regional Commonwealth in the Field of Communication, 12 countries
REGULATEL[11]	Latin American Forum of Telecom Regulator, 20 Regulators
SADC	Southern African Development Community, 15 countries
WATRA	West Africa Telecommunications Regulators Assembly, 15 countries

Table 1-2 specifies intergovernmental groups; most intergovernmental organizations are grouped by geography; some are associated by language: Arabic for AREGNET, Portuguese for ARCTEL-CPLP, French for CAPTEF and English for CTO.

7 The tables are based on forthcoming John Wiley & Sons publication, ‘Radio Spectrum Management: Policies, Regulations, Standards and Techniques’; author: Haim Mazar.

8 *Conférence Européenne des administrations des Postes et des Télécommunications*.

9 *Comisión Interamericana de TELecomunicaciones*.

10 *Past Russian dominance, present Russian influence*.

11 *Foro Latinoamericano de Entes REGULAdores de TELecomunicaciones*.

TABLE 1-2

Intergovernmental organizations influencing telecommunications' regulation

Name	Regional and Intergovernmental Organizations
AICTO	Arab Information and Communication Technology Organization, 22 Arab League countries
ASEAN	Association of Southeast Asian Nations
ARCTEL-CPLP[12]	Association of Communications and Telecommunications Regulators of the Community of Portuguese Speaking Countries, 8 countries
AREGNET	Arab Regulators Network, 20 countries
ARICEA	Association of Regulators of Information and Communications for Eastern and Southern Africa
AUB	African Union of Broadcasting
BEREC	Body of European Regulators for Electronic Communications
CAATEL[13]	Andean Committee of Telecoms, 4 countries (of *CAN*)
CAN	*Comunidad Andina de Naciones*, 4 countries
CANTO	Caribbean Association of National Telecommunication Organizations, 27 countries
CAPTEF[14]	Administrative conference of Posts and telecoms of French speaking countries, 22 countries
CJK	China, Japan and South Korea, 3 countries
COMTELCA[15]	Telecommunications Regional Technical Commission, 6 Centre- America countries
CRASA	The Communication Regulators' Association of Southern Africa, 13 countries (CRASA is the renamed TRASA)
CTO	The Commonwealth Telecoms Organisation, 54 countries
CTU	Caribbean Telecommunications Union, 13 countries
EAC	East African Community Burundi, Kenya, Rwanda, Tanzania, Uganda
ECTEL	The Eastern Caribbean Telecommunications Authority, 5 countries
ECO	European Communications Office, 48 CEPT countries
ECOWAS*[16]	Economic Community of West African States, 15 countries
EFTA	European Free Trade Association, including Iceland, Liechtenstein, Norway and Switzerland
EU, EC[17]	European Union and European Commission, 28 countries
FRATEL[18]	Francophone Telecoms Regulatory Network, 47 countries
GCC	Cooperation Council for the Arab States of the Gulf Telecommunications Bureau, UAE, Bahrain, Saudi Arabia, Oman, Qatar, Kuwait
ICNIRP	International Commission on Non-Ionizing Radiation Protection

[12] *Associação de Reguladores de Comunicações e TELecomunicações da Comunidade dos Países de Língua Portuguesa*.

[13] *Comite Andino de Autoridades de TELecomunicaciones*.

[14] *Conférence Administrative des Postes et Télécommunications des pays d'Expression Française*.

[15] *COMmission technique régionale des TÉLécommuniCAtions*.

[16] Also West Africa Telecommunications Regulators Assembly (WATRA) www.trasa.org.bw/ .

[17] European Community; subsequently also European Union, EU.

[18] *Réseau FRancophone de la régulation des TÉLécommunication*.

TABLE 1-2 (*end*)

Name	Regional and Intergovernmental Organizations
IIRSA[19]	South American Regional Infrastructure Integration, 12 countries
MERCOSUR[20]	Common South American Market: Argentina, Brazil, Paraguay, Uruguay , Venezuela and Bolivia (in process)
NAFTA	North American Free Trade Agreement: Canada, Mexico and US
PITA	Pacific Islands Telecommunications Association, telecommunication entities in Melanesia, Micronesia, Polynesia, Australia and New Zealand
PTC	Pacific Telecommunications Council, members represent more than 60 countries
SCG	Spectrum Coordination Group, 5 countries[21]
UNASUR[22]	Union of South American Nations, 12 countries
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific, 53 countries
WHO	World Health Organisation, 193 countries

In parallel to the above, bilateral agreements with neighbouring countries help to settle operational issues for the purpose of coordinating the establishment of radiocommunication systems and other items of mutual interest. Agreements may be necessary to resolve interference cases across international borders.

1.6.7.2 World Telecommunication Development Conference (WTDC)

The Telecommunication Development and Radiocommunication Sectors of the ITU, in their joint activities, assist developing countries with their national spectrum management functions. This activity was established by Resolution 9 of WTDC-98, as revised by WTDC-02, WTDC-06 and WTDC-10. The results of this joint activities were reported to the above-mentioned WTDCs and to WTDC-14 (see at http://www.itu.int/pub/D-STG-SG02.RES09.1-2014). WTDC-14 further revised Resolution 9 (see the relevant part of WTDC-14 Final Report at: http://www.itu.int/pub/D-TDC-WTDC-2014). A group of spectrum management experts from developed and developing countries continue to meet regularly to coordinate and progress the work.

1.6.8 National cooperation (liaison and consultation)

In order to be effective, the national spectrum management organization should communicate and consult with users, including businesses, telecommunications industries, government users and the general public. It should disseminate information on the policies, rules and practices of the administration and provide mechanisms for feedback to evaluate the consequences. A liaison unit maintains media relations, issues public notices, conducts meetings, and acts as an intermediary in resolving interference problems between users, drawing on support from inspection, monitoring and investigation units.

This liaison can take the form of informal direct contact between individuals with spectrum interests and the spectrum management authority, formal contact through a set of specific administrative review procedures, representative contact through the creation of advisory committees, or combinations of these and other methods. Direct contact with the spectrum authority allows for efficient dialogue and quick results, but may exclude many viewpoints since all interested parties may not receive identical treatment. Transparent administrative procedures ensure fair and impartial treatment, but can also become burdensome and inefficient. Public advisory committees can bring together different viewpoints and be effective in major decision processes. National administrations are encouraged to establish procedures for individuals and

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19 *Iniciativa para la Integración de la Infraestructura Regional SudAmericana*.

20 *Mercado Común del Sur*.

21 Brunei, Indonesia, Malaysia, Singapore and Thailand.

22 *Unión de Naciones Suramericanas*.

organizations to request the spectrum manager to make changes in the spectrum regulations and assignment or allocation decisions. Those affected by the regulations would then have a means for bringing about change and for ensuring that spectrum managers have adequately considered the needs of all portions of the national constituency.

1.6.9 Spectrum engineering support

Since spectrum management involves decisions pertaining to a field of technology, engineering support is required to adequately evaluate the information, capabilities, and choices involved. Though social and economic considerations enter into most decisions, many of them are based on an engineering analysis of the technical factors. Therefore, a part of the organization versed in electromagnetic compatibility analysis techniques and knowledgeable in technological developments and system capabilities is needed to provide unbiased assessments to those who develop policies and plans. Spectrum engineering tools are discussed in Chapter 5.

1.6.10 Computer support

The extent to which computer support facilities are available to, and used by, the spectrum management authority depends on the resources, priorities, and particular requirements of the country concerned. The use of computers is essential to the effectiveness of any spectrum management effort, no matter how small. Computer support is not limited to licensing records or complex engineering calculations but should assume responsibility for the development, provision, and maintenance of support facilities for nearly all spectrum management activities, including record keeping, forecasting and financial management related to licensing. Computer automation for spectrum management is discussed in Chapter 7.

1.7 Development of a spectrum management organizational structure

1.7.1 General

The organizational structures for alignment with strategy of business are typically flatter than they used to be and flexible enough to accommodate changes and to maximize communications among different operational units. The two major types of structures that may be required for spectrum management organizations are:

– a small spectrum management organization;

– a traditional spectrum management organization.

In the first case, the spectrum management organization is comprised of a small permanent staff of perhaps 10 to 15 spectrum experts, with a changing network of spectrum users. The work relationships are temporary, project-oriented and dependent on the particular spectrum management task being undertaken. In the second case, the organization is so-called “line organization”, an example of which is given in Figure 1.3.

1.7.2 Decentralization versus centralized management

A centralized spectrum management structure (which is the case for a majority of countries) can result in an efficient process through economies of scale and standardization of the processes and systems throughout the organization, and with the decision-making at the top of the organization. The advantage of a decentralized management is the ability to provide on-the-spot management and real incentives that can improve, or make more efficient, the outputs of the organization.

Overall management is improved by making strategic decisions on a centralized basis, while making operational day-to-day decisions on a local basis. The decentralized process will work effectively if the required information (e.g. frequency assignment) can be made available to all through a centralized information process. In some countries having a centralized management structure, some elements of the spectrum management responsibilities are decentralized, e.g. all elements related to maritime issues are managed by another governmental body (as may also be done for aeronautical issues and broadcasting).

1.7.3 Matrix structure management

A project-oriented, team organization can usefully lead to a matrix approach to spectrum management. A matrix approach is one in which the functional capabilities are grouped together. The following five-step matrix approach is possible:

– Define the process and functions involved.

– Define who does what, and how the work is accomplished.

– Identify the spaces in the organization between the functional components of the organization through which the most important processes pass.

– Design the team infrastructure.

– Identify opportunities to improve team effectiveness.

1.7.4 Summary of principles

The following summarizes the basic principles that should be kept in mind when designing a structure for the national spectrum management organization:

– *General* – Minimize the number of levels of management (a flat structure). All spectrum management approaches require computer techniques and advanced software. The spectrum management organization needs to be information-based to be efficient. Complex spectrum management problems require a project-team management approach.

– *Large organizations* – The structure of the organization needs to be decentralized if the major problems are in a local area that is different from the area of the centralized management structure. Decentralized structures can lead to timely and effective solutions. Matrix management is an effective approach for solving complex problems with a moderate-sized staff.

– *Small organizations* – Minimize the levels of management. Small organizations in particular, require computer techniques and advanced software and they need to be information-based. Complex problems should not be addressed by small organizations.

1.7.5 Spectrum management systems

Figure 1.1 contains a block diagram of the relationships between the functional requirements and spectrum management outputs. This assumes that the spectrum management authority has a sufficiently large staff to support all the activities, and that the government ensures that all the specified functional activities are undertaken.

The first question here is, "Do the telecommunication law and the associated regulations require all these functional requirements?" The second question is, "Do the spectrum management authorities have sufficient resources to staff all these functions?" Three examples are described, where the first two may apply to many developing countries.

There are a number of ways to determine the size of the professional staff relative to the functional requirements. The staff size should be based on the functional requirements and these could be based on the current value of the telecommunication structure in the country, the number of new licenses required, or the number of current and projected frequencies. The simplest to use and understand is related to the number of frequencies required. Table 1-3 describes typical ranges of frequency assignments for each of the three spectrum management systems. Although it is not possible to accurately define the various categories, this table may assist countries in planning a functional spectrum management system.

TABLE 1-3

Typical ranges of frequency assignments for different size structures

Spectrum management system	Typical range of actions, licenses or frequency assignments	Estimated range of professional staff size	Comments
Small	100 to 10 000	5 to 10	
Medium-sized	10 000 to 100 000	10 to 50	
Large	above 100 000	above 50	Typically a developed country with greater than 100 000 frequency assignments

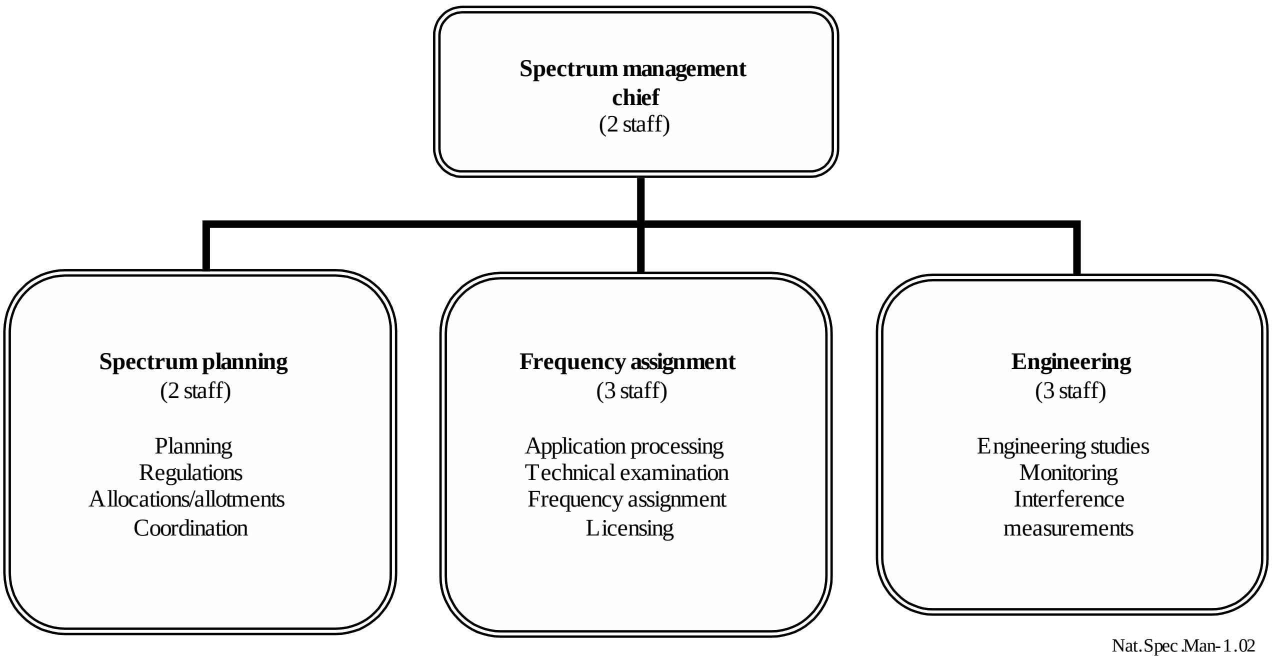
The typical range of main actions is a function of the number of licenses/frequency assignments per week that are processed, or of the changes made to a parameter(s) of an existing license. Staff size also depends on the expertise, education and technical background of the staff.

Small spectrum management system

A small spectrum management organization that has few telecommunication systems and few frequency assignments requires a basic staff of 5 to 10. Since the frequencies actually in use are probably greater than the records indicate, a small monitoring function is desirable. Such a staff is not adequate to do extensive planning and engineering functions. In this case, certain licence fees may be needed so that the number of staff functions can be increased. Although an automated system is not required, it is desirable to keep database records and to do basic engineering.

FIGURE 1.2

Small spectrum management organization of professional staff



Medium-sized spectrum management system

A medium-sized spectrum management system with professional staff numbering from 10 to 50 provides sufficient resources to accomplish all of the functional elements previously described. The functions could be structured in many different ways. Figure 1.3 provides an example that assumes a total frequency assignment record of 75 000 with approximately 1 000 applications for new assignments per month. This does not include all administrative functions required by the spectrum management department. Using this guide, approximately 50, (or 75 000/1 500) staff members would be required. Figure 1.3 provides a structure for effectively implementing the functional elements for a medium-sized spectrum management organization. There are four divisions in this model with relationships as follows:

– The Frequency Assignment Division handles frequency assignments as indicated. This analysis is done by the technician and engineering staff using an SMS4DC. No detailed engineering investigation is part of the normal frequency assignment process. If an assignment requires detailed analysis this task should go to the Spectrum Engineering Division.

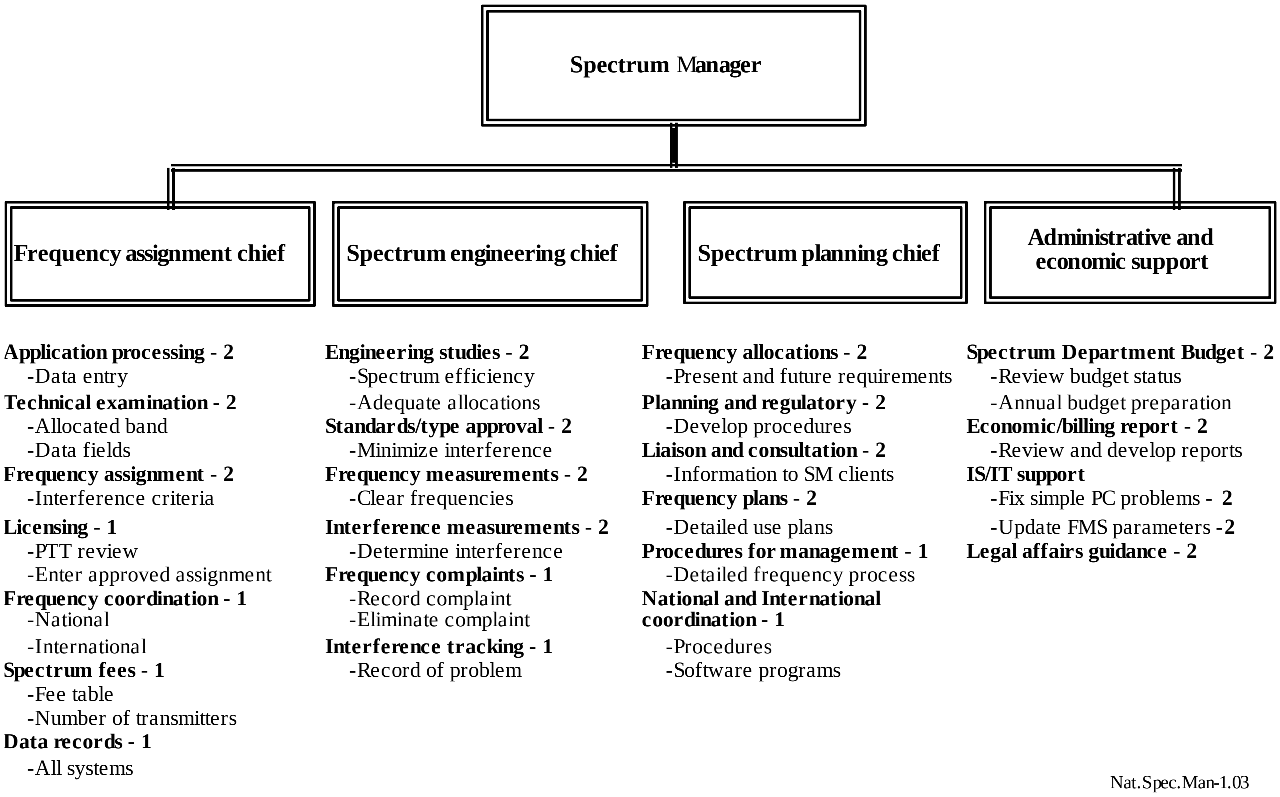
– The Spectrum Engineering Division ensures that the radio systems employed are efficient and effective. The Division normally uses an automated spectrum management system, augmented with measurements. The outputs support the Frequency Assignment and Spectrum Planning Divisions, and assist the Spectrum Manager in special tasks.

– The Spectrum Planning Division develops the Plan established through coordination with the appropriate national organizations. This often requires the support of the Frequency Assignment and the Spectrum Engineering Divisions.

– The Administration and Economic Support Division collects licence fees and performs various administrative and economic planning functions for the Spectrum Manager.

FIGURE 1.3

Medium-sized spectrum management structure for professional staff



Large spectrum management system

A large spectrum management organization should again follow the functions described above. Typical professional staff numbers greater than 100, and the number of total frequency assignments is greater than 100 000. The system requires an advanced spectrum management computer system that keeps records for all services and provides engineering analysis support for all frequency ranges and systems. The structure could be organized like those previously described, it could be organized by radio service or it could be organized in a matrix structure by the basic function that applies to all services. Other organizational structures are also possible.

1.8 Use of E-Government, quality management systems and excellence models in spectrum management

1.8.1 General

The spectrum management organization must function at an optimum level based on efficiency and effectiveness. Serving the public interest requires offering the spectrum authorization and licensing activities efficiently and to the satisfaction of the radio users. In recent years, spectrum management organizations have increasingly started using online portals where applications for radio spectrum allocation and assignment can be received and processed through the computer based systems. These systems are generally part of the E-Government and offer online payment and other services like invoices, authorizations, etc. Customer satisfaction measurement is also used by spectrum management organizations as part of the excellence models (e.g. EFQM) and implemented through quality management systems.

1.8.2 Use of quality management system (ISO 9001:2008)

To keep customers satisfied, the organization needs to meet their requirements. The ISO 9001:2008 standard provides a tried and tested framework for taking a systematic approach to managing the organization's processes so that they consistently turn out product that satisfies customers' expectations.

The ISO 9000 family of standards represents an international consensus on good quality management practices. It consists of standards and guidelines relating to quality management systems and related supporting standards.

ISO 9001:2008 is the standard that provides a set of standardized requirements for a quality management system, regardless of what the user organization does, its size, or whether it is in the private, or public sector. It is the only standard in the family against which organizations can be certified – although certification is not a compulsory requirement of the standard.

Annex 3 to this Chapter describes an example outline of a quality management system manual used by a spectrum management organization.

Bibliography

FCC, Federal Communications Commission, Title 47 Telecommunications. U.S. Code of Federal Regulations, Part O, Organizations.

MALONE, T.W., SCOTT, M., HALPERIN, M. and RUSSMAN, R. [July/August 1996] Organizing for the 21st Century: Research on Effective Organizational Structure for the Future. Strategy & Leadership, Vol. 24, 4, p. 6-11.

NTIA [February 1991] National Telecommunications and Information Administration. U.S. Department of Commerce, NTIA Special Publication 91-23, U.S. Spectrum Management Policy: Agenda for the Future.

ITU-R texts

ITU Radio Regulations (Edition of 2012)

ITU-R Handbook	Spectrum monitoring (Edition of 2011)
ITU-R Handbook	Computer-aided techniques for spectrum management (Edition of 2015)
Rec. ITU-R SM.855	Multi-service telecommunication systems
Rec. ITU-R SM.1047	National spectrum management
Rec. ITU-R SM.1049	A method of spectrum management to be used for aiding frequency assignment for terrestrial services in border areas
Rec. ITU-R SM.1131	Factors to consider in allocating spectrum on a worldwide basis
Rec. ITU-R SM.1132	General principles and methods for sharing between radiocommunication services or between radio stations
Rec. ITU-R SM.1133	Spectrum utilization of broadly defined services
Rec. ITU-R SM.1138	Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions
Rec. ITU-R SM.1265	National alternative allocation methods
Rec. ITU-R SM.1413	Radiocommunication Data Dictionary for notification and coordination purposes
Rec. ITU-R SM.1603	Spectrum redeployment as a method of national spectrum management

ANNEX 1

TO CHAPTER 1

International spectrum management and the International Telecommunication Union

1 History

The first record of international cooperation in telecommunications is found in the creation of the International Telegraph Union in Paris, France, in 1865. International cooperation in radiocommunication began in 1903 with the Preliminary Conference on Radiotelegraphy, but was not fully consolidated until the first international Radiotelegraph Conference, held in Berlin 1906. The ITU Table of Frequency Allocations goes back to the first Radiotelegraph Conference, which allocated frequencies from 500 to 1 000 kHz for public correspondence in the maritime service, a frequency band (below 188 kHz) for long-distance communication by coast stations, and another band (188-500 kHz) for stations not open to public correspondence.

In order to facilitate this international cooperation, organizational structures and procedures were developed. In 1927, the Washington conference established the International Radio Consultative Committee (CCIR) to study technical radio problems. In Madrid, in 1932, the plenipotentiaries decided to create a single organization known as the International Telecommunication Union (ITU), governed by a single International Telecommunication Convention and supplemented by Telegraph Regulations, Telephone Regulations and Radio Regulations. The results of the Madrid Conference, with implications for radiocommunications, included the following:

– division of the world for frequency allocation purposes into two Regions (Europe and other regions);

– establishment of two technical tables (one of frequency tolerances and the other of acceptable bandwidths); and

– setting of standards for the registration of new transmitting stations.

In 1947, the ITU held a plenipotentiary conference in Atlantic City with the aim of developing and modernizing the organization. Under an agreement with the United Nations, it became a specialized agency of the United Nations on 15 October 1947, and the conference decided that the headquarters of the organization should be transferred from Bern to Geneva. More information about ITU history can be found at: http://www.itu.int/en/history/Pages/DiscoverITUsHistory.aspx.

2 Organizational structure

The ITU Plenipotentiary Conferences, as the highest legislative body, meet every four years to review the general policies for fulfilling the purpose of the ITU. They revise the Constitution and Convention, as appropriate, establish the financial plan with fiscal limit of expenditures and elect the Secretary-General, the Deputy Secretary-General, Member States of the Council, individual members of the Radio Regulations Board, and the Directors of the three Sectors. The Council that is composed of one-quarter of the ITU Member States (48) meets annually to take policy and budget decisions in-between two Plenipotentiary Conferences. The Council supervises the administrative functions of the ITU, and approves the bi-annual budget as well as Sectoral Operational Plans.

The ITU has three Sectors: Radiocommunication, Telecommunication Standardization and Telecommunication Development.

ITU activities and decisions have a significant impact on the national spectrum management environment. It is therefore essential that administrations understand and are fully aware of these activities so that they may participate to ensure their national interests are taken into account.

The level of participation will depend on the type of activity, together with the priorities, interests and resources of the administration.

Frequency coordination, notification and registration are essential tasks for administrations and their radiocommunication services to obtain international protection. This activity may be performed by correspondence with the ITU and other administrations, or in the case of satellite coordination, in bilateral or multilateral negotiations.

The Radiocommunication Sector and Radiocommunication Bureau

The Radiocommunication Bureau (BR) of the Radiocommunication Sector is headed by a Director assisted with the BR Secretariat.

The Bureau:

– provides administrative and technical support to World and Regional Radiocommunication Conferences, the Radio Regulation Board (RRB), Radiocommunication Assemblies and Study Groups, including Working Parties and Task Groups;

– applies the provisions of the Radio Regulations and various Regional Agreements;

– records and registers frequency assignments and allotments and also orbital characteristics of space stations, and maintains the Master International Frequency Register;

– provides advice to Member States on the equitable and effective use of the radio-frequency spectrum and satellite orbits, and investigates and assists in resolving cases of harmful interference;

– coordinates the preparation, editing and dispatch of circulars, documents and publications developed within the Sector, necessary to carry out its responsibilities; and

– provides technical information and seminars on national frequency management and radiocommunication, and works closely with the Telecommunication Development Bureau in assisting developing countries.

Radio Regulations Board

Twelve elected members of the Radio Regulations Board (RRB) representing five (5) administrative regions of the ITU, perform their duties on a part-time basis, normally meeting up to four times a year, in Geneva.

The Board:

– approves Rules of Procedure, used by the Radiocommunication Bureau in applying the provisions of the Radio Regulations and registering frequency assignments made by Member States;

– addresses matters referred by the Bureau which cannot be resolved through application of the Radio Regulations and Rules of Procedure;

– considers reports of unresolved interference investigations carried out by the Bureau at the request of one or more administrations and formulates Recommendations; and

– provides advice to Radiocommunication Conferences.

The Director of the Bureau is the Executive Secretary of the Radio Regulations Board.

World and Regional Radiocommunication Conference (WRC and RRC)

World Radiocommunication Conference

World Radiocommunication Conferences (WRCs) establish and revise the texts of the Radio Regulations, international treaty, covering the use of the radio frequency spectrum by radiocommunication services. Following its agenda, the WRCs may:

– revise the Radio Regulations and any associated Frequency Assignment/Allotment Plans, as appropriate;

– address any radiocommunication matter of worldwide or ITU regional character;

– instruct the Radio Regulations Board and review their activities; and

– determine the areas of study by the Radiocommunication Study Groups in preparation for future Radiocommunication Conferences.

WRCs are normally convened every three/four year cycle. The agenda is set by the Council on the basis of the draft agenda as agreed by the previous WRC.

Changes in international frequency allocations may have a major impact on the operation of existing national services. Most administrations have the opportunity to prepare themselves for WRCs through participation in the preparatory groups of regional organizations (CITEL, CEPT, APT, ASMG, RCC and ATU). These regional groups prepare common proposals for each agenda item together with technical and regulatory information on the background. Regional preparations can ease the burden on administrations with limited resources by sharing the results of any necessary technical and regulatory studies.

Many countries establish a national coordination group with members representing both government and non-government radio users to provide a broad consultation process. The goal is to develop agreed national positions and briefing material for each WRC agenda item. In many cases, it may be sufficient for the national position to support the relevant regional position.

After each WRC, follow-up action is required nationally to implement WRC Decisions. As part of the on-going consultation process, the first step is usually to publish a report of the outcome, with suitable explanations of the expected impact on existing users and opportunities for new services. The second step will be to revise the national allocation table to comport with the agreed global changes, including any time-scales for the changes to come into force.

Regional Radiocommunication Conferences

Regional Radiocommunication Conferences (RRCs) deal with radiocommunication issues relevant to a particular Region (region) and the needs of its Member States.

Radiocommunication Assembly

The Radiocommunication Assembly (RA) is responsible for the structure, programme and approval of radiocommunication studies. The Assembly may:

– approve ITU-R Recommendations and Questions developed by the Radiocommunication Study Groups;

– set the work programme for Study Groups, and disband or establish Study Groups according to need.

Radiocommunication Assemblies are normally convened every three or four years and are in principle associated in time and place with WRCs.

Radiocommunication Advisory Group

The Radiocommunication Advisory Group (RAG) is a part of the Radiocommunication Sector as defined in ITU Constitution (CS84A) and Convention (CV160A-160I), with the following responsibilities:

– review the priorities and strategies adopted in the Sector;

– monitor progress of the work of the Study Groups;

– provide guidance for the work of the Study Groups; and

– recommend measures for fostering cooperation and coordination with other organizations and with the other ITU Sectors.

The RAG provides advice to the Director (BR) and the Radiocommunication Assembly may refer specific matters within its competence to RAG (CV137A).

ITU-R Study Groups

Many thousands of specialists from telecommunication administrations and other organizations and entities throughout the world participate in the work of the Radiocommunication Study Groups where they:

– develop draft ITU-R Recommendations and Reports on the technical characteristics of, and operational procedures for, radiocommunication services and systems; and
– compile Handbooks on spectrum management and emerging radiocommunication services and systems.

The draft ITU-R Recommendations may be approved either by correspondence or by the next Radiocommunication Assembly.

At present, there are six Study Groups (SGs):

– SG 1 Spectrum management[23]
– SG 3 Radiowave propagation[24]
– SG 4 Satellite services[25]
– SG 5 Terrestrial services[26]
– SG 6 Broadcasting service[27]
– SG 7 Science services[28]

In addition the following specialised groups report to the Radiocommunication Assembly:

– SC Special committee on regulatory/procedural matters, which mainly prepares a Report to the CPM;
– CCV Coordination committee for vocabulary;
– CPM Conference preparatory meeting, which mainly prepares a Report to the WRCs.

Recommendations, Reports and other material developed by the Radiocommunication Study Groups, through the participation and contributions of ITU Members and Associates, provide the technical bases for spectrum management. These include recommendations on criteria for sharing between radiocommunication services as defined in the RR. Each Study Group has one or more Working Parties dealing with a sub-set of issues within its scope and in some cases, may have Task Groups to deal with a specific and urgent issue.

The Study Groups and their Working Parties arrange meetings at least once each year, usually at ITU headquarters in Geneva. Because of resource limitations, administrations need to identify their interests so that their participation can be targeted effectively to those activities that have a direct national interest.

Conference Preparatory Meeting

Conference Preparatory Meetings (CPMs) prepare a consolidated report on the technical, operational and regulatory and procedural bases for the forthcoming WRC.

Studies of a technical or operational nature are undertaken by the appropriate Study Groups. Studies of regulatory/procedural matters may also take place within the relevant Study Groups and Working Parties identified by the CPM. Regulatory and procedural matters are also addressed by the Special Committee on this subject, if so decided by the RA and the CPM, which is operating in the same manner as a Study Group.

The CPM updates and rationalizes the material from the Study Groups and Special Committee, together with any new material submitted to it.

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23 http://www.itu.int/en/ITU-R/study-groups/rsg1/Pages/default.aspx.

24 http://www.itu.int/en/ITU-R/study-groups/rsg3/Pages/default.aspx.

25 http://www.itu.int/en/ITU-R/study-groups/rsg4/Pages/default.aspx

26 http://www.itu.int/en/ITU-R/study-groups/rsg5/Pages/default.aspx

27 http://www.itu.int/en/ITU-R/study-groups/rsg6/Pages/default.aspx

28 http://www.itu.int/en/ITU-R/study-groups/rsg7/Pages/default.aspx

ANNEX 2

TO CHAPTER 1

Example of an outline of a national document of regulations and procedures for Radio Spectrum Management

1 General

A document of frequency management regulations and procedures should be available to all users of the spectrum. This Manual would provide regulatory guidance to spectrum users and act as a consolidated set of spectrum management information. A manual, consisting of 11 chapters, could be organized as follows:

– Chapter 1: Spectrum management organization

– Chapter 2: Authority to assign frequencies

– Chapter 3: Objectives for national spectrum management

– Chapter 4: International agreements

– Chapter 5: Definitions used in spectrum management

– Chapter 6: Frequency allocations, and channeling plans

– Chapter 7: Applications for frequency use

– Chapter 8: Licensing procedures

– Chapter 9: Regulations applicable to special radio services and applications

– Chapter 10: Spectrum-dependent equipment standards

– Chapter 11: Uses of monitoring in frequency management.

2 Discussion

Chapter 1 of the Manual would describe the spectrum management infrastructure. Spectrum management is typically performed by an independent regulatory authority. This organization has the basic responsibility for frequency assignments and licensing. An organization chart and corresponding descriptions should be included.

Chapter 2 contains the laws and regulations giving the independent regulatory authority the responsibility to assign frequencies and issue licenses. This Chapter would contain the Telecommunication Law.

Chapter 3 discusses national frequency management in terms of national objectives for the use of telecommunications systems. For spectrum management to effectively provide for future telecommunications systems, the priority of these systems should be understood in the context of national objectives.

Chapter 4 describes the International Telecommunication Union (ITU) and its functions in international frequency management, including the activities of the Radiocommunication Bureau. International agreements regarding frequency use form a basis for national frequency allocations and allotments.

Chapter 5 contains a set of definitions that are used in the international spectrum management. These definitions (radio services, radio station classes, and technical parameters of stations, etc.) enable spectrum managers to communicate the particulars of a frequency assignment and provide for common understanding of the assignments contained in the ITU International Frequency List.

Chapter 6 is the most important part of the document. This Chapter consists of international and national frequency allocations and national frequency allotments and channelling plans. The National Table of Frequency Allocations should be the table used by the independent regulatory authority in planning the spectrum availability. Those bands that do not have a specific national allocation are allocated in conformity with the allocations of the relevant region in the Radio Regulations. Special national provisions are referenced where appropriate as “Country Notes”. International footnotes applying to the National Table are also referenced. Channelling plans are included after the allocation table for those frequency bands that have recommended channelling schemes. These plans are to be used as guidelines for frequency assignment purposes.

Chapter 7 discusses the process involved for an applicant requesting the use of a frequency assignment or authorization to use specialized frequency bands (e.g. maritime mobile). The frequency assignment process within the independent regulatory authority is outlined, and a flow diagram of the process is included.

Chapter 8 discusses the licensing system for radio equipment in use. By use of licensing, the independent regulatory authority exercises control over importing, exporting, possession, and use of radio transmitting equipment. Radio operators are also required to obtain a license in the cases of the maritime and amateur services. The various application and license forms are shown in an annex to the document.

Chapter 9 contains regulations for four special classes of radio service. These services are amateur, experimental, ISM (industrial, scientific, medical devices), and low-power devices.

Experimental radio stations are required, in the process of research and development, in many areas of technology. These stations do not perform a communications function, but are necessary in the development of new radio systems and to support scientific research. No rules, other than that no harmful interference may occur, exist in most countries to accommodate this station class.

Industrial, scientific, and medical (ISM) radio frequency devices include such items as radio-frequency-stabilized arc welders, medical diathermy equipment, radio-frequency surgical instruments, and microwave ovens.

Radio laws do not typically distinguish between normal radiocommunication equipment and the low power transmitters used in such applications as remote control and cordless telephones. Pending a revision of the laws, the manual should specify the characteristics that describe a low-power device and establish overall policy with respect to their exemption from licensing requirements.

Chapter 10 should list the independent regulatory authority standards for spectrum-dependent equipment. These standards can be used as the criteria for testing radio equipment at the relevant laboratory and for screening import license applications to ensure compliance with the standards.

Chapter 11 should discuss radio spectrum monitoring and the independent regulatory authority policies regarding the use of monitoring for the frequency management process.

ANNEX 3

TO CHAPTER 1

Quality Manual of a spectrum management organization

1 Scope and purpose

1.1 General

This Annex specifies the scope of the quality management system of Spectrum and International Affairs Department within the Telecommunications Regulatory Authority (hereinafter referred to as SIA).

The manual governs all activities and processes of the quality management system of the SIA. The activities involved in the SIA are spectrum allocation, broadcasting, spectrum monitoring, spectrum strategy and international Affairs.

Exclusions

SIA has excluded clause 7.3 (Design and development) from the scope of its quality management system as it is not involved in any design and/or development activity as well as 7.5.2 as SIA does not require validation for any of its processes.

1.2 Purpose

The purpose of the quality manual is to provide the scope of the quality management system as well as to give reference to the documented procedures established for the quality management system. Quality manual also provides description of the interaction between various processes of the quality management system.

2 Introduction about SIA

The Telecommunications Regulatory Authority (TRA) of the United Arab Emirates (UAE) has been established according to the UAE Federal Law by Decree No. 3 of 2003 as amended – Telecom Law.

The organizational objectives of the TRA are derived from the UAE Telecommunications Law, its Executive Order and the UAE National Telecommunications Policy. These objects may be summarized by ensuring adequacy of telecommunications services throughout the UAE; achieving enhancement of services, both in terms of quality and variety; ensuring quality of service and adherence to terms of licenses by licensees; encouraging telecommunications and IT services within the UAE; promoting and enhancing the telecommunications sector within the UAE; promoting and developing the telecommunications sector in the UAE by training, development and the establishment of relevant training institutions; resolving any disputes between the licensed operators; establishing and implementing a regulatory and policy framework; promoting new technologies; ensuring that the UAE becomes the regional ICT hub; developing the country's human capital; and encouraging research and development.

Spectrum and International Affairs department is involved in all spectrum and international affairs such as planning, allocation, coordination, monitoring and enforcement. SIA has the following sections:

– Spectrum strategy
– Spectrum allocation
– Broadcasting
– Spectrum monitoring
– International Affairs.

The SIA is headed by Executive Director, Spectrum and International Affairs. Each section is headed by Senior Manager. The SIA operates from Abu Dhabi as well as Dubai.

Main purpose of each section is as described below:

– **Spectrum strategy** – Regulate and manage efficiently the radio spectrum being a scarce natural national resource, draft the spectrum regulatory instruments (policies, regulations, rules, procedure, orders, resolutions, etc.) for issuance and attract new wireless technologies to the UAE market.

– **Spectrum allocation** – Deals with the spectrum authorization (allocation and assignments) for all users in the UAE for all radio services except orbital resources and broadcasting.

– **Broadcasting services** – Manage and regulate all broadcasting services including "Sound, multimedia & data and TV offered via terrestrial, satellite or cable" and deal with related matters and projects, both from technical and regulatory point of view.

– **Spectrum monitoring** – Undertake monitoring for radio spectrum enforcement, measurement and resolution of harmful interference reports and conduct interference and other surveys.

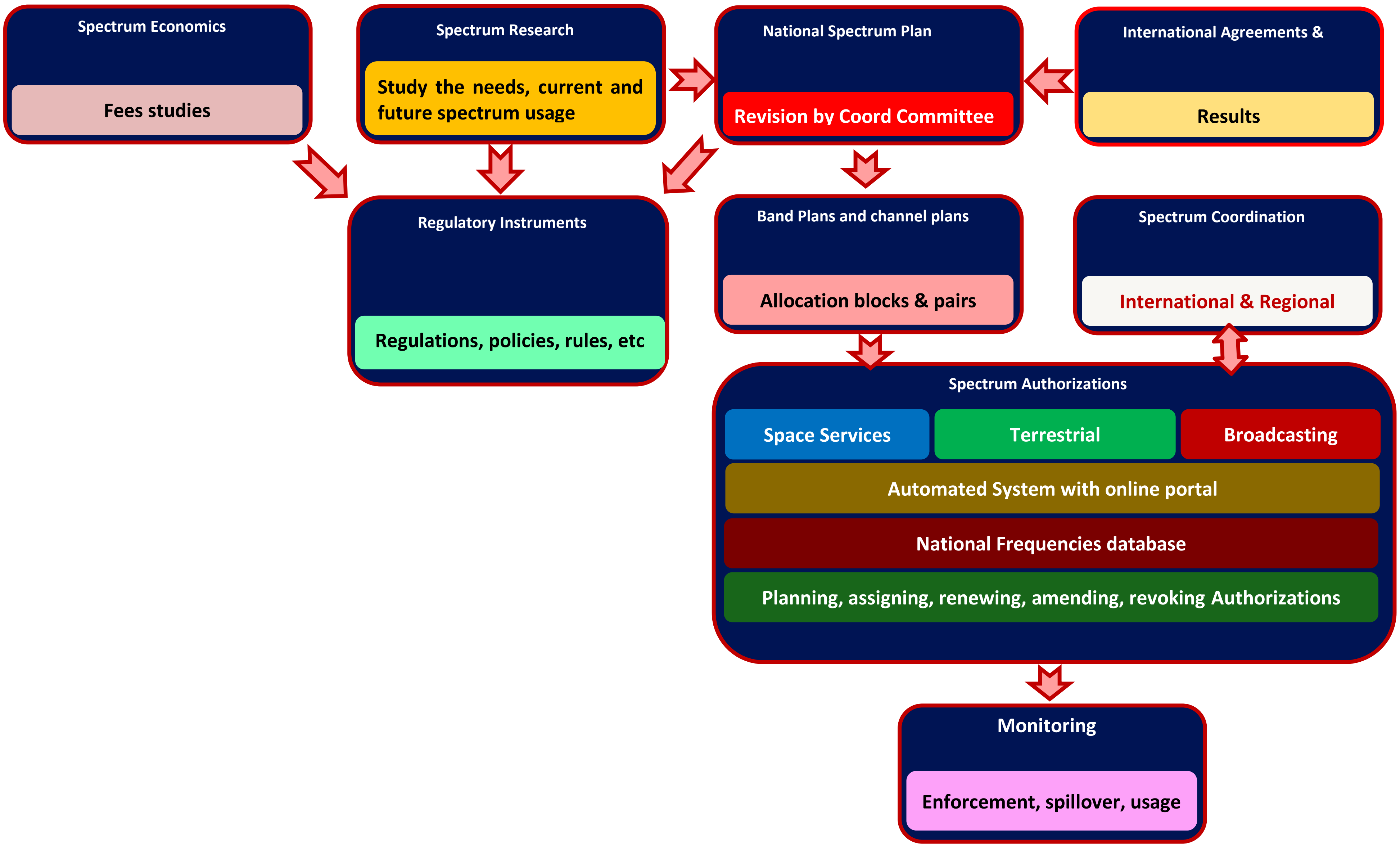
– **International Affairs** – Undertake radio spectrum coordination with other countries represent the UAE at all international forums as the UAE Administration for Telecom and ICT and manage and regulate the space services of UAE.

3 Processes description

SIA has various processes which are put in place to carry out all the tasks entrusted to the SIA within TRA. SIA has interactions with department which are within TRA, within UAE and other international entities. The following Figure highlights some of the entities with which SIA interacts.

SIA also maintains database of all spectrum authorizations. SIA has tied up with a supplier for providing SIA with the latest tools for spectrum data base management. SIA has also tied up with three suppliers to provide spectrum monitoring tools and equipment.

The following depicts interactions between various SIA sections:


Spectrum Economics
Fees studies
Spectrum Research
Study the needs, current and future spectrum usage
National Spectrum Plan
Revision by Coord Committee
International Agreements &
Results
Regulatory Instruments
Regulations, policies, rules, etc
Band Plans and channel plans
Allocation blocks & pairs
Spectrum Coordination
International & Regional
Spectrum Authorizations
Space Services
Terrestrial
Broadcasting
Automated System with online portal
National Frequencies database
Planning, assigning, renewing, amending, revoking Authorizations
Monitoring
Enforcement, spillover, usage

4 Quality management system

4.1 General requirements

SIA has established documented, implemented, maintains and continually improves a quality management system covering the requirements of ISO 9001:2008. SIA has:

a) determined various processes needed for the quality management system;

b) determined the sequence and interaction of these processes;

c) determined criteria and methods required to ensure the effective operation and control of these processes;

d) ensured the availability of information necessary to support the operation and monitoring of these processes;

e) put in place measures to monitor and analyse these processes;

f) implemented actions necessary to achieve the planned results and continual improvement.

SIA manages these processes in accordance with the requirements of ISO9001:2008 standard.

4.2 Documentation requirements

4.2.1 General

The company has prepared its quality management system documentation, which includes:

a) **Quality system Manual:** Quality system Manual is a top level policy document outlining the structure and general principles of the quality management system. It describes the interaction of various elements of ISO9001:2008 with the quality management system in SIA.

Quality system Manual is prepared by the *QCR – SS*, reviewed by *QMR* and approved by *EDSIA*. Controlled copies of Quality System Manual are distributed to all the concerned persons in the controlled distribution list, given on the second page of the Quality Manual.

b) **Procedures:** The procedures are the second level quality system documents, which contain a detailed description of how requirements, as specified by ISO 9001:2008 standard, have been addressed and implemented in various functions of the company. Procedures are prepared by the concerned sections, reviewed by heads of sections and approved by EDSIA. The procedures serve as an operational guide for all the concerned staff to ensure that processes are carried out in a controlled and systematic manner. Controlled copies of Procedures are distributed to all the concerned persons in the controlled distribution list, given on the second page of the each procedure.

c) **Quality records:** Quality records, which are generated as a result of activities that SIA is involved in, are properly referenced in all the relevant procedures, and include data/records such as reports, log sheets and other reports generated while performing routine activities.

4.2.2 Quality manual

The scope as well as details of exclusions is included in section 1 and section 3 describes the process interactions.

4.2.3 Control of documents

The organization has established a procedure for controlling documents used in its quality management system. This control ensures that the:

a) documents are approved for adequacy prior to release;

b) documents are reviewed, updated as necessary and re-approved;

c) documents are identified with current revision status;

d) the relevant versions of documents are available at all locations where activities essential to the effective functioning of the quality operating system and process are performed;

e) documents remain legible, readily identifiable and retrievable;

f) applicable documents (regulations, notifications, etc.) of external origin are identified and their distribution controlled;

g) obsolete documents are removed from all points of issue or use, or are otherwise controlled to prevent unintended use. Any obsolete documents retained for legal or knowledge preservation purposes are suitably identified.

It must be noted that all the latest controlled copies are kept with the QMR. All copies which are downloaded from the server and printed and which do not display any stamp are deemed as uncontrolled copies. The established procedure for control of documents is Internal procedure for “Document and data control” TRASIAP21.

4.2.4 Control of records

Quality records are maintained and controlled to demonstrate conformance to requirements and effective operation of the quality management system. SIA has established and maintains quality management system procedures for record identification, storage, retrieval, protection, retention time and disposition of quality records. The established procedure for control of documents is Internal procedure for “Document and Data Control” TRASIAP21.

5 Management responsibility

5.1 Management commitment

SIA management is fully committed to quality and demonstrates commitment to the development and improvement of the quality management system by:

a) communicating at all sections in SIA the importance of meeting customer as well as regulatory and legal requirements;

b) having established SIA quality policy and quality objectives which are developed for each individual section and ensuring that they are deployed effectively;

c) performing management reviews and ensuring that quality performance is effectively reviewed every six months; and

d) ensuring the availability of necessary resources to help implemented and maintain the quality management system.

5.2 Customer focus

SIA is constantly engaged in promotion of latest telecommunications related developments through active participation at ITU and other international and national forums. SIA top management ensures that SIA is proactive in ensuring that it is prepared to cater to any current and future requirements for its customers.

5.3 Quality policy

SIA has established a quality policy. The quality policy is communicated through awareness sessions, training, displayed in Arabic and English at appropriate locations in offices. The quality policy will be reviewed at least once every year in the management review meetings to ensure that its continuous suitability.

The quality policy is produced on the following page for reference. The original copy of the quality policy can be found with QMR.

"QUALITY POLICY (Spectrum and International Affairs)

Spectrum and International Affairs Department at Telecommunications Regulatory Authority of the United Arab Emirates is committed to apply the highest standards of quality in offering services to its customers and partners using advanced systems in assigning, allocating, monitoring and coordinating frequency spectrum in accordance with international best practices in spectrum management.

The Department is also committed to safeguard the United Arab Emirates interest of its customers and partners, efficiently and effectively at Regional and International ICT forums."

5.4 Planning

5.4.1 Quality objectives

SIA has established quality objectives at in all sections within the SIA. These objectives are defined in measurable terms and are based on Key Performance Indicators identified for each section. These objectives are reviewed periodically as defined in the quality objectives matrix and are consistent with the quality policy, and the commitment to continual improvement and meeting requirements for products.

5.4.2 Quality management system planning

SIA has established various tools of planning which includes quality objectives set by the top management. SIA participation in various International and Regional forums also contributes towards the planning of the various activities undertaken by SIA within TRA.

5.5 Responsibility, authority, and communication

5.5.1 Responsibility and authority

SIA is one of the departments in the TRA responsible for Spectrum and International Affairs services. Within TRA, Human Capital section in the Support Services Department is responsible for defining roles and responsibilities for each position. The Quality System Procedures through processes also describe the responsibilities of personnel in relation to various quality system requirements. The organisation chart is reproduced on the following page for reference. The original copy of the quality policy can be found with QMR.

5.5.2 Management representative

EDSIA has appointed the Senior Manager, Spectrum Strategy as the Quality Management Representative (QMR) who, irrespective of other responsibilities, has defined responsibility and authority for the quality management system, which includes:

a) ensuring that processes of the quality management system are established and maintained in accordance with the requirements of ISO 9001:2008;

b) reporting to top management on the performance of the quality management system, including needs for improvement;

c) promoting awareness of customer requirements throughout the organization.

d) liaison with external parties on matters relating to the quality management system.

5.5.3 Internal communication

SIA has established internal communication between various levels and functions. All the relevant functions have individual e-mail addresses as well as dedicated internal communication equipment. In addition, desktops and laptops have been provided to all relevant functions and levels as the case may be. EDSIA also regularly interacts with senior managers as well as other staff to ensure smooth communication. Departmental meetings are held whenever required to ensure that all the people are aware about planning and execution of various strategies formulated by the top management.

5.6 Management review

SIA will review the overall quality management system through regular management reviews. The management review will be held at least once in six months. These reviews would ensure the continuing suitability, adequacy and effectiveness of the whole quality system. The review includes evaluation of the need for changes to quality management system, including quality policy and quality objectives. The agenda for the management review meeting would be circulated at least one week prior to the management review meeting.

The management review would include discussion on the following as a minimum:

a) results of internal and external audit reports;

b) customer feedback including any customer complaints that need to discussed in the management review;

c) process performance and product conformance;

d) status of preventive and corrective actions;

e) follow-up actions from earlier management reviews;

f) changes that could affect the quality management system;

g) review of quality policy and quality objectives;

h) Recommendations for improvements.

The management review would document the decisions made in the management review meeting and also allocate responsibilities and time-frame to implement the decisions. Management reviews are recorded through the minutes of meeting of each management review meeting.

6 Resource management

6.1 Provision of resources

In light of the management reviews and other management controls, the top management considers the requirements for appropriate resources, and ensures that they are provided on a timely manner. In each section of the SIA, a quality circle representative is nominated. As SIA is part of TRA, customer relationship is managed by the corporate communications affairs department however relevant records of customer communication are maintained by the EDSIA.

6.2 Human resources

6.2.1 General

The management of human resources is considered as one of the most important processes of the Quality Management System. Within TRA, Human Capital Section is mainly involved in ensuring that competency requirements are met. The data with relation to each employee’s competency and training is also kept with Human Capital.

6.2.2 Competence, training and awareness

SIA which is a part of TRA is not directly involved in all processes involving training, awareness and competency. As TRA is an entity of Government of United Arab Emirates and since Emiratization drive is one of the main focus of the Human Capital Section, Emiratis are recruited on the basis of their education and subsequently given on job training for building up the necessary competency.

In SIA, competency requirements for positions are developed by EDSIA and if needed, in consultation with relevant senior managers. Training requirements are evaluated at the end or beginning of every year and communicated to EDSIA for further processing. All the training needs are then put on a training schedule. The feedback on training is given at the end of training to the training service providers. Evaluation of the eventual effect of training on the employee performance is done through annual performance appraisals.

6.3 Infrastructure

SIA has been provided with all necessary infrastructure by TRA to adequately discharge its assigned tasks. SIA has two location from which it operates, one is in Abu Dhabi and the other is in Dubai. Adequate workspace has been provided in well designed buildings. Associated facilities provided include desktops, work equipment, desks, cubicles, etc. to all employees. In case of any new infrastructural requirements, relevant communication is made to the Administration department of TRA by the EDSIA. As one of the main roles of SIA is spectrum management hence a spectrum management system has been provided to handle cases related to applications. Regular updates are made to the spectrum management system by the supplier. Maintenance is also done regularly by the supplier. One of the key aspects of effective spectrum management is effective spectrum monitoring. A spectrum monitoring system has been provided to handle cases related to spectrum verification, etc. Maintenance of Spectrum Monitoring System is done as per internal procedure for “Maintenance Procedure for Spectrum Monitoring System” (TRASIAP05).

6.4 Work environment

Adequate work environment is one of the important factors affecting any organization. to manage the quality system. In this regard, SIA ensures that a healthy, safe, and conducive environment is maintained at the workplace. SIA has determined and manages the work environment needed to achieve conformity to product requirements. This includes reasonable ambient working conditions such as noise, temperature, etc.

7 Product realization

7.1 Planning of product realization

SIA is involved in various activities in relation to spectrum management and international affairs. SIA is further divided into five sections namely:

– Spectrum strategy
– Spectrum allocation
– Broadcasting
– International Affairs, and
– Spectrum monitoring.

International affairs section interacts with the international entities in relation to spectrum and communicates the requirements to the spectrum strategy and spectrum allocation as well as Broadcasting along with the EDSIA. Co-ordination also happens with various other entities within UAE as well as regionally and with other departments within TRA.

Spectrum allocation is the section responsible for the delivery of service to its SIA customers as it is the section which issues spectrum authorizations. Spectrum Monitoring Section is responsible for speedily resolving all spectrum monitoring related issues for SIA customers.

Effective planning of executing all planned arrangement is done by:

a) setting quality objectives for each section in relation to their processes;

b) required verification, validation, monitoring, inspection and test activities for spectrum application as well as spectrum monitoring;

c) records of spectrum application processing as well as spectrum monitoring along with relevant records of other sections;

Arrangement exists within the internal procedures for required verification of spectrum applications and other controls.

7.2 Customer-related processes

7.2.1 Determination of requirements related to the product

SIA receives spectrum authorization applications through online SPECTRAweb system. Spectrum monitoring may receive any interference complaint or any other issue through any mean of communications. Determination of requirements of spectrum authorization is done through the SPECTRAplus system as per the internal procedure for "Application handling including technical analysis and frequency assignment" (TRASIAP01). Spectrum monitoring is done through internal procedure for "Interference Complaint Handling and Monitoring" (TRASIAP04) and Spectrum Enforcement (TRASIAP07). For other section such as broadcasting, internal procedure for "Analysis of BR-IFIC" (TRASIAP03) gives requirements with relation to analysis of BR-IFIC. BR-IFIC is also analysed by International Affairs and hence, requirements of BR-IFIC for International Affairs is also mentioned in the TRASIAP03. International affairs section is also entrusted with the responsibility of international and regional co-ordination and is involved in various international interactions. An internal procedure has been developed for "Preparation for International Meetings" (TRASIAP02). Spectrum Strategy section is involved in development of regulatory instruments which is done through internal procedure for "Preparation, co-ordination, approval, issuance and review of SIA regulatory instruments" (TRASIAP06).

7.2.2 Review of product requirements

SIA reviews the requirements related to the product. This review is conducted prior to the issue of spectrum authorization to customers. The review process ensures that:

a) spectrum frequency requirements are clearly defined;

b) appropriate approvals are obtained from relevant functions.

The results of reviews and subsequent follow-up actions are recorded. It is ensured that relevant spectrum authorization parameters are amended as per the result of review. If in case any change occurs in the process of review, then relevant communication is made to all the relevant personnel within SIA.

7.2.3 Customer communication

SIA is a department within TRA and TRA has a Corporate Communications Affairs department which is tasked with handling all customer communication. SIA does not directly liaise with its customers however records pertaining to customer communications including spectrum applications, interference issues as well as any feedback is kept with the EDSIA office. EDSIA office keeps a log of customer communications which they received from the Corporate Communications Affairs Department and then forward to the relevant section and also follow-up with them for ensuring that a feedback is given promptly.

7.3 Design and development

SIA as a department is not involved in any design and/or development activities and hence, this clause is excluded from the scope of the quality management system.

7.4 Purchasing

SIA department exerts no direct control on the selection of suppliers however it has a major role in the selection of suppliers which also involves interactions with other departments within TRA. SIA has two major suppliers whose performance directly affects its capacity to discharge its tasks. LS Telcom, TCI, Rohde & Schwarz and ASCOM Network Testing are the suppliers of Spectrum Management System and Spectrum Monitoring System, respectively. LS Telcom, TCI, Rohde & Schwarz and ASCOM Network Testing are evaluated regularly and the results of such evaluation communicated to the suppliers. Internal procedure for "Suppliers selection and evaluation procedure" (TRASIAP26) details the process.

7.5 Production and service provision

7.5.1 Control of production and service provision

SIA carried out its tasks in a planned manner through the relevant procedures and processes. The specifications with relation to the spectrum authorizations are managed by the spectrum management system. State-of-the-art monitoring systems are used to monitor and enforce the use of spectrum.

7.5.2 Validation of processes

SIA does not need validation for any of the processes that it carries out and hence, it is excluded from the scope of the quality management system.

7.5.3 Identification and traceability

All spectrum authorizations have a unique identification number and can be used to trace the path from the application to the final issue to authorization. Relevant records are stored within the spectrum management system.

7.5.4 Customer property

SIA classified all customer information received in form of spectrum application as customer property and as standard practice does not share or allow this information to be shared with unauthorized personnel.

SIA stores the customer details in the database which is kept off-site at Data Hosting Centre.

7.5.5 Preservation of product

SIA ensures that all spectrum authorizations are handled adequately, are identified and packaged properly to ensure that it is protected from damage during delivery.

7.6 Control of measuring and monitoring devices

SIA uses spectrum monitoring system for carrying out monitoring at various locations within UAE. TCI has supplied a self-calibrating spectrum monitoring system and hence there is no need for calibration. Operation manual and maintenance manual specify all the steps to be followed to ensure that spectrum monitoring system is operating as per the requirements.

8 Measurement, analysis and improvement

8.1 General

SIA uses suggestions and complaints system in combination with KPIs for each section to effectively monitor measure, analyse and subsequently improve the processes.

8.2 Measurement and monitoring

8.2.1 Customer satisfaction

SIA has determined and established process for monitoring information on customer satisfaction and/or dissatisfaction to assess whether the SIA has met the customer requirements. A customer service questionnaire has been developed and used to determine customer satisfaction. The survey shall be conducted at least once every twelve months. The results of the customer survey shall be analysed and discussed in the management review meeting. SIA has documented an internal procedure for “Handling of Customer Complaints & Feedback” (TRASIAP25) which includes relevant details for conducting customer satisfaction survey.

8.2.2 Internal audit

The internal audit process acts as a management tool for independent assessment of any designated process or activity.

SIA established an internal procedure for "Internal Quality Audit" (TRASIAP22). SIA plans the audit schedule at the end of every year. SIA has competent internal auditors to conduct the internal audits. The result of the audit is an audit summary report containing findings.

The findings are classified into following types:

– positive findings

– observations

– non-conformities.

The results of internal quality audit shall be presented in the management review meeting.

8.2.3 Measurement and monitoring of processes

SIA applies suitable methods for measurement and monitoring of processes necessary to meet customer requirements and to demonstrate the processes continuing ability to satisfy its intended purpose. In case of non-conformance with the planned result, correction and corrective action are taken to ensure conformity of product as per the relevant procedure given in section 8.3.

8.2.4 Measurement and monitoring of product (clause 8.2.4 of ISO 9001:2008)

SIA applies suitable methods for measurement and monitoring of the spectrum authorizations. Spectrum authorizations are given after appropriate approvals and are also forwarded to the spectrum monitoring section for their reference. If needed, processes also exist to ensure that the spectrum authorization to be issued is free of interference. Evidence of implementation of required measurement and monitoring and conformance with the acceptance criteria used is recorded.

8.3 Control of nonconforming product

SIA ensures that products that do not conform to requirements are controlled to prevent unintended use or delivery. The controls and related responsibilities and authorities for dealing with non-conforming products are defined and documented in internal procedure for "Control of Non-Conforming Service" (TRASIAP23).

8.4 Analysis of data

SIA collects and analyses appropriate data to evaluate the suitability and effectiveness of the quality management system and to identify areas for continual improvement. This includes data generated by measuring and monitoring activities and other relevant sources. Decisions based on facts are based on effective and efficient use of appropriate statistical techniques.

The analysis of data provides information on:

a) customer satisfaction and/or dissatisfaction;

b) characteristics of processes and products and their trends.

8.5 Improvement

8.5.1 Continual improvement

SIA continually strives to continually the effectiveness of improve quality management system through the use of quality policy, quality objectives, audit results, analysis of data, corrective and preventive actions and management review. The quality objectives are reviewed in each management review meeting with a focus to improve performance of different sections.

8.5.2 and 8.5.3 Corrective action and preventive action

SIA ensure that corrective and preventive actions are taken to eliminate the causes of non-conformities in order to prevent their recurrence. The extent of corrective actions taken shall depend on the impact of the problems encountered.

A corrective / preventive action request may be raised by any employee. Any customer complaints received shall also be treated as non-conformity and a corrective / preventive action request shall be raised.

SIA has documented the process for taking corrective and preventive action in internal procedure "Corrective & Preventive Action" (TRASIAP24).

CHAPTER 2

Spectrum planning

Table of Contents

Page

2.1 Introduction

The purpose of any planning effort is to organize and focus thoughts and actions for the efficient and effective achievement of directed, or agreed goals and objectives. This effort is important for any country (and especially important for developing countries) which wants to initiate or improve a national spectrum management process.

A plan promotes action, rather than reaction. It may be applicable for a specific period or event with finite time bounds, or it may be a standing statement, periodically updated to reflect changing policy or events. It may be written or verbal, general or specific, each form having advantages or disadvantages. A written plan is recommended.

Planning is a process that must precede the efficient and effective conduct of any activity, be it governmental or business. Immediate or "crisis" resolution of issues generally means that the best solutions are no longer available. Spectrum planning is no different. Optimum solutions require a forward-looking perspective that gives adequate time to consider all the factors involved. Planning, however, requires the establishment of, and the commitment to processes to carry it out, because crisis situations can always divert attention from long-term tasks. Short term, medium term and long term planning is an absolute necessity for management of the spectrum that adequately satisfies dynamically changing spectrum requirements.

Management and use of the radio spectrum demand the direction of effort and cohesion provided by planning if the electromagnetic spectrum resource is to adequately support national goals and objectives. Spectrum planning is the process of setting spectrum management goals for the future and establishing the steps to achieve those goals. Thus, planning provides the framework within which spectrum is available for the constantly evolving radio spectrum needs, and the spectrum management system itself is developed and improved. Planning facilitates decision-making by creating the bases for consideration and evaluation of courses of action. Spectrum planning must support, and follow, the major directions and needs of the current and future spectrum users.

The purpose of spectrum management planning is to optimize accommodation of users through the:

– development and implementation of an effective spectrum management organization;

– development and implementation of spectrum policies, rules, and regulations;

– establishment of capabilities that promote efficient and effective spectrum use;

– allocation of spectrum to radio services and radio applications; and

– organization, structuring, and authorization of specific radio systems or services.

For instance, if needs for mobile spectrum will increase over five or ten years, the spectrum management process should attempt to anticipate those developments and ensure that adequate spectrum will be allocated to the mobile service to meet those needs. To be able to achieve that goal, it is essential that analysis capabilities, coordination procedures, and supporting databases be in place to support the accommodation of mobile systems. These capabilities take time to develop. At the same time, the difficulty of identifying additional spectrum to be available in the future places pressure on equipment developers to produce more efficient equipment that will enable meeting the need for telecommunications while using less spectrum than under existing technology.

The most basic, well recognized and essential form of a spectrum plan is the Table of Frequency Allocations. The national table derives from the international table and both represent a fundamental effort to structure the spectrum to meet future needs. While the *international* Table of Frequency Allocations represents the outcome of a process of identifying future needs, setting radioconference agendas, study, negotiation and agreement, the *national* plans of the ITU Member States provide the power behind this process, leading to a recommendation of future agenda items, studying sharing considerations, and proposing allocations with related regulations. The national plan then draws from the framework of international agreements to revise or implement the national plan through the national allocation table and associated regulations.

This Chapter covers the value of spectrum planning, related definitions, establishment of planning objectives, the planning process itself including techniques to apply, and the sources of data on which planning is based.

2.2 Significance of planning

Spectrum applications are crucial to stimulate economic growth, will being of citizens and participation in the international community. Furthermore, the level and variety of radio use is rapidly expanding and, by virtue of radio propagation properties at higher frequencies, many new requirements can be accommodated by moving into higher frequency bands. In many cases, spectrum managers are using increasingly complex engineering solutions to allow adjacent or overlapping use of frequencies and geographic locations, placing new and increased burdens on the spectrum management structure and staff. In some cases, accommodating new uses means moving or redeploying existing operations, but often at significant cost. Possible relevant trade-offs are indicated in this Chapter.

The spectrum is a very flexible resource and with sufficient decision lead-time, new spectrum requirements can be accommodated. Advance identification of spectrum conflicts will help ensure cost-effective or efficient solutions while continuing to encourage telecommunications growth. Timely development of advanced spectrum management tools will be essential to finding such solutions. Development or purchase of telecommunications equipment generally requires a long-term commitment because of the equipment’s expense and complexity. Therefore, spectrum management plans and spectrum-related decisions may be in effect for many years, accommodating some users, while possibly delaying others or increasing the potential for interference to existing users, while technical or administrative solutions are sought. Delineation of strategic national goals could provide spectrum users and equipment manufacturers a framework for successful application of spectrum technology and new services in the future.

Good planning is crucial if the maximum economic and social benefit is to be achieved from the implementation of radiocommunications systems. Spectrum planning can facilitate radiocommunications growth, and the importance of planning will grow as the demands for spectrum increase and spectrum management efforts turn toward prevention of interference and identification of spectrum for growing needs.

In all areas of endeavour, managers tend to give the most attention to immediate issues. Attention to planning is often forgotten in efforts to deal with current problems. It seems that planning can always be postponed. Yet a spectrum management system of the quality required to facilitate economic growth and meet modern demands will almost certainly need such planning. Few fields of government or business can venture ahead successfully without it.

2.2.1 Planning benefits versus costs

Any planning effort is intended to maximize benefits by preparing for the future. Dealing with a chaotic circumstance that has developed from a lack of direction, or having to change direction rapidly or frequently carries with it great cost, lost time, and lost opportunity. Moving equipment designed for one band into another (redeployment of frequency bands), on one hand can be extremely costly, but on the other hand, if planned well, can be cost-beneficial by allowing earlier application of better and spectrum-efficient technology. Ineffective, interference ridden, poorly planned services can slow economic growth and frustrate development. Delays in implementation of systems due to a lack of available spectrum, or the lack of an adequate regulatory plan can cause significant losses for the promoters of the system and loss of the benefit provided by the system’s operation.

As with any task there will be costs associated with providing adequate resources. These costs involve collecting, reviewing, and maintaining information; consulting users and international representatives; coordinating positions; preparing plans; and negotiating agreements. However, the primary argument against long term spectrum planning is not the cost of performing the function but that spectrum use and technology are so dynamic that only reactive decisions or short lead-time decisions can be made. Thus, the argument goes, planning will inevitably be flawed, and cost will be experienced through incorrect plans. It can also be argued that spectrum management has proceeded well in the past without long term projections and that inaccurate projections can lead to allocations to services that do not develop as anticipated (because of technological or economic difficulties). While such allocations are in theory reversible, it may be difficult to do so as a practical matter, once some level of service has been established and investments in equipment by service providers and their customers have been made.

The prospects of planning are more problematic as efforts move from short term into long term; however, a refusal to plan is not an adequate solution. The more costly short term movement of pre-existing uses is likely to be the result of failure to plan. When new uses and services are not adaptable to higher frequencies (where spectrum is still available and will be for some time), spectrum managers could face no other choice than to make room for them by moving pre-existing uses and services that are not frequency-limited. Pressures to move pre-existing uses could be especially great where the new uses appear to be very valuable and offer opportunities for rapid service and economic growth. These decision criteria put many users and related investment in jeopardy if spectrum managers do not provide sufficient lead-time for the redeployment. If planning does not provide the lead-time, then implementation of new systems will slow.

One argument against long term planning presupposes an inability on the part of spectrum managers to update plans as better information becomes available. However, any process of planning, and particularly long term planning, must be linked to a schedule for regular review and revision.

Plans are not useful if they become rigid and dogmatic. In a dynamic field like radio spectrum management, such plans should avoid irreversible decisions that lock-in particular results, but should survey a long period of time to set out a path to achieve spectrum management objectives. Any commitment to long term planning must include a commitment to a process of revision in which managers regularly reconsider plans in the light of developments.

Spectrum managers still bear responsibility to plan for new uses of the publicly held spectrum resource, and planning should deal more with improving the management and use of the spectrum rather than extending regulatory authority. In spectrum plans, some aspects of spectrum use and management might be dealt with through general policies, while others need the delineation of more specific steps. Greater flexibility in the methods of spectrum management may provide room for innovation and changes of direction, but even the methods for achieving that flexibility must be planned. Thus, for example, developing and implementing greater reliance on market principles and user flexibility in the spectrum management process are appropriate components of spectrum planning, particularly in developing countries.

2.2.2 Definitions of spectrum planning

An understanding of spectrum planning requires some agreement on terminology. Spectrum planning can be broken into categories in terms of time (short term, long term, and strategic) and in terms of the areas covered (spectrum use, and spectrum management systems). All definitions listed in Table 2-1 are for the purposes of this discussion. Similar terminology may have a different application in other fields.

Service or network planning is best left to the service or network operator and is, therefore, not treated further in this Handbook.

TABLE 2-1

Definitions

Short term planning	Planning that considers issues needing resolution or systems to be implemented within from 3 to 5 years
Long term planning	Planning that considers issues needing resolution or systems to be implemented within 5 to 10 years
Strategic planning	Planning involving the identification of a limited number of key issues, which require concentrated spectrum management attention for solutions which need more than 10 years to be implemented
Spectrum use planning	Planning involving spectrum use issues i.e. allocation, allotment, assignment, standards, etc.
Spectrum management system planning	Planning involving spectrum management techniques, analysis methods, organization, resources, computer implementation, etc.
Service or network planning	Planning of specific systems' characteristics and operations

2.3 Planning processes

Spectrum planning processes cover any of the spectrum management actions or decisions that directly govern how the spectrum will be used. This includes such aspects as allocations, policies, allotments, assignment rules and standards. Actions in each of these areas determine how bands will be used, how radio services are implemented, and in some cases, which technologies will be accepted or if the market alone will establish what technologies prevail. The national allocation table serves as the primary plan for spectrum use. Other planning actions form subsets of that framework.

The allocation, allotment, and assignment of spectrum, and setting of spectrum standards are crucial aspects of spectrum management. Plans to account for and accommodate changing spectrum use can greatly facilitate the implementation of spectrum services and assist national development. Spectrum use plans should account for such factors as major shifts in spectrum use, emerging technologies, new services for which the current allocation table makes no provisions, user plans for changes in use, projected crowding in specific bands or locations, and finally potential changes in allocations or allotment plans that will result from a WRC.

The scope of a spectrum use plan may be limited by the period for which it applies, limited in frequency range or services considered, or limited to some other specific issue. Long range plans generally cover larger topic areas, taking into account, for example, the results of a WRC. The information considered within spectrum use planning must include data on current use, allocations, assignments and technologies, future use requirements, and available spectrum. Analysis of spectrum use requirements, to be of value, must evaluate non-technical economic and political factors. Where technical solutions allow for all economic and political criteria to be met, plans can be formed easily. More often, all the trade-offs, namely, political, legal, economic, social, ecological, and technical, must be considered. Final decisions must be made and plans derived that will assist the administration toward its goals. Usually these plans are developed in concert with new national allocations, policies, or rules and regulations. In many cases, plans with milestones for implementation are presented. Such plans, not being implemented all at one time, allow opportunity for future revision. A list of factors that may influence spectrum planning is shown in Table 2-2.

2.3.1 Establishing spectrum planning objectives

The identification and establishment of spectrum planning objectives is a necessary part of the planning process. To do so requires consideration of how to optimize use of the radio spectrum. This consideration includes the potential growth of existing radio services as well as the introduction and growth of new services and applications. Moreover, consideration should be given to changes in use of the spectrum by industries, businesses, government, and the general public. It is critical in identifying and establishing objectives to include inputs from local and national government agencies, relevant industries (both large and small), and from all appropriate geographically-dispersed interests. An evaluation should be made of the current national spectrum planning processes and elements to determine strengths and weaknesses as perceived by industry and government. The outcome of this evaluation will form the basis for the development of spectrum planning objectives.

TABLE 2-2

Factors that may influence spectrum planning

Policy and legal factors National radiocommunication law Regulatory requirements International frequency allocation (ITU) Regional frequency management bodies National frequency allocation procedure Frequency management procedures of neighbouring administrations Standardization policy Telecommunications infrastructure Industrial issues User needs Security and public safety **Economic factors** Globalization Overall economic development Structure of prices and tariffs for equipment and services Market needs and marketing issues Procedures and practices used by service providers Spectrum auctions or fees The economic impact of new services and technologies	**Social and ecological factors** Changes in demand as a result of changes in social structure Changes in demand as a result of changes in daily and life-time working hours Public acceptance of wireless applications Electromagnetic pollution and radiofrequency interference Public dislike of large antenna structures and proliferation of sites Debris in space **Technical factors** User mobility Basic technologies Microelectronics Signal processing Data processing in telecommunications Equipment components Power supplies Batteries Communication media Coding (source and channel) and modulation techniques Channel access techniques and transmission modes Spread spectrum techniques Diversity techniques, e.g. time, frequency, space Antenna design or optimization Antenna characteristics, e.g. direction or adaptive Reduction of side-lobe level of antenna pattern

2.3.2 Elements to consider

Spectrum planning under any of the planning definitions may determine future, broad-based national spectrum requirements for radio services based on technological, legal, social, ecological, policy and economic factors, all of which may influence spectrum use. In order to satisfy spectrum use needs, spectrum managers must first identify current and future requirements[29], and available spectrum, before they can determine how best to accommodate those requirements. Spectrum managers must have adequate information to permit analysis upon which to base planning estimates and decisions. The identification of future requirements must be timely, in order to ease any necessary redistribution (including redeployment) of spectrum or spectrum assets. Before the spectrum can be efficiently managed, it is necessary to have an inventory of spectrum users, and to identify what spectrum resources are available. These resources depend on:

– the number of spectrum users (i.e. the number of frequency assignments granted, along with the number of radio stations);
– relevant characteristics of the radio stations;
– geographical distribution of the radio stations to a certain, uniform degree of precision;
– potential influence of the radio stations on one another.

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[29] The term “requirements” is intended to be a general term for current and future spectrum needs, incorporating concepts of capabilities required, systems and their characteristics, and associated required frequencies.

National frequency register

Information is normally drawn from the national frequency register but it may be supplemented by, and integrated with information available from other sources as well, e.g. the ITU international frequency register, national monitoring, inspection records, etc. A database of calculated values of spectrum usage indicators could be an important supplementary resource. Depending on the type of planning underway, the spectrum usage database will be helpful to different degrees.

National frequency registers should serve as the primary resource for evaluating current use. To make decisions impacting spectrum users, the register must provide an adequate level of technical and management information. A register consisting of frequency, user name, and location alone will not provide adequate information for considering most issues. Information associated with the function performed by equipment, costs involved with system implementation, and detailed technical characteristics are often essential elements in the decision process. In cases where international use must be considered, the national register may need to be supplemented by the BR International Frequency Information Circular (BR IFIC).

Monitoring

Information, obtained through spectrum monitoring, about the actual use of frequencies may be used to supplement national registers. Spectrum monitoring, consisting of spectrum occupancy measurements, enables spectrum managers to correlate the actual level of use associated with assignment records or to provide information when no register is available.

In assessing the level of use, the type of service must be taken into account. Some public service users pose special issues in measurement. For example, because of government agencies' roles in emergency or defence services, measurements of everyday use may not help in portraying these spectrum requirements. Therefore, care should be taken in trying to estimate spectrum use through monitoring methods, and results should be critically examined in the light of other information about the expected uses (see Chapter 4).

Exchange of information with other administrations

The outcome of planning activities will often impact spectrum users outside the national borders. In those cases, planning activities may include coordination of information, and plans under consideration, with neighbours or the international community as a whole. Information available from administrations will vary. In some cases, the issue of classified information makes obtaining adequate information more difficult.

General consultative inquiries

The national spectrum manager may also gather information through the use of inquiries as part of a general consultative approach. Public inquiries permit the spectrum manager to gather a wide range of information on specific topics, such as frequency ranges and the provision of radio services. An inquiry can be performed through the use of an open process where information is collected through a public written request or through an open speaking forum, or through a more restrictive process employing direct consultation with specified national groups. These groups can be standing committees or groups drawn together for the specific purpose of answering the inquiry. Regardless, the inquiry should ask questions with respect to the essential issues involved in the particular planning decision.

Future spectrum use

Any spectrum use plan must take into consideration future national and international uses of the spectrum. Obviously, assignment registers and monitoring cannot be used as the total source of this information, although rates of change of information provided by either source, or monitoring of experimental uses, can be used as supplementing information to produce some estimates.

International trends

Because of the worldwide implementation of many radio systems, international trends can be crucial to plans involving future use. In cases where the use of widely distributed equipment is involved, it makes little sense for one country to go about setting rules, e.g. establishing a channelling plan, when the only available equipment is being built in accordance with different standards. These trends can be identified through professional literature, through direct consultation with businesses or government representatives of other countries, or through participation in ITU-R study groups and in world radiocommunication conferences.

Spectrum use forecasts

Another means of trying to understand the future state of spectrum use is through spectrum use forecasting. Forecasting can be defined as the processes and methods of estimating spectrum requirements based on projections. Forecasting can entail prediction of application of new technologies or spectrum demand trends, and estimation of their impact. Spectrum managers may base such forecasting on both empirical methods and fully informed judgment.

Since most planning involves some estimates concerning the future, the spectrum manager's choice is whether forecasts are explicit and well structured, or implicit and based on unstated and unproven assumptions. Among the virtues of structured methods are that they can be taught and results are repeatable. Furthermore, with such methods, the assumptions and data relied upon are clearly stated and the analytic methods employed are open to review. As a result, the limitations and qualifications applicable to such forecasts are more easily understood. Rapid and unpredictable technological changes are often given as reasons for not using spectrum forecasts. However, technological breakthroughs seldom occur without some warning, and major changes usually involve incremental steps.

Four primary sources of forecasting information could be applied to spectrum planning. They are expert input, trend analysis, technology tracking, and experiences in other countries. These sources are available to most administrations. Expert input consists of querying of experts for their predictions in the field of radiocommunications. The larger the group, and the more controlled the approach, the better the resulting feedback. Responses will primarily be intuitive responses, but the foresight of these experts can give great insight into future spectrum activities. Trend analysis consists generally of an empirical extrapolation of past performance into the future. This approach is particularly useful in considering the growth of frequency assignments in an area and predicting when action will be required to prevent spectrum congestion. Empirical trends can be developed from other data, such as the technical characteristics of equipment, e.g. transmission bandwidth. In some of the analogue land mobile bands, the operating bandwidths of equipment have been incrementally decreased a number of times with new developments. The rate of this decrease can be considered when analysing whether additional spectrum is needed for growing requirements. If the ability to decrease the bandwidth continues, or alternatively to apply more efficient modulation techniques, the need to provide additional spectrum for the same purpose may be avoided. Tracking of technological improvements can also give insight into the future. Technologies under development now will probably be on the market in a few years. Following these developments in trade publications and symposia, as well as contacting administrations where developments are taking place, could help spectrum managers in considering the impact of these events on their national spectrum use.

Adaptation of forecasting techniques to the spectrum planning process requires careful definition of the scope of spectrum manager forecasting responsibilities. Because spectrum managers generally do not develop telecommunication technology, their primary role has been to respond to current and future user needs to manage spectrum in such a way that there is a long term optimisation of spectrum use in the national interest. Accordingly, forecasts should be based to a great extent on analysis of user predictions of spectrum requirements. Despite the obvious utility and indeed practical necessity of relying on this approach, there are risks involved in accepting user predictions, since they may often be overstated to obtain a larger portion of the resource. User forecasts are bound to favour the purposes of those that prepare them, and spectrum managers should only rely on user forecasts that describe their forecasting methods and assumptions, and discuss how the forecasts might err.

To generate more useful predictions, spectrum managers can add their own forecasting insights to user inputs. Although it would probably not be reasonable for spectrum managers to predict growth for individual users, the accumulation of user estimates, as adjusted based on spectrum manager evaluations, can provide insight into broad, future needs and assist in the allocation of spectrum. In addition, spectrum managers can develop quantifiable trends based upon spectrum use data for all their users.

All forecasts are risky to some degree, but decisions about future spectrum demands can be improved if they take into account well-structured and carefully analysed predictions. Forecasts of usage, technologies, congestion, etc., could be very helpful to the management process, particularly for spectrum allocation decisions.

2.3.3 Spectrum availability

Determination of spectrum availability across all national radio services, with the objective of accommodating spectrum requirements initially identified, must be accomplished. Inputs are primarily derived from within the administration itself but also can come from the ITU International Frequency List, ITU plans and any existing regional spectrum planning studies.

2.3.4 Planning options

Suitable spectrum planning options must be developed, with the objective of satisfying spectrum requirements, on the basis of data derived in identifying spectrum availability. Any analysis for the development of spectrum options would need to take account of technical, legal, social, ecological, political, and economic factors. The analysis would also assess the various opportunities for services given existing and projected radiocommunication environments and/or allocations. Recommendations regarding those service requirements unable to be accommodated within current national allocations will be based on these analyses and any available spectrum monitoring results. Allocation options are developed and the relative costs of any reallocation to and/or movement of existing spectrum users assessed.

2.3.5 Process implementation

Implementation of various spectrum planning strategies could be expected to be an ongoing process. The introduction of new services may require changes to spectrum allocation tables and revisions to national and ITU regulations. Revisions to international regulations would be undertaken at the periodic World Radiocommunication Conferences.

2.3.6 Iteration process

Previous decisions can be re-evaluated periodically or triggered by specific events and, if necessary, modified on the basis of the updated information. The planning process is therefore a continuous process of exploration and data processing rather than a linear process. A record of all changes can be maintained to provide a history of developments for a long term plan.

2.3.7 Plan to support the planning of radio spectrum

To support the planning of spectrum, administrations may set and develop plans for continuous application or certain periods of time (annually or longer term) to determine the actual use of spectrum, in order to provide feedback to the planning process.

Review assigned frequencies. It is convenient to formulate and implement an ongoing plan to the revision of assigned frequency in order to determine the real and effective use that is being given to spectrum assignments. The objectives of this plan should focus on:

- validate and standardize all information concerning the assigned frequencies;
- ensure that the assigned frequencies are used properly and such assignments are contained in the databases of automated spectrum management and control;
- verify that the assigned frequencies are necessary for the provision of telecommunications services and the exercise of the telecommunications activities, according to the licenses to use spectrum;
- ensure that the frequency assignments follow existing regulations;
- update the National Frequency Register with the appropriate level of management and technical information about equipment, locations and detailed technical parameters.

Plan measurement of radio spectrum. It is convenient to design and implement a spectrum monitoring plan, which could be performed annually, in order to determine the technical parameters of radio stations authorized. The objectives of this plan may focus on:

- determine whether the radio stations operate according to the licensed parameters;

- analyse the occupancy of the spectrum and the convenience of reassign and/or refarm radio frequencies in a particular area or region;
- assist to prevent or resolve radio frequency interference;
- review and update permanently the spectrum planning processes in order to optimize them and make them more efficient and effective.

Spectrum destination plan for specific purposes. Administrations should have plans to determine the destination of frequency bands for specific uses. One of the most important aims is allocate frequency bands for national security and first responders. This plan should focus on:

- determine the frequency bands for defence;
- develop and constantly update plans distribution channels and frequency plans in a local and national level.

Similarly, correspond to administrations to develop plans for new technologies.

Spectrum refarming. It is convenient to formulate and implement programs for spectrum redistribution. This plan may focus on:

- determine the new use of RF;
- analyse the occupancy of the existing and refarmed spectrum in a particular area or region;
- determine which frequency bands should be subject to refarming according to the international trends, the ITU radio regulation, country's needs and technological developments.

2.4 Consultative approach

The consultative approach is based on the premise that spectrum planners can, through collaborative proceedings involving, as far as practicable, spectrum users, service providers, and equipment manufacturers, arrive at a reasonably accurate and cost-effective determination of long-term spectrum requirements and use. Thus, consultation takes into consideration analytical and intuitive inputs from the spectrum managers, placing the weight of responsibility for much of the analysis and forecasting on those who have the most at stake. The detail given to the analysis of factors is up to the user community. Given the rapid change of the radiocommunications industries, such an approach represents a cost-effective option for spectrum planners.

2.4.1 Inquiry into future spectrum/service requirements

The consultative approach starts with an initial public notice or announcement, informing all interested parties that a spectrum plan, or, in some cases, specific strategic components of a plan, are to be developed, and requesting all information relative to such a plan. The notice should be openly and widely distributed, preferably in an official publication known to have a widespread audience. The public nature of the notice is essential to gaining maximum interest and feedback from potential system operators. Limitations on its availability will limit the response. However, in countries where such official publication methods do not exist or in cases where time is limited, the use of ongoing advisory bodies may represent an effective approach to gathering information. In some countries, this consultation may be carried out by sub-contractors or by advisory bodies set up for this specific purpose.

The scope of the inquiry must be defined, as well as the timetable for responses. Responses can be expected from spectrum users groups, radio service providers, equipment manufacturers, government organizations, including the military, and the general public. Spectrum planners can require that responses be in writing or through direct dialogue. For the sake of completeness and openness in a public proceeding, direct dialogue usually requires filing a written report in the official inquiry record. In any case, the responses received from these groups form the basis for determining spectrum requirements and help lead to spectrum planning decisions.

As noted above, a number of groups provide information to this consultative process. User groups are end-users of telecommunications services that have a common interest in receiving the best service at the lowest cost. These user groups may be able to voice requirements for new or expanded radio services. Radiocommunication service providers are those commercial entities that supply services to the end-users.

Service providers have expectations of service growth bas their own surveys and business acumen. This service growth could be reflected in a demand for additional spectrum. Radio equipment manufacturers have a vested interest in the growth of radio-based systems, and can provide technical comments on the suitability of various frequency bands for a proposed radio service, along with forecasts of technical advances that may improve spectrum efficiency.

The governmental users, on the national and local levels, will have spectrum requirements for the satisfaction of future radiocommunications systems. Although commercial services can satisfy a portion of governmental requirements, many may be unique and will require dedicated spectrum and unique radio systems for these purposes. It is probable that some of the systems involve national security to the extent that knowledge of these systems will not be in the public domain. Such information must be protected by the regulatory body.

The underlying principle of the consultative process is that the users, service providers, and manufacturers are the ones best able to evaluate their spectrum needs. Because they operate businesses or fulfil a government function, they must be able to evaluate their needs, costs, and user demands or they will not be successful in their businesses or professions. Therefore, societal and economic factors must be considered and identified by the participants in stating their requirements.

Because those who want spectrum respond to the inquiry, there may be an understandable tendency to exaggerate their spectrum and service requirements. Therefore, national spectrum managers may use interactive dialogue and their analysis of usage trends to help ensure sufficient accuracy.

2.4.2 Interaction among/with representative groups

Formal consultative processes can be carried out through a several-step, iterative approach. While interaction of interested parties can occur through formal responses and counter responses to a public inquiry, this increases the amount of time required to complete the inquiry process. In many cases, this time may be invaluable in giving the national spectrum manager adequate opportunity to consider the issues. Furthermore, it ensures that all ideas are recorded and considered.

In the interest of maximizing interaction and, in some cases speeding the process, it may be appropriate to meet with representatives of the major responding groups (if any) during the period of inquiry. This interaction affords the opportunity of establishing a dialogue among users, service providers, and regulators to make clear the intent of the proceeding and to reduce or eliminate possible exaggeration of spectrum requirements. It places each requirement in the context of other requirements (both new and old) thereby bringing a note of reality to negotiations for spectrum and ultimately to the planning outcome. In many cases such a dialogue helps proponents revise their requests as they work together with others.

There are initiatives like the opening of thematic work groups where the interested parties can provide information and points of view to the administrations in order to prepare the world radiocommunications conferences, show their trends on spectrum use and possible future needs, among other topics that could help administrations to collect as much information as possible to take into account in the making decision process.

Some administrations are now using various Internet tools to facilitate the exchange of views and/or to extend consultations to previously unrepresented stakeholders, e.g. policy/planning development fora, webcast of hearings, and publishing of comments received.

2.5 Analytical approach

The analytical approach comprises a detailed analysis of the factors affecting the trend to be forecast. The assumptions and findings of the analysis are converted into comprehensible figures that are mathematically calculated with the aid of available software. Software that uses, e.g. the Monte Carlo method for analysis can be a significant aid to this approach. This method combining analysis and mathematics has the following advantages:

– A comprehensive, bottom-up method based on detailed data is used to produce and record the results.

– The data for the influencing factors are derived from statistics of previous years. The data for future years may be extrapolated from these statistics.

– The weighting for each influencing factor can be determined using surveys and/or other research material (e.g. evaluation of external studies, technical reports and advertising material).

– Any effect that changes an individual influencing factors with respect to the forecast results can be determined immediately.

– The analytical method does not necessarily require extensive input from outside the spectrum management organizations and can be applied using existing statistics.

– The detailed and comprehensive analytical method using reliable statistics produces a relatively objective result.

Implementation of the analytical approach requires the following five steps:

Step 1: thorough analysis of the current situation;

Step 2: making reasonable assumptions with respect to influencing factors (see Table 2-2);

Step 3: development of scenarios (see section 2.6):

- one reliable scenario or sensitivity analysis, as far as can be predicted, indicating any elements of uncertainty and their underlying reasons,
- further scenarios which focus on the most significant factors of uncertainty;

Step 4: assessment of scenarios:

- for completeness, validity of the factors and their individual risks, benefits and priorities;

Step 5: presentation of a set of conclusive outputs.

2.6 Scenario approach

A scenario is a hypothetical sequence of possible events, based on past occurrences and known developments related to a specific field (e.g. a country's population trends), or to specific periods of time that in some manner relate to each other. A scenario is not itself a prediction but a complement to traditional forecasting by providing a record of a possible sequence of individual events related to one particularly interesting system aspect.

However, within the framework of planning, scenarios may be used in helping to predict possible developments. Scenarios serve to:

– increase the reliability of forecasts and interpret risks (reliability);

– identify potential strategic options.

Scenarios are based on the main factors of influence, i.e. the political, legal, economic, social, ecological, and technical factors (see Table 2-2). They can be developed systematically with different configurations of factors and estimated degrees of probability.

A number of factors may be common, at least in broad terms, to all or most of the scenarios. Those factors represent the favoured basis on which to develop spectrum planning. Remaining differences would be more clearly exposed and represent the risk factors in a plan. These may be put to experts in a way, and with a clarity, that would not have been possible had the scenario exercise not been carried out. They also represent the areas where developing changes and trends need to be most closely watched.

"Scenario approach" is a concept which may be of more use in the longer term of spectrum management planning where the trends and needs are much less well defined. For example, the convergence of telecommunications and broadcast arenas, using new technologies, heralds a substantial increases in wireless bandwidth to-the-home, and the expectation of similar capability while mobile. Such changes are difficult to predict and even more difficult to accommodate in planning. They defy trend analysis as they are not incremental changes. Radical changes may require fairly dramatic adjustment in spectrum planning assumptions, with consequential adjustment of plans.

Scenario approaches could include procedures where non-radio bodies visualize a number of possible changes in society and business behaviour that may occur in a defined period of time. These indicated changes could result in a number of scenarios, all quite different and, potentially, all equally likely to occur but mutually exclusive. The telecommunications and spectrum management needs of these different scenarios may then be analysed.

Depending on the national outlook, available resources, and the spectrum regulatory framework, a national spectrum manager may select from a number of methods to evaluate scenarios with respect to their potential impact on spectrum use. The evaluation of the scenarios that impact spectrum use, can rely on consultative or analytical approaches, or a combination of approaches. The evaluation can be very detailed, considering all potential factors, or more cursory in an overview. Furthermore, the responsibility for consideration of factors can be primarily that of the national spectrum manager or be distributed to interested constituents. This evaluation of scenarios ultimately helps to form the basis for national spectrum management decisions regarding spectrum allocation or regulations.

2.7 Usage trends

The results of any inquiry should be compared with requirements based on an analysis of the usage trends for current radio services. Increased spectrum requirements for a user population that is stable or declining would be, of course, suspect, unless a current lack of available service keeps the number of users from growing. Extrapolation of usage data, and the computation of the required spectrum, assuming spectrum-efficient technologies, will provide the regulator with an approximation of future usage to compare with the results of the inquiry. Forecasting based on usage trends can be somewhat misleading in the case of non-linear trends (breakthroughs). These are cases where usage may rise exponentially in the near future due to a breakthrough in technology or more likely, because of significant price reductions for the service. However, in a consultative approach, the emphasis is on cost-effective processes. Therefore, the extent of the analysis of usage trends must be evaluated in terms of the improved accuracy, which is judged to result from them.

Following the usage trends could give to the administration some early warnings about inefficient or decreasing use of the spectrum. Those early warnings help the administrations to start looking the best way to use spectrum in the near future. In Chapter 8, some useful measurements of spectrum utilization efficiency can be founded.

2.8 Supplementary approaches

In the planning process, supplementary approaches should be considered, and employed where possible. Reliance on market forces to apportion spectrum resources and increased flexibility in management approaches may hold potential for relieving some of the planning burden. Increased efficiency brought about by market incentives could lessen the need for spectrum managers to alter allocations or perform detailed engineering analyses-based spectrum determinations. Greater flexibility in the allocation, assignment, and use of frequencies may help spectrum managers by making the management processes more adaptable to evolving spectrum needs.

No system of planning and forecasting will predict all requirements for systems or services in sufficient time to ease their entrance into the spectrum environment. If an unforeseen requirement is to be accommodated without severely straining the existing allocation structure, that structure must be sufficiently flexible to allow for the limitations of planning.

The use of existing registers and in some cases monitoring to identify lightly used (having been assigned) or unused spectrum, can help identify frequencies for future uses. An inventory of such frequencies constitutes a ready resource.

Another method to increase flexibility would be to set aside or reserve spectrum for unspecified requirements. The availability of unused bands of sufficient size to accommodate unforeseen uses would allow for quick and simple action when conflicts arise. Spectrum could be provided for new systems, and be withdrawn if the service failed to materialize. One approach to creating and managing a spectrum reserve would be to identify frequency bands, or portions of bands, years before they will be available for new users, possibly opening a portion of spectrum every year or two in a different range of the spectrum. Ten years is an example of a reasonable number of years. The actual cycle could be governed by the natural obsolescence identified for equipment used in that band. This would give innovators flexibility and pre-existing users adequate notice and the time to vacate.

An undesirable effect of having frequencies available as long term reserves would be the inefficiencies associated with maintaining such reserves in the face of increasing demand. However, the reserve approach may be preferable if it eliminates costly, unplanned displacement of other systems. Decisions to move incumbent users for the sake of new innovative uses can be extremely costly and disruptive because spectrum managers may be able to only provide little warning of such displacements. These costs and disruptions create strong incentives for incumbent users to resist vigorously the spectrum reallocation efforts, which can stop or substantially delay the introduction of innovative new services. Reserves can be useful in creating both technological and political flexibility for spectrum managers in addressing the unanticipated, but socially desirable, new uses for the spectrum resource.

2.9 Spectrum management system planning and review

Planning of the national spectrum management process should include such items as regulations, analysis methods, and data processing capabilities. Changes that are required should be identified. A plan can then be developed to improve those aspects of the national system. The completion of a plan can set in motion the step-by-step improvement of the management system. For example, specific plans for improving software models, data gathering and mathematical manipulation capability, and data retrieval capabilities are increasingly important. Concrete plans are needed to put market and flexibility concepts into action. Specific improvements to the spectrum management system and ongoing analysis and assessment tasks need to be prioritized and scheduled in accordance with available funding.

The following areas related to spectrum planning should be regularly reviewed:

– decision-making process and sourcing options;
– regulatory procedures;
– computer hardware, software, and networking;
– database requirements;
– cross-border coordination process;
– participation in international and regional activities;
– analysis techniques;
– monitoring/inspection capability;
– standards and type approval processes.

2.10 Planning implementation

Planning either spectrum use or development of infrastructure of the spectrum management system can be performed over a short term, long term, or on a strategic basis. Each of these three implementation approaches requires a commitment to regular and in some cases, scheduled activity. Planning ceases to be planning when it is driven by immediate crisis or consequence. Therefore, the first step in implementing successful planning is to create a recognized process for considering issues and updating plans. This process should include specific means for conducting short term, long term, and strategic planning. Short term and strategic planning, in that they deal with specific or focused issues, will not fit prescribed outlines or formulas. However, they should always delineate requirements, resource availability, policy decisions, and implementation. A long term plan, on the other hand, will generally fit a standardized pattern and cover certain areas as a minimum.

The evaluation of the individual courses that can be chosen via the planning process will depend, as indicated in Table 2-2, on the relevant political, legal, economic, social, ecological and technical factors. Each administration must consider the impact of plans on its constituents, its neighbours, equipment manufacturers, service providers, and spectrum users. Decisions must be made based on national priorities. Therefore, simple rules specifying how the individual factors must be considered cannot be applied.

2.10.1 Short term (within three to five years)

Short term planning is generally considered such because of the lack of lead-time available. For example, the determination of a scheme of assigning frequencies for a new nationwide system for which development is underway could be considered a short term issue. Since the system will be ready for deployment in a few years, plans must quickly become actions and options are limited, particularly the choice of frequency bands. Choices of moving existing users over a long term, for instance, are also not possible in this time frame. Nonetheless, the steps of planning should be followed. Keeping in mind this new requirement, uses of the bands under consideration must be reviewed, including the identification of unused or lightly used frequencies. Compatibility issues with current users should be analysed and interested parties queried for suggestions concerning the best approach to accommodating the new use. Coordinating or negotiating committees may be required to help resolve conflicts. Modification to system design or limitations in operation may be recommended to enable implementation of the new system. Factors included in Table 2-2 should be considered, along with international agreements that may guide or limit national choices. Analytical tools such as frequency assignment models may be used to set up an assignment plan.

Most short term plans will result in some sort of decision document stating the selected course of action and milestones required to achieve an objective.

In the short term, the inflexible environment becomes a primary consideration. Therefore, the short term plan must lay out a process of fitting into the existing environment. However, the implications of short term planning are still, in most cases, long term, because the new spectrum use, or the new spectrum management capability will be around for a long time.

The short-term plan should be sufficiently comprehensive to accommodate the national spectrum requirements of both known and anticipated radiocommunication systems within its stated timeframe. It also leads to:

– revision of the national table of frequency allocations;
– development of national positions on international radio conference agendas;
– revisions to spectrum regulations, policies and standards.

2.10.2 Long term (within five to ten years)

At present, most planning is short term. However, if spectrum resources are to adequately support national goals and objectives, long term planning is essential. It can provide a basis for effective spectrum management to ensure that spectrum is efficiently allocated and assigned to accommodate constantly evolving spectrum requirements by new systems and their applications. It also facilitates decision-making by providing a basis for the practical consideration and evaluation of alternative courses of action. Long-term planning should endeavour to:

– make today’s decisions on spectrum planning strategies in view of their consequences for the future;
– identify expected impact of past decisions on the future;
– periodically adjust decisions to changing circumstances.

The outline in Table 2-3 indicates many of the areas that should be covered as a minimum in a long term plan. However, the plan need not be limited to these areas.

Long term planning should be sufficiently comprehensive to accommodate the national spectrum requirements of both known and anticipated radiocommunications systems within the stated timeframe.

Long term planning, on the other hand, has a great deal of flexibility. Current uses may, in accordance with their natural obsolescence, be moved or expanded to other bands or locations. Characteristics can be changed through revised standards or channelling plans. Spectrum management techniques can be altered to a greater extent when databases can be restructured, new services defined or old ones redefined, or new approaches to management developed.

Long term planning and updating of the established plan must be broad in scope all possible directions are to be considered. It is necessary to review the plan regularly in light of the factors included in Table 2-2, even though not all portions of the plan will need to be updated. Usually, with an existing long term plan, portions are updated when identified within a review, not when needed to deal with a specific activity within the radio community. With respect to a spectrum-use long term plan, current, future and forecast uses across the spectrum must be taken into account since the migration of some uses to another may be necessary. Long term costs and national priorities must be reviewed. The direction of neighbours and trading partners should be understood. New approaches to spectrum management are often considered within this type of planning.

TABLE 2-3

Long term planning

Spectrum use plan	**Spectrum management system plan**
Spectrum use objectives – Objectives for meeting of requirements of stakeholders in accordance with national policies, for example: – Safety and law enforcement – Commerce and transportation – National security – Broadcasting – Education – Users *Spectrum resource* – National table of frequency allocations – Lightly or unused bands, and shortages *Spectrum requirements* – List of frequencies in use – Future requirements – Emerging technologies – Forecasts – International and regional trends *Spectrum availability* – Government file data – Measured data *Long term plan* *Schedule of activity and milestones*	*Authorities* – Radiocommunications law – Delegated authority – Regulations and procedures *Spectrum management functions* – Policy development – Enforcement and regulation – Licensing and fee collection *Spectrum engineering and computer support* – Equipment standards – Channelling plans – EMC models – Engineering analysis methods – Computer hardware and software *International and regional activities* – Strategies for participation in ITU, or – other international and regional fora – International and regional agreements – Coordination along borders *Resource requirements* – Source of funding – Personnel resources – Future needs *Schedule of activity and milestones*

From the standpoint of the spectrum itself, a national table of allocations serves as the primary long term plan for spectrum use. Each administration should have a table that it and its constituents recognize as the guide for implementation of radio services.

Developing countries in particular, may choose to focus on steps for upgrading the national radiocommunications infrastructure, which will often involve establishing or improving the spectrum management structure and capability. It may also include a plan for implementation of radio technologies and a national policy on the role of private enterprise in developing the national communications system.

A spectrum plan may, in accordance with certain circumstances and under appropriate long-range decisions, result in redeployment of services. This could mean transitioning existing users of a spectrum band to either new technologies or to new frequency bands. The requirement for redeployment can arise for several reasons:

– a spectrum allocation may have been in operation for a considerable period of time and currently no longer meets the requirements of users, or the capabilities of modern systems;
– an allocation within a specific range of frequencies is required for a new radio service and these frequencies are occupied by services with which the new service cannot share; or
– a decision by a World Radiocommunication Conference to allocate or allot a currently occupied frequency band to a different service on a global, regional, or national (allocation footnote) basis.

As a national spectrum planning tool, spectrum redeployment can, in theory, apply to any frequency band and any system. However, in practice, spectrum redeployment is more limited as it usually is applied only in cases where an administration can justify the commensurate overall effort and expense. Spectrum redeployment may be either voluntary (in which case planning is not required other than to allow for it within regulatory provisions), or obligatory.

Voluntary spectrum redeployment

This method represents the case when an existing user voluntarily decides to employ new technologies within the band where the user is authorized to operate, or to return frequencies to the spectrum manager for reassignment. When new technologies are desired, and there are no preventative regulations, the user is free to adopt the new technologies at will, e.g. transition from second generation wireless to third generation. If a user recognizes that it no longer requires the spectrum occupied, or the benefits gained from using the spectrum are less than the costs of continuing to use it, an authorization may be relinquished. This situation may arise when the cost of the authorization increases, the existing equipment must be serviced or replaced, or continuing financing for operation is not available.

Voluntary redeployment may occur naturally, but it usually tends to be on a small scale. An administration may wish to take into account this potential voluntary process as spectrum regulatory policies are established.

Obligatory spectrum redeployment

Obligatory spectrum redeployment is associated with an affirmative administrative planning policy. In this case, long term planning is generally necessary to ensure an orderly transition, and amortization or replacement of equipment and service. The approach an administration attaches to spectrum redeployment depends on the time-scale in which the spectrum needs to be made available. Often this decision is made for political or national security reasons. Usually, detailed market analyses, consumer needs, and growth predictions accompany redeployment planning as justification for such action, as there is certainly an associated expense. Proven mechanisms which speed redeployment are incentive fees and compensation, including the provision by new entrants of new, modern equipment for the redeployed users.

Redeployment techniques

In addition to the potential redeployment of radiocommunication services on a wholesale, band-by-band basis, there are other advanced redeployment techniques that might be considered as part of the planning process. These include imposed operational etiquette procedures (i.e. either listen before transmitting, or automatic sensing of the existence of signals that temporarily preclude operation or cause a transmitter to change frequency), reducing channel bandwidth (or splitting channels), improving coding or modulation techniques, and applying new spectrum sharing criteria. If redeployment within an existing band is contemplated, some measure of backward compatibility and interoperability is essential. Table 2-4 is a synopsis of technical methods that may be used to facilitate sharing and which could be taken into account as part of a long term planning and redeployment process.

TABLE 2-4

Technical methods to facilitate redeployment

Frequency separation	**Spatial separation**	**Temporal separation**	**Orthogonal signal separation**
Channelling plan Dynamic real-time frequency assignment Dynamic variable partitioning Frequency division multiple access Coding: – Error correction – Compression Control of emission spectrum characteristics Frequency tolerance limits	Site selection Antenna pattern discrimination Physical barriers Site shielding Interference power: – Dynamic transmitter level control – PFD limits – Power spectral density limits – Energy dispersal	Duty cycle control Time division multiple access Coding: – Error correction – Compression	Code division multiple access Antenna polarization

It goes without saying that wireline networks could be used as an alternative to wireless or radiocommunication systems to reduce demand on spectrum, especially in congested areas and for broadband applications. Planning policies and regulations should be drawn to encourage the use of advanced intelligent network technologies to permit seamless interfaces between wireline distribution systems and short-distance wireless links, minimizing the need for redeployment.

2.10.3 Strategic planning

The development of strategies for national spectrum use will require the implementation of a national strategic spectrum planning process.

Strategic planning can be considered a reasonable method of long term planning that simplifies or scales down the level of ongoing planning efforts by identifying a small number of key issues that require planning attention while assuming that the majority of activities can proceed on the current course. In this case, the important aspect that is different from long term planning is that a process for identifying the key issues must be established. If an administration has more than one agency involved in spectrum management, then the process of issue identification must be recognized by all groups and the selection of the issues must be agreed.

The benefit of strategic planning is that it lessens the need for continuous, broadly aimed planning activities and focuses on fewer issues. This decreases the manpower levels required to develop the plan and avoids time being spent considering issues that may not need to be considered. Generally, only a few strategic issues at any particular time require resolution and planning. Therefore, the frequent update of a broad, long term plan is often unnecessary. Instead, a few issues can be better accommodated in a strategic planning process.

Given the increasing importance of commercial applications of spectrum use and related market considerations, all of the relevant players including regulatory bodies, operators, manufacturers, and consumers should be involved in the strategic planning process as the coordination and management tasks have grown more complex. Rapid changes in technology, liberalization of markets, globalization and the public welfare are all dynamic forces that go into strategic planning.

Critical strategic and fundamental principles that lead to more efficient spectrum usage are:

– need for market-driven spectrum allocations;

– promotion of competition;

– accommodation of foreseen and unforeseen technological advances;

– the requirements for international harmonization and cooperation.

Except for narrowing of the focus, these same steps apply to strategic activities which are part of other planning activities. First, current and future requirements must be identified. Approaches to resolution of issues must be developed and analysed. Recommendations from concerned parties should be sought, including recommendations and concerns from other administrations that may be affected.

2.11 Technical aspects on spectrum planning process

Another aspect to consider in spectrum planning process is the technical efficiency (see Chapter 8), which has as main purpose to achieve maximum use of spectrum by different socio-economic sectors. In order to achieve this goal, there are different mechanisms which are explained in the following sub-sections.

2.11.1 Spectrum planning for current and future services

Taking into account that spectrum is a limited resource but key to the development and growth of the industry. Spectrum planning must satisfy the resource availability for current demands and anticipate future demand. Spectrum planning may be carried out in line with technological developments, flexibility in use, international industry trends, innovation in the communications, market fluctuations, user needs, technological neutrality, especially considering public policies on national defence, education, environment and social integration.

In this sense the combination of these needs requires different plans and develop of strategies to deliver an effective and timely response regarding the use of spectrum for current and future services.

2.11.2 Technology alternatives

Some of the most wireless innovated technologies are International Mobile Telecommunications (IMT), software defined radio (DSR), cognitive radio systems (CRS), open wireless architecture (OWA) and next generation networks (NGN).

2.11.3 Reserve frequencies for future developments

Quick and continuous technological developments in telecommunications, the convergence of services, growth in the sector of information technology and communication (ICT), the continued expansion of mobile telecommunications and the changing habits and lifestyles of the general population have accelerated, and will increase considerably in the future the spectrum demand. Technological progress leads to the development of new services, which require some investment security regarding the availability of spectrum. The new systems provide a range of services, blurring the identity of a system/service; for example, mobile communication systems and satellite broadband can combine various traditional services such as telephony, data transmission, and Internet access.

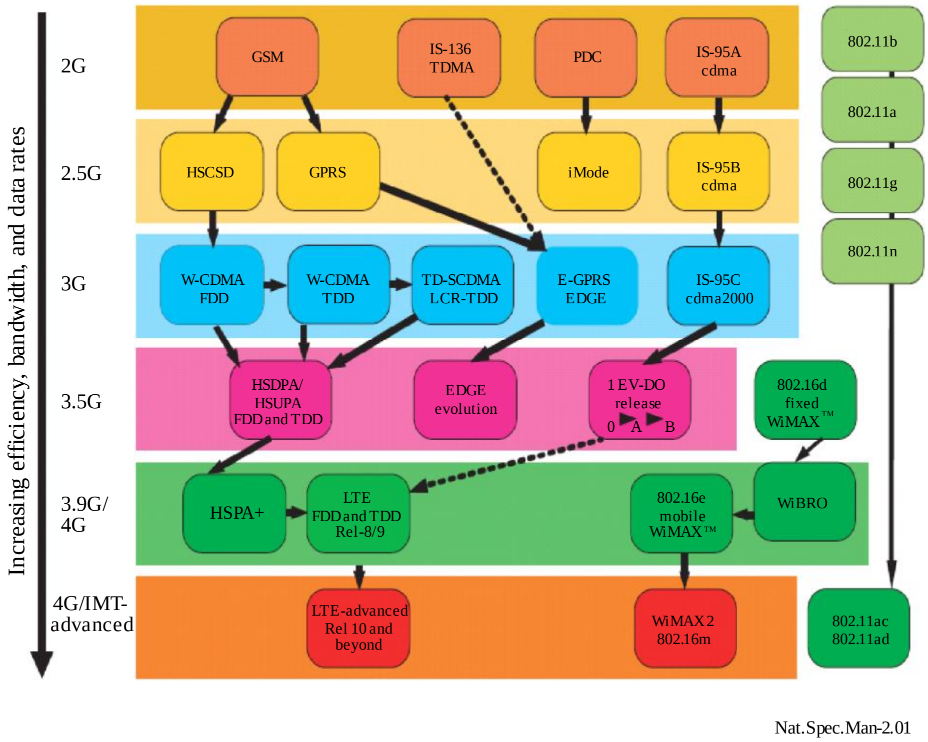
The availability and use of spectrum affects the level of competition between market participants, which is not only limited to radio services competing for access to spectrum, but may affect providers and users of communications optical fibre, satellite or cable local loop. There is a need to balance between spectrum for public applications, defence and state security and the spectrum for business or commerce. Furthermore, digital technologies for radio communications are advancing the use of spectrum and, therefore, how to plan, manage and control this resource.

Administrations may allocate and establish structured frequency bands for multiple new applications, and regulate their use to ensure the operation of this applications free of harmful interference.

The use of the internet and particularly TCP/IP, VoIP and IPTV protocols generates an higher traffic on the LAN nodes, which leads to a greater demand for bandwidth and speeds, and the establishment of smaller cells designed to meet entertainment needs at home and office environments,. The future of telecommunications is towards mobile and multimodal communication, specifically the International IMT. Consequently, administrations may have special attention to the spectrum identified for IMT and required, in accordance with their national needs, in order to ensure the IMT ecosystem deployment within their countries, while promoting global/regional harmonization for these uses. The mobile industry has carried out the migration path AMPS / TDMA / GSM / GPRS / EDGE /W-CDMA and TD-SCDMA /HSPA / LTE, as illustrated in Figure 2.1. Separately the evolution of CDMA and CDMA2000

FIGURE 2.1

Mobile technologies evolution[30]



Source: Agilent Technologies Inc., 2010.

To continue successfully in this migration path is relevant that the managing body make the decisions that will allow to receive the maximum benefits arising from national implementation of these technologies:

- Allocate preferably harmonized spectrum, as recommended by ITU or regional organizations for IMT-Advanced deployment taking into account the users trends and technology developments.
- Allow mobile operators to provide a wide variety of services fully exploiting the data rates of DSL type IMT-Advanced provides, to support advanced applications and services (e.g. according to Recommendation ITU-R M.1645, quality of services requirement were established 100 Mbit/s for a high mobility scenario and 1 Gbit/s for low mobility scenario).

These decisions generate, among other, the following benefits:

- Economies of scale offered by advanced wireless data.
- Production and access to terminals and IMT global services from research and development of the mobile industry.
- Advanced wireless data solutions for educational institutions, businesses and public and private entities, in order to lessen the digital divide.

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30 Agilent Technologies, Introducing LTE-Advanced, United States of America: Agilent Technologies, Inc., 2010, p. 3.

In accordance with the considerations above, it is important that the administrations consider the best ways to optimise frequency usage for radio applications of software defined radio (SDR), cognitive radio systems (CRS), open wireless architecture (OWA) and similar applications that use spectrum in a more flexible manner.

2.11.4 Spectrum release and refarming

Methods of frequency planning may consider to avoid licenses for operation of telecommunications systems with old technologies that not use efficiently the spectrum (see Chapter 6 for more details about spectrum efficiency).

Before the transition to digital TV, the TV channel separation of the American NTSC standard was 6 MHz, 7 MHz (at VHF) and 8 MHz (at UHF) for SECAM and PAL; the bandwidth multiplied by the number of channels at the service area was required to provide the service in terms of quality, transparency, equity and efficiency. At the eighties of the 20th century, it was required 30 kHz bandwidth per channel for narrowband cellular mobile systems. Today, these paradigms have changed due the introduction of new technologies.

Today it is possible to pack three or more channels of HDTV on a single 6 MHz carrier; using QPSK or QAM is possible to reduce 2, 4 , 8, ... , 128 times the spectrum required by the FM station, so that it is feasible for greater quantities of information through the same carrier; with GSM-GMSK twenty possible simultaneous users can establish communication with only one carrier; UMTS can accommodate as many users as possible codes, through a broadband carrier itself; the number of codes that a chip can store sometimes seems limitless.

Administrations may consider to implement redistribution techniques of frequency bands by using heuristics together with empirical data. Administrations may accelerate the transition from analogic broadcasting to digital in order to retrieve the available spectrum and increase spectrum capacity.

After define the real needs in terms of spectrum required for operation of the various radio equipment in different frequency bands, administrations must compile information about frequencies and bandwidths is possible to release; for which it must prepare the relevant regulations. As it is not possible to predict the future uses of spectrum released, the Administration may allow flexibility to allow a wide variety of future radiocommunication services and use of new technologies. Studies of occupation and use of the authorized spectrum are needed also to identify regulatory measures to release frequencies used inefficiently or not used, in order to redistribute the spectrum freed for other purposes.

Administrations may consider when a user has to give up an assigned frequency band (completely or partially) and move to a different frequency band or platform or adjust the use of the frequency band to accommodate another user. While the move should not generate benefits to the outgoing user, whether to provide an incentive to abandon the frequency band, from the calculation of just compensation that considers factors such as the costs of moving and having to endure the same situation if the user had not had to change their current situation.

2.11.5 Effective use of new technologies to improve the reuse of frequencies

Frequency reuse can be defined as the number of times that the same frequency can be used in a given geographical area without affect any user of the frequency. Frequency coordination is usually one of the determinant issues in the reuse technique. The efficient use of the spectrum can be carried out with the use of advanced engineering techniques to increase frequency reuse, reduce channel bandwidth, improved coding techniques and modulation strategies to improve access, improve band sharing without interference, introduce new criteria for spectrum sharing, develop strategies for frequency assignment and spectrum usage patterns, and the use of other techniques of engineering and operation. Those activities affect directly the amount of spectrum needed to satisfy the demand from a specific radiocommunication service and the planning activities. Administrations are aware about use of reuse techniques in order to maximize the spectrum use and perform their planning activities according with this reality.

2.11.6 Channel Split

This activity involves the use of the spectrum by a new planning of bands by use of existing channels of width narrower band spectrum. The channel split multiplies the channels and promotes introduction of new technologies. Channel split procedures must consider that the spectrum that is considered for a new schedule is used, usually, intensely. The other issues to be analysed to develop a plan of channels division are:

- *Continuity of Service:* redistribution is to be performed without service interruption.
- *Costs:* application of an approach to reducing the costs to the user of the spectrum.
- *Compatibility:* it is essential to some measure of interoperability and backward compatibility, as it is expected to improve the functionality which will provide by the new technology.
- *Risk:* a balance should be made between policies to provide additional capacity and user needs of low risk solutions.
- *Harmonization*: Activities must be harmonized (where is possible), with neighbouring countries and internationally.

2.11.7 Overlap of services and sharing of frequency bands

Effective sharing of frequency bands for a number of services can play an important role in reducing the demand for new spectrum. Identification of current and future shared bands is essential.

A typical example of overlapping service is the ability of the systems to operate effectively widened conventional spectrum. Techniques such as Orthogonal Frequency Division Multiple (OFDM), Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA) are commonly used to provide co-sharing systems. Overlapping systems should be examined case by case, specifically analysing individual protocols and architectures of possible interfering services. It may require new approaches to spectrum sharing, frequency allocation strategies and models of spectrum use.

2.11.8 Use of unused spectrum

The spectrum planning policies, regulations and programs should encourage the use of the spectrum above 40 GHz, especially for services that require exclusive radio spectrum and broadband applications. The spectrum above 40 GHz is usually slightly used. This spectrum segment has the ability to support very broadband services, and reuse can be made in a high scale due to small cell size, narrow beam width and excessive propagation loss. This portion of the spectrum also provides various advantages of implementation, such as smaller antenna, narrower beam widths, reduced size and weight equipment, and ease of installation and reconfiguration.

Besides the above, it is recommendable that administration ensure the widespread use of bands commonly used frequencies.

2.11.9 Particular considerations

Several factors can affect the benefits derived from the use of radio communications in a particular country. These include the size of the country, its geographical configuration, soil structure, the number of neighbour countries within a coordination distance and radio infrastructure.

In general, this means that countries with many neighbours will have to coordinate most of their radio systems and therefore adapt its radio infrastructure to neighbouring countries. The more developed infrastructure of these neighbouring countries, the more the need to coordinate their spectrum use in order to not have difficulty to introduce new services. This may not constitute a major problem in countries with low population density ask for less radio spectrum assignments.

At the other end of the scale, large countries have more freedom to plan services over specific frequency bands without resorting to coordination. This freedom is greater if they have few neighbours. Countries that do not have neighbours within the distance of a specific frequency coordination benefit from the fact that they have unlimited access to this frequency at any point within their border areas. For this chapter, soil structure means the mountainous regions, dense forests and desert areas. In combination with the other elements of the geography of the country and the population characteristics, soil structure helps determine which frequency bands may be the most suitable for a specific service.

2.11.10 Population concentration and spectrum congestion

The geography of a country and the distribution of demand can be combined to assess the level of available frequencies throughout the country. The equal distribution of the population across the country is highly unlikely and the concentration of the population in various population centres with different sizes. In practice, this grouping should represent an advantage the provision of radio services, but the level of demand can be disproportionate to the area in which this has its origin and this can lead to problems availability of frequencies, and finally of spectrum congestion. This congestion is a serious problem for administrations, and many authorities consider it as one of the main factors when adopting a pricing structure of the spectrum. For example, in Colombia, about 93% of the population lives in approximately 44% of the total land area[31]. This concentration of population and industry creates a huge demand for all types of services (i.e. mobile, fixed, broadcast), while significantly limiting the frequency reuse existing because of the short separation. In addition, proximity to neighbouring countries requires coordination in many frequency bands and represents another limitation to the availability of spectrum. The mobile telecommunications services have grown dramatically, registering an increasing competition between new telecommunications operators, but the deployment of services is based in the main centres of population and major links which allow connection. Consequently, there may be a shortage of spectrum in certain parts of the country, while in other areas it is not a problem.

2.12 Improving the spectrum management planning system

Plans for improving the management system are often as important as national plans for spectrum use. The development of such improvement plans closely follows the process of spectrum use plans in that the scope of any plan must first be defined, the current capability must be inventoried, future spectrum management requirements identified, other available technologies and capabilities surveyed, and then steps established to get from the current state to a position seen necessary to handle future spectrum management needs. The scope of a particular review may cover the entire process. On the other hand it can be limited to a specific activity or capability, such as data processing support and databases.

2.13 The management or administrative body

The establishment of a management or administrative body providing leadership and supervision for the implementation of the spectrum planning programme is necessary to ensure that issues relating to long term spectrum utilization strategies can be addressed. This will include the introduction of an early issue-recognition system within the framework of its planning procedures. The process may be supported by special planning bodies such as project or focus groups, and task forces.

Planning of all types is always a primary task at management level and one which cannot be delegated, due to the consequences and significance of the decisions to be taken. Such planning bodies are responsible for:

– developing detailed strategic policies and solving problems concerning the conversion of strategic policies into operational plans;
– allocating financial and human resources;
– strategic review of procedures, results, and requirements in conjunction with the implementation of strategies;
– any necessary recommendations concerning adjustments to organization and management systems;
– updating the planning data used as a basis for frequency management.

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[31] More information on http://www.dane.gov.co/files/investigaciones/poblacion/proyepobla06_20 and http://www.todacolombia.com/.

Bibliography

CEPT/ECC [September 2002] Report 16 – Refarming and Secondary Trading in a Changing Radiocommunications World. European Conference of Postal and Telecommunications Administrations (CEPT)/Electronic Communications Committee (ECC).

NALBANDIAN, A. [February 1998] ITU-R Studies on spectrum management, ITU Radiocommunication Bureau, International Telecommunication Union, Geneva.

NTIA [February 1991] NTIA Special Publication 88-21, NTIA TELECOM 2000 – Charting the Course for a New Century, Chapter 9. National Telecommunications and Information Administration, U.S. Department of Commerce.

NTIA [February 1991] NTIA Special Publication 91-23, U.S. Spectrum Management Policy: Agenda for the Future. National Telecommunications and Information Administration, U.S. Department of Commerce.

NTIA [December 1991] NTIA TM-91-152, Assessment of Technological Forecasting for Use in Spectrum Management. National Telecommunications and Information Administration, U.S. Department of Commerce.

ITU-R texts

ITU-R Handbook	Spectrum Monitoring (Edition of 2011)
ITU-R Handbook	Computer Aided Techniques for Spectrum Management (Edition of 2005)
Rec. ITU-R SM.667	National spectrum management data
Rec. ITU-R SM.856	New spectrally efficient techniques and systems
Rec. ITU-R SM.1047	National spectrum management
Rec. ITU-R SM.1131	Factors to consider in allocating spectrum on a worldwide basis
Rec. ITU-R SM.1132	General principles and methods for sharing between radiocommunication services or between radio stations
Rec. ITU-R SM.1599	Determination of the geographical and frequency distribution of the spectrum utilization factor for frequency planning purposes
Rec. ITU-R SM.1603	Spectrum redeployment as a method of national spectrum management
Report ITU-R SM.2015	Methods for determining national long-term strategies for spectrum utilization.

CHAPTER 3

Frequency Assignment And Licensing

Table of Contents

Introduction

This Chapter considers regulatory and technical aspects of the frequency assignment and licensing process for national radio systems. On one hand, frequency assignments must provide for the normal operation of existing radio systems as well as for new systems with a specified performance. On the other hand, in view of a great and ever growing public demand, frequency assignment procedures should strive to ensure the permissible level of interference among radiocommunication services, among stations within each service, as well as efficient utilization of the radio-frequency spectrum and the satellite orbits. For some applications (e.g. broadcasting and mobile services) appropriate frequencies for different sites may be determined in the aggregate in advance and these frequencies are assigned later during creation and expansion of relevant networks, as necessary. Such activity may be referred to as a “frequency-site” planning process. This may be an allotment process in some administrations.

A national process for assigning frequencies should be implemented to ensure that new frequency uses do not cause harmful interference to existing users, either on a national or international basis.

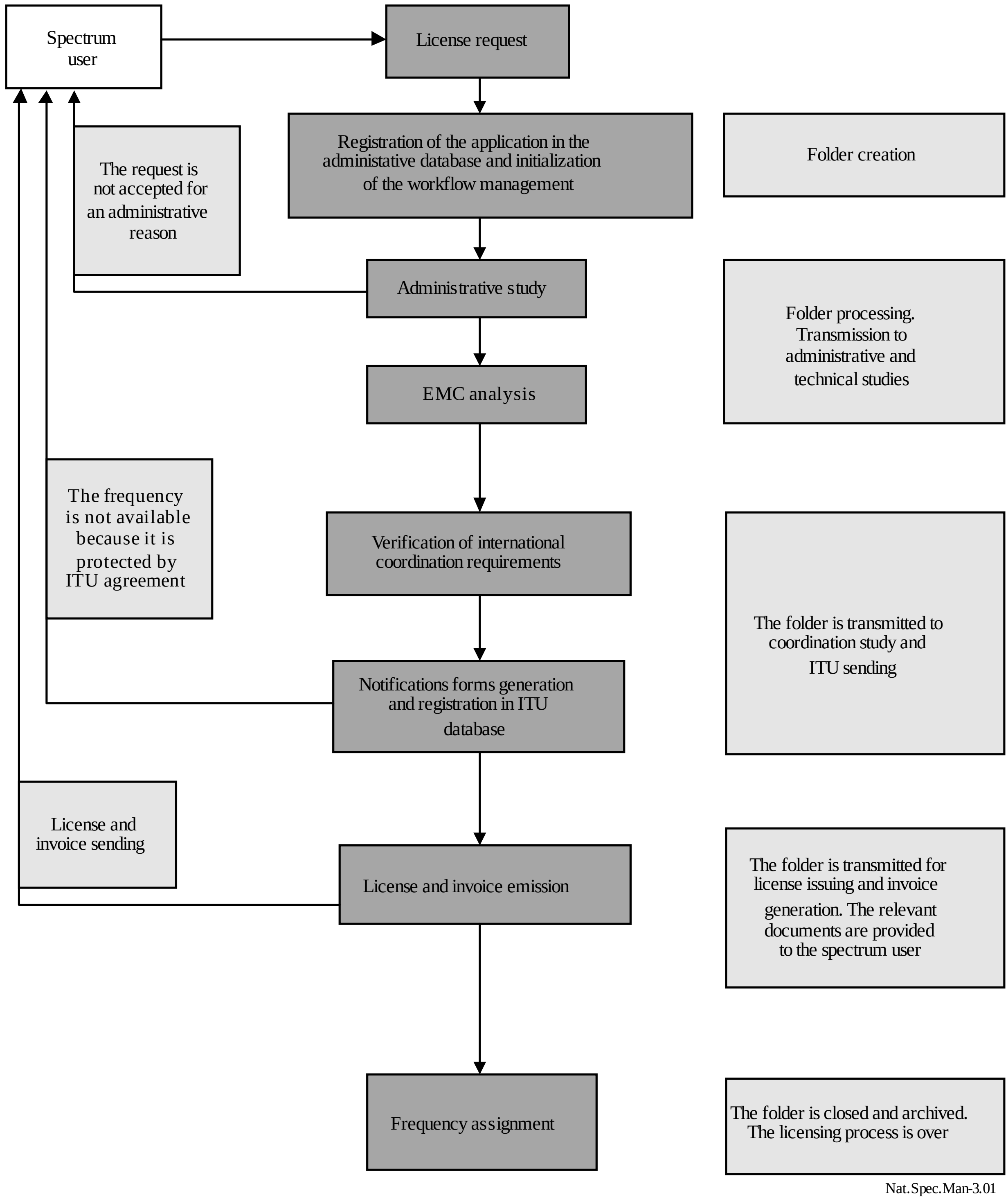
The assignment process includes the analysis of requirements for proposed radio services together with any relevant studies, and the assignment of frequencies in accordance with a national frequency allocation plan. This plan may also include references to related actions necessary to protect the country’s radiocommunication systems from potential interference from another country’s assignments published in the Master International Frequency Register (MIFR), a copy of which is available on compact discs from the ITU, and which is updated bi-weekly in the BR International Frequency Information Circular (BR IFIC).

Successful implementation of the frequency assignment process results in licensing under relevant license fees and other possible charges. Figure 3.1 illustrates the general procedure used in processing the associated request for frequency assignment. This procedure provides the basis for both technical and administrative planning. The administrative procedure accounts for the majority of the work and staffing in many frequency-management organizations. Therefore, the operational version of this procedure, prepared for a frequency-management organization, should be carefully considered when it is being planned (see Chapter 1). It should also be the subject of regular review, with changes made based on practical experience.

To apply for a frequency assignment, a user will typically prepare and submit an application form (which may be different for each radio service or groups of services). The application for a frequency assignment will usually be included as a part of the more general radio license application. In those cases where only a permit or authorization is required (as may be the case when a government agency is requesting a frequency assignment), the information required for a frequency assignment will be similar to that for a license application, but without most of the administrative and business-related information.

FIGURE 3.1

General procedure for the frequency assignment and licensing process



Forms should contain all administrative, technical and operational data concerning transmitting and/or receiving stations necessary to proceed with the relevant electromagnetic compatibility (EMC) analysis. The forms should also contain data for coordination at the national and/or international level. The appropriate frequency or frequencies should be assigned to complete the licensing process. Radio systems containing several transmitting and receiving stations may only require one generalized application form for the whole system accompanied by several detailed application forms for different stations. Structures of forms should be closely related to the sequence of data entering into a database of the relevant spectrum management system (SMS) to simplify the data entry process. Some SMS systems accept automatic data entries from application forms in some machine-readable format.

Figure 3.1 shows an example of a block-diagram of a typical frequency assignment and licensing sub-system of an SMS.

The functional scheme of the database (see Figure 3.2) presents examples of the possible different entities of the database and the links between each entity.

In Figure 3.2 all the entities used are described. The main entities appear in blue, the secondary ones, in white. Tables of less importance or related to technical aspects are not listed, but are included in the entity blocks. Entities are associated by links. Each link has cardinality. For example, the relation:

site 0,*n* ----------- 1,1 station

shows that one site can be used by any number of stations (from 0 to *n*) and one station uses only one site. (One site can be used from 0 to *n* stations, and one station can only use one site). Entities are then gathered in a domain to show the functional use of each entity.

The technical and administrative database is made up of different domains: *n*

– the core: technical database; and

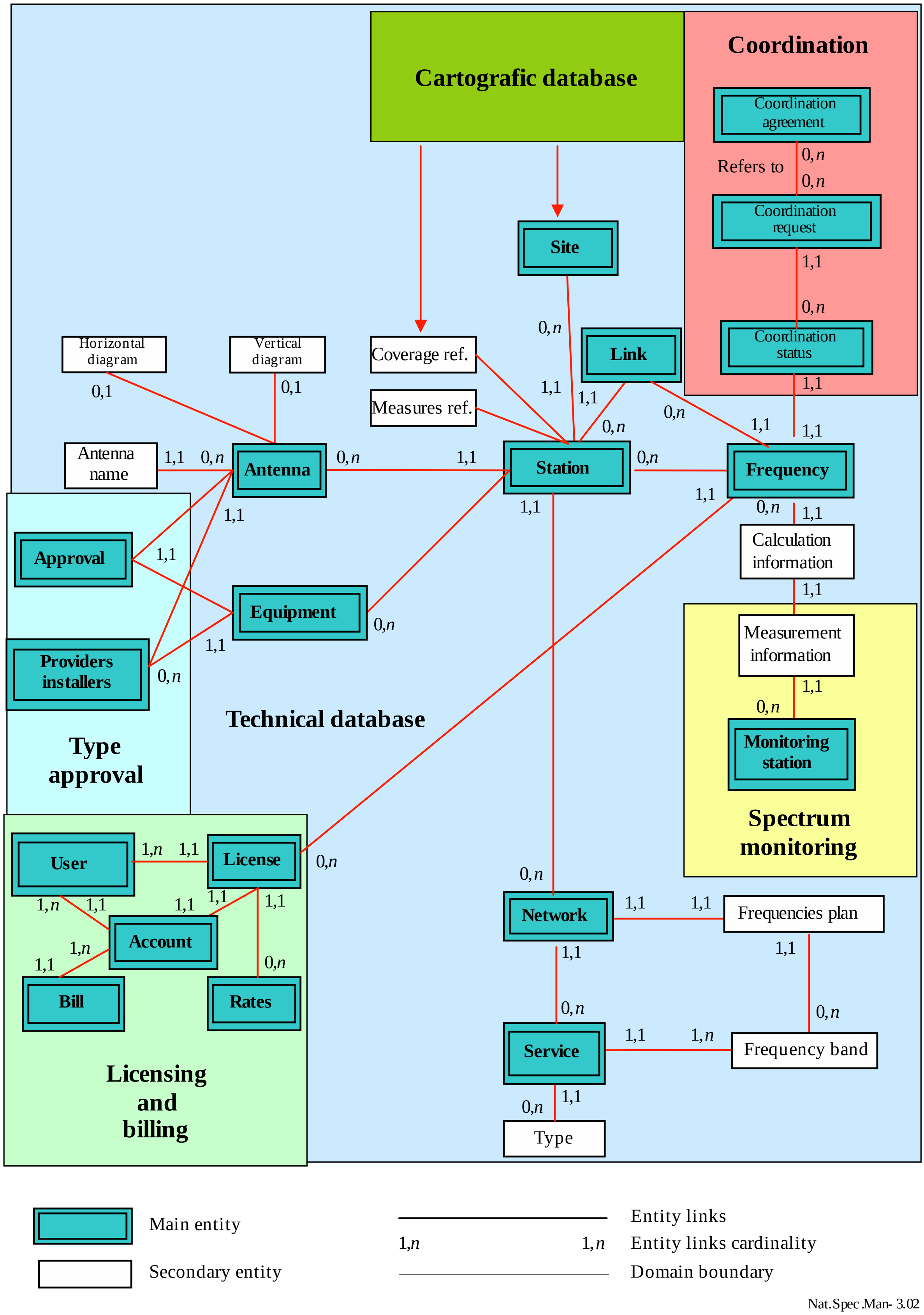
– the administrative extensions: coordination, licensing and billing, equipment approval, and activity statistics.

Once a frequency has been assigned to a transmitting or receiving station, all the administrative, technical and operating data from the application form (with possible modifications during the frequency assignment process) should be entered in the national frequency register. It may be the same database, as at Figure 3.2, with different status of a relevant data set (see Recommendations ITU-R SM.1370 and ITU-R SM.1604). This register not only serves as a reference when subsequently selecting other usable frequencies but also provides the basic material for taking effective measures required to adapt national planning to the real requirements of the various users. Care should be taken in compiling the national register and keeping it up to date; it must have room for recording a sufficient number of assignments and all the information needed for the clear and complete description of each frequency assignment. With the present low cost of computer software and hardware it is advisable to employ a computer database for processing and recording frequencies assignments (ITU-R Handbook – Computer-Aided Techniques for Spectrum Management (Edition of 2015)).

In addition to the frequency assignment and licensing processes described in this Chapter, spectrum managers may, in some cases, be able to adopt license-exempt processes for some technologies, e.g. Wi-Fi, Wi-Max, RFID, UltraWideBand (UWB) and other short range systems.

FIGURE 3.2

Spectrum management system database organization for frequency assignment and licensing purposes



PART A

Assigning frequencies to radio stations

Frequency assignment is a central part of the spectrum management process and is required for all radio services. This section considers the regulatory and technical aspects of the frequency assignment process. Administrative matters are considered here as a part of the regulatory process.

3.1 Regulatory aspects of the frequency assignment process

National frequency management agencies should make provisions for a special department that would be responsible for frequency assignments for radio systems. This department should handle both regulatory and technical matters. Depending on the size of the spectrum management organization, specific individuals or units within the department should be given the responsibility for assigning frequencies.

National regulation: Special management groups in the national agencies with appropriate terms of reference could be charged with the assignment of frequencies to systems in individual services. Alternatively, a single management structure could be made responsible for different categories of services with authority for managing appropriate frequency allocations. Such groups may provide frequency assignments for several services, including services sharing bands. The possibility of assigning frequencies to specific radio systems using frequency bands for different services or users could be taken into account. It is, therefore, a decision for the national administration as to the procedures regarding the assignment of frequencies and the methods used to ensure the efficient use of the radio-frequency spectrum.

For example, according to the ITU Radio Regulations, the land mobile services and the broadcasting services share a number of frequency bands, with the broadcasting service using these bands on a primary basis. Users that represent the interests of governmental organizations could be given primary status in the utilization of the radio spectrum with respect to commercial users, who have a lesser status.

All these administrative and technical matters, as well as issues concerning auctions, license fees, other possible charges, fines, etc., should be specified in relevant national regulations. They may be in the form of consolidated national radio regulations and/or in the form of separate decrees, orders, or rules approved by appropriate national authorities.

Frequency coordination procedures: Frequency coordination is the process of obtaining agreement between existing spectrum users and a prospective spectrum user when there is some potential spectrum conflict. Coordination may involve technical, administrative, legal, comity, or other considerations.

Coordination of national spectrum utilization is an important area of activity in the department responsible for the frequency assignment process as it is shown in Figure 3.2. Frequency coordination at the national level is essential because the same frequency band is, typically, shared by radio systems that belong to different users. For example, some microwave links may be operated by different governmental agencies, others by national or local carriers, and some by one or more private companies – all using the same frequency allocations. The process of coordination must be regulated by appropriate national rules. All users potentially affected by a new radio system under consideration must be obliged to examine the possibility of interference with that assignment.

Frequencies are assigned with due account of any restrictions on their use, stipulated by the national regulations. Some countries may place local limitations on the use of specified frequency bands for individual services. These can be restrictions on the utilization of some frequencies by particular users, on the radiated power in specific services operating in a specified frequency band, or in certain geographical areas.

In some cases, and especially under the frequency assignment process in border areas, there is a need for international frequency coordination. The spectrum must be shared among administrations, among radio services, and among stations. On the other hand, each administration is autonomous. It thus becomes apparent that the best way of serving the interest of every administration is to obtain an international agreement on general rules and procedures for the management of the spectrum. The main objective is to avoid unacceptable interference between stations of different administrations. For this purpose, coordination procedures should be agreed upon to advise administrations with common borders, how to exchange information, and how to take all necessary steps to ensure that harmful interference will not occur.

The main approach to the coordination of terrestrial frequency assignments in border areas is to divide available frequency resources equitably between parties or, in the case of great difference in the number of frequency assignments or population in a border area, proportionally to this amount between parties. One party could use one agreed set of frequencies and the other party, another set. Acceptable interference conditions are to be agreed and frequency assignments under consideration are to be checked against agreed criteria using agreed calculation procedures. The coordination process can be divided into three principal parts: administrative provisions; exchange of information; and technical calculations. Typical international frequency coordination procedures can be found in flowcharts in Recommendation ITU-R SM.1049 which presents detailed guidance on coordination procedures for terrestrial frequency assignments. Additional information concerning spectrum engineering matters related to coordination can be found in Chapter 5. Calculations of coordination distance and coordination area are sometimes simple to carry out manually. In other cases, calculations may become complex and time consuming, and the use of computer analyses becomes essential.

A possible example of a multilateral agreement for the attribution of preferential frequencies for fixed and land mobile services on a regional level is the Vienna Agreement, 2000[32] which contains not only all the necessary regulatory procedures but also all the necessary technical criteria and calculation procedures. It is supplemented by relevant software. All of these materials may also be successfully used at a national level. Principal provisions of the Vienna Agreement are given in Recommendation ITU-R SM.1049. International frequency coordination can also be exemplified by the frequency coordination of broadcasting stations in border areas.

International registration of a country’s frequency assignments by the ITU provides international recognition and, in particular services and frequency plans, protection for a station’s operation. It is in the best interests of an administration to register all of its frequency assignments which are believed to need protection from interference from other international users[33].

The procedures governing notification and registration of frequency assignments in the MIFR may be broadly sub-divided into the acts of coordination, notification, examination, and registration. The procedures to be followed are contained in the RR. Where a frequency assignment is made, in accordance with a Regional Allotment Plan or Assignment Plan, the appropriate Plan may also include coordination procedures to be followed.

It is also the responsibility of national agencies to examine any new frequency proposals, or modifications to existing frequency assignments, circulated through the BR IFIC. The examination should ensure that any of these published frequency requirements that may cause harmful interference to existing or planned national radio services are commented upon by the due date indicated by the BR.

3.2 Technical aspects of the frequency assignment process

In most cases, a frequency assignment seeks to settle on a frequency that will provide an applicant with the required level of service while protecting both the applicant and existing licensees from interference. The need for spectrum efficiency further dictates that an assignment be chosen that assures the maximum opportunity to accommodate future applicants for frequency assignments.

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[32] Since 2001 the Vienna Agreement of 2000 is also referred to as the Berlin Agreement.

[33] It is necessary to note that many situations may occur where this coordination is not needed, especially in geographically large countries or in countries that are isolated from nearest neighbours.

3.2.1 Procedures for assignment of frequencies to radio stations

The procedures for assignment of frequencies to radio stations could use:

a) a computer database which includes a national frequency register, i.e. an ensemble of data blocks associated with all operating radio stations indicating administrative information, geographical locations, and technical characteristics;

b) a special indication of those frequency assignments coordinated with other administrations;

c) a topographical database which can be used to carry out calculations of wanted and unwanted signal levels with allowance for propagation path profiles;

d) an electronic library of type-approved transmitting and receiving equipment, and antennas, as well as libraries of frequency-planning criteria (minimal/nominal usable field strengths, protection ratios, permissible interference levels, etc.);

e) an EMC analysis including various calculation techniques (see Chapter 5); and

f) an electronic library of license fees and other spectrum management charges, or calculation blocks to determine them.

3.2.2 Information required for frequency applications

It is highly desirable to ensure that national application formats are, as far as possible, consistent with ITU-R Recommendations and contain all data used by the BR as is presented in the BR IFIC and in appropriate regional frequency plans.

3.2.3 Methods of interference analysis for frequency-site planning

The need for an interference analysis arises when performing frequency-site planning for radiocommunication and broadcasting networks at international and national levels, and in carrying out frequency coordination between administrations of different countries.

Interference analysis starts with determination of the field strengths of wanted and interfering signals at a receiving point or at a border of the service area, e.g. for broadcasting and point-to-multipoint communications, and the comparison with requirements for a minimal/nominal usable field strength and protection ratios for the particular radio service. In this respect it is vitally important to follow the definitions for the different levels of interference stipulated by the RR. The Regulations contain the following definitions of interferences and protection ratio:

No. 1.166 *interference:* The effect of unwanted energy due to one or a combination of *emissions*, *radiations*, or inductions upon reception in a *radiocommunication* system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

No. 1.167 *permissible interference* [34] *:* Observed or predicted *interference* which complies with quantitative *interference* and sharing criteria contained in these Regulations or in ITU-R Recommendations or in special agreements as provided for in these Regulations.

No. 1.168 *accepted interference*[34]*: Interference* at a higher level than that defined as *permissible interference* and which has been agreed upon between two or more administrations without prejudice to other administrations.

No. 1.169 *harmful interference: Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations (CS).

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[34] **1.167.1** and **1.168.1** The terms "permissible interference" and "accepted interference" are used in the coordination of frequency assignments between *administrations*.

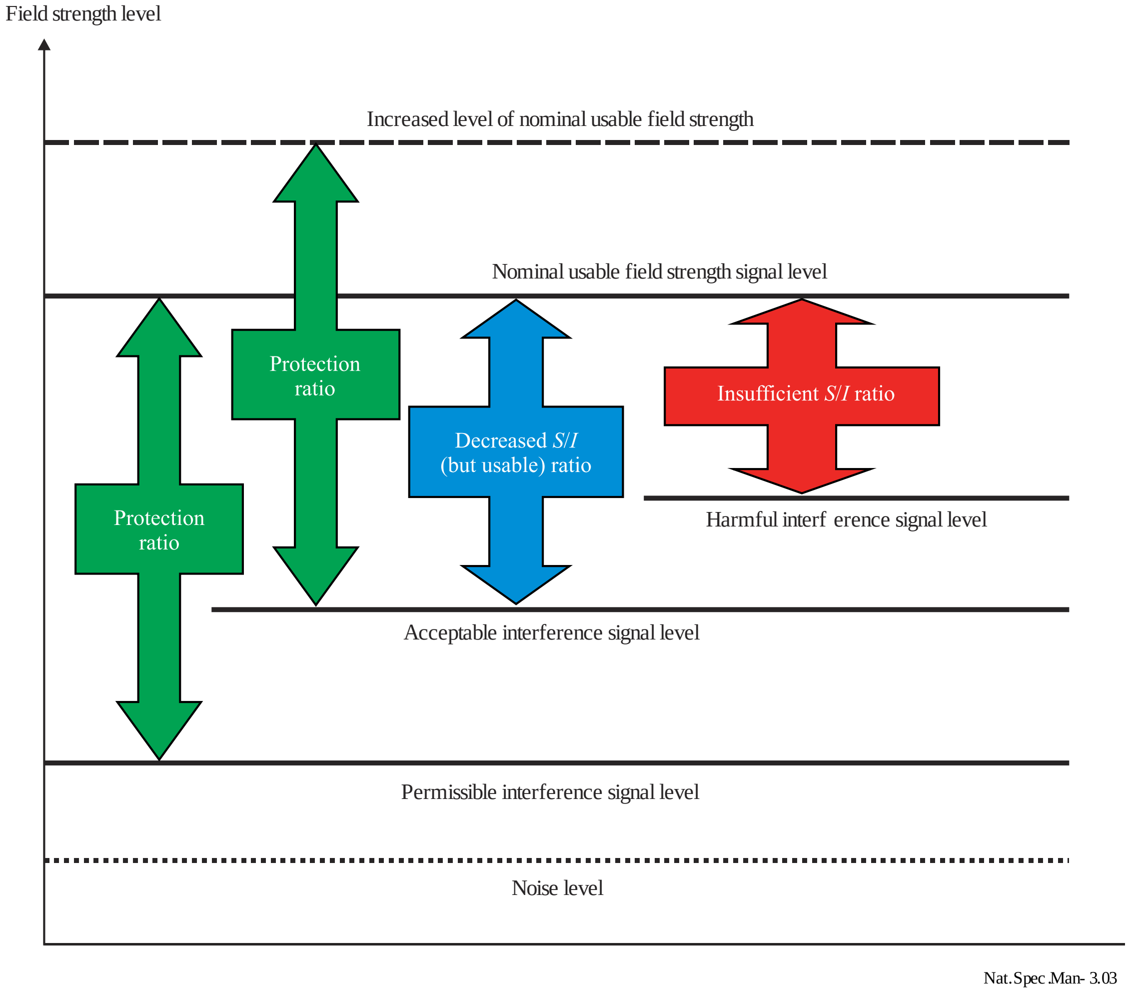
No. 1.170 *protection ratio* (R.F.)*:* The minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels, at the receiver input, determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output.

For purposes of the Regulations, the terms *permissible interference* and *accepted interference* are used in the coordination of frequency assignments between administrations. However in practice these terms are also used for purposes of planning and frequency assignment coordination among spectrum users at a national level.

The interrelationship of *harmful interference* with nominal usable field strength, *protection ratio,* and *permissible interference* (Recommendation ITU-R BS.638), for some terrestrial radio services, and the single interference case, is presented at Figure 3.3.

FIGURE 3.3

Relationship between usable and interfering signal levels



Nominal usable field strength is an important factor in frequency planning and coordination. It represents the signal level received (or assumed) from the desired transmitter that provides adequate signal reception (or system performance) in the presence of interfering signal from other transmitters. Unwanted signals in the same channel must be limited to a low level if interference is to be avoided. The degree to which unwanted signals must be constrained is defined by the *protection ratio* (or margin) as depicted by the two leftmost arrows in Figure 3.3. The corresponding interference signal level is defined as the *permissible interference* signal or the *accepted interference* signal level (received or assumed).

In many situations, protection against any occurrence of interference is unnecessary or impractical. Radio service can be provided even in the presence of low-level or occasional unwanted signals. The signal level that defines this situation is somewhat higher than the *permissible interference* level and is shown here as the *acceptable interference* signal level. This corresponds to a situation where there is *accepted interference* from the unwanted signal. See the definition shown in RR No. **1.168** above. Nevertheless, in this situation, adequate performance from the system can still be derived. The same *protection ratio* is used to define the "increased level of nominal usable field strength".

As it can be seen from Figure 3.3, the conditions of acceptable interference can be met by increasing the "nominal usable field strength level" or increasing the signal-to-interference (S/I) ratio. However, increase of the interfering signal level will eventually result in insufficient S/I ratio and lead to harmful interference.

Levels of wanted and interfering signals are not constant in time but vary in strength due to signal fading. To ensure the needed quality of reception, additional margins for nominal usable field strengths are generally used. Their values may range from 6 to 12 dB and higher for some microwave point-to-point systems for high values of percentage of time.

Particular values of "nominal usable field strength level" and the *protection ratio*, indicated in Figure 3.3 in generalized form, depend on the specific service, frequency band, quality of the service, and other factors. Existing automated spectrum management systems contain these values in libraries used for relevant frequency assignment and frequency-site planning procedures.

Sometimes, well-developed radio networks are referred to as "interference-free". In fact it concerns the networks that are designed to meet assumed, specific interference conditions. Indeed, real interference-free operation (when interference is negligible) may require large geographical separations between stations using the same or adjacent frequencies and that would result in decrease of the spectrum-use efficiency. Thus, the spectrum is used effectively when all stations of networks operate with permissible levels of interference that can be different for stations of different radio services. This means that the *permissible interference* concept plays a positive role in the frequency – site planning process. On one hand, the *permissible interference* level is an indicator of required quality of transmissions and, on the other hand, it is an indicator of efficient spectrum utilization.

Techniques of interference analyses are covered in detail in Chapter 5.

3.3 Frequency plans

Frequency planning involves an optimal distribution of a given set of frequency channels from a spectrum efficiency viewpoint, between base stations or broadcasting stations which form either a mobile communication network or a broadcasting (television or sound) system. Planning can result in an approach that provides the most complete coverage of an area where the network in question operates.

Planning may start based on assumptions of uniform geographic and topographic conditions through the areas for which the plan is developed. These assumptions allow the use of standard estimates for propagation loss. The resulting plans provide for uniform area coverage but do not accommodate the differences in demand or conditions that arise in different locations within the planning area. In such cases, the "master plan" could provide for adjustments to be made (sometimes requiring special coordination). In other cases, the master plan can provide an initial arrangement of sites and frequencies which are subject to adjustment as practical experience dictates. Modern emphasis on flexibility in frequency planning suggests that site plans of this kind include careful consideration of possibilities for future modification and change.

The availability of radio frequency coverage and frequency assignment computer programs makes adaptation of these plans more practical. Note that it is not necessarily the responsibility of regulatory agencies to provide these plans. For example, for cellular telephony, these plans are usually provided by cellular operators.

In addition to the five methods described below, other frequency assignment plans may be used. Traditionally, two methods have been employed for the preparation of a frequency plan. These are:

– lattice-based – a systematic and geographically regular distribution of frequency resources over an area;
– non-lattice-based – an irregular, but spectrum-utilization-efficient distribution of frequency resources over a geographical area.

Either of the two methods is suitable for assignment/allotment planning, and either is capable of use in the presence of pre-existing constraints. With regard to the choice of a planning method or methods, lattice-based methods have successfully provided the basis for most of the past frequency plans and would be appropriate for use in digital broadcasting planning in areas of relative uniformity of requirement characteristics. This method essentially applies in areas where existing or planned assignments are converted from analogue to digital assignments and will form part of the digital plan.

However, in areas where there are non-uniform requirements for digital broadcasting (e.g. very different sizes of service area and various reception conditions), or in areas where there is a requirement for digital broadcasting stations and there are already networks of analogue stations, non-lattice-based planning will provide an optimum means to achieve both the desired coverage and the most efficient use of the available spectrum. This method permits the addition of assignments which are not distributed across the total area in any regular way and which may not have equal-sized service areas.

The planning process in either method can be split into "compatibility analysis" and "synthesis" stages. The analysis stage would enable incompatibilities to be identified and appropriate responses to these incompatibilities to be considered.

The planning process may be summarized by the following steps:

Step 1: Submission of the input requirements for digital broadcasting.

Step 2: Identification of the analogue broadcasting stations and of other services that need to be taken into account.

Step 3: Performance of compatibility analyses.

Step 4: Assessment of the results from Step 3.

Step 5: Allowance for administrative input concerning compatibility between requirements, with a return to Step 3 if necessary.

Step 6: Performance of synthesis, the output of which is a plan.

Step 7: Review of the results, with a loop back to Step 5 and then to Step 3 if the desired result is not achieved.

Step 8: Adoption of the final plan.

3.3.1 Linear frequency-site planning

Linear frequency-site planning was developed in the Radio Broadcasting Institute in Hamburg (Germany). It was used at many international conferences on radio broadcasting (Stockholm, 1961; Geneva, 1963; RARC 1+; Geneva, 1984).

This method can also be applied to frequency planning in mobile radiocommunication systems [Gamst, 1982 and Hale, 1981] including cellular systems.

The linear frequency planning method is based on the following theoretical assumptions:

– all transmitters are identical, their output power and antenna height being the same;
– antenna radiation patterns are isotropic in the horizontal plane; and
– propagation losses are not a function of direction or frequency.

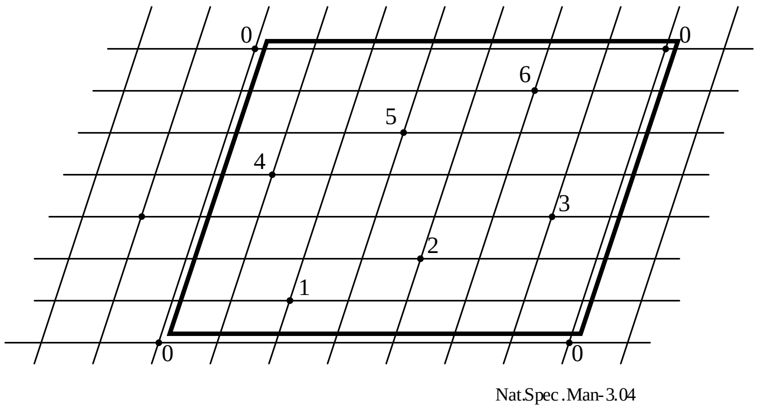
Under the above assumptions, the boundary of a service area for each transmitter is a circle, the radius of which depends on the type of service (sound or television broadcasting, mobile, etc.), and the propagation characteristics in the frequency range under consideration.

Application of this method results in a homogeneous transmitter network plan where the nearest co-channel transmitters are nodal points of a geometrically regular lattice at the Earth's surface. With such a lattice there are six co-channel transmitters in a lattice.

Figure 3.4 shows a regular lattice distribution of transmitters where seven co-channel assignments are available. The theoretical network is formed by a map-coordinates lattice using an oblique coordinate system, where the oblique angle is 60°.

FIGURE 3.4

Regular lattice for radio stations



The co-channel rhombus at nodal points at which transmitters using the frequency channel $i = 0$ ... are located, is highlighted. The transmitters nearest to the one located at the origin are marked by numbers 1 … 6. The co-channel rhombus at the nodal points of the station numbered by 0 is called a main co-channel rhombus. Radio stations whose locations are numbered $i = 1$ ... 6 are located at nodal points inside the co-channel rhombus. The allocation of location numbers among radio stations located within the rhombus is the same for each adjacent rhombus.

The following input data are used:

– service area radius to be ensured by one transmitter in the network; and

– allowable distance between transmitters of different frequency channels.

The planning exercise results in the following parameters for a regular transmitter network:

– the minimum required number of frequency channels;

– the number of frequency channels designated to the radio stations in the planned network;

– the actual distance between the transmitters of different frequency channels *i*; and

– the coordinates of a network mode (in the main co-channel rhombi) where the radio station operating on channel *i* is located.

The distances between the transmitters of different frequency channels are calculated by using a different procedure to ensure that the level of mutual interference between the different service areas does not exceed predetermined acceptable values.

It should be noted that actual transmitter networks do not conform to the regular geometrical form shown in Figure 3.4 and their technical performance does not comport with that of the theoretical network. Deviations from geometrical regularity, theoretical powers, and antenna height, inevitably reduce the efficiency of a frequency plan. Nevertheless, using the above method it is possible to draw a clear picture showing the efficacy of a frequency plan as a function of the limitations adopted as input data for its preparation.

As noted above, the preparation of a frequency plan obtained by using the above methods is heuristic in nature and does not readily lend itself to normalization.

The results of the linear frequency planning can be applied in the following manner. The transmitter grid of an ideal planned network is marked on a map of the area and a designated frequency channel is assigned to the nearest grid node location. In assigning frequency channels for specific map locations, transmitter power, antenna height, etc., may be modified relative to the values adopted for the planning purposes.

On completing this plan, it is necessary to check the service area radius for each transmitter in the network using more accurate prediction methods, along with actual data for each site.

In some cases, especially for broadcasting, several frequency channels are required for each location rather than one. This can be achieved by the linear planning procedure based on multiple, matched regular lattices under the condition that differences in channel frequencies in each location, are the maximum possible. Additional limitations can be imposed by requirements to avoid intermodulation interference.

3.3.2 Sequential frequency planning and assignment process

This approach seeks to find a frequency for each station in a list of stations from a fixed list of available frequencies.

The following input data are required for network planning using this method:

a) a list of base stations or broadcasting stations to which frequencies are to be assigned, with their geographical coordinates;

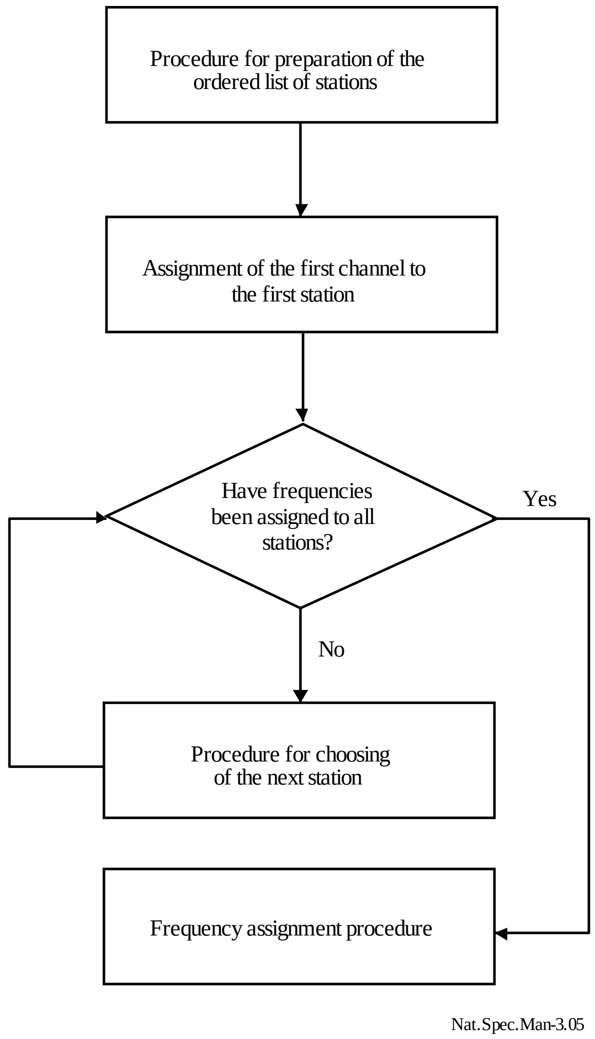
b) a list of available frequency channels; and

c) a table indicating the required distance between radio stations when separated by a given frequency.

Figure 3.5 shows a general algorithm block diagram. The frequency planning algorithm includes three procedures, as shown. The initial procedure provides for the preparation of a regular list of radio stations for which frequencies need to be chosen. The sequence of radio station entries in the list corresponds to the effort required to designate a frequency to the transmitter. In particular, the effort can be defined by the number of radio stations within a co-channel interference area of a given radio station. The more radio stations there are in the co-channel interference area, the more difficult it is to designate a frequency to this radio station and the earlier it appears in the list.

FIGURE 3.5

General algorithm of frequency planning



The designation of frequencies to a radio station begins with the first radio station in the list which is assigned the first (lower) frequency channel.

In order to choose each of the subsequent radio stations from the list and to designate a frequency to it, a certain procedure is sequentially applied from several procedures which have been developed for this purpose. The simplest procedure is to ensure that the priority of radio stations to be chosen corresponds to their sequence in the list.

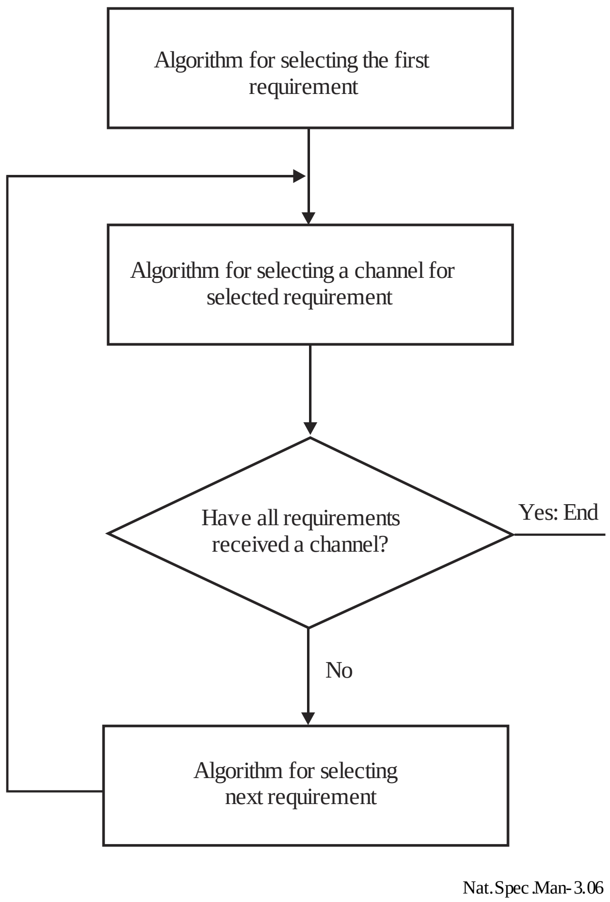
In practice, a problem sometimes arises with designating frequencies for new radio stations. These stations must be accommodated within the existing network assignments. For example, it can become complex for a television system which needs a number of low-power repeaters covering small service areas (where the reception of programs from the high-power television stations is either difficult or impossible) in order to achieve full program coverage.

This particular problem of frequency planning for a low-power television subsystem can be resolved by using the method described in literature [O'Leary, 1984; Hunt, 1984 and Stocer, 1984].

The flowchart of the planning method adopted by the RRC-04 for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3 is presented in Figure 3.6.

FIGURE 3.6

General flowchart of sequential frequency-synthesis planning



3.3.3 Cellular frequency-site planning method

Over the past several decades, the rate of growth in the land mobile service has been especially high as mobile cellular systems have been brought into use. The radio-frequency spectrum is most efficiently used in these systems because the number of users-per-band allocated for their operation is much higher than that in conventional land mobile systems. This efficiency is achieved by the parameters of each base station which are chosen to serve small areas, or cells, with specified boundaries. Cells cover the area where a base station network operates, as well as roads and highways between different base locations.

In cellular networks the distance D between the cells using the same channels is normally not greater than $D = 3.5\ R_0$ to $D = 5.5\ R_0$, where R_0 is the nominal radius of a cell. There is, therefore, a high rate of frequency re-use in cellular systems and the efficiency of frequency spectrum utilization is relatively high [Lee, 1989].

A set of neighbouring cells, where it is not possible to use the same frequency channels due to interference limitations, is called a cluster. The number of cells in a cluster is its dimension [Lee, 1989].

Base stations may employ both omnidirectional vertically polarized antennas, and sector antennas having a beam width of 60° or 120°. Using sector antennas, each cell is divided into 3 or 6 sectors respectively, with different frequency channels being assigned to each sector [Lee, 1989].

In order to prepare a comprehensive frequency plan for a cellular mobile system, it is necessary to specify the basic parameters of such a plan:

– a cluster dimension;

– a number, M, of service sectors in a cell ($M = 1$ for $\theta = 360°$; $M = 3$ for $\theta = 120°$; and $M = 6$ for $\theta = 60°$; where θ is the base station antenna beamwidth);

– the number of base stations;

– the radius of a cell;

– the base station transmitter equivalent radiated power; and

– the base station antenna height (the height of a mobile station is usually assumed to be 1.5 m).

This procedure enables all the parameters required for a frequency plan to be determined. To develop a comprehensive plan based on the number of channels for each base station and a cluster configuration in a cellular system, it is necessary to define the particular frequency assigned for the operation of all base stations belonging to one cluster. In doing so it is also indispensable to minimize interference between the cells where adjacent frequency channels are employed as well as intermodulation interference between channels in the same sector of a cell.

For the preparation of a comprehensive frequency plan for cellular systems, the methods described in [Gamst, 1982 and Hale, 1981] can be used.

3.3.4 Flexible frequency-site planning process

For some radio services and their applications such as fixed service including microwave systems or private mobile radio (PMR) systems, predetermined, rigid frequency-site plans are not usually developed. A frequency assignment for each new application is determined by providing a compatibility analysis of each proposed new entry against existing frequency assignments listed in the national frequency register, and by deciding a frequency for this new entry which does not affect existing frequency assignments and/or is not affected by them. Procedures of the relevant electromagnetic compatibility analysis are presented in Chapter 5 and in the Vienna Agreement, 2000.

To expedite choosing an appropriate frequency for assignment at a required site, procedures given in Recommendation ITU-R SM.1599 can be used. This method, in fact, produces relevant data on occupancy of particular frequency sub-bands at different sites. The method considerably simplifies the frequency assignment process because it allows making EMC analyses for a new entity at a required site, against a limited number of frequency assignments in a narrower frequency sub-band which is less occupied than other sub-bands.

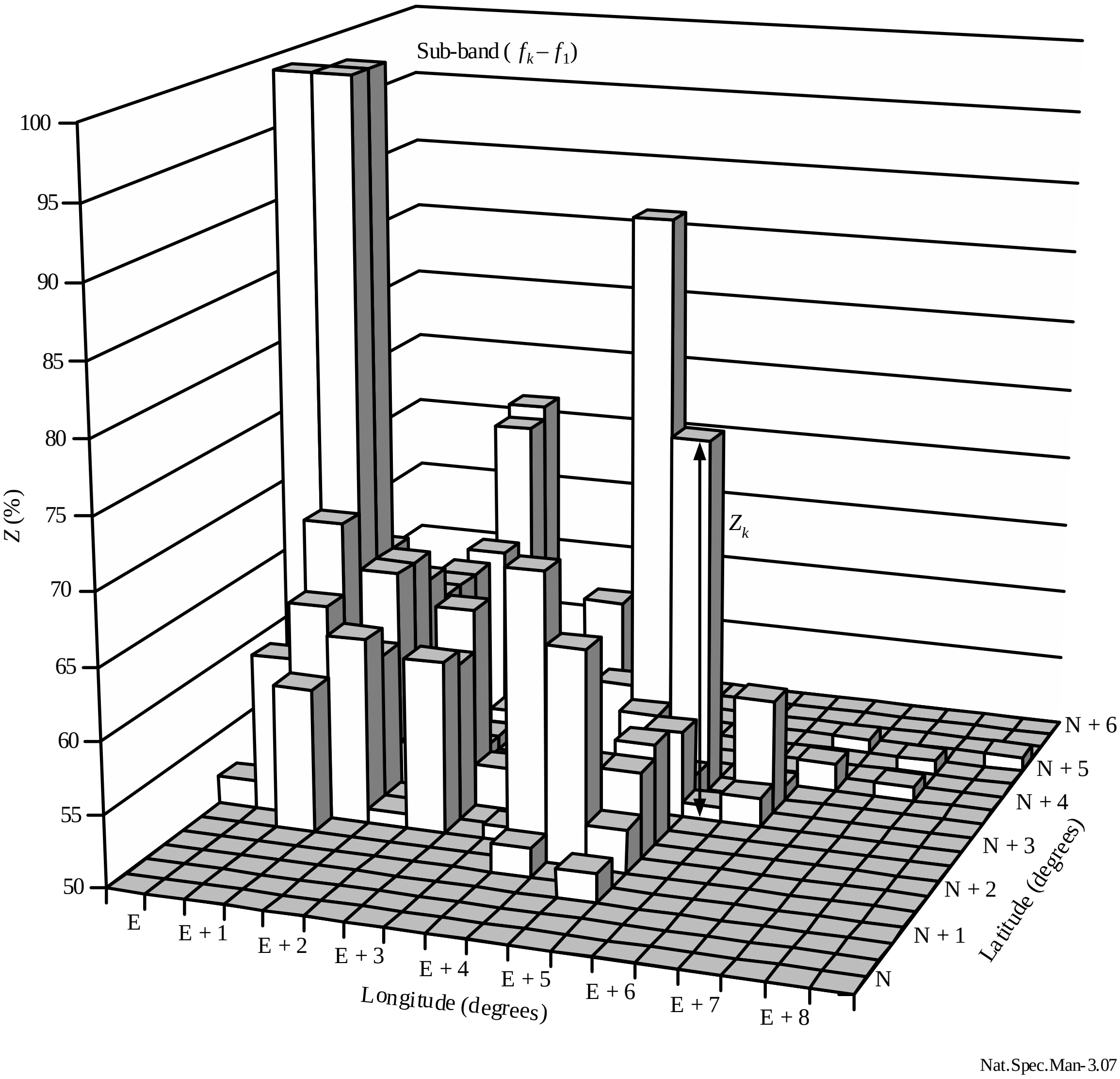
For example, Figure 3.7 shows distribution of a spectrum utilization factor, Z, (defined in Recommendation ITU-R SM.1046) in one sub-band ($f_k – f_1$) among territory cells of dimension $1° \times 1°$ within a total region of about $8° \times 8°$. It is seen for which cells the sub-band, Z_k, is suitable for further EMC analysis and for which it is unsuitable.

3.4 Software and automation

Frequency assignment and licensing sub-systems require computers and storage media as is described in the ITU Handbook on Computer-Aided Techniques for Spectrum Management, (Geneva, 2005). Computer software can perform calculations for compatibility analyses and frequency planning based on the methodology described in the above section. Modern spectrum management system (SMS) computer software provides possibilities for easy customization depending on particular requirements of the user. Required documentation forms can be generated, and specific propagation [Topcu *et al.*, 2000] and license fee calculation models can be programmed. A licence fee calculation model specifically developed for purposes of SMS customization is available [Pavliouk, 2000]. Modern computer SMS software is also easily adjustable to operate with various digital terrain data maps.

FIGURE 3.7

Example of spectrum utilization factor, *Z*, distribution over a territory for selected frequency sub-bands

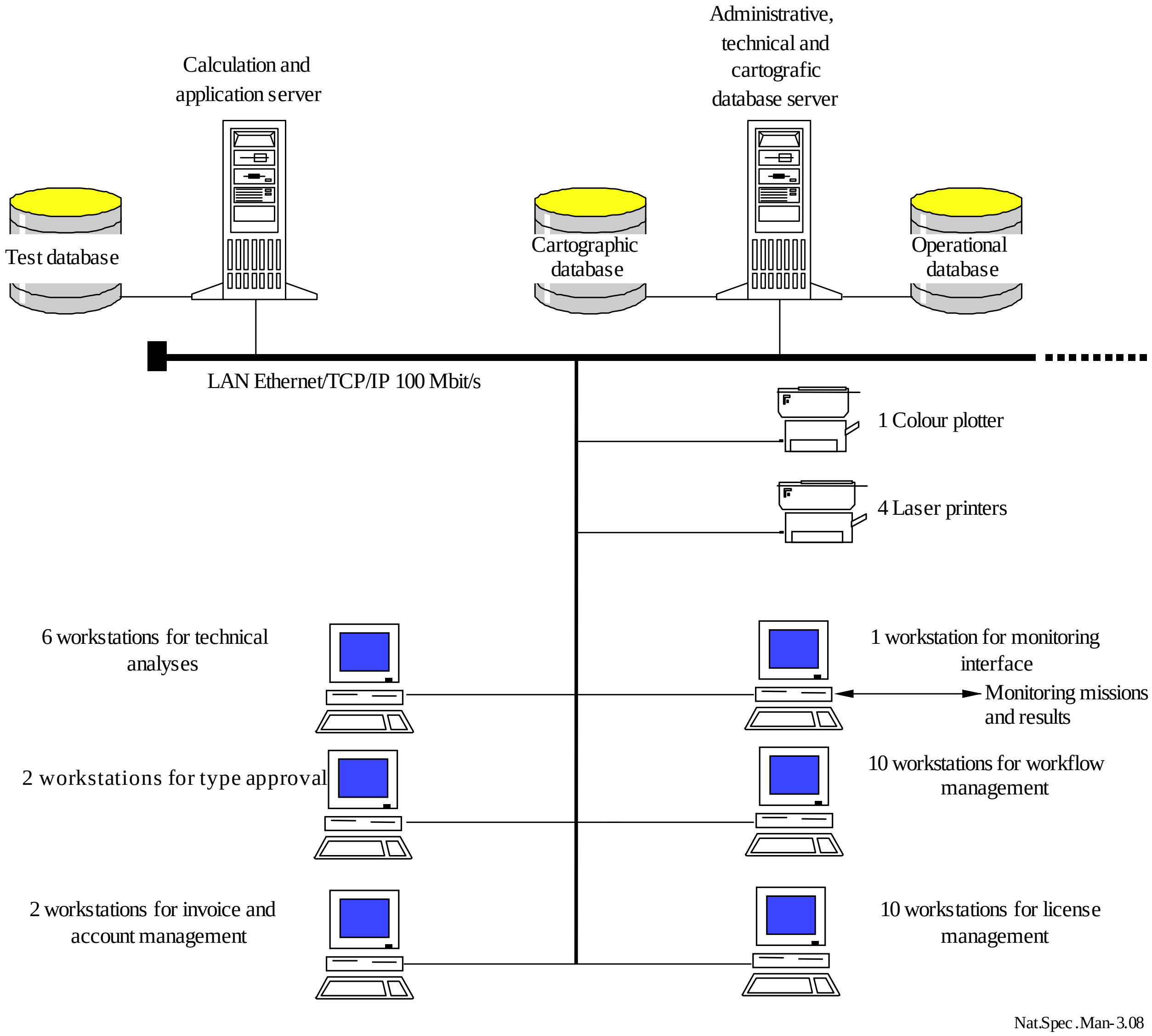


In many countries there are common automatic spectrum management systems covering radio facilities in all radio services [Bare, 1990 and Bykhovsky *et al.*, 2002] Automatic, local systems intended for individual services such as television and VHF sound broadcasting, land mobile and fixed services, etc., may use personal computers [Vasiliev *et al.*, 1986 and Dotolev *et al.*, 2003].

An operational configuration example of a model SMS is given in Figure 3.8.

FIGURE 3.8

Example of an SMS operational configuration



This model SMS contains:

– Calculation and application server: SMS software, calculation file management, backup and restore management.
– Administrative, technical and cartographic server: operational databases management.
– Test database: database used for tests and new SMS evaluation.
– Operational database: database used for the administration's operational work.
– Cartographic database: digital terrain model, clutter, administrative limits, scanned maps.
– Colour plotter: graphical representations, coverage maps.
– Laser printer: official documents.
– Technical analyses workstations: workstations to make the EMC analysis using graphical representation.
– Type approval workstations: workstations to conduct the equipment approval management including importation and dealer certificate.

- Account and invoice workstations: workstations to access accounts and invoice management data.
- Monitoring interface workstation: workstation to generate missions and integrate monitoring results.
- Workflow management workstations: workstations to deal with the internal processes of the administration regarding spectrum management.
- Licenses management workstations: workstations to manage the licensing process and issue invoices.

The number of particular devices depends on needs of the regulatory agency.

PART B

Licensing

3.5 Introduction

"Licensing" is a widely applied term for many different situations in telecommunications and many other aspects of commercial and government activities. "Licensing," as the term is applied to radio operations, is also used to mean different things. Often a single licensing document incorporates aspects of business operations and of radio frequency usage (and so both permission to conduct a certain find of business and permission to use a radio frequency appear). In this part, "licensing" is considered as it specifically applies to radio frequency usage – the "radio frequency license".

Radio frequency licensing is used as a means to manage the use of the radio spectrum (as specified in the Radio Regulations, No. **18.1**). However, effective spectrum management must consider all users of the radio spectrum including private entities, enterprises, and government. It is common for government (and other non-private) spectrum users to operate under some form of permission granted by a spectrum manager. Such "permits" or "authorizations" are frequently considered as a form of "license" even when they have different legal authority. The following discussion of licensing applies to the most general form of the process, including permits, authorization and other similar documents, unless specific comments indicate otherwise.

3.6 Requirements of licensing

Radio licensing serves several important purposes. The most important is to limit the technical and operational characteristics of a radio station with the benefit of conserving the limited assets of the radio spectrum in the national, public interest. Another important purpose is to maintain a comprehensive frequency register as required to manage spectrum use, to avoid interference while improving spectral efficiency.

RR No. **18.1** requires all transmitting stations established or operated by private persons or enterprises to be licensed by the administration, unless a national decision is taken to allow operation on a non-interference basis. Other provisions of RR Article **18** deal with basic responsibilities of the licensee and provide guidance for administrations on various problems that may arise in licensing mobile stations that may enter the jurisdiction of other administrations.

All licenses should identify the licensee by name and address, the geographical location of the transmitting station or stations or the area within which they move (if mobile), technical parameters and operational conditions of the station(s), the purpose for which the frequency assignment(s) may be used, and the period of validity of the license. These conditions are all intended to help ensure that interference is not caused to other users (see RR Article **3**). In most cases the assigned frequency, the parameters of the emission and essential characteristics of the transmitting antenna will be stated, although the authority to transmit may have to be defined in another form where a single document authorizes the use of more than one transmitter or more than one frequency assignment. A license may also be issued for a receiving station, indicating essential parameters. A fee will usually be charged for a license. Key issues that arise in licensing are, "Who is entitled to be licensed to transmit, and how to achieve efficient usage of the spectrum?"

Recently, administrations have provided frequency bands, for access to public networks from mobile networks. In this case, it is the responsibility of the mobile network operators to manage frequencies, define the transmitting powers, and establish other relevant parameters of the stations of their network all within generally licensed limits.

For public mobile networks, frequency management authorities do not license each mobile transmitting station individually. This however, does not preclude the operators from having the obligation to announce to this authority the location and essential characteristics of the network stations as they are put into service.

3.7 Licensing radio stations

Licensing of spectrum use is essential to prevent interference between services and stations. However, it may be possible to exempt the requirement for individual licensing for some low power applications such as Citizen Band stations, cordless telephones, short range devices, ultra-wideband systems, electronic devices, security systems, etc., so as to reduce the administrative and economic burden on both the administration and users.

It should be recognized that without the discipline of a spectrum licensing system, radio interference could reach unacceptable levels, reducing the value of investment in equipment for transmission or reception of radio signals. Spectrum users, having invested in a communication system, would want a licensing regime with its accompanying assurance of protection from interference under normal operating conditions.

Some administrations use procedures known as “type approval” or “type acceptance” to provide an assurance that, in terms of its design, a product is technically and actually capable of meeting the prescribed regulatory requirements relevant to that product. These regulatory requirements exist to enable radio equipment and their users to co-exist with each other, to ensure maximum practicable economy in the use of the frequency spectrum and to facilitate the orderly development and use of radio equipment. The requirement for limited immunity from interference could be an additional requirement.

Type approval requires a sample of the equipment to be submitted for testing by an approved (sometimes government) test laboratory to an agreed, published technical specification or standard. If the equipment is approved, a numbered certificate is issued and the manufacturer places a special mark or indicator on the product to indicate that it is “type approved”.

Type acceptance requires only that manufacturer’s test data be submitted to the administration for review. Conditions of the testing and the number of samples required for testing are prescribed. If the submitted data are acceptable, again a certificate is issued and the manufacturer places a special mark or indicator on the product to indicate that it is “type accepted”.

Type approval or acceptance can be an expensive and lengthy procedure for both the manufacturer and an administration, especially if each administration develops its own technical specifications and requires the manufacturer to obtain approval or acceptance in each country where the equipment is intended to be placed on the market. Recognizing this, some administrations have established “mutual recognition agreements” to recognize each other’s type approval and acceptance results. Increasingly, the concept of type approval is seen as unnecessary regulation and a potential barrier to trade, especially as more equipment is intended to be marketed, circulated and operated internationally without regulatory restriction, e.g. public mobile telephones. There is a trend to transfer the responsibility from the regulator to the manufacturer or supplier for ensuring equipment conformity to the essential requirements (conformity assessment). Market surveillance will identify non-compliant equipment and penalties can then be imposed on the negligent manufacturer or supplier.

An example procedure established by the Member States of the European Union (EU) is applied through the legally enforceable Radio and Telecommunications Terminal Equipment (R&TTE) Directive. As of 8 April 2001, the R&TTE Directive replaced more than 1 000 nationally approved regulations and governs the marketing and use of such equipment. The Directive covers all equipment that uses the radio-frequency spectrum. It also covers all terminal equipment attached to public telecommunication networks. The Directive requires radio equipment to effectively use the spectrum and not cause harmful interference.

Assessment of the conformity of a product is a responsibility for the equipment manufacturer. The manufacturer makes a “declaration of conformity” and does not need to obtain an approval or acceptance certificate from an official body after having passed tests in a legally recognized laboratory. When standards are not available or not appropriate, a manufacturer still has a route-to-market by demonstrating more extensively how technical requirements are met. EU States are obliged to publish the rules to access the radio-frequency spectrum so that manufacturers are fully aware of national differences in allocation and usage and may build products capable of operating in as large a market as possible. The manufacturers are obliged to inform users of the intended use and the limitations of use, both on the packaging and in the manual. This means, that the manufacturer needs to inform the user clearly for which part of the radio spectrum it has been designed.

In accordance with provisions of the World Trade Organization, many countries have established Mutual Recognition Agreements among themselves. These agreements rely on the mutual acceptance of certificates, marks of conformity, and test reports issued by the laboratories or conformity assessment bodies of parties in conformity with the regulations of other countries.

Licenses should be renewable for a period applicable to the use as decided by the administration. Renewable licenses have an important, economic impact on the future use of the radio spectrum. It is possible by license terms, and by limiting the type approval or type acceptance period, to ensure that new technology is eventually adopted that is more spectrally efficient.

Data obtained from licensing records may be used to provide statistical information on access to the spectrum and be used to indicate trends in national use. It can also be used as an aid to predict trends and future spectrum requirements.

Licensing can be used to restrict the manufacture, sale, possession and importation of certain radio equipment that is inherently likely to cause harmful interference.

Radio license data is invaluable to enforcement agencies engaged in tracing interference complaints and can assist in prosecuting illegal radio stations.

3.8 Deregulation of licensing

The potential of low-power, short-range devices to cause interference to other radio users is minimal provided that they operate under the correct technical conditions. Under these conditions it is possible to exempt from licensing many low-powered devices.

This will provide a more liberal regulatory regime for users, manufacturers, and suppliers, while being less burdensome for administrations. Users will no longer have to pay fees or complete license application forms; and manufacturers and suppliers can market products in a less regulated environment leading to substantial public interest benefits. Equipment falling into this category may include devices such as metal detectors, radio controlled models, anti-theft devices, local alarms, cordless telephones, and ultra-wideband devices.

These devices usually share frequencies with other applications and so, are generally prohibited from causing harmful interference to those applications. If a short-range device does cause interference to authorized radiocommunications, even if the device complies with all of the technical standards and equipment authorization requirements in the national rules, then its operator is required to cease operation until the interference problem is solved. Low-power, short-range devices are unprotected from interfering with each other. More information on such equipment may be found in Report ITU-R SM.2153 – Technical and operating parameters and spectrum requirements for short-range devices.

3.9 Licensing practices

A licensing system plays a major role in any well-structured spectrum management unit. It exercises control over the operation of stations and the use of frequencies by:

– allowing examination of license applications and supporting documents to determine the license eligibility of the applicant from a legal and regulatory point of view, as well as to determine the technical acceptability of the radio equipment;
– granting either specific or blanket authorization to entities which may not require a license, such as for government agencies or for popular consumer-use communication devices;
– assigning identifying call signs to individual stations;
– issuing license documents and collecting fees, as appropriate;
– renewing and cancelling licenses, as appropriate; and
– conducting examinations of operator competence (i.e. amateurs) and issuing operator certificates.

Generally, a radio spectrum licensee is subject to a number of different general requirements, although specific radio services may have requirements imposed that are particular to that service:

– Operation of a radio service without a license is an offence unless that service is exempt from licensing.
– All changes to parameters within a radio license should be authorized by the frequency management authority, according to the national laws. Proposed changes in the details of the licensee should be provided to the appropriate frequency management authority.
– A licensee should ensure that any persons operating the radio station(s) observe the conditions of the license.
– Where appropriate, all messages should start and end with a call sign or identity.
– The license could include a statement about conditions pertaining to interference, immunity from interference, and to safety precautions including the intrinsic safety of the equipment.
– The license could include a comment about maintenance through a quality assurance scheme.
– Site engineering conditions could also be included in licensing specifications.

Administrations may charge users of the spectrum a fee for licenses. The fee may reflect the degree to which the spectrum is used, the RF spectrum denied to others, as well as the economic benefit derived. The level of fee may also be used as a way of optimizing spectrum use. This issue is covered in detail in Chapter 6.

In many countries, the administration takes into account two kinds of users: non-commercial radio users and commercial radio users.

3.9.1 Licensing non-commercial radio users

Non-commercial licensees are one of the main categories of a radio user. These organizations use radio because it is a resource that is essential for the pursuit of an activity that is of public concern. The communications and navigation requirements of ships, aircraft, police, emergency fire and medical response services, and certain public utilities come into this category. It is also convenient to include here the users of the science radio services. Almost all of radio services are used by non-commercial users to some extent, and for some services they are the sole users.

Operator license examinations may be required by an administration to ensure the capability of individuals to either operate or maintain non-commercial radio transmitting apparatus. Additionally, the Safety of Life at Sea Convention and the RR specify that only licensed individuals can either operate or be responsible for transmitting under certain circumstances.

Typically, radio operator licenses are related to safety services, amateur radio, or to other services where safety communications may be used. Examples of these are aircraft pilot licenses; maritime radio operators in the Global Maritime Distress and Safety Service; and commercial operator’s licenses for individuals who install, repair, or maintain ship, aircraft, and other transmitters; and operators or maintainers of broadcast transmitters. Some countries require some minimum amount of specialized education as a prerequisite for an operator’s examination. Other countries do not require any level of education, but prefer to rely either on proof of certain experience (apprenticeship), or on an examination. Countries should consider accepting for national purposes, radio operator certificates issued by another country with known qualifying standards. This applies directly to aeronautical and maritime operators. This can facilitate efficient and economical operator certification, particularly if the national workload is relatively light and there is insufficient justification for the efforts needed to develop and administer up-to-date operator examinations. This latter case applies especially if examinations need to include aspects of high technology.

While the administration may insist on the collaboration of non-commercial users in ensuring that spectrum assigned to them is used efficiently, the case for providing for the essential radio needs of these organizations is not usually at issue. However, a license fee or some equivalent transfer of funds will usually be charged, sufficient to meet some appropriate fraction of the administration’s costs.

3.9.2 Licensing commercial radio users

Commercial licensees of transmitters fall into two basic categories: service providers and private radio users. Service providers set up systems for other parties to use. Private radio users typically use their own radio systems in the course of their own business. Disregarding non-commercial use, service providers are virtually the sole users of the broadcasting service, and the broadcasting-satellite service (BSS), and they are the dominant users of the fixed-satellite service (FSS) and the mobile-satellite service (MSS). Private users are the sole users of the amateur and amateur-satellite service. Both categories of user share in commercial use of the fixed service and the mobile service.

The products that service providers supply and private radio users obtain from the fixed service and the land-mobile service, are similar. However, in some circumstances private systems can be less costly and more flexible than facilities leased from a service provider, but the latter can be expected to make more economical use of the spectrum. Thus, where spectrum is not abundant, administrations may be more willing to license service providers rather than private radio users. However, the administration may prefer to maintain competition between several providers.

In conventional licensing of commercial radio users, an administration ensures that an applicant has requirements that justify the grant of a license, and would use equipment that would use spectrum efficiently. If appropriate frequencies can be found for applicants, a license is issued and a license fee may be charged. If appropriate frequencies cannot be found for all applicants of both categories of commercial radio user, an administration must find some basis for deciding which applications are to be accepted. This decision could involve a choice between service providers and private users, and between one service provider and another service provider.

Different ways of optimizing spectrum use and of choosing between applicants for licenses have been employed. The application of economic solutions to both issues, known as spectrum pricing or auctions, has been favoured in some countries.

An administration is responsible for managing assignments for all commercial radio services, but by far the most extensive are the fixed service, the mobile service, and the broadcast service. Where telecommunications or broadcasting are monopolies, many of the problems of managing the frequency bands allocated for these services can be delegated from the administration to the service providers. However, in a country where competition between the suppliers of these services is a significant element in the regulation of quality and prices, the administration must retain authority for use of the spectrum involved.

3.9.3 Licensing fixed service for telecommunication service operators

Public telecommunications operators use the fixed service for several purposes. Line-of-sight inter-city links, typically covering distances of 10-50 km, often formed into long radio-relay chains, occupy a large part of the 3 to 30 GHz spectrum. Short links are used within urban areas for wideband connections to subscribers, avoiding the delays that installing new underground cables might involve. Radio links such as these are also being used extensively to connect land-mobile base stations together and into the public switched telephone network (PSTN). Short-distance multiple access systems, typically operating between 300 and 3 000 MHz, are being brought into use to connect subscribers into the telephone network in rural areas.

In each of these applications the objectives of an administration are typically:

– to maintain conditions of fair competition between operators;
– to ensure that an efficient pattern of assignments is employed; and
– to ensure that the industry as a whole makes constructive use of both wire service and radio if the usable range of the radio medium should approach limits.

Above about 20 GHz the fixed service allocations may not be in heavy use. These bands, at least up to 55 GHz, are very suitable for short-distance, wideband connections between the switched network and the premises of major subscribers, and the base stations of land mobile networks. It may be found practicable to delegate the detailed management of an allotment of spectrum intended for these purposes, under terms that ensure efficient use.

An assignment made to a public wireless telecommunications operator for delegated management would be the subject of a formal agreement. The assignment would consist of a defined RF block of frequencies for use within a defined area or a specific RF channel. It would desirably be free from assignments to other radio users and capable of providing enough assignments to satisfy the operator’s foreseen need for new links for several years. Guidelines on the parameters of links to be operated in the band should be provided by the administration, to place limits on the distance at which interference to or from radio users in the same frequency band occurs in other areas. There should be provision for consultation with the administration before selecting a frequency that may interfere with a foreign station. When a frequency has been selected by the operator for a link, the administration would normally be asked to make a formal assignment, so as to enable adding the assignment to the national register, and if appropriate, to notify the ITU-R for registration of the assignment in the MIFR. Periodically, and in particular if the operator asks for more bandwidth, the administration should audit the efficiency with which the operator is managing the assignment. Having regard to the need for fair competition between operators, and to the special value of radio for urgent new requirements, a point may be reached when an application for a new assignment will be refused. Established routes can then be transferred to cable.

There should be a fee paid by public wireless telecommunications operators for access to spectrum (initial auction or yearly regulatory fee), whether for a block of frequencies, or for a single channel assignment. A fee would probably be made proportional to the assigned RF bandwidth, as appropriate. It may also be desirable to include a factor reflecting the relative scarcity of spectrum at the frequency in question, to encourage the use of other bands under less demand, or cabled transmission media instead of radio. The use of auctions in assigning fixed service spectrum has been implemented in some countries (see Chapter 6).

3.9.4 Licensing mobile services

A common practice in mobile service systems is that frequency assignments of stations are not notified to the ITU-R for registration in the master register. However, transmitting and receiving assignments from land stations and the areas within which their associated mobile stations travel can be registered in the frequency register. This provides indirect protection from foreign interference to the associated mobile stations. Both land stations and mobile stations must be licensed to use their assignments, although a single license may cover a fleet of mobiles in a particular band.

There is wide variety of mobile services. Some are used in great numbers but, even so, their impact on spectrum may be quite small. If some administrative action is required to ensure that interference will not arise, it is appropriate that a fee should be charged to cover the cost of that action, but the cost per mobile station will usually be quite small and the fee may be expected to be correspondingly small. However, there are also several kinds of land mobile systems, which have large and rapidly growing requirement for spectrum, tending to deny access to spectrum for other desirable radio facilities. Administrations should consider whether licensing policy, and in particular fees, could be designed to optimize the use of this spectrum. Private mobile radio (PMR) networks, cellular networks, and large-scale public access mobile radio (PAMR) networks are specific cases. It may be desirable to deal similarly with wide area paging and related systems.

Licensing for PMR: PMR uses spectrum less efficiently than cellular and PAMR networks, but there is scope for substantial improvement in private network efficiency through the general use of narrow bandwidth equipment. This is a matter of importance, since the demand for cellular system spectrum is large and increasing.

For some users, a PMR network configuration is advantageous. For example, the design of the terminal equipment may be optimized to suit the specific needs of some users. For others, the option that all mobile stations may listen to all messages from the base station is operationally desirable. Some users prefer PMR because, for them, it costs less than cellular systems. Thus an administration may find it expedient to set fees for PMR licenses to encourage current PMR users to use narrow bandwidth equipment or to abandon the use of PMR in favour of cellular networks.

Licensing public cellular and large scale PAMR networks: Public access networks, with many channels and large, perhaps national service areas comprise major telecommunication facilities. They are of great utility to their subscribers and have potential for profit for their owners. Each network has a substantial spectrum requirement and, in aggregate, they are among the major users of commercial spectrum below 2 GHz. The administration should ensure that there is a progressive improvement in the efficiency with which these networks use spectrum. The administration will want to ensure that licensees make vigorous use of the opportunity for service to the public and that subscribers exert competitive pressure on the licensees, thereby minimizing real costs of facilities.

An administration, conscious of a need to license service providers to offer more or new facilities to the public, may arrange preliminary discussions to identify the available technical options. Potential service providers, equipment manufacturers and the relevant government agencies might participate in these discussions. A decision would be reached on the system design option to be implemented for the next generation of systems. Then the administration may announce that blocks of RF spectrum will be assigned for new networks with a chosen specification. Proposals would then be invited for providing such systems to serve stated geographical areas. It is expected that five-year or ten-year licenses would be offered to two or more service providers, whose proposals are considered best. Proposals should include:

– a statement of the relevant technical, commercial and financial resources of the proponent;
– details of plans for "rolling out" the network over the area to be served;
– information on facilities to be provided and intentions on tariffs;
– indications as to how the proponent would respond to an unexpectedly low, or unexpectedly high level of demand; and
– assurances that there will be no barriers to competition among the networks.

An annual regulatory fee could apply. Alternatively, proponents might be asked to arrange an annual sum of money that would be paid for a license.

It may be supposed that several proposals would be received, at least some being satisfactory in general terms. If a fixed fee had been announced, it would be necessary to choose the successful proposals on the basis of their quality and credibility. Such judgments can be difficult for government agencies. Judgments may be appealed, leading to delay. An auction between a short list of proponents, each having made a proposal that was satisfactory, is less likely to be disputed and may yield more revenue to the government.

Successful proponents would then be licensed and their systems would be implemented. The networks of base stations would be planned and built. Transmitting and receiving frequencies, for assignment to the base stations would be chosen and proposed for formal assignment. In the absence of reasons for rejecting the proposals, an administration would confirm the assignments and, if appropriate, in due course, notify them to ITU-R for inclusion in the MIFR.

After some years, demand for the service might have outstripped the capacity of these networks. New equipment, either more spectrum-efficient, or offering desirable new features for the user, might meanwhile have become available. If so, new networks might be established in the same way as before, using this later technology in different frequency bands, the new networks competing with one another and with the networks of the earlier generation. Alternatively, if original band assignments were made to a service provider with technology-neutral specifications, the provider is able to implement new technology in the original band, using backwards-compatible migration.

3.9.5 Licensing broadcasting services

Broadcasting uses emission characteristics that are nationally standardized and which are relatively uniform, worldwide. The standards have changed little in several decades, although a phase of extensive technical change, springing from internationally coordinated development of digital systems, has recently begun. The more important broadcast frequency assignments are usually planned at government level, nationally and internationally. Thus, the main function of the licensing process is to identify the organizations that are to be authorized to broadcast. The auction mechanism, in some countries, is being used increasingly to resolve the choice between applicants of broadly equal merit.

In licensing the satellite broadcasting services, an administration may wish to regulate, to one degree or another, the use that broadcasting service providers make of the medium. For digital broadcasting satellite, there is a close analogy with terrestrial broadcasting. Access to radio frequencies, feeder links and service downlinks, is firmly under the control of the government of the country to which programming is directed, although this may not be true of the outer fringes of the satellite coverage area.

Thus, any administration may take responsibility for a satellite used for broadcasting and for assigning and coordinating frequencies used. Feeder link earth stations may be located anywhere within line-of-sight of the satellite. The service area of the downlink beams may include the territory of several or many countries where the consent of the relevant administration is not necessary. Thus, the control which an administration can exercise over satellite broadcasting is through regulation of earth stations.

3.10 On-line licensing

A number of governments have, or are introducing, overall policies on increased use of the Internet for delivery of public services. These electronic facilities, often referred to by terms such as "e-government" or "e-commerce", may also be used to help dynamic spectrum management or "e-licensing". In licensing regimes where licenses are considered as "products" and license applicants as "customers", the introduction of more automated, on-line licensing procedures and license information will benefit the customers by providing them with a faster, more easily understood and visible decision process. In addition, the spectrum management organization will benefit because its staff do not need to become involved in the licensing process until a much later stage and are free to work on other, less routine, issues.

Facilities provided by e-licensing systems can include simple website information on license types, requirements and fees, and electronic application forms. More complex systems may offer on-line licensing and payment, as well as a comprehensive suite of interactive support tools (e.g. propagation prediction and interference analysis programs) that applicants may use to assess the available technical options and to select the most appropriate type of authorization to meet their communications needs.

3.10.1 Simple on-line licensing system

To the applicant, obtaining a licensing can appear to be a complex business. There are many types of services that are licensed, with different amounts of information that the applicant is asked to supply, and different fee structures. Administrations may need to provide comprehensive facilities to assist the applicant, so the availability of a well-designed, yet reasonably simple Internet website can provide most of the assistance and relieve the administration from setting up a far more resource-intensive, telephone-based equivalent. This type of on-line system could also be expanded to issue authorizations, with electronic payment, for those licenses that require a minimum of administrative information from the user (name, address, phone, etc.), and no engineering assessment to assign a frequency. Examples of this will depend on national licensing policies but, in general, they would be low-power systems that operate on specific frequencies selected by the supplier, the licensee, or automatically by the equipment. Other examples may include, for example, rapid site clearance for transportable earth stations that need approval to operate in a temporary location. This is often the case for operators of electronic news-gathering equipment. The operator can supply the geographical coordinates on-line, a simple program can check if that location is in an area where this type of operation is permitted or compatible (e.g. outside an area that requires EMC protection), and a temporary authority can be issued.

3.10.2 More complex on-line licensing system

Some administrations are developing fully interactive frequency assignment systems that will allow applicants to enter the details of a proposed radio system and make changes to this system on-line, in exploring and taking advantage of the various options available. The only limit to the facilities that can be offered is the technical ability of the applicant to supply the correct technical details and to understand how to correctly use the interactive process. While some applicants may have this expertise, they could also employ consultants to act on their behalf.

3.10.3 Multiple country on-line licensing system

While licensing of systems operating within national territories will always remain the sovereign right of each administration, there is an increasing number of radio systems that provide services that can, by agreement between the administrations concerned, provide services across national borders. An example of this is the provision of satellite services. The provider of such services often faces considerable differences in the licensing processes and application requirements of the countries concerned. Some administrations have cooperated to provide a single point of application that collects and sends the correct information to all the participating countries, automatically using the correct application form for each country. This is sometimes known as a "One-Stop-Shop" and such systems have been established by the regional organizations CEPT (Europe) and CITEL (Americas).

3.10.4 Other issues for on-line licensing

Some administrations have introduced or are considering the introduction of "secondary trading", which is the ability to privately lease, sell, or purchase spectrum on the market. The availability of on-line licensing, in particular the use of fully interactive spectrum management tools, will enable users to try various options for their systems and provide information on other users who may be interested in trading their spectrum.

3.11 Information security issues

Information security issues, both commercial, national, and for privacy protection of personal information, in addition to the potential for fraud using electronic payment, are clearly an area that an administration should take into account when designing spectrum management systems (see Chapter 2 of the Handbook for Computer Aided Techniques for Spectrum Management, Geneva, 2005).

REFERENCES

BARE, S. V. [1990] EMBOWS nazemnyh i kosmicheskih radiosluzhb (EMC in terrestrial and space radio services). *Radio i Sviaz*, p. 272.

BYKHOVSKY, M. A., PASTUKH, S. Y., TIKHVINSKY, V. O. and KHARITONOV, N. I. [2002] Prinsipi postroenia gosudarstvennoi avtomatizirovannoi sistemi upravlienia RCHS v Rossii (Principals of development of state automated spectrum management system in Russia). *Electrosviaiz*, **8**.

DELFOUR, M. C. and DE COUVREUR, G. A. [1989] Interference-free assignment grids – Part II: Uniform and non-uniform strategies. *IEEE Trans. on Electromag. Compati.*, Vol. 31, **3**, p. 293-305.

DOTOLEV, V. G., KRUTOVA, O. and SMOLITCH, L. I. [2003] Programni kompleks dlia upravlenia radiochastotnim spectrum v slujbe veschania (Spectrum management software for broadcasting). *Electrosviaiz*, **7**.

GAMST, A. [1982] Homogeneous Distribution of Frequencies in a Regular Hexagonal Cell System. IEEE Tr., VT-31, **3**, p. 132-144.

HALE, W. K. [1981] New spectrum management tools. Proc. of IEEE International Symposium on EMC, Boulder, Colorado, United States of America, p. 47-53.

HUNT, K. J. [1984] Planning synthesis for VHF/FM broadcasting. *EBU Techn. Rev.*, **207**, p. 195-200.

LEE, W. C. Y. [1989] *Mobile cellular telecommunications systems*. Mc Graw-Hill Book Company.

O'LEARY, T. [1984] Planning considerations for the Second Session of the VHF/FM Planning Conference: the method of foremost priority. *EBU Techn. Rev.*, **207**, p. 190-194.

PAVLIOUK, A. P. [2000] Incentive radio license fee calculation model. ITU/BDT website at http://www.itu.int/ITU-D/tech/spectrum-management_monitoring/MODEL_FULL.pdf.

STOCER, F. [1984] A computerised frequency assignment method based on the theory of graphs. *EBU Techn. Rev.*, **207**, p. 201-214.

TOPCU, S., KOYMEN, H., ALTINTAS, A. and AKSUN, I. [2000] Propagation prediction and planning tools for digital and analog terrestrial broadcasting and land mobile services. Proc. of IEEE 50th Annual Broadcast Symposium, Virginia, United States of America.

VASILIEV, A. V., KAGANER, M. B., RUBINSTEIN, G. P. and SABUROVA, Z. M. [1986] Avtomatizirovannaya sistema ekspertizy elektromagnitnoi sovmestimosti radioreleinyh linii, rabotajuschih v diapazone chastot 160 MHz (An automatic system for EMC examinations of microwave links operating at the frequency range of 160 MHz). *Trudy NIIR*, **4**.

VIENNA AGREEMENT [30 June 2000] Agreement between the telecommunications authorities of Austria, Belgium, the Czech Republic, Germany, France, Hungary, the Netherlands, Croatia, Italy, Lithuania, Luxembourg, Poland, Romania, the Slovak Republic, Slovenia, and Switzerland, on the co-ordination of frequencies between 29.7 MHz and 43.5 GHz for fixed services and land mobile services. Vienna, 2000.

BIBLIOGRAPHY

BYKHOVSKY, M. A. [1993] Chastotnoye planirovanie sotovyh setie podvizhnoy sviazi (Frequency planning of mobile cellular systems). *Electrosviaiz*, **8**.

ITU-R Texts

Rec. ITU-R BS.412 Planning standards for terrestrial FM sound broadcasting at VHF

Rec. ITU-R BS.597 Channel spacing for sound broadcasting in band 7 (HF)

Rec. ITU-R BS.638 Terms and definitions used in frequency planning for sound broadcasting

Rec. ITU-R BS.703 Characteristics of AM sound broadcasting reference receivers for planning purposes

Rec. ITU-R BS.704 Characteristics of FM sound broadcasting reference receivers for planning purposes

Rec. ITU-R BS.1615 "Planning parameters" for digital sound broadcasting at frequencies below 30 MHz

Rec. ITU-R BS.1660 Technical basis for planning of terrestrial digital sound broadcasting in the VHF band

Rec. ITU-R BT.417 Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service

Rec. ITU-R BT.1125 Basic objectives for the planning and implementation of digital terrestrial television broadcasting systems

Rec. ITU-R BT.1368 Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands

Rec. ITU-R F.382 Radio-frequency channel arrangements for fixed wireless systems operating in the 2 and 4 GHz bands

Rec. ITU-R F.383 Radio-frequency channel arrangements for high capacity fixed wireless systems operating in the lower 6 GHz (5 925 to 6 425 MHz) band

Rec. ITU-R F.384 Radio-frequency channel arrangements for medium- and high- capacity digital fixed wireless systems operating in the 6 425-7 125 MHz band

Rec. ITU-R F.385 Radio-frequency channel arrangements for fixed wireless systems operating in the 7 110-7 900 MHz band

Rec. ITU-R F.386 Radio-frequency channel arrangements for fixed wireless systems operating in the 8 GHz (7 725 to 8 500 MHz) band

Rec. ITU-R F.387 Radio-frequency channel arrangements for fixed wireless systems operating in the 10.7-11.7 GHz band

Rec. ITU-R F.497 Radio-frequency channel arrangements for fixed wireless systems operating in the 13 GHz (12.75-13.25 GHz) frequency band

Rec. ITU-R F.595 Radio-frequency channel arrangements for fixed wireless systems operating in the 17.7-19.7 GHz frequency band

Rec. ITU-R F.635 Radio-frequency channel arrangements based on a homogeneous pattern for fixed wireless systems operating in the 4 GHz (3 400-4 200 MHz) band

Rec. ITU-R F.636 Radio-frequency channel arrangements for fixed wireless systems operating in the 14.4-15.35 GHz band

Rec. ITU-R F.701	Radio-frequency channel arrangements for digital point-to-multipoint radio systems operating in frequency bands in the range 1.350 to 2.690 GHz (1.5, 1.8, 2.0, 2.2, 2.4 and 2.6 GHz)
Rec. ITU-R F.746	Radio-frequency arrangements for fixed service systems
Rec. ITU-R F.747	Radio-frequency channel arrangements for fixed wireless systems operating in the 10.0-10.68 GHz band
Rec. ITU-R F.748	Radio-frequency arrangements for systems of the fixed service operating in the 25, 26 and 28 GHz bands
Rec. ITU-R F.749	Radio-frequency channel arrangements for systems of the fixed service operating in sub-bands in the 36-40.5 GHz band
Rec. ITU-R F.1098	Radio-frequency channel arrangements for fixed wireless systems in the 1 900-2 300 MHz band
Rec. ITU-R F.1099	Radio-frequency channel arrangements for high- and medium- capacity digital fixed wireless systems in the upper 4 GHz (4 400-5 000 MHz) band
Rec. ITU-R F.1242	Radio-frequency channel arrangements for digital radio systems operating in the range 1 350 MHz to 1 530 MHz
Rec. ITU-R F.1243	Radio-frequency channel arrangements for digital radio systems operating in the range 2 290-2 670 MHz
Rec. ITU-R F.1337	Frequency management of adaptive HF radio systems and networks using FMCW oblique-incidence sounding
Rec. ITU-R F.1496	Radio-frequency channel arrangements for fixed wireless systems operating in the band 51.4-52.6 GHz
Rec. ITU-R F.1497	Radio-frequency channel arrangements for fixed wireless systems operating in the band 55.78-66 GHz
Rec. ITU-R F.1520	Radio-frequency arrangements for systems in the fixed service operating in the band 31.8-33.4 GHz
Rec. ITU-R F.1567	Radio-frequency channel arrangement for digital fixed wireless systems operating in the frequency band 406.1-450 MHz
Rec. ITU-R F.1568	Radio-frequency block arrangements for fixed wireless access systems in the range 10.15-10.3/10.5-10.65 GHz
Rec. ITU-R M.1036	Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications (IMT) in the bands identified for IMT in the Radio Regulations (RR)
Rec. ITU-R M.1090	Frequency plans for satellite transmission of single channel per carrier (SCPC) carriers using non-linear transponders in the mobile-satellite service
Rec. ITU-R M.1390	Methodology for the calculation of IMT-2000 terrestrial spectrum requirements
Rec. ITU-R M.1391	Methodology for the calculation of IMT-2000 satellite spectrum requirements
Rec. ITU-R SM.669	Protection ratios for spectrum sharing investigations
Rec. ITU-R SM.1049	A method of spectrum management to be used for aiding frequency assignment for terrestrial services in border areas
Rec. ITU-R SM.1413	Radiocommunication Data Dictionary for notification and coordination purposes
Rec. ITU-R SM.1599	Determination of the geographical and frequency distribution of the spectrum utilization factor for frequency planning purposes
Rep. ITU-R BO.633	Orbit and frequency planning in the broadcasting-satellite service

Rep. ITU-R BO.634	Measured interference protection ratios for planning television broadcasting systems
Rep. ITU-R BO.811	Planning elements including those used in the establishment of plans of frequency assignments and orbital positions for the broadcasting-satellite service in the 12 GHz band
Rep. ITU-R BO.812	Computer programs for planning broadcasting-satellite services in the 12 GHz band
Rep. ITU-R BO.814	Factors to be considered in the choice of polarization for planning the broadcasting-satellite service
Rep. ITU-R BS.944	Theoretical network planning
Rep. ITU-R BS.946	Frequency-planning constraints of FM sound broadcasting in band 8 (VHF)
Rep. ITU-R BT.485	Contribution to the planning of broadcasting services
Rep. ITU-R M.319	Characteristics of equipment and principles governing the assignment of frequency channels between 25 and 100 MHz for land mobile services
Rep. ITU-R M.908	Channel requirements for a digital selective-calling system
Rep. ITU-R SM.2153	Technical and operating parameters and spectrum requirements for short range radiocommunication devices

CHAPTER 4

Spectrum monitoring and inspection

Table of Contents

4.1 Introduction

This Chapter provides information for the spectrum manager on the role spectrum monitoring has in supporting spectrum management functions such as frequency planning and engineering, licensing and enforcement.

The ITU Handbook on Spectrum Monitoring, edition 2011, provides detailed information on how to perform and automate spectrum monitoring, type of equipment, and background information on all types of measurements. For this reason, the reader should refer to this Handbook for further guidance on spectrum monitoring.

Radiocommunication has become an increasingly vital part of the telecommunications infrastructure and consequently of the economy of a country. For this reason also economic considerations regarding national spectrum management are becoming more essential. These considerations help to promote economic, technical, and administrative efficiency, and help to ensure that radio services are able to operate on a non-interference basis. This includes protection of safety of life services, exposure hazard protection and coverage measurement.

Theoretical planning alone is not sufficient for the spectrum manager. Knowledge of the actual use of the spectrum is needed for a number of reasons, before decisions can be made on frequency assignments, and frequency/spectrum band allocations, and even national policies governing spectrum use.

Spectrum monitoring supports the overall spectrum management effort by providing the actual use by general measurements of channel and band usage, including channel availability statistics and the effectiveness of spectrum management procedures. Spectrum monitoring can be viewed as a validation check on the spectrum planning activity, confirming that existing planning policies are actually working in practice and if not, provide advice for improvement.

As part of the overall enforcement efforts, inspection and investigation activities also support the general process of spectrum management. Inspection of new licensed transmitters before they become active, locating and getting unauthorized transmitters turned off and interference elimination are also necessary for a usable and interference free spectrum.

4.2 Spectrum monitoring as an element of the spectrum management process

Spectrum monitoring serves as the eyes and ears of the spectrum management process. It is necessary in practice because in the real world, authorized use of the spectrum does not automatically ensure that the spectrum is used as intended. This may be due to the complexity of the equipment, interaction with other equipment, a malfunction of equipment, or deliberate misuse. This problem has been further exacerbated due to the accelerating proliferation of terrestrial wireless and satellite systems and of equipment that may cause interference, such as computers and other unintentional radiators. The monitoring system provides a method of verification and “closes the loop” on the spectrum management process.

Use of the spectrum occurs 24 h/day, 7 days/week, every week of the year, whether locally, regionally, or globally. Likewise, spectrum monitoring should also be performed on the same continuous or statistically correct basis if the purposes and goals of monitoring are to be appropriately fulfilled.

Depending on the national resources available, it is possible to decide on the capacity that should be dedicated for a certain monitoring activity. Especially for developing countries it is advised to participate within the available technical and personnel resources.

On a national basis, a spectrum regulator has to decide the priorities for the monitoring service, whether besides the national tasks, one can cooperate in international monitoring activities as e.g. in the preparations for World Radio Conferences.

The purpose of spectrum monitoring is to support the spectrum management process in general, including frequency assignment, spectrum planning and enforcement functions. Specifically, the goals of monitoring (not necessarily in priority order) are to:

– provide valuable monitoring data to an administration's electromagnetic spectrum management process concerning the actual use of frequencies and bands (e.g. channel occupancy and band congestion), verification of proper technical and operational characteristics of transmitted signals, detection and identification of illegal transmitters, and the generation and verification of frequency records;

– assist in the resolution of electromagnetic spectrum interference, whether on a local, regional or global scale, so that radio services and stations may coexist compatibly, reducing and minimizing resources associated with installing and operating these telecommunication services while providing economic benefit to a country's infrastructure through access to interference free, accessible telecommunication services;

– assist in ensuring an acceptable quality of radio and television reception by the general public;

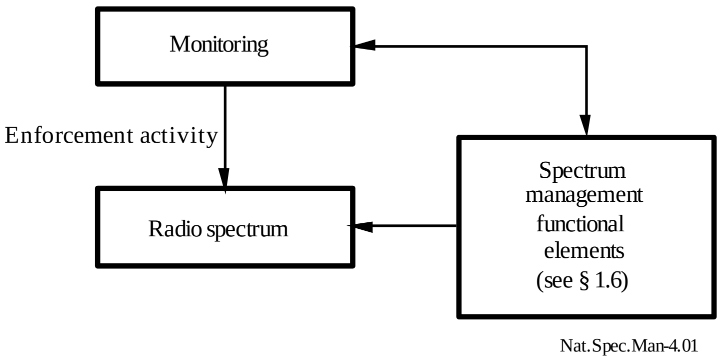
– provide valuable monitoring information for programmes organized by the ITU Radiocommunication Bureau, for example in preparing reports to radiocommunication conferences, in seeking special assistance of administrations in eliminating harmful interference, in clearing out-of-band emissions, or in assisting administrations in finding suitable frequencies.

Monitoring can identify the need for future spectrum requirements.

To indicate the role of monitoring in the spectrum management process, the simplified chart is shown in Figure 4.1.

FIGURE 4.1

Monitoring in the spectrum management process



The spectrum is used for all kinds of radio transmissions. The spectrum management elements (e.g. frequency allocation, assignment, licensing, and enforcement) are of overriding importance for the efficient and effective use of the radio spectrum. National authorities are setting the rules for the use of the radio spectrum via assignments, licence parameters, etc.

The monitoring service observes the radio spectrum and the monitoring operators have the duty to compare whether the use of the radio spectrum matches the policy of the various elements of spectrum management.

In observing the radio spectrum, monitoring can also provide information to elements of spectrum management for e.g. refarming or on (hitherto) unforeseen use of the radio spectrum. When spectrum management sets up an experimental authorization for new services before a policy (regulations) on that new service has been developed, monitoring can observe the experimental operation and provide information on the implementation of it in order to allow spectrum management to "fine-tune" the proposed regulations.

Monitoring can also address radio spectrum users directly in case of interference or technical infringements of national (or international) regulations. After identifying interference, infringements or violations of regulations, the monitoring operators can provide details of the violations/infringements to radio users in order to correct their operations to conform to the regulations. This type of Enforcement activity may occur directly at the monitoring level. Actions can vary from verbal and written warnings to more severe sanctions such as monetary fines, seizure of offending equipment or license revocation, depending on the severity of the infringement and the level of cooperation of the offending user.

4.3 Monitoring to assist spectrum management functions

Spectrum monitoring supports the overall spectrum management effort by providing a general measure of channel usage and band usage including channel availability statistics. This provides information for the frequency planning and assignment process and allows verification of the efficacy of that process. Monitoring is useful for planning, in that it can assist spectrum managers in understanding the level of spectrum use as compared to the assignments that are recorded in data files. Monitoring performs the following specific functions to assist the frequency planning/engineering and assigning process:

4.3.1 Support to frequency planning/engineering

Monitoring data supports the frequency planning/engineering functions by providing an overview of the actual usage of the spectrum by:

– frequency band occupancy graphs (spectrograms), which can be used for e.g. refarming of the spectrum;
– practical data on sharing possibilities and radio compatibility;
– the evaluation of theoretical considerations e.g. propagation models.

4.3.2 Support to frequency Licensing

Monitoring data supports the frequency licensing function by providing an overview of the actual usage of the spectrum by:

– frequency channel occupancy;
– coverage measurements;
– check of licensing conditions.

4.3.3 Support to enforcement and regulation validation

Monitoring data supports the enforcement function by providing:

– all type of measurements to check the various technical parameters of an emission;
– interference handling;
– the identification of unauthorised or illegal usage of the spectrum.

4.3.4 Database verification

Accuracy and correctness of spectrum management databases are of prime interest. New assignments made based on an inaccurate database can result in interference problems. Monitoring data can be utilized to help verify the accuracy of these databases and to help bring them up to date.

4.3.5 Detection of anomalous propagation effects

The VHF and UHF bands are not immune to the effects of anomalous propagation. High atmospheric pressure areas over water can give rise to ducting. Areas of unusually high ionization in the ionosphere are also prone to causing anomalous propagation effects, e.g. sporadic-E propagation at lower frequencies. The result is interference from distant systems normally considered too distant to warrant great efforts in coordination. These effects are usually transitional and, while statistical data on them is available, it is only by monitoring that the implications of these anomalies on particular wireless systems can be judged. The appropriate interference cure will be case-specific and good monitoring data will greatly aid identifying the causes of the problem.

4.4 Spectrum monitoring, on-site inspections and enforcement as elements of the spectrum management process

Effective management of the spectrum depends, in part, on the spectrum manager's ability to supervise the spectrum use and to enforce the relevant regulations. This supervision is primarily built on spectrum monitoring and on-site inspections of radio stations followed by adequate law enforcement actions which in turn rely on a suitable legal basis. This strengthens and improves the spectrum management process.

However, it should be noted that there are no precise definitions of the terms "monitoring", "inspection" and "enforcement". The distinction of the corresponding entities such as "radio monitoring service" and "radio inspection service" vary from administration to administration according to their decade's history of legal and administrative tradition. Furthermore, technical developments such as radio heads may prohibit a clear distinction of monitoring and inspection in future. Limitations in staff and budget may also require the integration of monitoring and inspection functions into a unique organisation. Therefore the following considerations are based on tasks and equipment rather than on organisational units.

4.5 Tasks of radio monitoring and radio inspection services

4.5.1 Verification of technical parameters with license conditions

– Monitoring of emissions

  Regular monitoring of national emissions for compliance with conditions and subsequently eliminating any non-compliance aims to prevent radio interference. Technical parameters such as frequency, bandwidth, frequency deviation and class of emission need to be monitored.

– Similar to the monitoring of emissions, the on-site inspection of radio equipment strives to foster compliance with license conditions and to prevent radio interference. The specific choice of one of these tools depends on technical and economic considerations. At on-site inspections parameters such as the output power are measured at the transmitter. More information on inspection is included in Report ITU-R SM.2130.

  In cases where special antenna patterns are defined in a license to cover a geographical area, the verification can be achieved by monitoring. The verification of the antenna patterns of an FM broadcasting station should be conducted with the assistance of a helicopter. This is needed as the best accuracy is achieved by performing the measurements ideally at free-space propagation conditions.

– Pre-use inspection of the equipment

  To have certainty that the equipment to be used is installed in compliance with the technical conditions of the license, in some countries so called pre-use inspections are conducted. The measurements are of the same type as at regular on-site inspections.

4.5.2 Frequency band registrations and frequency channel occupancy measurements

Frequency band registrations aim to support the frequency planning and engineering function by providing information on which frequencies/channels are used by whom and how. Automated measurements measure a frequency band, specified by start and stop frequency, with a step width (or frequency resolution) that is usually smaller than the channel spacing, to determine the degree of occupancy over the whole band. The results are shown in spectrograms. Figures 4.2 shows an example of such a presentation from a measurement in the 868 MHz European SRD band. Figure 4.3 shows the band occupancy plot which is based on the same monitoring data.

FIGURE 4.2

Example Frequency Band measurement (spectrogram)

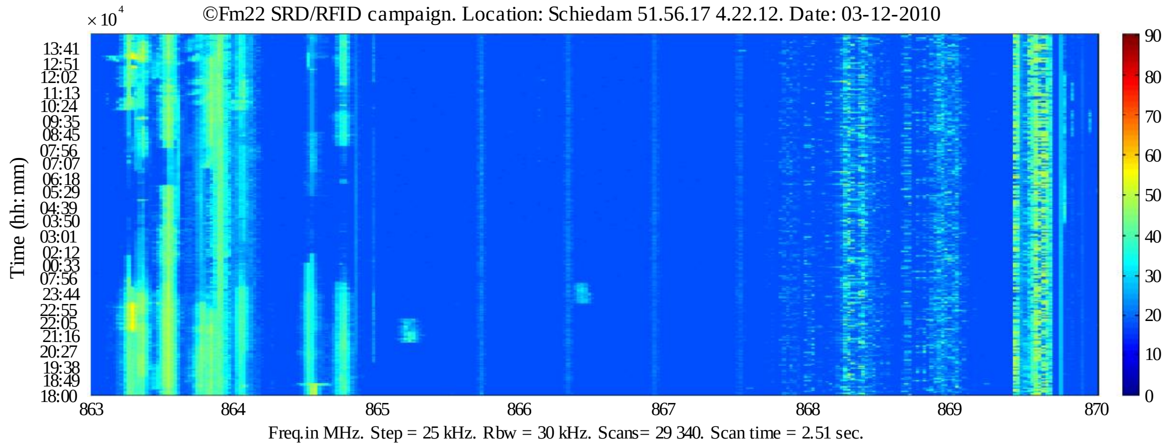


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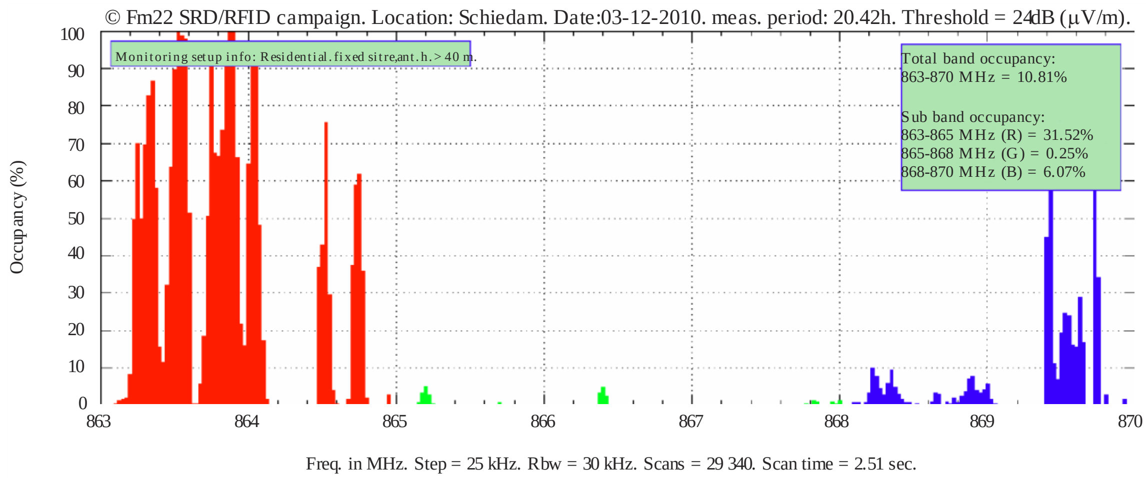
FIGURE 4.3

Example Frequency Band measurement (occupancy analysis)



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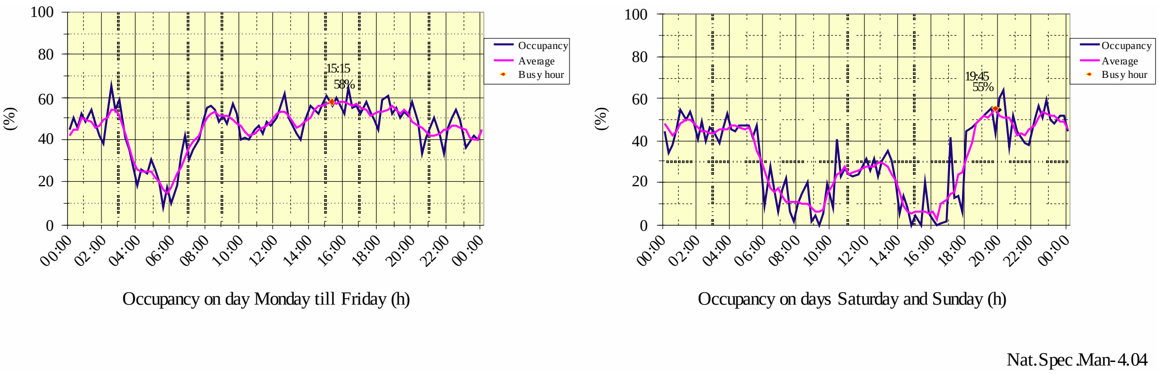
The advantage of this presentation method is that it provides a good, although subjective, impression on the band occupancy at a glance. The disadvantage is that it does not quantify the occupancy on each frequency so that there is no objective value allowing direct comparison with other results. This, however, may be provided by an accompanying diagram showing the relative time during which each frequency was occupied.

To provide information how a certain frequency channel is occupied over a period of time – and hence also which frequencies are unused – Frequency Channel Occupancy measurements are performed. This type of measurements can provide the minimum, maximum or median occupancy values of specified intervals, e.g. over 15 minutes.

Figure 4.4 shows an example of such a frequency channel occupancy measurement.

FIGURE 4.4

Report of occupancy on a single channel



An important parameter for frequency channel occupancy is the so called 'busy hour'. On the above shown example the busy hour during weekdays is different than during the weekend days. This all depends on the type of service on the frequency channel. In this case the channel is used by taxis.

More advanced measurement methods allow also determining how many channels of a radio system are simultaneously in use.

4.5.3 Interference resolution

In view of the increasing role played by radio applications in every area of life, swiftly and effectively investigating and eliminating radio interference is a task of economic importance. Special priority is to be given to eliminating interference to safety services such as the aeronautical, police and fire services.

Even though the victim of interference may know best about the occurrence and the technical parameters, in most cases, the source of interference to radio receivers cannot be identified by the receiver operator. Therefore, complaints of interference will often require action by the spectrum authority to identify the source of interference and to initiate appropriate measures for its resolution.

4.5.4 Identification and elimination of unauthorised emissions

Illegal use of the radio electric spectrum, contrary to the previously planned use, constitutes one of the reasons of interference for its users; therefore, the spectrum management organization should take sufficient action against illegal use of the spectrum through observation of illegal usage on a regular basis. Stopping unauthorized emissions aims primarily to prevent radio interference but also to guarantee income, since fees are paid only by authorized frequency users. The regulator should take the required measures to protect the performing measurements and applying procedures. It should be underlined that there must be a very good cooperation with other governmental authorities in case illegal equipment has to be confiscated. The investigating staff has to collect all relevant information that might be necessary for any legal activities such as confiscation, fining and prosecution.

4.5.5 Assistance at special occasions such as major sporting events and state visits

At state visits, Formula One races and other large-scale events, a large number of radio equipment are used within a confined space. The users are often not aware that they need a frequency assignment or that they may not be able to use the same frequencies in all countries. In the interests of preventing interference and intervening immediately should interference occur, it is expedient for the monitoring service to be on site to monitor spectrum use and act swiftly to investigate and eliminate any interference. Close cooperation with the staff responsible for frequency assignments is essential.

4.5.6 Radio coverage measurements

If for a certain new network the license condition includes the requirement that in a certain period of time a certain geographical area of a country this service should be available for its users, spectrum monitoring can perform measurements to check requirement. However, it should be noted that it is not possible to measure the coverage in a given area directly. But it is possible to verify the results predicted by planning tools.

Radio coverage measurements comprise the measurement of parameters such as field strength, quality parameters such as bit error rate (BER) and adjacent channel power. Frequency managers should clearly define their understanding of coverage. Is it simply exceeding a certain field strength? Or does coverage mean that a customer can use the service with a defined quality?

4.5.7 Radio compatibility and EMC studies

Before frequencies are allocated for a new radio application, compatibility with existing radio systems and with non-radio devices must be ensured. Purely theoretical radio compatibility studies are often not adequate. The monitoring service may be called to assist with the necessary practical studies.

4.5.8 EMF measurements

Measurements of the electromagnetic field emanating from radio transmitters are done to indicate human hazards from electromagnetic fields. Measurements of Human exposure are important around high power transmitters, and in sensitive places, like schools and hospitals. In some countries EMF measurements are part of the licensing process.

4.6 Monitoring stations and facilities

4.6.1 Types of monitoring stations

In some countries the population density varies considerably. The population is concentrated in certain areas with high population density and hence high radio usage, whilst big parts of the country are very lightly populated. This demands that those specifying the system elicit the coverage needs and determine if monitoring information is needed over the whole country or just concentrated on those more densely populated areas. The system must be designed to provide results where needed. The deployment of monitoring stations is always a compromise in terms of radio coverage and budget limitations.

Fixed monitoring stations often cover a large area. They may be equipped with receivers, analysers and direction finders for the required frequency range. The main drawback of fixed, manned monitoring stations is the very fact that for financial reasons they cannot be established in sufficient numbers. Therefore such stations are frequently complemented by remote controlled monitoring stations, Advanced equipment not only allows stations to be operated by a remote operator, but also allows measurement programmes to be carried out automatically, with results being transmitted to the manned monitoring station at a later time.

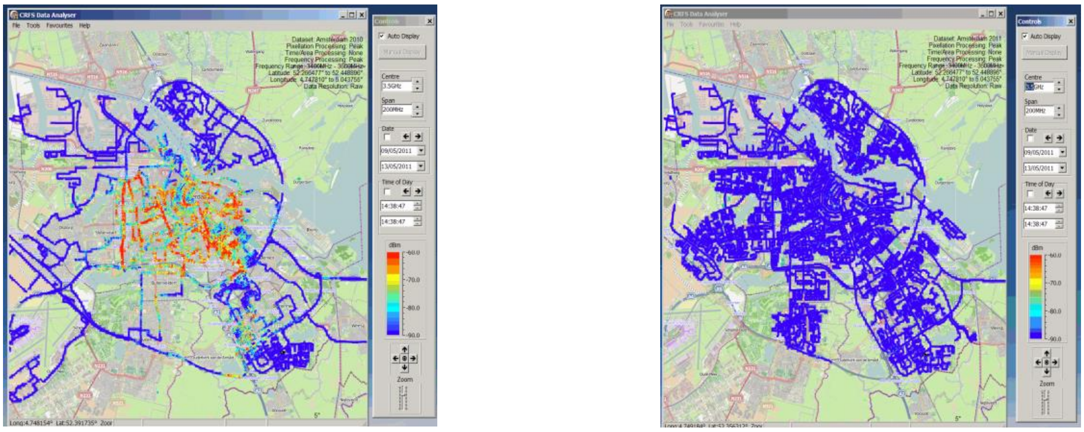
A special type of fixed monitoring stations are those for space radio monitoring.

Mobile monitoring stations have the function to carry out all those monitoring operations where the low power of the transmitters, the high directivity of the antennas and the particular propagation characteristics make it impossible for measurements to be made by fixed stations. One example for the usage of mobile monitoring stations is the mobile data collection. Mobile stations can be used with a full automated high speed recording of the spectrum (i.e. RF level as a function of frequency from 20-6 000 MHz) to produce detailed maps of spectrum usage down to individual street locations enabling regulators to understand and anticipate bottlenecks and vulnerabilities, identify and monitor trends of spectrum usage over the long term. Figure 4.5 shows the use of WiMax in 2010 at 3.5 GHz. A year later the same measurements where repeated and by that time WiMax was gone.

FIGURE 4.5

Usage by WiMax in two consequent years

2010 2011



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Transportable monitoring stations combine some of the features and advantages of fixed stations with some of the features and advantages of mobile stations. The equipment for transportable stations is typically installed inside of an equipment shelter which can be redeployed.

Handheld equipment is used for the localisation of radio sources on the last metres. Such type of equipment is inevitable for the localisation of interference sources and illegal transmitters, particularly at higher frequencies.

4.6.2 Equipment

The monitoring services have a large variety of equipment at their disposal to fulfil the different tasks. The different frequency bands require different types of antennas, receivers, analysers, direction finders and data recorders. Depending of the specific tasks various types of system specific analysers have to be available too. For detailed information on equipment Chapters 2, 3 and 5 of the ITU Handbook on Spectrum Monitoring should be consulted.

4.6.3 Automatic Violation Detection

An integrated, automated spectrum management and monitoring system can perform measurements, such as signal activity, technical parameters like frequency and bandwidth, and DF, and compare these measurements with information on licensed stations in the management system database. This automatic violation detection process allows the automatic detection of both unauthorised signals, and licensed signals, which are deviating from their authorized parameters. The system indicates possible violations which require further investigation by the operator to confirm any violation.

A valid, complete license database is essential to successfully perform automatic violation detection. It needs to be mentioned that automatic violation detection is a method that may work well in specific situations and environments but is not always applicable. A number of examples of this method, although differently named, are given in Annex 1 of Report SM.2156.

4.6.4 Integration spectrum management and monitoring systems

Administrations which perform both spectrum management and spectrum monitoring should consider using an integrated, automated system with a common relational database (see Recommendation ITU-R SM.1537). This integration allows exchange of information between the management and monitoring databases, tasking of the monitoring system by the management system, and reporting of monitoring results to the management system, and other useful features such as remote access to system resources.

However, it should be noted that there is probably no single integrated spectrum management and monitoring system available that would be able to cover all spectrum monitoring tasks in all frequency ranges and for all radio applications. It should be also kept in mind that procuring integrated systems might imply the dependency on a single supplier at least to a certain extent.

CHAPTER 5

Spectrum engineering practices

Table of Contents

Page

5.1 Introduction

5.1.1 Importance of technical basis

Normally, the Governments or delegated national bodies are responsible for the management of the spectrum in their territories. They determine national policies, allocation plans, permissible standards and specifications of equipment to permit a harmonious use of the spectrum in the national interest. Physical laws of propagation, and the technical characteristics of transmitters and receivers, constrain the range of feasible spectrum management options. They also determine the frequencies that can be assigned at any given location.

The radio spectrum is under increasing pressure for both the introduction of new, and expansion of existing, services. At the same time, current users should be provided an appropriate level of protection from interference in an environment where increased spectrum sharing is inevitable. This places an increasing technical demand on spectrum management organizations. It is increasingly evident that modern radio technology is rapidly advancing and finding its way into new and conventional telecommunication services with increasingly shorter production and deployment cycles. Nevertheless, any spectrum management option selected has to remain technically feasible and needs to be implemented in accordance with technical rules and restrictions applicable to that option. These restrictions have to be identified and quantified through engineering studies. Rules have to be formulated by the administrations with the participation of relevant spectrum stakeholders.

5.1.2 Scope of the Chapter

This chapter investigates the spectrum engineering practices and analysis tools of spectrum management. The technical parameters section discusses equipment specifications, certification, and definitions. The section of engineering analysis tools includes frequency assignment techniques, and models of propagation. The section on interference analysis includes sharing frequency bands. Further sections address protection ratios, noise, radiation limits and site engineering considerations.

5.2 Technical parameters

5.2.1 Equipment specifications and certification

Equipment specifications are primarily utilized to specify the minimum acceptable technical characteristics of equipment generally deployed in quantity by a large number of users in the same radio service. Two categories of equipment specifications exist, one which deals with licensed radio stations; and the second one which deals with licence exempt radio equipment. The equipment specifications deal almost exclusively with the minimum technical parameters that equipment must meet strictly from the points of view of effective spectrum usage and minimization of interference at transmitters and receivers. They normally are not concerned with quality of service, this is left to the discretion of the user, thus enabling a choice of quality of equipment to meet the needs.

The second category of equipment specifications generally deals with low power equipment that is exempted from licensing because of its limited range. The operation of such equipment is permitted in specified frequency bands. Apart from garage door openers, alarm and control devices for toys and cordless telephones, there are many other examples of such equipment which are increasingly being used in the commercial sector, e.g. radio local area networks (RLANs) and radio frequency identification (RFID) systems. This category of equipment specifications deals exclusively with the characteristics of transmitters like maximum power, permissible harmonic levels and stability, and is not afforded protection from interference.

The equipment specifications should also include the minimum acceptable technical characteristics of broadcast transmitters (analogue and digital, radio and TV) such as modes and depth of modulation, frequency bands and stability limitations, permitted power and noise suppression criteria.

Due to the cost of setting up and maintaining test facilities, there are benefits for administrations making agreements for mutual recognition of test results. This is particularly applicable in the case of low volume production equipment requiring complex testing.

The next section provides definitions of these important parameters. Also, methods of calculation of these parameters are included.

5.2.2 Equipment parameters

In this section of the Handbook a brief overview is provided of those equipment parameters that, if not controlled, could cause interference to other systems and adversely impact the efficient use of the frequency spectrum. These parameters are summarized as follows:

a) Carrier frequencies

b) Transmitter power

c) Frequency tolerance

d) Bandwidth

e) Unwanted emissions

f) Intermodulation products

g) Sensitivity of radio receivers.

Other parameters may have an impact on the quality of service, but not directly impact other services through potential interference. These parameters may require regulation in the case of certain applications, e.g. safety of life services. In other cases, it may be appropriate to have little, or no, regulation. In such cases, manufacturers determine the parameters along with the other quality related aspects of the design and ultimately the consumer makes the choice based on cost versus quality. In creating this environment, an administration will need to give careful consideration to developing and publicizing its policies with regard to the solution of interference complaints which for example, result from poor receiver performance.

For the purposes of spectrum engineering, it is necessary to identify the values of both the essential and other parameters. Where parameters are not regulated, it may be necessary to establish values for planning purposes. Furthermore, it may be appropriate to publish such values for use on a voluntary basis and link this activity to the policy on interference investigation.

These parameters are defined further in this section, and in addition receiver parameters are examined.

a) Carrier frequencies

It is of fundamental importance to ensure that the operating frequency of transmitters corresponds to their assigned frequency, otherwise interference to other services is almost inevitable.

b) Transmitter power

Transmitter power is defined in Article **1** of the Radio Regulations in terms of either: peak envelope power; mean power; or carrier power. Transmitter power should be limited to the minimum level consistent with satisfactory operation of the radio system. A lack of effective control of this parameter is likely to lead to interference to other users assigned the same frequency in different geographic areas.

c) Frequency tolerances of transmitters

Frequency tolerance is defined in Article **1** of the Radio Regulations (RR) as the maximum permissible departure by the centre frequency of the frequency band occupied by an emission from the assigned frequency or, by the characteristic frequency of an emission from the reference frequency. The frequency tolerance is expressed in parts per million or in Hertz.

A major consideration, with respect to the efficient use of the frequency spectrum, is that the frequency space lost because of instability should be a small part of the necessary bandwidth used for communications. The figure of ±1% of the representative bandwidth has been used to provide a guide to the value of frequency tolerance that may be acceptable from the standpoint of spectrum economy. In some cases, e.g. A3E broadcasting the frequency tolerance must be small enough to reduce common channel interference caused by the beat note between off-frequency carriers.

In single-sideband radiotelephone nets with several stations on a single frequency, the tolerance should be small enough to permit the suppression of the carrier and to provide good voice intelligibility without the readjustment of receivers.

There are certain categories of stations that may not be required to meet a strict tolerance for operational and administrative reasons. An example is mobile radar systems, where the administrative problem of rigid frequency assignments is now unnecessary and, from an operational standpoint, interference is reduced by permitting normal manufacturing tolerances to cause a distribution within the assigned bands.

The greatest difficulty in adopting improved tolerances is the economic problem created by the large number of transmitters in operation and which were manufactured in accordance with existing tolerances. Appendix **2** of the RR defines the maximum permitted frequency tolerance for different categories of transmitters. Recommendation ITU-R SM.1045 contains the details of the tolerances achievable today and also long term design objectives for certain frequency bands, categories of stations and classes of emission. The power shown for the various categories of stations is the peak envelope power (p.e.p.) for single-sideband transmitters and the mean power for all other transmitters, unless otherwise indicated. The term "power of a radio transmitter" is defined in Article **1** of the RR.

d) Bandwidth of emissions

Number **3.9** of Article **3** of the RR requires that the bandwidths of emissions shall be such as to ensure the most efficient utilization of the spectrum. In general this requires that bandwidths be kept at the lowest values which the state of the art and the nature of the service permits. Article **1** of the RR, No. **1.152** defines the necessary bandwidth as follows: "For a given *class of emission*, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions." The necessary bandwidth can be calculated using the general approach given in Recommendation ITU-R SM.328 for the different classes of emission. Recommendation ITU-R SM.853 provides a method to calculate the necessary bandwidth for multi-channel FDM systems, and Recommendation ITU-R SM.1138 (incorporated by reference in the Radio Regulations) provides a method for calculation of necessary bandwidth, together with examples.

The emission outside the necessary bandwidth is called the unwanted emission The occupied bandwidth is defined by the provision No. **1.153** of the RR as: "The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage β/2 of the total *mean power* of a given *emission*. Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of β/2 should be taken as 0.5%." According to Recommendation ITU-R SM.328, "an emission should be considered optimum from the standpoint of spectrum economy when its occupied bandwidth coincides with the necessary bandwidth for the class of emission concerned".

Due to the difficulty to directly apply these definitions in the case of measurements, a third definition is given Recommendation ITU-R SM.328 for the "*x* dB" bandwidth as follows: "The width of a frequency band such that beyond its lower and upper limits any discrete spectrum component or continuous spectral power density is at least *x* dB lower than a predetermined 0 dB reference level."

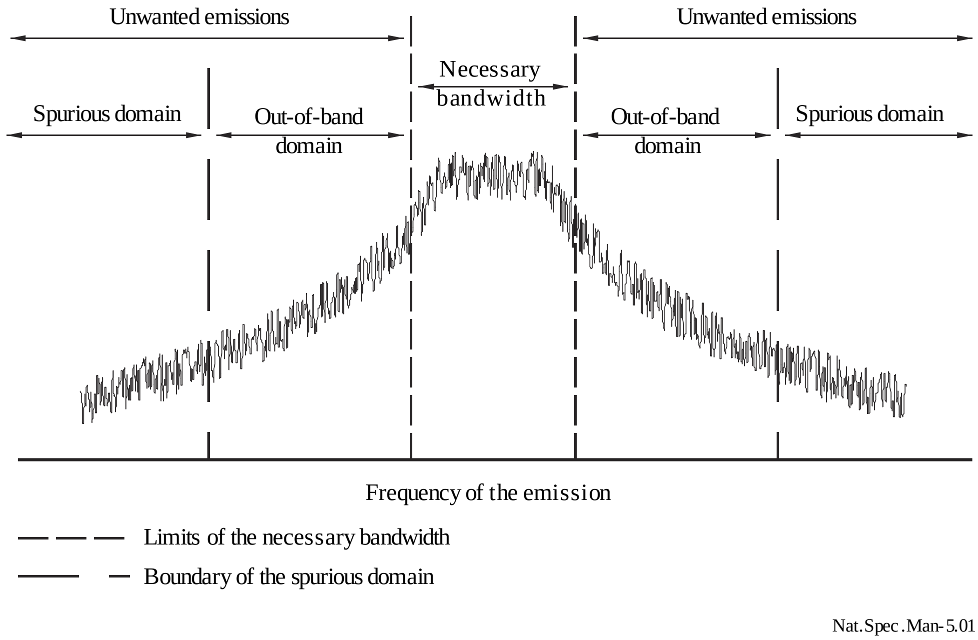
Further guidance on the bandwidth of specific emissions can be found in Recommendation ITU-R SM.328, furthermore the ITU-R Handbook on Spectrum Monitoring provides further guidance on practical measurement of bandwidth.

e) Unwanted emissions from transmitters

Unwanted emissions consist of out-of-band and spurious emissions. Out-of-band emissions are the main component of the unwanted emissions close to the fundamental emission, and the spurious emissions become dominant further from the fundamental, however there is no definite boundary between the two. For the purposes of setting practical limits on unwanted emissions, recent work in the ITU-R has led to the definition of the out-of-band and spurious domains.

FIGURE 5.1

Out-of-band and spurious domains of an emission



The out of band domain is the frequency range, immediately outside the *necessary bandwidth* but excluding the *spurious domain*, in which *out-of-band emissions* generally predominate.

The spurious domain is the frequency range beyond the *out-of-band domain* in which *spurious emissions* generally predominate.

Out-of band *emissions*, defined based on their source, occur in the out-of-band domain and, to a lesser extent, in the spurious domain. Spurious emissions likewise may occur in the out-of-band domain as well as in the spurious domain

The domains are characterized by the type of unwanted emissions which are predominant, the boundary between the domains is determined is generally 2.5 times the necessary bandwidth, but with certain exceptions. Guidance on these exceptions is given in Recommendation ITU-R SM.1539.

Appendix **3** of the RR contains spurious emission limits for different radiocommunication services. Recommendation ITU-R SM.329 provides further detail on unwanted emissions in the spurious domain.

Recommendation ITU-R SM.328 provides a general approach for the determination of the necessary bandwidth and guidance on out-of-band emission characteristics for various radiocommunication services. It should be noted that the characteristics provided are “safety net” limits derived from examples of characteristics successfully implemented on a regional, or national basis.

One of the spectrum engineering main considerations related to unwanted emissions, is the impact of emissions in the out-of-band domain which fall in an adjacent band allocated to another service. This is of particular concern in the case of high power transmitters operating in adjacent bands to sensitive receivers. Satellite downlinks operating adjacent to radioastronomy bands is an obvious example, which has been subject to extensive study as a result of Recommendation 66 (Rev.WRC-2000). However, at national level, careful attention should be paid to high power radar and broadcasting transmitters that may impact on users of adjacent bands. Further guidance is given in Recommendation ITU-R SM.1540.

f) Intermodulation products

Intermodulation products are generated when two or more signals are incident on a non-linear device. Third order intermodulation frequencies are of the form: $2f_1 \pm f_2$, and $f_1 \pm f_2 \pm f_3$, where f_1, f_2 and f_3 are the carrier frequencies of transmitters 1, 2, and 3 respectively. For a single transmitter, intermodulation products generally arise due to intermodulation between the modulation sidebands. These products fall into the adjacent channels. A more serious problem occurs when two or more transmitters are co-sited and the signal from one is coupled into the output stages of the other.

The most important intermodulation products are those of the third and higher odd orders and these are difficult to reduce by filtering, since these products are close to the frequency spectrum of the wanted signals. The frequencies of the third order products are formed from the fundamental frequencies of two or more co-sited transmitters. Higher order products may need to be considered when a large number of transmitters are co-sited.

Mutual coupling between antennas causes unwanted signals to be fed back into each transmitter power output stage. The output stage of a power amplifier can present an effective non-linear impedance to unwanted signals fed back into the transmitter and hence intermodulation products can be generated and re-radiated. The magnitude of the resultant radiated spurious signal depends primarily on the:

– power of the interfering transmitter;
– antenna coupling loss;
– conversion loss: the ratio of the power of the interfering signal from an external source to the intermodulation product, as measured at the output of the victim transmitter, when the frequency selectivity of the transmitter is excluded; and,
– frequency selectivity at the transmitter output circuits and antenna.

The conversion loss of a transmitter output stage is determined by the broadband non-linear function of the output stage, and by the degree of isolation between the non-linear function and load. For FM transmitters using solid-state class C power amplifiers, the conversion loss is in the range of 3 to 20 dB. For linear transmitters designed for SSB, the conversion loss is of the order of 50 dB. For LF, MF and HF broadcasting transmitters, the conversion loss of a typical high power valve amplifier may be as low as 10 dB.

Transmitters feeding a common power amplifier may generate intermodulation products**.** Multiple transmitters may be connected to a common antenna by combining the signals prior to amplification. For transmitters sharing a common power amplifier inter-modulation products are likely to be generated in the high power amplifier. Typically the level of internally generated products is inversely related to the amplifier efficiency.

Intermodulation products may be generated by non-linear elements close to antennas. Unwanted harmonics and inter-modulation components can also be generated by the excitation of conductors containing non-linear contacts in antennas or metallic structures in the vicinity of the transmitters. Non-linear elements can be formed at metal-to-metal junctions in antenna masts and feeders. Some non-linear elements are caused by the unavoidable use of dissimilar metals and corrosion.

Corrosion is an ever-present threat especially at coastal sites or in areas of atmospheric pollution. Careful attention to the bonding of all joints in metallic structures and antennas is the only way to avoid this undesirable effect. Further details are provided in the section on co-site engineering.

Further information and guidance on intermodulation is contained in Recommendation ITU-R SM.1446 and Report ITU-R SM.2021.

g) Sensitivity of radio receivers

The following text is based on Recommendation ITU-R SM.852. It defines the signal-to-noise ratio criteria commonly used for measuring the sensitivity of radio receivers. According to it, the measure of sensitivity of single-channel analogue receivers of emission class F3E used in the land and maritime mobile services, is defined as:

The "SINAD method" which uses the ratio (Signal + Noise + Distortion)/(Noise + Distortion) or SND/ND = 12 dB, measured at the output in the presence of modulation with a test signal rejection filter.

The measurement of sensitivity needs to be made with the actual baseband filters, if any, used in the receiver. In most cases the receiver sensitivity will be degraded by the presence of unwanted signals at the receiver input. For a complete characterization of a receiver, the sensitivity should therefore be measured with and without the presence of interfering signals. The most likely modes of degradation are discussed later in this section.

For digital modulation receivers in which direct access to the recovered data stream is achieved easily, the sensitivity is best measured using an error rate criterion.

5.2.3 Performance criteria

For digital speech systems the performance of the speech processor must also be evaluated by subjective methods, however the performance of the transmission path may be evaluated by a measurement of the error rates. Curves relating bit error rate to signal to noise and voice quality are available for waveform follower digitization systems such as pulse code modulation (PCM) and continuing variable delta slope modulation (CVSD). As source follower digitization systems such as code excited linear prediction (CELP) become standardized similar curves relating bit error rate to speech quality should become available.

For data transmission the error rate probability is the preferred performance criteria. This is independent of the message structure or content and can be made applicable to all systems. Curves are available showing the bit error rate as a function of E_b/N_0 for all of the popular digital modulation modes and error correction techniques.

5.2.3.1 Articulation score and index

The basic measure of intelligibility of a voice system is expressed in terms of the percentage of words correctly understood over a channel perturbed by interference. This measure of intelligibility indication is called an articulation score (AS). In order to circumvent the difficulties associated with the AS tests, the Articulation Index (AI) procedure was developed and calibrated for various type of interference.

Experience has shown that the smallest value of AI which consistently provides correct information transfer of normal language is 0.7 on a scale ranging of 0 to 1, and the lowest acceptable value of AI for a useful link is 0.3.

5.2.3.2 Minimum interference thresholds

The minimum interference threshold (MINIT), although not a performance threshold measure, is useful in assessing the effects of interference on voice transmissions. It is the level at which interference is first detected in the audio output. Since this level is obtained through a subjective evaluation, there is an inherent variability due to the human observer and one due to the manner in which the threshold is defined to the observer. In particular, the threshold level can be determined by decreasing or increasing the interference level relative to a fixed desired signal level. In the first case, the test begins with very noticeable interference and stops when the interference is just perceptible. In the second case, the interference is increased until the subject records that the interference was first heard.

The test can also be made without the presence of a desired signal. This type of test would be used for high fidelity or television sound systems where the presence of interference during the time the desired signal is absent may be unacceptable. A lower threshold interference level would be required for this case than if the desired signal were present, since the desired signal can mask the presence of the interference.

Measurements have shown that MINIT is a function of the interference to noise ratio. For a specified signal to noise ratio, the MINIT therefore also corresponds to a signal-to-interference ratio. The MINIT is a threshold that can be used as the boundary between a region of negligible interference and a region of permissible interference and can be used in frequency coordination problems.

5.2.3.3 Digital speech

The articulation score for waveform follower speech digitizers such as PCM and CVSD is generally insensitive to error rates of less than 10^{-4} and degrades to 0.7 at error rates of 3×10^{-2} for PCM and 10^{-1} for CVSD. At higher error rates the degradation is so rapid that they are generally considered unusable. In applications where a high signal to noise ratio is required high data rates must be used and degradation can occur for bit error rates as low as 10^{-6}. It is generally expected that source follower models will provide similar characteristics albeit at much lower data rates.

5.2.3.4 Digital systems

The minimum bit error ratio for a digital system has been chosen as a bit error probability of 10^{-6}. The maximum and middle bit error ratio for digital systems has been chosen as a bit error probability of 10^{-2} and 10^{-4}, respectively. The thresholds have been given in terms of bit error probabilities instead of character error rates, so that the results will be applicable to all systems independent of message structure. The required E_b/N_0 to achieve these thresholds is defined for various modulation types.

5.2.3.5 Aeronautical systems

Recommendation ITU-R SM.851 defines interference thresholds for aircraft ILS localizer, VOR and COM receivers.

5.2.3.6 Television signals

Analogue

Two scales have been used to define impairment levels of the video component of TV signals: the TASO 6-level scale and the ITU-R double-stimulus 5-level scale. The 5-level scale has been recommended since 1974 and is shown in Table 5-1. For terrestrial broadcasting (television) service under the effect of short-term tropospheric interference the maximum permissible interference level should correspond to grade 3 on the ITU-R scale and to grade 4 in the case of interference for greater than 50% of the time. For the broadcasting-satellite (television) service, the permissible interference level should correspond to grades 4 and 5.

TABLE 5-1

Double-stimulus impairment scale

Grade	Criterion of interference
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Digital

Recommendation ITU-R BT.2033 provides the required protection ratios of digital video broadcasting (DVB) systems over a variety of channels when carrying out the compatibility study for the Long-Term Evolution (LTE) base stations (BS) and user equipment (UE) in the VHF/UHF band.

5.3 Engineering analysis tools

5.3.1 Models of propagation

Radio-wave propagation loss is one of the key parameters that has to be considered in determining the practical size of the coverage zone of a radio system and the extent of unwanted interference.

Propagation modes may include: Wave guide, Ground Wave, Sky Wave, Space Wave (consisting of a direct wave and a ground reflected wave), Diffraction, Tropospheric Scattering, and Line-of-Sight (point-to-point or Earth-to-satellite). The propagation modes, ranges, bandwidths usage, potential for interference for the frequency bands from VLF to EHF are summarized in Table 5-2.

TABLE 5-2

Propagation modes and usages for various frequency bands

Band	Frequency	Mode	Range	Bandwidth	Interference Volume	Usage
VLF	3-30 kHz	Wave guide	Several 1 000 km	Very limited	Wide spread	Worldwide, long range radionavigation and strategic communications
LF	30-300 kHz	Ground wave, sky wave	Several 1 000 km	Limited	Wide spread	Long range radionavigation and strategic communications
MF	0.3-3 MHz	Ground wave, sky wave	A few 1 000 km	Moderate	Wide spread	Medium range point-to-point, broadcasting and maritime mobile
HF	3-30 MHz	Sky wave	Up to several 1 000 km	Wide	Wide spread	Long and short range point-to-point, global broadcasting, mobile.
VHF	30-300 MHz	Space wave, tropospheric scatter, diffraction	Up to a few 100 km	Very wide	Confined	Short and medium point-to-point, mobile, LAN, audio and video broadcasting, personal communications
UHF	0.3-3 GHz	Space wave, tropospheric scatter, diffraction, line-of-sight	Generally less than 100 km	Very wide	Confined	Short, medium and long point-to-point, mobile, LAN, audio and video broadcasting, personal communications, satellite communications
SHF	3-30 GHz	Line-of-sight	30 km; several 1 000 km for multihop and satellite	Very wide up to 1 GHz	Generally confined	Medium to short range point-to-point, audio and video broadcasting, LAN, mobile/personal communications, satellite communications
EHF	30-300 GHz	Line-of-sight	20 km; several 1 000 km for multihop and satellite	Very wide up to 10 GHz	Generally confined	Short range point-to-point, microcellular, LAN and personal communications, satellite communications

The radio signal received after propagation from a transmitting antenna depends upon the characteristics of the intervening terrain and upon the characteristics and variability of both the ionosphere and troposphere. A detailed estimate of the signal strength or transmission loss and of the signal attenuation must therefore account for the location of the terminals, the season and the time of day, and the statistical parameter (e.g. percentage of time) required. Radiocommunication Study Group 3 is the expert group on radio wave propagation. Radio propagation models are complex since there are a variety of effects, such as reflection, diffraction, scattering and ducting to be considered. For many spectrum analysis and frequency assignment purposes, simplified assessments of the propagation losses are required. A synoptic review of the propagation aspects which affect radiocommunication services and interference analysis is included in [Bem, 1979].

The spectrum user requires a detailed estimate of the coverage or reliability of his transmission. For frequency management or planning purposes, it may be sufficient to make simple and optimistic assumptions about the coverage or signal strength; for example, free-space propagation, which accounts for spatial spreading losses (Recommendation ITU-R P.525) and is uninfluenced by atmospheric, or by terrain screening effects. A wanted signal should have high reliability so that it may only be necessary to consider the level of an unwanted signal which is expected to occur for a small fraction of the time. But note that more accurate methods are needed to provide this level of certainty for the shorter time occurrence of unwanted signals (interference).

In this section, several propagation methods are briefly discussed. More complete discussions may be found in the ITU-R P Series Recommendations.

VLF (f < 30 kHz)

At frequencies below 30 kHz, propagation losses approach those of free-space propagation. At VLF a wave guide mode between the ionosphere and the Earth allows propagation over global distances.

LF (30 < f < 300 kHz)

In this frequency range, two distinct propagation modes are important: the ground-wave mode, which will often determine the limit of the wanted signal, and the ionospheric (sky-wave) mode will often propagate the unwanted signals. The sky-wave signal amplitude has a pronounced diurnal variation due to changes in ionospheric absorption. This mode of propagation is characterised by regions where the sky-wave does not reach the ground (i.e. skipped) and the distance to each interception with the ground is the skip distance.

Sky-wave propagation at these frequencies is dealt with in Recommendations ITU-R P.1147 and propagation curves for ground wave are included in Recommendation ITU-R P.368.

MF (300 kHz < f < 3 MHz)

In this frequency band the propagation modes are also ground wave and sky wave; therefore many texts cover both the LF and MF band.

Ground-wave propagation for frequencies between 10 kHz and 30 MHz is considered in Recommendation ITU-R P.368 and a computer program, GRWAVE, is available from the ITU-R website. When assessing the ground wave, it is necessary to know the electrical properties of the ground, particularly the conductivity. Maps are given in Recommendation ITU-R P.832. However, these maps are primarily intended for use at VLF and they are not currently available in numerical form for computer applications.

Sky-wave propagation for frequencies from 150 kHz to 1.7 MHz is discussed in the ITU-R Handbook on the ionosphere and its effects on terrestrial and Earth-space radiowave propagation and a prediction method is given in Recommendation ITU-R P.1147. In the MF broadcasting band, it is often sufficient to assume that sky-wave propagation only occurs at night. At frequencies above 1.6 MHz, the HF propagation prediction methods described below begin to be valid. Also above 1.6 MHz the sky wave becomes increasingly important for mobile communication systems.

HF (3 < f < 30 MHz)

Within this frequency range, signal propagation is generally via the ionosphere and, as a consequence, displays considerable variability. The nature of ionospheric propagation implies that long-range circuits will be subject to multipath distortion, signal interference and intermittent operation. The long distances and involved physical processes within the ionosphere necessitate the use of relatively complex propagation prediction models.

Numerical maps of ionospheric characteristics (Recommendations ITU-R P.1239 and ITU-R P.1240) are employed within computer-based models used to predict HF propagation. The computer program REC 533 is a computerized version of Recommendation ITU-R P.533 which predicts, for any path, any season and sunspot number, the basic and operational MUF, field strength, received power, signal-to-noise ratio and reliability.

VHF and UHF (30 MHz < f < 3 GHz)

In these bands propagation via the regular ionosphere does not occur except at the lowest frequencies in this range. Weather effects are confined to super-refraction and ducting that can be caused by variations of the normal gradient in the refractive index of the air. Other important departures from free space propagation are tropospheric scattering and diffraction caused by intervening obstacles, including the Earth’s curvature and diffraction from terrain and buildings.

Depending upon the particular propagation environment, the following can be used to estimate propagation losses:

– Free-space attenuation. In some circumstances it will be sufficient to assume that the wanted signal is only subject to the attenuation due to propagation in free space (Recommendation ITU-R P.525).

– Diffraction around a smooth Earth. For wanted signal predictions at ranges greater than the line-of-sight distance, it may be desirable to account for the Earth's curvature. The computer program GRWAVE treats this case and a treatment of propagation by diffraction is also contained in Recommendation ITU-R P.526 (see also ITU-R Handbook – Curves for radio wave propagation near the surface of the Earth).

– Propagation over specific regions of the world or over ground of specific roughness. Recommendation ITU-R P.1546 is suitable for point-to-area prediction of field strength for the broadcasting, land mobile, maritime mobile and certain fixed services (e.g. those employing point-to-multipoint (P-MP) systems) in the frequency range 30 MHz to 3 000 MHz. It is intended to be used on radio circuits over land paths, sea paths, and/or mixed land-sea paths between 1-1 000 km in length for effective transmitting antenna heights less than 3 000 m. And it presents compatible results to the Okumura-Hata Model for mobile services in an urban environment. Additionally, there are more variables than just distance and equivalent antenna height. This model has correction factors to predict attenuation in Suburban Areas and Open Areas. This model is used as reference in Report ITU-R SM.2028-1 and the conditions. But it is not specific to a particular polarization and it is not complete in the paths less than 1 km. And since it does not fit the required short-range scenario, appropriate adjustments should be made to account for effects such as street-canyon propagation, building entry, indoor sections of path, or body effects.

– Propagation over a specific terrain profile. Recommendation ITU-R P.1812 is suitable for predictions for radiocommunication systems utilizing terrestrial circuits having path lengths from 0.25 km up to about 3 000 km distance, with both terminals within approximately 3 km height above ground. And it is recommended for use in connection with terrestrial point-to-area services in the VHF and UHF bands. It may be used to predict both the service area and availability for a desired signal level (coverage), and the reductions in this service area and availability due to undesired, co- and/or adjacent-channel signals (interference). Point-to-area predictions using this method consist of series of many P-MP (i.e. transmitter-point-to-receiver-multipoint) predictions, uniformly distributed over national service areas. The number of points should be large enough to ensure that the predicted values of basic transmission losses or field strengths thus obtained are reasonable estimates of the median values, with respect to locations, of the corresponding quantities for the elemental areas that they represent. When necessary, a detailed calculation may be made for propagation over a terrain profile obtained from a topographic database. So, it is assumed that users of this Recommendation are able to specify detailed terrain profiles (i.e. elevations above mean sea level) as functions of distance along the great circle paths (i.e. geodesic curves) between the terminals, for many different terminal locations (receiver-points). For most practical applications of this method to point-to-area coverage and interference predictions, this assumption implies the availability of a digital terrain elevation database, referenced to latitude and longitude with respect to a consistent geodetic datum, from which the terrain profiles may be extracted by automated means. And Longley-Rice (ITS) model is now uncovered by Recommendation ITU-R P.1812. The ITS model for frequencies between 20 MHz and 20 GHz, which is based on electromagnetic theory and on statistical analyses of both terrain features and radio measurements, predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time and in space.

In addition it may also be necessary to account for other propagation mechanisms that may result in interference. These mechanisms include:

– *Ionospheric propagation.* During certain seasons and times of the day the ionospheric propagation modes, such as that via the sporadic E layer, may permit long distance propagation at frequencies up to around 70 MHz (see Recommendation ITU-R P.534);

– *Super-refraction and ducting.* These effects are dealt with in Recommendations ITU-R P.834 and ITU-R P.452.

SHF and higher frequencies (*f* > 3 GHz)

The propagation factors described previously (except for sky wave) are appropriate at even higher frequencies. However, it is necessary to consider the attenuation, scattering and cross-polarization produced by precipitation and other atmospheric particles. Above about 15 GHz, it becomes increasingly necessary to account for signal attenuation by atmospheric gases.

Rainfall and other precipitates occurring along a propagation path can create several problems. At frequencies greater than about 10 GHz, attenuation by raindrops can result in serious impairment in signal quality. The methods for estimating the probability distribution for attenuation are generally based on the value of rainfall intensity $R_{0.01}$ (mm/h), exceeded 0.01% of the time. This value should be based on long-term rainfall observations made with rain gauges having a time resolution of approximately 1 min. If such long-term data are not available for the region of interest the value can be estimated from the model given in maps presented in Recommendation ITU-R P.837. For the frequency and polarization of interest, the "specific" attenuation can then be calculated according to Recommendation ITU-R P.838. Recommendation ITU-R P.530 gives a method for estimating the attenuation level for other percentages of time on a line-of-sight path.

Terrestrial propagation can, during clear-air conditions, experience fading due to diffraction, atmospheric and surface multipath, and refraction effects (beam spreading, antenna defocusing), attenuation due to atmospheric gases and in some regions, sand and dust storms. Recommendation ITU-R P.530 provides information on how to treat these effects. Refractivity data are given in Recommendation ITU-R P.453. When local information is not available Recommendation ITU-R P.836 provides guidance on the mean water vapour densities in the atmosphere and their seasonal variability near the surface of the Earth that most likely concern systems operating above 20 GHz.

Earth-space propagation

On Earth-space paths the propagation effects of prime concern are signal attenuation, scintillation fading and signal depolarization, where the importance of each effect depends on path geometry, climate and parameters of the communications system. Supplementary information is found in Recommendation ITU-R P.679 (broadcast satellite), Recommendation ITU-R P.680 (maritime mobile-satellite), Recommendation ITU-R P.681 (land mobile-satellite) and Recommendation ITU-R P.682 (aeronautical mobile-satellite).

When considering unwanted signals, attention must be given to the cross-polarization due to hydrometeors (Recommendation ITU-R P.618), polarization rotation in the ionosphere and the effects of ionospheric scintillation (Recommendation ITU-R P.531). As path elevation angles become small, path losses will exceed the free-space value and, of course, the possibility of blocking by obstructions increases.

Recommendation ITU-R P.618 provides the primary source of propagation data and engineering advice on effects of the troposphere on the wanted signal for the design of Earth-space links. Recommendation ITU-R P.618 contains methods to estimate the signal loss for gaseous absorption and rain attenuation. Techniques for frequency and polarization scaling of attenuation statistics are provided in Recommendation ITU-R P.618, and estimation of worst-month statistics are prescribed in Recommendations ITU-R P.581 and P.841. Sky-noise temperature increases that accompany any path loss also causes a degradation in receiver figure-of-merit for an earth station which can be estimated from an expression in Recommendation ITU-R P.618. Site diversity can significantly reduce the attenuation level corresponding to a given annual time percentage on paths subject to severe attenuation, and also reduce the effects of scintillation and depolarization. Calculation procedures to estimate diversity performance are found in Recommendation ITU-R P.618.

Signal scintillation is the rapid fluctuation in signal amplitude caused by variations in tropospheric refractive index. Recommendation ITU-R P.618 contains a prediction method to estimate the scintillation fade depth for time percentages between 0.01 and 50 percent of the year.

Asymmetric scatterers (raindrops, ice crystals) on a propagation path generate signal depolarization in dual-polarization frequency-reuse communications systems. Recommendation ITU-R P.618 supplies a method to estimate the cross-polarization discrimination (XPD) for frequencies of 8 to 35 GHz (and frequency scaling to 4/6 GHz) and path elevation angles of 60° and below. An empirical correction for ice depolarization is also prescribed as a factor of the estimated rain XPD.

5.3.2 Topographic data

In many cases, the presence of terrain features can make a large difference to the levels of both the wanted and unwanted (interfering) radio signals. Knowledge of the terrain must be available to apply some of the methods of estimating the propagation loss. Different classes of terrain that are useful are: sea, other bodies of water, desert, dense forest, forest, rural, suburban and urban areas. For further information see Recommendation ITU-R P.1058 – Digital topographic databases for propagation studies.

The extraction of path profiles from topographic maps has traditionally been done by hand. This is a laborious, time consuming and expensive process. However, extensive work has been done by cartographic institutions to provide digital maps for selected geographical areas. From these maps, the important features for radio propagation prediction can be extracted. Terrain height, surface vegetation, building height and density, street width, ground geology are the features which can also be used but may be expensive. The terrain information described above can be obtained from aerial photographs or images captured by satellites including the use of multi-frequency synthetic aperture radar.

The method most frequently used in terrain databases produces height data at uniformly spaced intervals on a grid structure. The resolution of the data is governed by the digital storage capacity and the accuracy of the survey. The resolution of the terrain data required depends on the frequency band under study. It could vary from less than 1 m for UHF/SHF to more than 1 km for HF. The accuracy of the data (heights of obstacles) should be in the range of 1 m to 1000 m, again depending on the frequency band. Using stored terrain data, a path profile of the altitude can be generated between any two geographical points included in the terrain database. These profiles are useful in determining the line-of-sight points or the shielding effects of surrounding terrain. While terrain features are important, building heights should not be neglected, especially in urban or suburban areas. Computer techniques for propagation loss calculations can automatically access a terrain database [Chan, 1991 and Palmer, 1981]. Recently a compilation of cartographic and other data have resulted in a topographic data-set known as GLOBE. A version of this is currently the basis of the ITU product known as the IDWM. The resolution of this set is about 30 arcsec (about 1 km at the equator). NASA flew a SAR mission in 2000 capable of producing higher resolution topography (3arcsec) together with height and some clutter data. This is known as GLOBE 2 and is a more uniform data-set.

5.3.3 Selection of propagation model

The analysis of spectrum management problems often utilizes spectrum engineering models and appropriate databases. An engineering model of a physical process has a number of advantages: it is quicker and easily modified. The accuracy of a model simulating a process is determined by its design and use. Unusual attributes of a particular problem demand ingenuity, flexibility and intuition in conducting the analysis. With this consideration in mind the data and models described are intended to provide basic material, which can be used routinely or adapted as appropriate.

Based on the appropriate propagation model, the propagation loss and hence the desired signal level or interference level can be calculated.

5.3.4 Antennas and reference radiation patterns

As identified in Report ITU-R F.2059, antenna radiation performance is a dominant factor in determining the extent of possible frequency reuse or “spectrum efficiency”. This conclusion is derived after statistical studies using several models of commercial antennas within the point-to-point fixed wireless service. Furthermore, this result could be extended to most of the radiocommunication services.

Reference radiation patterns defined in ITU-R Recommendations are used in the absence of particular information about the actual antennas involved in a planning study. They are mathematical models which state the gain of a hypothetical antenna in each direction of the space. Usually, this modelization is derived either from theoretical models or empirical radiation patterns measured from commercial antennas.

5.3.4.1 A brief example in the Fixed Wireless Service

In the point-to-point Fixed Wireless Service (FWS), parabolic antennas are mainly utilized. Fundamental characteristics of these antennas are high directivity and linear polarization.

For coordination studies and assessment of mutual interference between fixed wireless systems, and between stations of such systems and earth stations of space radiocommunication services sharing the same frequency band, it may be necessary to use reference radiation patterns for FWS antennas. An example of this necessity is the case where information about the radiation pattern of the actual antennas involved in the study is not available.

Thus, Recommendation ITU-R F.699 states the reference patterns in the frequency range from 100 MHz to 70 GHz, where the gain relative to an isotropic antenna, at a given off-axis angle, is a function of the antenna diameter (D) and the operating wavelength (λ). Also the main lobe antenna gain and the beamwidth are modelized as a function of D/λ.

Recommendation ITU-R F.699 gives the peak envelope of side-lobe patterns; nevertheless, the usage of these patterns in the assessment of the aggregate interference consisting of many interference entries, the predicted interference will result in values that are greater than values that would be experienced in practice. In Recommendation ITU-R F.1245, a mathematical model of the average radiation pattern is stated, which is necessary in the following cases:

- To predict the aggregate interference to a geostationary or non-geostationary satellite from numerous radio-relay stations;

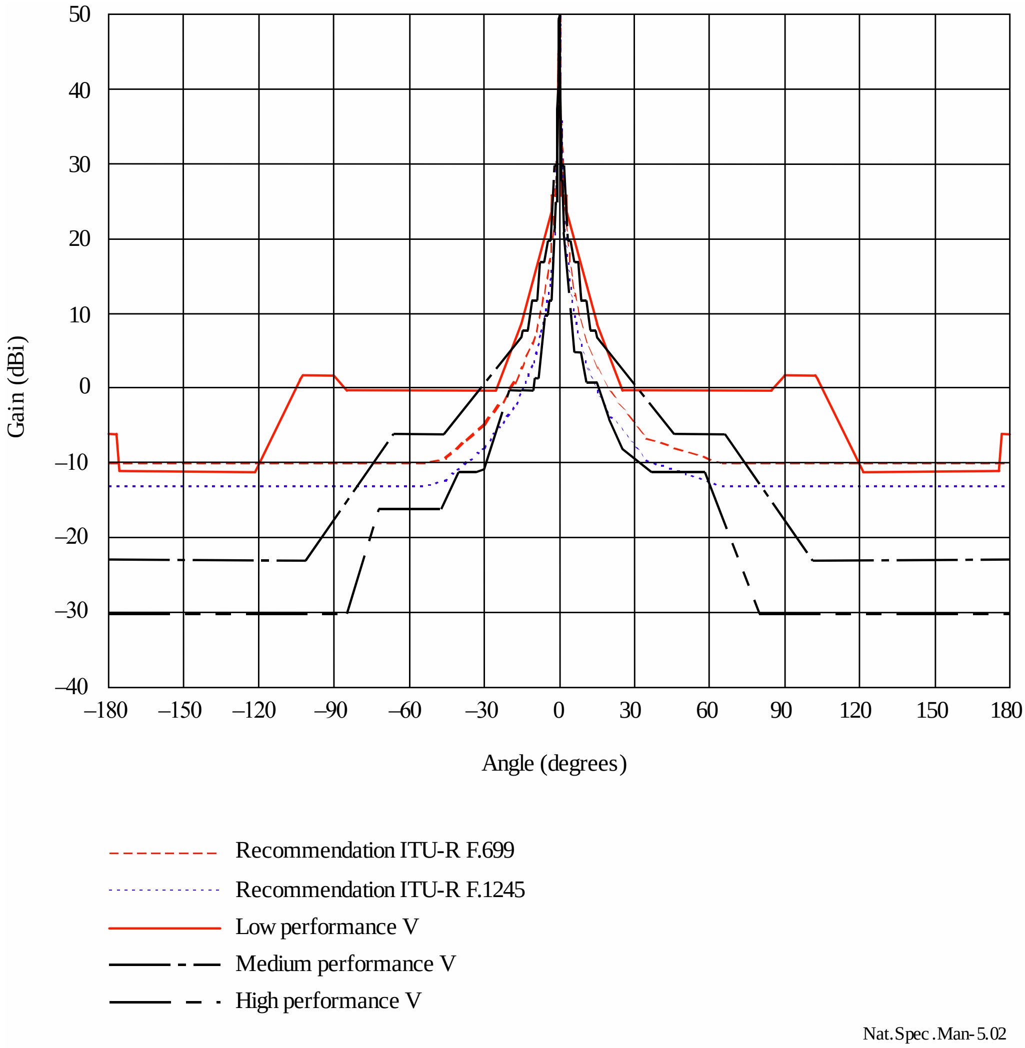
- To predict the aggregate interference to a radio-relay station from many geostationary satellites;

- To predict interference to a radio-relay station from one or more non-geostationary satellites under the continuously variable angle that should be averaged.

A comparison between some practical antenna pattern envelopes and the corresponding reference patterns derived from Recommendation ITU-R F.699 and Recommendation ITU-R F.1245 can be seen in Figure 5.2.

FIGURE 5.2

10.7 GHz point-to-point (P-P) antenna of 3 m diameter (*D*/λ = 114; gain = 49.8 dBi)
(H: horizontal polarization, V: vertical polarization)



5.3.4.2 ITU-R Recommendations defining reference radiation patterns and other antennae concerns

Table 5-3 summarizes the wide set of ITU-R Recommendations which define reference radiation patterns to be taken into account in sharing and coordination studies, and interference assessment from single or multiple interferers.

Some of the listed ITU-R Recommendations sets design objectives (i.e. Recommendation ITU-R S.580 that states radiation diagrams to be met by new earth-station antennas operating with a geostationary satellite). Recommendation ITU-R S.1717 details a format in which gain data on specific FSS earth station antennas may be submitted by administrations in electronic form to. This information may be needed in some studies where reference patterns do not provide enough detail, or when a reference pattern is to be refined/developed.

5.3.4.3 Suggested practices for administrations

It is recommended for administrations to keep records of measured radiation patterns from actual antennas in order to allow the use of new and improved reference radiation patterns in coordination studies and interference assessment to be developed and proposed.

Besides, it is essential that every effort be made to utilize the actual antenna pattern in coordination studies and interference assessment. Hence, those recorded radiation patterns should be used to perform studies even if it is possible, and where more detailed information is necessary.

TABLE 5-3

Summary of ITU-R Recommendations related to reference radiation patterns and/or characteristics of antennas to be considered in sharing, coordination and planning studies and/or interference assessment

Number	Title	Service	Frequency band	Antenna/ Pattern type	Issues
BO.652	Reference patterns for earth-station and satellite antennas for the broadcasting-satellite service in the 12 GHz band and for the associated feeder links in the 14 GHz and 17 GHz bands	Broadcasting -Satellite	12 GHz 14 and 17 GHz	Earth Station Antenna (receiving) Satellite antenna (transmitt-ing)	Co-polar and cross-polar reference patterns for receiving earth-station antennas and satellite transmitting antennas.
BO.1213	Reference receiving earth station antenna pattern for the broadcasting-satellite service in the 11.7-12.75 GHz band	Broadcasting -Satellite	11.7- 12.75 GHz	Earth Station Antenna	Reference earth station co-polar and cross-polar antenna patterns for the BSS.
BO.1296	Reference receive space station antenna patterns for planning purposes to be used for elliptical beams in the revision of the Appendix 30A (Orb-88) plans of the radio regulations at 14 GHz and 17 GHz in Regions 1 and 3	Broadcasting -Satellite	14 GHz 17 GHz	Space Station Antenna	Circularly polarized reference antenna co-polar and cross-polar patterns, for elliptical beams for planning purposes.
BO.1443	Reference BSS earth station antenna patterns for use in interference assessment involving non-GSO satellites in frequency bands covered by RR Appendix 30	Broadcasting -Satellite		Earth Station Antenna	Tri-dimensional reference earth station antenna patterns for the BSS that can be used for the calculation of interference generated by non-GSO FSS satellites into BSS earth station antennas.
BO.1445	Improved patterns for fast roll-off satellite transmit antennas of the Regions 1 and 3 BSS plans of RR Appendix S30	Broadcasting -Satellite		Satellite antenna	Improved satellite antenna co-polar and cross-polar patterns with fast roll-off in the main beam, for elliptical beams of fast roll-off when such fast roll-off antenna is required in studies in accordance with Resolution 532 (WRC-97).
BO.1900	Reference receive earth station antenna pattern for the broadcasting-satellite service in the band of 21.4-22 GHz in Regions 1 and 3	Broadcasting -Satellite	21.4-22 GHz	Earth Station Antenna	Co-polar and the cross-polar reference receive earth station antenna patterns for the BSS for sharing studies.

TABLE 5-3 (*continued*)

Number	Title	Service	Frequency band	Antenna/ Pattern type	Issues
BS.80	Transmitting antennas in HF broadcasting	Broadcasting	HF	Non-directional Directional	Guidance on the choice of a suitable transmitting HF antenna and HF antenna patterns for system design and planning.
BS.599	Directivity of antennas for the reception of sound broadcasting in band 8 (VHF)	Broadcasting	VHF		Characteristics of directivity of receiving antennas for planning of sound broadcasting in VHF.
BS.705	HF transmitting and receiving antennas characteristics and diagrams	Broadcasting	HF	Arrays, log-periodic, rhombic, monopole, curtain, quadrant, crossed dipole	Formulae to evaluate the performance of HF transmitting/receiving antennas for planning purposes.
BS.1195	Transmitting antenna characteristics at VHF and UHF	Broadcasting	VHF UHF	Arrays, antenna systems	Transmitting antenna pattern calculation, practical aspects and calculation software.
BS.1386	LF and MF transmitting antennas characteristics and diagrams	Broadcasting	LF MF	Antenna systems, monopoles, arrays and others	Transmitting antenna characteristics and diagrams used to evaluate the performance of LF and MF transmitting antennas, particularly for planning purposes. Practical aspects
BT.419	Directivity and polarization discrimination of antennas in the reception of television broadcasting	Broadcasting	TV Bands I, III, IV, V (Rec. ITU-R BT.417)		Characteristics of directivity of receiving antennas used for planning terrestrial television service; advantages to be gained using orthogonal wave polarizations; polarization of emission in television broadcasting.
BT.1195	Transmitting antenna characteristics at VHF and UHF	Broadcasting	VHF UHF	Arrays, antenna systems	Transmitting antenna pattern calculation, practical aspects and calculation software.
F.162	Use of directional transmitting antennas in the fixed service operating in bands below about 30 MHz	Fixed	4-28 MHz	Directional	Performance: directivity, gain, service sector, antenna directivity factor.
F.699	Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz	P-P Fixed	100 MHz- 70 GHz	Directional	Reference radiation patterns (peak envelope of side-lobes) for coordination studies and interference assessment.

TABLE 5-3 (*continued*)

Number	**Title**	**Service**	**Frequency band**	**Antenna/ Pattern type**	**Issues**
F.1245	Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz	P-P Fixed	1-70 GHz	Directional	Reference radiation patterns (average) for certain coordination studies and multiple or time-varying interference assessment.
F.1336	Reference radiation patterns of omnidirectional, sectoral and other antennas for use in sharing studies in the frequency range from 400 MHz to about 70 GHz	P-MP Fixed Land Mobile	400 MHz-70 GHz	Omnidirectional and sectoral	Reference radiation patterns (peak and average) for sharing studies.
			1-3 GHz	Low gain directional	
M.694	Reference radiation pattern for ship earth station antennas	Mobile-Satellite	1 518-1 660.5 MHz	Ship Earth Station Antenna	Reference radiation pattern for ship earth station antennas used for coordination studies and the assessment of interference between earth stations in the Mobile-Satellite Service and terrestrial and space stations which are the same frequency bands.
M.1091	Reference off-axis radiation patterns for mobile earth station antennas operating in the land mobile-satellite service in the frequency range 1 to 3 GHz	Land Mobile-Satellite	1-3 GHz	Transportable or vehicle-mounted earth station antennas	Reference radiation pattern used for statistical assessment of interference and for use in coordination between land mobile earth stations and the space stations of different satellite systems sharing the same frequency bands.
M.1851	Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses	Radiodetermination radar systems	420-33 400 MHz	Omni, Yagi element array, parabolic reflector, phased array	Radiodetermination radar systems antenna patterns (peak and average) to be used for single entry and aggregate interference analysis.

TABLE 5-3 (*continued*)

Number	Title	Service	Frequency band	Antenna/ Pattern type	Issues
RA.1631	Reference radio astronomy antenna pattern to be used for compatibility analyses between non-GSO systems and radio astronomy service stations based on the epfd concept	Radio astronomy	150-5 000 MHz 10.6-43.5 GHz		Mathematical model of the average radiation pattern used for compatibility analyses between non-GSO systems and RAS stations.
RS.1813	Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz	Earth exploration-satellite	1.4-100 GHz		Reference antenna pattern for Earth exploration-satellite service passive sensors to be used in compatibility studies.
S.465	Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz	Fixed-Satellite	2-31 GHz	Earth Station Antenna	Reference radiation pattern used for coordination studies and interference assessment between earth stations in the FSS and stations of other services sharing the same frequency band as well as coordination studies and interference assessment between systems in the FSS.
S.580	Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites	Fixed-Satellite		Earth Station Antenna	Design objective for new antennas of an earth station operating with a geostationary satellite.
S.672	Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites	Fixed-Satellite		Single feed circular/elliptical beams Multiple feed shaped beams	Satellite antenna reference radiation patterns for use as a design objective.
S.731	Reference earth-station cross-polarized radiation pattern for use in frequency coordination and interference assessment in the frequency range from 2 to about 30 GHz	Fixed-Satellite	2-30 GHz	Earth Station Antenna	Reference cross-polarized radiation pattern of earth station antennas, used for frequency coordination studies and interference assessment between earth stations in the FSS and stations of other services sharing the same frequency band, and coordination studies and interference assessment between networks in the FSS.

TABLE 5-3 (*continued*)

Number	Title	Service	Frequency band	Antenna/ Pattern type	Issues
S.732	Method for statistical processing of earth station antenna side-lobe peaks to determine excess over antenna reference patterns and conditions for acceptability of any excess	Fixed-Satellite		Earth Station Antenna	Method for the statistical processing of earth station antenna side-lobe peaks in order to determine the percentage of side-lobe peaks that exceed antenna reference patterns provided in relevant ITU-R Recommendations; and conditions under which earth station antenna side-lobe patterns with peaks exceeding recommended envelopes will still be considered compliant with ITU-R Recommendations that allow a certain percentage of side-lobe peaks to exceed the recommended envelopes.
S.1428	Reference FSS earth-station radiation patterns for use in interference assessment involving non-GSO satellites in frequency bands between 10.7 GHz and 30 GHz	Fixed-Satellite	10.7-30 GHz	Earth Station Antenna	Reference earth station radiation antenna pattern used for interference calculations involving moving interfering sources and/or victim receivers of FSS interference.
S.1528	Satellite antenna radiation patterns for non-geostationary orbit satellite antennas operating in the fixed-satellite service below 30 GHz	Fixed-Satellite	Below 30 GHz	Multiple-beam non-GSO antennas (circular or elliptical beams)	Radiation patterns used as a design objective or to perform interference analysis.
S.1717	Electronic data file format for earth station antenna patterns	Fixed-Satellite		Earth Station Antennas	Format in which data on specific FSS earth station antennas may be submitted by administrations in electronic form.
S.1844	Cross-polarization reference gain pattern for linearly polarized very small aperture terminals (VSAT) for frequencies in the range 2 to 31 GHz	Fixed-Satellite	2-31 GHz	VSAT Earth Station Antennas	Cross-polarization reference gain pattern used for interference calculations involving VSAT earth stations in the FSS and stations of other services sharing the same frequency band, as well as coordination studies and interference assessment between systems in the FSS.

TABLE 5-3 (*end*)

Number	Title	Service	Frequency band	Antenna/ Pattern type	Issues
S.1855	Alternative reference radiation pattern for earth station antennas used with satellites in the geostationary-satellite orbit for use in coordination and/or interference assessment in the frequency range from 2 to 31 GHz	Fixed-Satellite	2-31 GHz	Earth Station Antennas	Reference radiation patterns for antennas used with satellites in the GSO for coordination and/or interference assessment between earth stations in the FSS and any station in other service sharing the same frequency band, or between systems in the FSS.
SA.509	Space research earth station and radio astronomy reference antenna radiation pattern for use in interference calculations, including coordination procedures, for frequencies less than 30 GHz	Space Research Radio astronomy	1-30 GHz	Large parabolic	Reference antenna radiation patterns to predict interference from single or multiple sources.
SA.1345	Methods for predicting radiation patterns of large antennas used for space research and radio astronomy	Space Research Radio astronomy			Electromagnetic modelling methods; Analysis using experimental data.
SA.1811	Reference antenna patterns of large-aperture space research service earth stations to be used for compatibility analyses involving a large number of distributed interference entries in the bands 31.8-32.3 GHz and 37.0-38.0 GHz	Space Research	31.8-32.3 GHz 37-38 GHz	Large-aperture Earth Station Antenna	Single deterministic reference antenna pattern (peak) for compatibility analysis, and gain model (average) for statistical compatibility analysis involving a large number of distributed interfering sources.

5.4 Interference analysis

Efficient spectrum utilization depends on the effective analysis of environmental and system parameters, typically statistical in nature, to minimize the area of interference. Since interference reduces system performance and spectrum efficiency, the technical parameters of the design and specification of radio systems licensed to operate in a given service and a given frequency band should be considered so that the licensees are not subjected to interference and do not cause interference to other users.

The important parameters which must be considered to prevent interference include definitions of centre frequencies, separation of carrier frequencies, frequency stability, types of emission (digital or analogue and the modulation used), the power level of the transmitter or of the carriers and the maximum equivalent isotropically radiated power (e.i.r.p.) per channel in a specified bandwidth, and the levels of emissions outside of the bandwidth. Antenna characteristics such as effective height, directivity of the radiation pattern for the polarization, the minimum front-to-back ratio, and the angle between the main lobe and other users such as geostationary satellites may also need to be considered.

The wanted signal at the input of the receiver is mainly degraded by four interference types: co-channel, adjacent channel, desensitization, and intermodulation. The first three types of interference may be described by one general equation.

Basically the interference level at the receiver is a function of P_t, the interferer transmitter power, G_t, the gain of the interferer antenna in the direction of the receiver (dBi), G_r, the gain of the receiver antenna in the direction of the interferer (dBi), $L_b(d)$, the basic loss for a separation distance d between the receiver and the interferer, and FDR (Δf), the frequency dependent rejection depending on Δf, and is expressed by:

$$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f) \quad (1)$$

The frequency dependent rejection is a function of Δf which is the difference between the interferer tuned frequency and the receiver tuned frequency. It is also dependent on the characteristics of the receiver. Further information may be found in Recommendation ITU-R SM.337. It should be noted that equation (1) can be used to calculate the desired signal level as well provided that the propagation loss is calculated by the appropriate propagation model.

Another general characteristic regarding radio interference in a multiple source interference environment is that the total interference power is the sum of individual interference powers:

$$I = I_1 + I_2 + ... + I_K \quad (2)$$

The following sections provide a brief description of these types of interference. Other types of interference such as harmonics, spurious emissions, parasitic emissions and cross-modulation are described in § 5.2.2.

5.4.1 Co-channel

Co-channel interference is caused by the presence of desired and interfering signals operating in the same channel within the bandwidth of the intermediate frequency (IF) amplifier. Since both the desired and interfering signals overlap, $FDR(\Delta f)$ of equation (1) equals zero, and the interfering signal cannot be filtered out by normal means. The level of co-channel interference is dependent on the co-channel rejection characteristics of the receiver and the emission characteristics of the transmitter.

In the different radio services the calculation of co-channel interference differs. In the land mobile service, co-channel stations are separated from each other at a distance of 120 km as a worst case. This distance varies with different terrain conditions and frequencies of operation. In cellular radio systems, the co-channel separation distance is much closer allowing channels to be re-used within the same city. In the fixed service, the directivity of the antenna plays a significant role in calculating co-channel interference levels. This is especially important when terrestrial stations and earth stations operate in the same frequency band.

Another cause of co-channel interference is due to uncoordinated frequency sharing situations. In these situations, both the number and location of possible interfering sources may not be known e.g. when the interfering radiation is from domestic equipment.

5.4.2 Adjacent channel

Adjacent channel interference may occur due to an interfering signal operating in the adjacent channel or transmitter spurious emissions. The level of adjacent-channel interference is dependent on the radio-frequency (RF) rejection characteristics of the receiver.

The basic effects of adjacent channel interference are the result of interaction between the wanted signals, interference and receiver characteristics for various frequencies and separations. These may be expressed in terms of frequency-distance (FD), frequency dependent rejection (FDR), or a relative radio-frequency protection ratio. FD is the minimum distance separation that is required between a receiver and an interferer as a function of the difference between their tuned frequencies. FDR is a measure of the rejection of an unwanted transmitter emission by the receiver selectivity. The level of adjacent channel interference depends on the value of $FDR(\Delta f)$ in equation (1). The protection ratio is a minimum required ratio between the wanted and unwanted signal, usually expressed in dB at the receiver input, when the carriers of the wanted and unwanted transmitters have the same frequency or a frequency difference of Δf. Protection ratios are further addressed in section 5.6 of this Handbook.

When a maximum value, I_M, of acceptable interference power for a receiver is specified, receiver performance is acceptable only if:

$$L_b(d) + FDR(\Delta f) \geq P_t + G_t + G_r - I_M \quad (3)$$

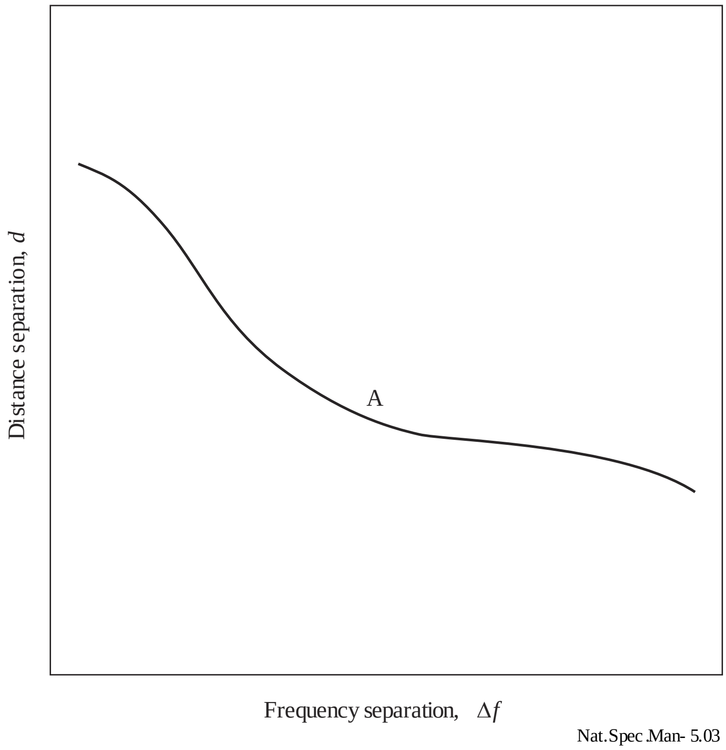
An illustrative curve of the various combinations of the separations and the area of acceptable receiver performance is shown below. The equation describing curve A is:

$$L_b(d) + FDR(\Delta f) = \xi \quad (4)$$

Above the curve is the region of acceptable receiver performance. Below the curve is the region of non-acceptable receiver performance.

FIGURE 5.3

Separations in frequency and distance. The equation describing curve A is $L_b(d) + FDR(\Delta f) = \xi$. Above the curve is the region of acceptable receiver performance. Below the curve is the region of non-acceptable receiver performance



The computations of FDR, FD and protection ratio can be implemented on a small computer, based on the methods of calculating the power in adjacent bands and channels described. It is also possible to determine separately the interference components in the adjacent channel caused by the carrier and by the sidebands.

5.4.3 Desensitization

Desensitization may occur when an interfering transmitter operates at close proximity to a receiver. If the interfering signal is sufficiently strong the receiver may be driven to saturation. The level of desensitization is dependent on the radio-frequency (RF) rejection characteristics, i.e. $FDR(\Delta f)$ of the receiver. Typically system specification advise users to select receiver selectivity characteristics that provide rejection of such harmful interference. Common methods that are used to avoid desensitization interference include the installation of filters, re-siting the stations and reducing the excessive transmitter power of the interfering station.

5.4.4 Probability of interference

No. 1.166 of the RR defines *interference* as: "The effect of unwanted energy...upon reception in a *radiocommunication* system, manifested by any performance degradation, misrepresentation, or loss of information which could be extracted in the absence of such unwanted energy".

In order to estimate the extent of interference, computer simulations, propagation models and traffic models have been developed to calculate interference power, carrier-to-noise and wanted-to-interfering signal ratios. Because of the variability of radio equipment, transmission losses, and traffic intensity, only probabilistic estimations of interference are realistic.

The probability of interference is dependent on a number of factors, a general equation can only outline the concept of the statistical nature of interference. The actual probability of interference has to be evaluated on a category by category basis.

As an example, from the previous section on intermodulation, third order intermodulation products may cause interference in a receiver when the frequencies of the product fall in the IF pass band of the receiver. The probability of intermodulation interference depends on a number of factors. In the case of RIM, these factors are receiver discrimination characteristics, the receiver RF amplifier and the receiver sensitivity for a given signal-to-noise ratio, and the dispersion of wanted and interfering signal power levels at the receiver input. For the TIM, the probability of intermodulation interference is a function of the attenuation in the antenna circuits of the affected transmitter, the intermodulation conversion losses in the transmitter, the co-channel protection ratio, the interfering transmitter power at the output terminals, and the attenuation of intermodulation products on the path between the transmitter and the receiver. The probability of interference due to intermodulation can be significantly reduced in the design stage of fixed point-to-point systems but is more difficult to reduce in the land mobile service.

The consideration of the probability of interference at the system level includes, e.g. for mobile communication systems, the effect of:

– the out-of-band radiation of the transmitter on the fundamental receiving channel of the radio;
– the harmonic radiation of the transmitter on the receiving channel;
– the fundamental radiation of the transmitter on the spurious receiving channel;
– the harmonic radiation on a spurious receiving channel;
– third order intermodulation interference.

The probability of acceptable reception requires that none of the interference modes would cause a problem. The cumulative distribution functions of the interference modes can be calculated. From this function it is possible to compare the effects of one mode of interference to another mode in terms of the total probability of reception. Furthermore, the cost of reducing one interference mode as compared to another to improve reception quality of a signal can be evaluated. This would provide information as to whether the EMC parameters of receiver and transmitter should be improved and optimized in relation to the criterion of the overall cost of the radio equipment.

Report ITU-R SM.2028 describes a statistical simulation methodology suitable for evaluation of complex scenarios, based on the "Monte Carlo" technique. The method was originally developed in order to reassess the limits for unwanted emissions within Appendix **3** of the RR. However, this methodology is also appropriate to be used to address the following items in spectrum engineering:

– sharing and compatibility studies between different radio systems operating in the same or adjacent frequency bands, respectively;
– evaluation of transmitter and receiver masks;
– evaluation of limits for parameters such as blocking or intermodulation levels, in addition to the unwanted emissions.

The Monte Carlo method can address virtually all radio-interference scenarios. This flexibility is achieved by the way the parameters of the system are defined. The input form of each variable parameter (antenna pattern, radiated power, propagation path, etc.) is its statistical distribution function. It is therefore possible to model even very complex situations by relatively simple elementary functions. Number of diverse systems can be treated, such as:

– broadcasting (terrestrial and satellite);

– mobile (terrestrial and satellite);

– point-to-point;

– point-to-multipoint, etc.

The principle is best explained on the following example, which considers only unwanted emissions as the interfering mechanism. In general the Monte Carlo method addresses also other effects present in the radio environment such as out-of-band emissions, receiver blocking and intermodulation. Some examples of applications of this methodology are:

– compatibility study between digital PMR (TETRA) and GSM at 915 MHz;

– sharing study between FS and FSS;

– sharing study between short range devices (Bluetooth) and RLANs in the ISM band at 2.4 GHz;

– compatibility study for IMT-2000 and PCS1900 around 1.9 GHz;

– compatibility study for ultra wideband systems and other radio systems operating in this frequency bands.

The methodology contained in Report ITU-R SM.2028 has been implemented in the Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT®). SEAMCAT is available free of charge from the European Communications Office (ECO) and may be downloaded directly from their web-site: www.cept.org.

SEAMCAT provides all the functionality described previously in this section via an easy to use graphic user interface. A sample result is shown in Figures 5.4 and 5.5.

FIGURE 5.4

Example of SEAMCAT graphic user interface

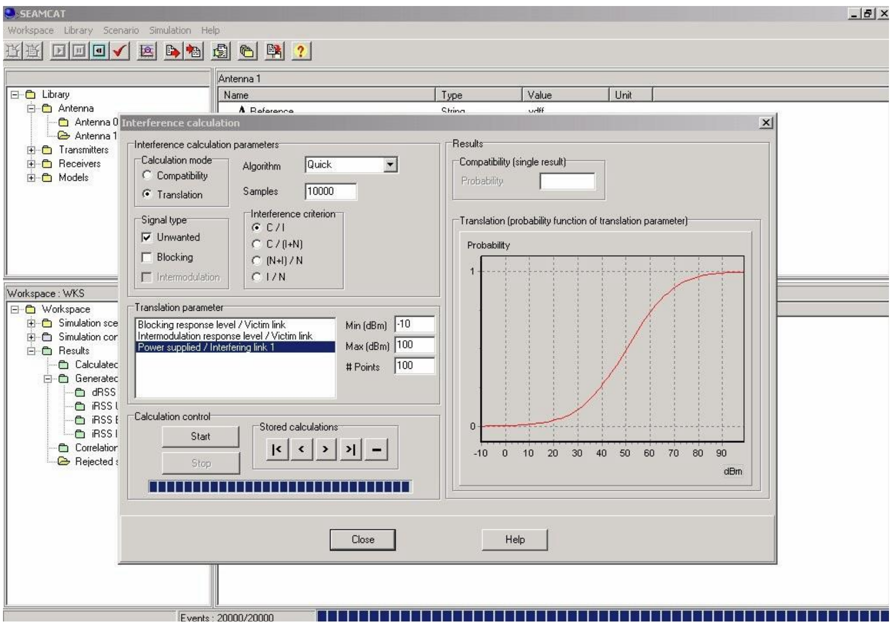


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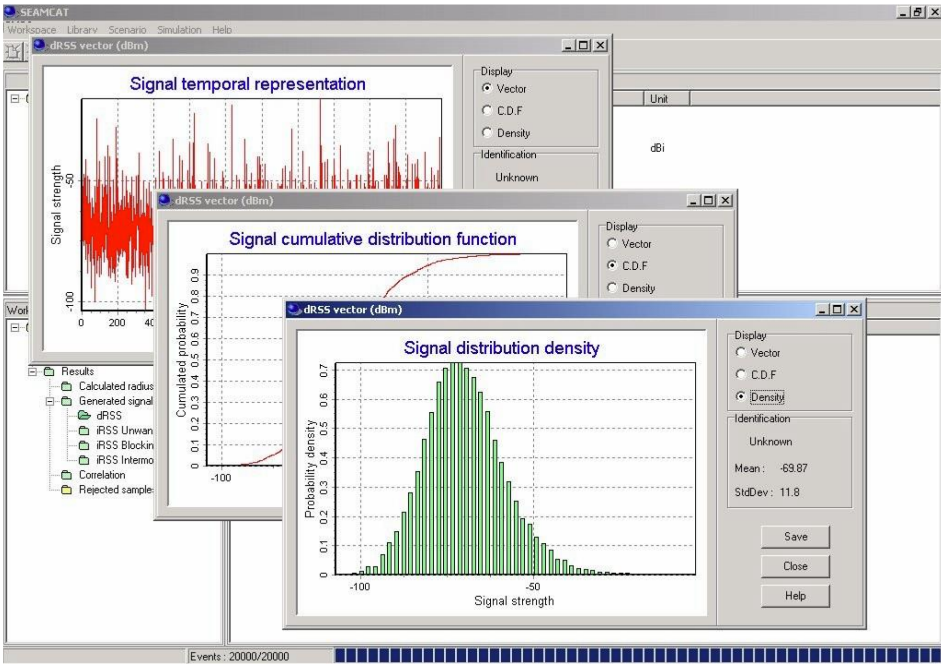
FIGURE 5.5

Further example of SEAMCAT graphic user interface



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5.5 Sharing frequency bands

The increasing demand for new, and expansion of existing, radiocommunication services places great importance on the development of technical means to achieve increased spectrum usage by sharing.

Inter-service sharing exists when two or more radiocommunication services effectively utilize the same frequency band. Article **1** of the RR (Nos **1.166** – **1.176**) defines the parameters to be taken into account in frequency sharing. Frequency sharing is an effective way in improving the utilization of the spectrum. The possibility of sharing existing frequencies should be considered before a new frequency is assigned.

Utilization of the radio spectrum is dependent upon frequency, time, spatial location, modulation/coding and orthogonal signal separation. Any sharing of the spectrum has to take into account one or more of these four dimensions. Sharing can be accomplished in a straightforward fashion when any two of these dimensions are in common and the third and/or fourth dimension differs by a degree sufficient to ensure that all the involved services (two or more) can operate satisfactorily. Sharing can also be accomplished when services have all four dimensions in common. In this case sharing is accomplished by applying technical conditions which do not compromise the performance requirements of the services involved.

5.5.1 Technical basis for sharing frequency allocations (sharing between different services)

Over time, there has been an increasing amount of spectrum sharing in order to accommodate new services and to utilize the spectrum resource more efficiently. Table 5-4 shows some of the technical methods which can be used to facilitate sharing. The sharing methods are grouped in columns based upon the four dimensions: frequency, time, spatial location and signal separation. Some of the methods are new or innovative and may make more efficient use of the spectrum or provide flexibility. Many of these methods result from the introduction of new equipment technologies, computerization of analysis, and new ideas. Some of the methods are complex involving real-time computer controlled frequency management. Often the specification of particular technical parameters for equipment is necessary to implement the sharing methods shown in Table 5-4. Examples of some of these parameters are:

– specification of geographic separation distance between equipment of the sharing services;

- specification of modulation characteristics for the sharing services, e.g. digital modulation, spread spectrum;
- transmitter power limits, power flux-density limits (pfds), transmitter antenna pointing angles;
- point-to-point transmissions only;
- utilization of directive and adaptive antennas;
- duty cycle and message type constraints on sharing service equipment, e.g. intermittent use only, analogue signals only, data only;
- specified interference criteria, i.e. bit error ratio criteria, error correction required; and,
- agreed relaxed technical sharing criteria to facilitate sharing.

TABLE 5-4

Methods to facilitate sharing

<table>
<tr><th>Frequency separation</th><th>Spatial separation</th><th>Time separation</th><th>Signal separation</th></tr>
<tr><td colspan="3">Licensed shared access
Spectrum database
Spectrum access controller
Geo-location database
Beacon
Sensing</td><td></td></tr>
<tr><td>Channelling plans
Band segmentation
Frequency agile systems
– Dynamic Frequency Selection (DFS)
Dynamic sharing:
– dynamic real-time frequency assignment(1)
Control of emission spectrum characteristics
Dynamic variable partitioning
Frequency tolerance limitation
Pilot channel</td><td>Geographically shared allocations
Site separation
Antenna system characteristics:
– adaptive antenna (smart antenna)
– antenna polarization discrimination
– antenna pattern discrimination
– antenna sectorization
antenna downtilting
Space Division Multiple Access (SDMA)
Physical barriers and site shielding
Transmit power control (TPC)</td><td>Duty cycle control
Dynamic real-time(1) frequency assignment
Carrier Sense Multiple Access (CSMA)</td><td>Signal coding and processing
Forward error correction (FEC)
Interference rejection
Spread spectrum:
– direct sequence
– frequency hopping
– pulsed FM
Interference power/bandwidth adjustments:
– co-channel
– dynamic transmitter level control
– power flux-density (pfd) limitation and spectral power flux-density (spfd) limitation (energy dispersal)
Modulation complexity
Antenna polarization
[Software-defined radio (SDR)]</td></tr>
</table>

(1) Dynamic real-time frequency assignment facilitates sharing by simultaneously using frequency and time domains. Therefore, this method is shown in both columns.

Within Table 5-4 some of the methods are new or innovative and may make more efficient use of the spectrum or provide flexibility. Many of these methods result from the introduction of new equipment technologies, computerization of analysis and new ideas. Some of the methods are complex, involving real-time computer controlled frequency management.

5.5.1.1 Frequency separation

Channelling plans

It is possible to arrange channels of operation on a homogeneous or inhomogeneous basis so as to interstitially configure one or more communications systems. This means of avoiding interference must be coordinated ahead of time so that the channels are appropriately separated to take advantage of the type of modulation

Band segmentation

The grouping of a number of channels, or the creation of a sub-band for non-channelized systems, for different users or uses of the spectrum is similar to the use of channel plans. In some situations this will be desirable because it has the advantage of minimizing or avoiding the need for coordination, while enabling multiple uses of a band.

Frequency agile systems

Frequency agile systems select frequencies of operation anywhere within a specified band on a real-time basis, using the techniques of listening before transmitting. These are systems that do not rely on a mutual coordination process or on another systems operator's decision. Frequency agile systems seek out unused spectrum for a communication. These types of systems may not be suitable for public telecommunications or for transfer of critical data because of a higher possibility for interference.

Dynamic sharing

Using advanced computer techniques, spectrum managers have greater opportunities to share frequencies, and thus greater opportunities to reduce inefficiencies created by rigid service boundaries. Dynamic sharing of frequencies between different systems in the same similar services allows more than one system to use the same frequencies but at different times, in the same geographic region.

FDMA

The FDMA technique consists of assigning to each user a fraction of the bandwidth and confining its access to the allocated sub-band. Orthogonality is achieved in the frequency domain.

Control of emission spectrum characteristics

The control of emission spectrum characteristics increases the amount of spectrum available to radiocommunications by limiting the amount of spectrum wasted to unwanted emissions (both spurious and out-of-band emissions).

Dynamic variable partitioning

Another sharing method which results in a flexible use of the spectrum is dynamic variable partitioning, which is real-time sharing of a block of spectrum among two services for which one service has priority over the other.

Frequency tolerance limitation

Frequency tolerance is defined as the maximum permissible departure by the centre frequency of the frequency band occupied by an emission from the assigned frequency or by the characteristic frequency of an emission from the reference frequency. The limitation of frequency tolerance cuts down the wasting of spectrum by controlling the wandering in frequency of the transmission signal increasing the number of systems that can operate within a portion of the spectrum.

Demand assignment multiple access (DAMA)

The main disadvantage for pre-fixed assignment of channels is that it is hard to match the traffic random variation. For the thin route case with little traffic for every station, where the network or system has a great number of stations, using DAMA technology is most suitable for increasing spectrum efficiency; DAMA

SCPC (single channel per carrier) system and SPADE (Single channel per carrier PCM multiple access demand assignment equipment) system are the typical examples of this type of application.

Frequency diversity

When radio propagation fading varies with frequency and the fading at different frequency location has a different level with small or negligible correlation, using the frequency diversity would obtain quite obvious diversity gain combined with the channel hitless (error-free) switching. The frequency diversity gain depends on the fading dispersion characteristics and the correlation factor between the frequency locations for diversity, as well as the performance of hitless (error-free) switching.

5.5.1.2 Spatial separation

Geographical shared allocations

Users in different geographical areas can reuse the same frequency if separated by sufficiently large distances. Geographical or area sharing of frequencies is a technique that speaks for itself and has long been considered of practical application.

Site separation

Site selection primarily involves the determination of an operating location that provides adequate distance separation from other operating stations at the same frequency.

Antenna system characteristics

Different possibilities exist for employing antenna system characteristics to facilitate frequency sharing or to minimize interference. The most obvious way is to use directional antennas to the extent that technology allows.

Space division multiple access (SDMA)

Techniques have been developed to allow transmission discrimination based on spatial orientation according to a controlled variation of antenna patterns. This technique has particular importance to new applications of satellite, wireless local loop and cellular mobile radio.

Physical barriers and site shielding

Shielding can limit the direction that a transmitter can radiate and therefore interfere with other systems and a receiver can receive interference. Such limitations allow greater sharing by fitting systems together geographically that might otherwise interfere with each other. Site shielding can be accomplished naturally through vegetation, terrain or buildings.

5.5.1.3 Time separation

Frequency sharing

Users can share spectrum in time, as when taxicabs alternately use the same frequencies or citizen band (CB) radio operators share frequencies.

Duty cycle control

Duty cycle is the product of the pulse duration and the pulse repetition rate. It is also the ratio of the average power output to the peak power output.

Dynamic real-time frequency assignment

Another sharing method which results in a flexible use of the spectrum is dynamic variable partitioning which is real-time sharing of a block of spectrum among two services for which one service has priority over the other. In dynamic variable partitioning there is a partition that divides the channels contained in a block of spectrum into two portions.

TDMA

The TDMA technique consists of assigning fixed predetermined channel time slots to each user; the user has access to the entire bandwidth, but only during its allocated slots.

5.5.1.4 Signal separation

Signal coding and processing

Several techniques generally classed under signal coding (or coded modulation) and processing are available. The coding may occur as part of the modulation process (channel coding, as with CDMA) and it may also occur in the original signal prior to transmission (source coding, as when data strings are compressed).

FEC

One method is the use of FEC on digital links to reduce the required $C/(N+I)$ ratio. The FEC design allows for decreased power margins at the expense of either throughput or bandwidth. In this case, source coding techniques are used to detect errors and control the transmitter to require retransmission of erroneous data blocks.

Interference rejection

An advanced interference mitigation technique is non-linear interference rejection using powerful signal processing algorithms that exploit the spectral correlation properties of both the desired signal and the interference signal.

CDMA

Spread spectrum modulation or CDMA offers significant advantages for uniformly sharing in either the same system or in several systems.

The CDMA technique allows overlap in transmission both in frequency and time. It achieves signal separation by the use of different signalling codes in conjunction with matched filters (or equivalently, correlation detection) at the intended receivers. Each user is assigned a particular code sequence, which is modulated on the carrier with the digital data modulated on top of that. Two common forms exist: the frequency-hopped and the phase-coded. In the former, the frequency is periodically changing according to some known pattern; in the latter, the carrier is phase modulated by the digital data sequence and the code sequence. Multiple orthogonal codes are obtained at the expense of increased bandwidth requirements (in order to spread the waveforms).

Spread spectrum

Transmitters using spread spectrum techniques spread the signal over a bandwidth many times larger than the original signal bandwidth, using a predetermined repeating code. The receiver uses the same code to put the signal back into its original form.

A benefit of spread spectrum is interference suppression. Commercial applications include personal communications, cellular telephones, wireless alarm systems, local area networks and paging systems.

While overlaying spread spectrum systems on frequency bands could improve spectrum efficiency (as with unlicensed low-power devices), the possibility of interference increases with an increasing number of spread spectrum systems. The proliferation of direct sequence systems may substantially raise the noise floor, degrading the operation of all narrow-band systems. If the number of frequency hopping systems increases dramatically, the occurrences of interference, though brief, may become as frequent as to degrade operation.

Interference power/bandwidth adjustments

If it can be assumed that noise and interference affect receiver performance equally, as is the case in some systems, the technique of power or bandwidth adjustment may be used to exploit the non-linear nature of acceptable carrier-to-interference (C/I) ratio, as a function of carrier-to-noise (C/N) for a constant $C/(N+I)$. The technique that is applied consist of increasing the transmitter power in the system being interfered with.

By increasing the transmitter power of a noise limited system by a small amount, e.g. 3 dB, the amount of interference that can be tolerated at the receiver is increased by a much larger amount, e.g. 10 dB.

Modulation complexity

The use of quadrature amplitude modulation (*M*-QAM) with higher numbers of states and advanced signal design provide the possibility of increasing the bit rate within a fixed channel bandwidth or decreasing the channel bandwidth for a fixed bit rate, as well also improving the power/spectrum utilization performance. Increasing the modulation complexity usually requires increased reliance on the use of error correcting codes and may require more complex dynamic channel processing to meet transmission performance objectives.

Coded modulation

FEC technology can improve power utilization. However it will reduce the spectrum efficiency due to inserting the redundancy in the time domain. An important technology to improve the power utilization while not reducing the spectrum efficiency is coded modulation, which combines the modulation with coding technology by mapping of redundancy into modulation signal parameters.

Adaptive signal processing

Advanced adaptive signal processing technology is a key to realize the benefits of new generation high speed wireless digital transmission. By using:

– the adaptive equalization in frequency and/or time domain;
– the adaptive transmitter power control;
– antenna diversities including vertical space diversity and/or horizontal space diversity with various adaptive diversity combiners;
– frequency diversity including using hitless (error-free) switching against the real time propagation delay variation;
– interference/echo cancellation or suppression and multi-user detection against the real-time interference;
– (orthogonal) multiple carrier parallel transmission (or OFDM) against the strong dispersion distortion for wideband signals;
– pre-distortion or non-linear equalization technologies against non-linear distortion, etc.

It will provide strong measures against the real-time transmission environment variation, such as the variation of received signal level and signal dispersion.

Antenna polarization

As mentioned previously, the antenna polarization performance, such as the orthogonal polarization performance is practically very important for enhancing the frequency reusing ability of terrestrial digital radio communications, satellite communications, narrowband/broadband wireless local loop, as well as mobile communications. A more detailed description of the methods given in Table 5-4 can be found in Recommendation ITU-R SM.1132.

In section 5.5.2, a number of sharing methods are discussed with examples.

5.5.2 Sharing between land mobile and broadcasting services

Spatial separation sharing between the land mobile service and the analogue broadcasting service in the VHF and UHF band is described in Recommendations ITU-R SM.851, M.1767 and F.1670. To allow satisfactory operation of the two services, maximum interference field strengths at the receivers are specified.

For the protection of analogue television and sound broadcast services from land mobile service using angle modulation, the median field strength for which protection against interference is provided in the case of television broadcast should be as given in Recommendation ITU-R BT.417. These values are the maximums quoted from worldwide values of median protected field strength values.

TABLE 5-5

Field strength for which protection is provided for broadcasting

Frequency band (MHz)	Field strength (μV/m)	
44-108	48	
66-108	54	for stereo FM service
137-254	56	
470-582	65	
582-960	70	

These values apply to an antenna height of 10 m above ground. Further study is required to determine the corresponding values of field strength for certain city areas where building heights are significantly higher than 10 m and for relay transmitters where higher field strengths may be appropriate. The interference potential of a base station in the land mobile service is calculated from the nuisance field:

$$F_i = E\,(50,T) + A + B.\,E\,(50,T) \tag{5}$$

is the field strength of the interfering transmitter exceeded at 50% of the locations for *T*% (between 1 to 10) of the time with an antenna height of 10 m and is determined from former Recommendation ITU-R P.370 (see Recommendation ITU-R P.1546). *A* (dB) is the required protection ratio for television broadcasting and is described in more detail in section 3.2.3 of this Handbook. *B* is the antenna discrimination (dB). For mixed polarization, $B = 0$; for horizontally polarized TV broadcasting, $B = -15$, except in some countries in Region 2 where $B = -9$; for sound broadcasting *B* should be calculated from Recommendation ITU-R BS.599. The effect of multiple interference from base stations is calculated by means of a power sum.

For the protection of land mobile service using angle modulation in shared frequency bands with respect to interference from broadcast services the desired median field strengths using 25 or 30 kHz channel spacing at the land mobile receiver are as follows:

TABLE 5-6

Field strength for protection of land mobile service

Frequency band (MHz)	Field strength (μV/m)	
	Annoying interference (Grade 3)	Noticeable interference (Grade 4)
44-68	16	19
68-87.5	15	20
87.5-108	14	20
137-254	14	21
470-582	20	24
582-960	30	38

As the grade decreases additional effort is required to understand the speech, hence a grade 5 interfering effect is almost nil, grade 4 produces "noticeable" interference, and grade 3 produces "annoying" interference. For 12.5 and 15 kHz channel spacing the above values should be 3 dB higher. Further study is required for channel spacing greater than 30 kHz.

The received power at the mobile receiver is calculated using the formula:

$$P_r \text{ (dBm)} = E - 20 \log F - L_c + G_r - 77.2 \quad (6)$$

where:

E: electric field strength (dB(μV/m))

F: frequency (MHz)

L_c: cable loss between the antenna and receiver (dB)

G_r: receiver antenna gain (dBi).

The field strength of the interfering transmitter exceeded at 50% of the locations for 10% of the time can be determined from former Recommendation ITU-R P.370 (see Recommendation ITU-R P.1546). The antenna discrimination against horizontally polarized TV broadcast emissions is 18 dB for base stations and 8 dB for land mobile stations. No antenna discrimination is assumed for vertical or mixed polarization emissions.

In the case of sharing between a grade 3 land mobile service and the sound broadcast service for different frequency separations between the carriers of the two services, the protection ratios for the land mobile service using 12.5 kHz channel spacing are:

TABLE 5-7

Protection ratios for the land mobile service

Frequency separation (kHz)	Protection ratio (dB)
0	8
25	6
50	–5.5
75	–17.5
100	–27.5

The protection ratios of DVB systems required in the presence of LTE BS and UE in the VHF/UHF band are described in Recommendation ITU-R BT.2033.

Further study is required for other service grades and channels spacing.

5.5.3 Sharing between fixed services and broadcasting services

The procedures used to determine the sharing criteria between the broadcasting service (sound and television) and the fixed service when they operate simultaneously in the same or in adjacent VHF or UHF bands are covered by Recommendation ITU-R SM.851 (for analogue systems).

5.5.4 Sharing with radar systems

Radar systems perform many functions including radiolocation, radionavigation, altimetry, meteorology, radar astronomy, and earth sensing. The wide diversity of functions provided by radar, in general, make it one of the larger user groups of the radio-frequency spectrum.

The diversity of radar characteristics, in terms of frequency, power, antenna properties and waveforms define an extremely complex electromagnetic environment. Most radar systems operate in the scanning mode and cover a 3-dimensional interference volume. Coupled with the fact that radar systems are operated from fixed and mobile land sites, aboard ship and aircraft and from space vehicles, the potential for interference between radar systems and other radiocommunication system services is inescapable. A common factor is that the sky and ground components of propagation are insignificant in the 200 MHz to 40 GHz band. However, atmospheric interference becomes important, particularly precipitation, for frequencies from about 5 GHz to 40 GHz.

Radar services are shared, usually, only with services operating on a secondary or non-protected basis. Care must be taken when considering sharing with non-radar systems. This is primarily due to the high power of radar systems and the potential for inter-system interference. There are, however, many examples of successful sharing between radars and other services.

One example of successful sharing between radar systems and other services is in the 5 GHz frequency bands. National regulations in many countries allow radio local area networks (RLANs) to operate successfully in the 5 GHz frequency range which is allocated to Radiolocation on a primary basis and used by various radar applications. The development of dynamic frequency selection (DFS), which allows RLANs to avoid frequencies used by radars, facilitates the possibility of sharing.

5.5.5 Sharing with the radio astronomy service

Radio astronomers detect signals that are 10^6-10^{12} times weaker than transmissions by the active services. For this reason, it is generally impossible for radio astronomy to share successfully with any active service with transmitters within the line-of-sight of a radio astronomy antenna. Because of this, radio astronomy sites are chosen specifically to minimize interference from Earth based transmitters. The sites are usually at a considerable distance from the major fixed sources of terrestrial interference and may be screened by nearby high ground. In some cases, administrations have also adopted radio quiet zones around radio observatories to shield them from terrestrial transmissions.

In some bands listed under RR No. **5.340**, all emissions are prohibited, and therefore, these bands are shared only among the passive (non-transmitting) services. Successful sharing in primary radio astronomy bands must be accomplished by geographical separation, time separation, or both. In shared primary bands, a data loss of 2% from any one service or 5% from all services is tolerable for the radio astronomy service as given in Recommendation ITU-R RA.1513. Even though geographical separation requires large radii with no transmitters, there are relatively few radio telescopes operating in any given band worldwide and therefore sharing is still possible.

Sharing with airborne and particularly satellite borne transmitters is not possible for radio astronomy stations, except under some time sharing arrangements.

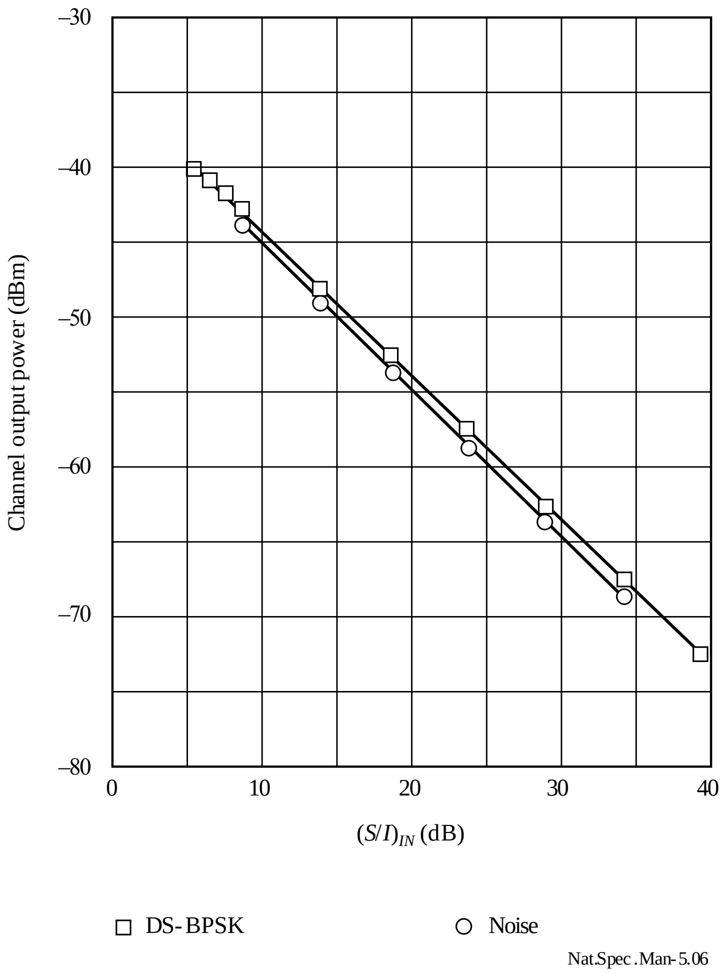
5.5.6 Sharing using spread spectrum techniques

A spread spectrum system can be defined as one in which the average energy of the transmitted signal is spread over a bandwidth which is much wider than the information bandwidth. These systems usually trade the wider transmission bandwidth for a lower average power spectral density and increased rejection to interfering signals operating in the same frequency band. They therefore have the potential of sharing the spectrum with conventional narrow-band systems because of the potentially low power that is transmitted in the narrow-band receiver passband. In addition the spread spectrum systems are capable of rejecting the narrow-band interference. It should however be noted that sharing of spread spectrum systems with other existing systems in the same band will raise the noise floor of the channel and can affect the performance of the narrow-band systems.

Recommendation ITU-R SM.1055 contains further information on the use of spread spectrum techniques, including examples of band sharing through the application of such techniques and procedures for analysing interference to conventional receivers. Example 1 from Recommendation ITU-R SM.1055, which is based on measured data and computer simulation results, shows that the performance of AM voice, FM voice, or FDM/FM voice signals will be the same operating in the presence of a DS signal or white Gaussian noise. Figure 5.6 shows the results of measurements in an upper channel of a simulated 600-channel FDM/FM system and noise and in the presence of a DS binary PSK interference. The small difference in the curves is due to the power spectrum density of the DS signal being slightly greater than that of the noise. The performance of AM, FM and FDM/FM voice signals operating in the presence of FH signals or a pulsed signal are the same and these results can be applied to the hybrid FH/DS signal case as well. For subjective intelligibility tests, the pulse repetition frequency and the pulse width of the pulsed signal are varied. These results are comparable with those in the case of random FH signal. A summary of trends indicated by measured data and computer simulations for the AM case is given in [Hatch *et al*., 1971].

FIGURE 5.6

Measured channel output power versus *S*/*I*
FDM/FM with DS/BPSK and noise



Based on the findings, the signal to interference protection ratios are determined and then used to compute the minimum required propagation losses, shown in Table 5-7, for each system to operate in a shared environment. Note these results should not be used to compare AM voice, FM voice, and FDM/FDM voice with each other due to the different wanted signal levels used in the three cases. From Table 5-7, the potential for sharing exists between co-channel SS systems, i.e. DS/PSK 10 Mbits/s and AM voice systems as the propagation loss requirement of 127 dB is lower than the propagation loss requirement of 144 dB between co-channel AM voice systems.

TABLE 5-8

Minimum required propagation losses (dB)

Emission bandwidth[(1)] (kHz)	Interference		Wanted signal					
			A3E		F3E		F8E	
		AI	0.7	0.9	0.7	0.9	0.7	0.9
1.4[(2)]	A3E (AM)		144	150				
1.5[(2)]	F3E (FM)				163	177		
400[(2)]	F8E (FDM/FM)						143.6	148.6
9 000	DS/PSK 10 Mbit/s		127	134	137	144	141.6	147.6
6 000	DS/MSK 10 Mbit/s		129.1	136.1	139.1	146.1	141.6	147.6
36 000	DS/PSK 40 Mbit/s		121	128	131	138	139	145
24 000	DS/MSK 40 Mbit/s		123.1	130.1	133.1	140.1	141.2	147.2
180 000	FH/DS/PSK (40, 100, 250, 5, 4.5)		111.7	123.7	134.7	145.7	131.7	137.7
120 000	FH/DS/MSK (40, 100, 250, 5, 3)		113.7	125.7	136.7	147.7	133.7	139.7
90 000	FH/DS/PSK (40, 100, 250, 2.5, 2.25)		114.7	126.7	137.7	148.7	134.7	140.7
60 000	FH/DS/MSK (40, 100, 250, 2.5, 1.5)		116.7	128.7	139.7	150.7	136.7	142.7

(1) 3 dB emission bandwidth (the emission bandwidth to be used in determining the bandwidth over which a transmitter and receiver are co-channel).

(2) This value is with respect to the peak sideband power spectral density.

Some of the tests on the effects of co-channel and adjacent channel interference on five standard North American television receivers in the 50-88 MHz bands using NTSC modulation illustrate a potential for sharing between FH SS systems and the television broadcast service. Further investigation is required to determine the relationships between the required S/I ratios and the number of FH transmissions.

In another example, band sharing of air navigation/distance measuring equipment (AN/DME) and a SS TDMA system exploits a number of factors in addition to low spectral density. The TDMA system transmitted energy is spread over the entire AN/DME band of 960 to 1 215 MHz compared to the AN/DME receiver bandwidth of 300 kHz. Minor modifications to both systems after the feasibility of sharing was demonstrated led to a higher spectrum utilization efficiency.

5.5.7 Summary of ITU-R Recommendations on sharing between services

TABLE 5-9

ITU-R Recommendations which address sharing between services

	Interferer:									
Victim:	**Broad-casting**	**Fixed**	**Mobile**	**EESS/ SR/SO**	**MSS**	**FSS**	**Radio-navigation**	**Radio-location**	**Met-sat/Met-aids**	**Inter-satellite**
Broadcasting		SM.851	SM.851							
Fixed	SM.851		F.1402	SA.1258 SA.1277 F.1502	M.1469 M.1472 M.1473 M.1474	SF.1006 SF.1486				
Mobile	SM.851	F.1402		SA.1154 SA.1277						
EESS/SR/SO		F.761 F.1247 SA.1277	SA.1154 SA.1277			S.1069 SA.1277 RS.1449			SA.1277	
MSS				SA.1277					RS.1264	
FSS		SF.1006 SF.1486	S.1426 S.1427 M.1454	SA.1277			S.1068 S.1151 S.1340			
Radio-navigation					S.1341	S.1151				
Radiolocation										
Met-sat/Met-aids					SA.1158 RS.1264					
Inter-satellite										
RNSS				RS.1347	M.1470					
Radio-astronomy(1)										
Aeronautical	SM.1009									

(1) Recommendation ITU-R RA.1031 addresses the protection of the radioastronomy service in frequency bands shared with other services.

5.6 Protection ratios

Article **1** of the RR, No. **1.170** defines *protection ratio* as: “The minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels at the receiver input, determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output.” The specified quality is expressed in terms of a given performance such as bit error rate, the degree of impairment of the picture quality or the intelligibility of speech depending on the type of emission.

Table 5-10 gives some protection ratios including the specified conditions for various performance levels. This Table also considers the co-channel (when the carriers of the transmitters have the same frequency) and off-channel (when the carriers of the wanted and unwanted transmitters have a frequency difference of Δf) cases as introduced in the section on adjacent channel interference analysis.

Recommendations ITU-R BS.559 and ITU-R BS.560 provide additional information on protection ratios for the sound broadcasting service.

Protection ratios can be determined for a class of emission and all other classes of emissions of the interfering signal including noise interference. The determination of protection ratio is based on calculations and measurement and is dependent on the specified quality of reception desired for the service being protected. It can also be seen from Table 5-10 that the protection ratios between some services still need to be determined.

The complications between terrestrial communications and FM broadcasting services operating in adjacent bands is examined in Recommendation ITU-R SM.1009. The ICAO Annex 10, Chicago convention provides specifications and characteristics relevant to the protection of aeronautical services such as Instrument landing systems (ILS) and VHF omnidirectional radio range (VOR) and navigation and communications equipment.

TABLE 5-10

Protection ratios (dB)

Interference → / Wanted signal ↓		Emission class	500HA1B			6K00A2B			6K00A3E			3K00A3E			5M00C3F			7M00C3F-8M00C3F			1K10F1B			16K0F3E			726KF8E			1M32P0N			Noise		
		Parameters	**100 Bd PW = 10 ms**			m_F = 1			m_F = 0.3						**525 lines**			**625 lines**			**50 Bd PW = 10 ms**						**24 channels**			**PW = 5 μs PRF = 300 pps**			**White Gaussian noise**		
Emission class	**Parameters**	Performance level[(1)]	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note	CO	OFF	Note
500HA1B	BW_{IF}= 500 Hz, 50 Bd $(S/N)_i$= 18 dB	P_E= 10^{-2}	11		3				6		4	14		4							12		3	8		4									
		P_E= 10^{-4}	12		3				7		4										13		3	11		4									
		P_E= 10^{-6}	13		3				8		4										14		3	13		4									
6K00A2B	BW_{IF}= 8 kHz m_s= 1.0 $(S/N)_i$= 18 dB	P_E= 10^{-2}	4		1				5		1													4		1							6	–	1
		P_E= 10^{-4}	4		1				5		1													4		1							9	–	1
		P_E= 10^{-6}	4		1				5		1													4		1								–	1
6K00A3E[(2)]	BW_{IF}= 8 kHz Δ f= 0.5 kHz m_s= 0.3 $(S/N)_i$= 45 dB	MINIT	44	61	1				43	48	1	50	50	1							47	55	1	48		1				20	10	1			
		0.7 AI	4	8	1				7	8	1	17	14	1							3	8	1	19		1				–17	–22	1	21	–	1
		0.3 AI	–7	–2	1				2	3	1	6	3	1							–2	4	1	8		1				–30	–37	1	10	–	1
		GCQ	39	35	2				32	42	2	44	43	2							37	41	2	40		2				–3	–2	2	41	–	2
		MCQ	21	20	2				14	24	2	26	25	2							19	23	2	22		2				–15	–20	2	23	–	2
		JUQ	12	11	2				5	15	2	17	16	2							10	15	2	13		2				–24	–28	2	14	–	2
3K00J3E or 3K00R3E	BW_{IF}= 2.7 kHz Δ f= 0.5 kHz $(S/N)_i$= 35 dB	MINIT	25	42	1				20	20	1	42	41	1							30	40	1	35		1	38		1	1		1		–	–
		0.7 AI	–14	–8	1				–14	–5	1	3	4	1							–25	–12	1	3		1	0		1	–38		1	9	–	1
		0.3 AI	–28	–24	1				–28	–19	1	–12	–16	1							–43	–37	1	–10		1	–12		1	–52		1	–3	–	1
		GCQ	10	27	2				13	30	2	31	32	2							21	30	2	27		2	26		2	–15		2	32	–	2
		MCQ	–8	9	2				–5	12	2	13	14	2							3	12	2	9		2	8		2	–33		2	14	–	2
		JUQ	–17	0	2				–14	3	2	4	5	2							–6	3	2	0		2	–1		2	–42		2	5	–	2
5M00C3F	BW_{IF}= 6 MHz, 525 lines $(S/N)_i$= 46 dB	TASO 2.5				50	15	5	50	15	5				47	25	5							50	15	5									
7M00C3F-8M00C3F	BW_{IF}= 6 MHz, 625 lines $(S/N)_i$= 46 dB	ITU-R 4							58	–	6							52	–	6															
		ITU-R 3							51	–	6							45	–	6															
1K10F1B	BW_{IF}= 1 050 Hz D_{PK} = ± 425 Hz 50 Bd $(S/N)_i$= 18 dB	P_E= 10^{-2}	0		1 & 3				2		1	10		4							6		3	0.5		1				–50		1	9	–	1
		P_E= 10^{-4}	0		1 & 3				3		1	13		4							7		3	1		1				–49		1	13	–	1
		P_E= 10^{-6}	1		1 & 3				3		1	15		4							8		3	2		1				–48		1	15	–	1
16K0F3E[(2)]	BW_{IF}= 16 kHz D_{PK}= 5 kHz Δ f= 0.5 kHz De-emphasis $(S/N)_i$= 22 dB	MINIT	38	38	1																33	33	1	31	31	1	32	32	1	–11		1	–1	–	–
		0.7 AI	0	0	1																2	2	1	2	2	1	4	4	1	–24		1	1		1
		0.3 AI	0	0	1																0	0	1	–5	–5	1	0	0	1				0	–	1
		GCQ	13	13	2																15	15	2	14	14	2	16	16	2				11	–	2
		MCQ	2	2	2																3	3	2	1	1	2	4	4	2				5	–	2
		JUQ	–1	–1	2																1	1	2	0	0	2	1	1	2				2	–	2
726KFBE[(3)]	24 channels Upper channel Δ f= 44.5 kHz $(S/N)_i$= 45 dB	MINIT	47	60	1				55	64	1										55	60	1	55	60	1	46	57	1	25	20	1	–	–	–
		0.7 AI	3	12	1				4	14	1										6	14	1	12	18	1	2	5	1		–34	1	9	–	1
		0.3 AI	0	–15	1				0	4	1										2	6	1	2	6	1	1	–3	1		–39	1	1	–	1
		GCQ	24		2				25		2										29		2				29		2				31		2
		MCQ	6		2				7		2										11		2				9		2				13	–	2
		JUQ	2		2				2		2										5		2				4		2				4	–	2

Notes to Table 5-10:

(1) P_E: probability of error

MINIT: minimum interference threshold

AI: articulation index

GCQ: good commercial quality

MCQ: marginal commercial quality

JUQ: just useable quality

TASO: Television Allocation Study Organization scoring grades

ITU-R Study Group 6: impairement scale of 1-5

CO: co-channel where frequency separation is zero

OFF: off channel separation given by Δf

Δf: frequency separation between wanted and interference signals.

(2) For broadcasting, see other protection ratio references. Numbers in this Table for A3E and J3E versus noise are 2 dB higher than values in Recommendation ITU-R F.339*, due to different modulation specifications.

(3) Single link only, for multi-link terrestrial microwave radio relay, see ITU-R F Series Recommendations.

NOTE 1 – OT/ECAC [August, 1975] Communications/Electronics Receiver Performance Degradation Handbook. The Frequency Management Support Division, Office of Telecommunications (OT), United States Departement of Commerce (DOC) and the Electromagnetic Compatibility Analysis Center (ECAC), ESD-TR-75-013. (Available from US DOC National Technical Information Service (NTIS), Springfield, VA, USA, Order No. AD-A016400.)

NOTE 2 – Obtained from transfer curves used in the Handbook described in Note 1.

NOTE 3 – Extrapolated from Recommendation ITU-R F.240*.

NOTE 4 – MAYHER, R. [1972] Interference Performance Degradation to Digital Systems. Record of the 1972 IEEE International EMC Symposium.

NOTE 5 – Extrapolated from ex-CCIR Recommendation 418-3 (Geneva, 1982).

NOTE 6 – Evaluated in accordance with Recommendations ITU-R BT.500* and ITU-R BO.600*.

m_I : modulation index of interfering signal

PW: pulse width

PRF: pulse repetition frequency

BW: bandwidth

m_S: modulation index of desired signal.

* ex-CCIR Recommendations 240, 339, 500 and 600.

TABLE 5-11

Protection ratio references from other Radiocommunication Study Groups

	Recommendation[1]	Notes
	ITU-R F.240	Many PRs including fading
	ITU-R M.589	Radionavigation PR
	ITU-R M.441	Aero. mobile (R) (ICAO An.10)
	ITU-R BS.638	Sound RF/AF PRs
	ITU-R BS.560	Sound, LF, MF, HF PRs
	ITU-R BS.641	FM sound PRs
	ITU-R BS.412	FM sound/VHF PRs
	ITU-R BT.655	AM TV PRs

(1) Ensure that the latest version of the Recommendation is obtained.

5.7 Noise levels

External noise such as atmospheric noise, galactic noise, sky noise and man-made noise adversely affect the operation of a radiocommunications system. The minimum external noise to be expected at terrestrial receiver sites from natural and man-made noise sources (excluding unwanted signals) in the frequency range 0.1 Hz to 100 GHz is specified in Recommendation ITU-R P.372. The external noise figure, $F_a = 10 \log f_a$, is presented for different frequency bands in Figures 5.7 and 5.8, shown via a solid curve. The other noises of interest are shown as dashed curves. The overall operating noise factor, f is:

$$f = f_a + (l_c - 1)(t_c/t_0) + l_c(l_t - 1)\,(t_c/t_0) + l_c l_t (f_r - 1) \tag{7}$$

where:

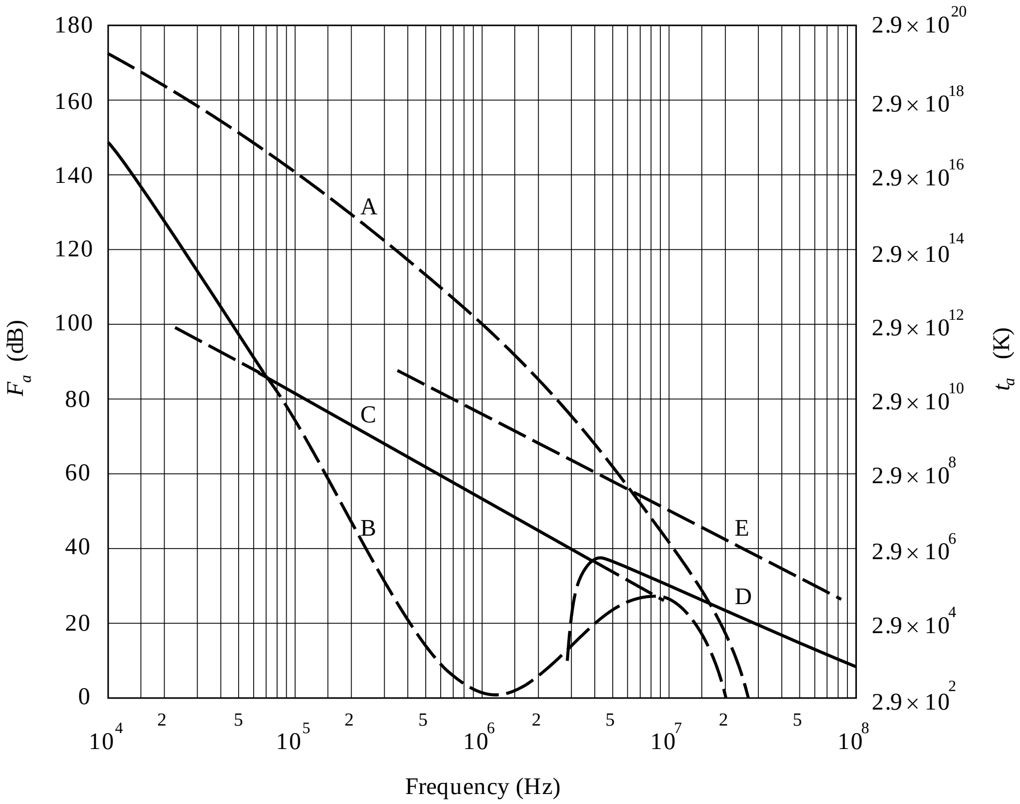
- f_a: external noise factor
- f_r: noise factor of the receiver
- l_c: antenna circuit loss
- l_t: transmission line loss
- t_0: reference temperature taken as 288 K
- t_c: actual temperature of the antenna and nearby ground
- t_t: transmission line temperature.

It should be noted that many of the external noises are impulsive in nature. Performance depends not only on the power of the interfering noise but also on the detailed statistical characteristics of the interfering noise.

This study indicates that electric power generation installations and distribution stations may be a source of severe interference to radiocommunications and that regular preventive maintenance is necessary to reduce noise interference to radiocommunications services.

FIGURE 5.7

***F_a* versus frequency (10^4 to 10^8 Hz)**

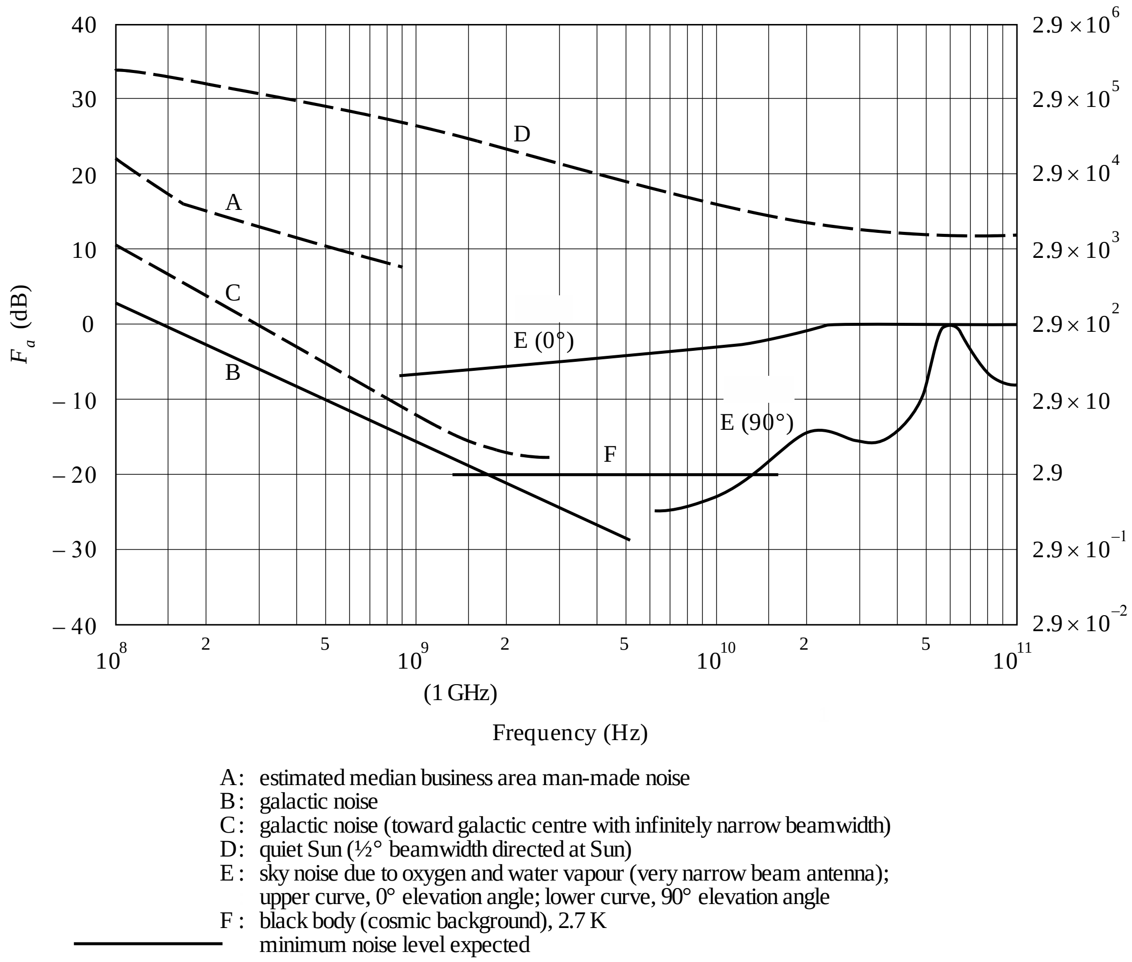


A: atmospheric noise, value exceeded 0.5% of time
B: atmospheric noise, value exceeded 99.5% of time
C: man-made noise, quiet receiving site
D: galactic noise
E: median business area man-made noise
—— minimum noise level expected

Nat.Spec.Man- 5.07

FIGURE 5.8

F_a versus frequency (10^8 to 10^{11} Hz)



Nat.Spec.Man-5.08

5.8 Radiation limits

5.8.1 CISPR limits

This section concerns the limits of radiation from equipment which generate or use radio-frequency energy for purposes excluding communications, such as computer systems and high power electric feeders. This includes ISM (i.e. industrial, scientific or medical) applications where radio-frequency energy is used to generate heat for the treatment of human tissue and for the processing of materials and the manufacture of products.

The frequencies currently employed for ISM and other non-communications applications cover a very wide spectrum. The internationally recognized standards-writing bodies are the CISPR, the International Electrotechnical Commission (IEC) Technical Committee 77 and its Subcommittees 77A and 77B. Various national standards bodies include the European CENELEC and the US FCC (Part 18, CFR Vol. 1).

The limits of the RF field strength are determined from measurements and statistically assessed to determine propagation characteristics and interference potential. The proposed CISPR limits are presented in Tables 5-10 and 5-11. The equipment is divided into two groups and each group is sub-divided into two classes.

Group 1 contains all ISM equipment in which there is intentionally generated and/or used conductively coupled radio-frequency energy which is necessary for the internal functioning of the equipment.

Group 2 contains all ISM equipment in which radio-frequency energy is intentionally generated and/or used in the form of electromagnetic radiation for the treatment of material, and spark erosion equipment.

Class B is equipment suitable for use in domestic establishments and for establishments directly connected to a low voltage power supply network which supplies buildings used for domestic purposes.

Class A is equipment suitable for use in all establishments other than domestic and those directly connected to a low voltage power supply which supplies buildings used for domestic purposes.

The determination of satisfactory radiation limits for ISM equipment is complicated by differences in national policies. For example, some policies relate to geography or population density; some administrations use strict rules, while others relax limits for manufacturers; some set limits for all users, while others apply standards only when interference is experienced. Some administrations will adopt the CISPR limits and others will continue to apply their own limits. The emission limits of Recommendation ITU-R SM.1056 have reference to the limits of the CISPR Publication 11 and the CISPR interference models introduced by Report ITU-R SM.2180 can be used for evaluating the compatibility between ISM equipment and radiocommuncation systems.

In some frequency bands, in spite of relatively high levels of radiation, the number of verified complaints of interference from ISM equipment is small in all countries, not only in absolute terms but also in comparison to the total number of ISM installations. The main sources of interference from ISM equipment are harmonics of ISM designated frequencies and ISM equipment which are operated outside of the designated ISM bands, such as those operating near the distress frequencies. However, further investigations are necessary as the interference source cannot be identified in some cases and some interference victims do not complain.

5.8.2 Health effects of exposure to electromagnetic fields

There has been a considerable amount of research, over several years, in the field of determining the influence of the exposure of the human body to electromagnetic fields. The immediate effects of short term exposure are known and appropriate limits are in place, for example to protect workers. Long-term effects are less well known and are the subject of on-going research. Recommendations ITU-T K.52 which is about guidance on complying with limits for human exposure to electromagnetic fields, and K.70 which is about mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations are closely related with human exposure to electromagnetic fields.

Safety standards: In order to ensure that human exposure to EMF should not have adverse health effects, and that man-made EMF generating devices are safe, various international guidelines and standards are adopted. Such standards are developed following reviews of all the scientific literature by groups of scientists who look for evidence of consistently reproduced effects with adverse health consequences. These groups then recommend guidelines for standards for action by the appropriate national and international bodies.

A non-governmental organization, formally recognized by WHO in the field of NIR protection, is the International Commission on Non-Ionizing Radiation Protection (ICNIRP). ICNIRP has established international guidelines on human exposure limits for all electromagnetic fields, including ultraviolet (UV) radiation, visible light and infrared radiation, as well as RF fields and microwaves.

Further information may be obtained from the World Health Organization (WHO) (see their website: www.who.int/).

5.9 Site engineering considerations

The growth of radio services has resulted in an increase in the number of radio sites required and the number of users sharing these facilities. Radio systems must be designed so that individual systems are efficient and operate with minimum interference to other systems. It may also be necessary to demonstrate the optimum use of a proposed installation to meet the constraints of the aesthetics of radio structures and the environmental concerns of the community it impacts. ETSI in its specific publications provides guidance for engineers who are concerned with the design, specification, installation, operation and maintenance of radio systems. It is particularly directed towards systems working in the VHF and UHF bands in the mobile service.

5.9.1 Co-site engineering

The close location of transmitters to each other causes various transmitter non-linearities to have significant impact by causing interference to the receiving equipment. Co-site interference problems range from minor annoyances to serious disruption of the system. There are three basic types of interference:

- radio frequency interference (RFI);
- electromagnetic interference (EMI);
- Intermodulation interference (Intermod).

RFI is the results of other RF devices, i.e. radio and television transmitters, etc., that generate radio frequency energy as part of their operations. EMI is caused by computers, digital equipment, electrical equipment, lighting systems, medical equipment (diathermy), etc. Intermodulation (or Intermod) is a type of interference that occurs as the result of internal oscillation in radio equipment as the result of an internal or external source. When several communications systems are co-located, the possibility of Intermodulation interference increases significantly.

The co-site problem can be addressed by improving:

- active site management;
- detailed database records of the co-site equipment and special interference parameters;
- co-site interference analysis capability.

The ability to successfully receive the desired radio signal at the fixed receiver is dependent upon providing the best possible radio frequency environment at the site.

To accomplish this, the level of undesirable energy occurring on the received frequency must be minimized. In most cases, minimizing the level of undesirable energy emitted by the local transmitters and filtering out undesirable signals coming into the receiver eliminates received interference in the receiver environment. Interference is more likely to be a problem at sites with multiple antennas. If measures have been taken and the receiver is still picking up noise, then interference sources in the surrounding environment must be identified and eliminated.

Common problem areas, and solutions, include:

- rust – All materials must be free of rust (to prevent a nonlinear mechanism from occurring);
- braided wire should not be used because it can corrode and cause intermodulation signals;
- metal to metal connections should be rigid;
- all loose metal should be removed from the site;
- chain link type fence material should be vinyl clad;
- connection of dissimilar metals should be done after review of a galvanic table for each metal. The connections must be rigid and tight;
- unjacketed transmission lines should be avoided;
- bare metallic cable ties should not be used;
- cracked Power line insulators (glass type) are a very likely source of broadband noise;
- ensure that all directional transmitting antennas are pointing at or away from receiving antennas to prevent possible burnout. Maintain a 20 m separation to avoid burnout;
- another item of consideration is antenna placement and spacing. Design criteria specifying a minimum spacing is often disregarded so that the tower or rooftop can be populated with additional antennas. Standards relating to tower and roof loading capabilities should be reviewed and followed where applicable;
- equipment standards must be applied to all installations of sites if interference problems are to be kept to a minimum.

Although interference free operations cannot be guaranteed, when all standards and good site management are followed, the chance for problems will be reduced and interference resolution time held to a minimum.

A co-site analysis model (COSAM), which is designed to evaluate the mutual interference on a single site where a large number of transmitters and receivers are installed. Report ITU-R M.2244 covers the horizontal, vertical, and slant space isolation calculations between two antennas in order to design the antenna configuration of co-located IMT BSs in the land mobile service.

5.9.2 Example of shared infrastructure: 3G Cellular networks

The 3G network infrastructure consists of four main parts:

- sites for installation of the radio equipment, including the passive equipment required (buildings, power supply, masts, etc.);
- radio antennas;
- access radio equipment, the base stations;
- the core network equipment.

Infrastructure sharing can be used in order to reduce the initial investments required by the 3G network operators, to perform the coverage of critical areas (tunnels, classified sites) and to enable coverage of rural or low density areas in a cost effective way. This solution allows evolution to separate networks to meet the increased needs of capacity and quality. Such arrangements are planned in Germany, Sweden and the United Kingdom. It is generally not the responsibility of regulatory agencies to specify this function in detail, but only to establish it in principle.

The analysis of the different possibilities about infrastructure sharing gives the following results:

- The solutions available (sharing levels) contribute to the objective of the initial reduction in investment, of the optimization of coverage as the 3G networks are deployed. They are technically available in the framework of international standards (IMT).
- These solutions allow evolution towards separated networks, in later phases of deployment, responding to the developing needs for traffic and services.
- They affect only the different elements of the infrastructure, the design and the operational management of the networks, without particular repercussions on the user terminals.
- In relation to the adapted sharing level; the sharing of the infrastructure elements requires coordination and also cooperation among the relevant operators. In addition to an adequate regulatory framework, the sharing necessitates efficient cooperation between the operators.
- Very detailed coordination is necessary between the operators concerned.
- All the sharing solutions have, with variable degrees, repercussions concerning the network implementation and their operational functions in particular:
  - synchronization of control and maintenance operations;
  - capacity to comply with the demands of each operator, the technical performance and the service quality, that is essential to develop in a sharing framework; and
  - allotment of available resources in a competition environment.
- We can assume that the deployment of IMT is on an individual basis with sharing of networks mixing in various degrees, according to covering zones.

The most efficient arrangement is that which allows, according the environment and circumstances, the desired economic effects, whilst preserving the frequency bands assigned to the operators of these services. Consequently, sharing policy should take account of the national situation with flexibility allowing adaptive solutions on a case by case basis. Infrastructure sharing is dependent on the regulatory situation.

REFERENCES

BEM, D. J. [November 1979] Propagation aspects in the planning of radiocommunicaiton services, *Telecomm. J.*, Vol. 46, **XI**, p. 680-688.

CHAN, G. K. [November 1991] Propagation and Coverage Prediction for Cellular Radio Systems, *IEEE Trans. Vehic. Techn.*, Vol. 40, **4**.

ETSI [1991] Radio site engineering for radio equipment and systems in the mobile service, Version 0.0.7, European Telecommunications Standards Institute, Valbonne Cedex, France.

HATCH, W., HINKLE, R. and MAYHER, R. [1971] Modelling of pulse interference in amplitude modulated receivers, IEEE International Electromagnetic Compatibility Symposium Record, Philadelphia, PA, United States of America.

PALMER, F. H. [1981] The Communication Research Center VHF/UHF Propagation Prediction Program: An Overview. *Can. Electron. Eng. J.*, Vol. 6, **4**.

BIBLIOGRAPHY

BERNOSKUNI, YU. V., BYKHOVSKY, M. A., PLEKHANOV, V. V. and TIMOFEEV, V. V. [1984] Effektivny method podavleniya impulsnykh pomwkh v troposfernykh sistemah svyazi (Effective method of suppressing pulse interference in trans-horizon communications systems). *Elektrosviaz*, 9, p. 11-14.

ITU-R Texts

ITU-R Handbook	Ionosphere and its effects on terrestrial and Earth-space radiowave propagation from VLF to SHF (1997)
ITU-R Handbook	Terrestrial land mobile radiowave propagation in the VHF/UHF bands (2002)
ITU-R Handbook	Radiowave propagation information for predictions for Earth-to-space path communications (1996)
Rec. 66 (Rev.WRC-2000)	Studies of the maximum permitted levels of unwanted emissions
Rec. ITU-R BS.412	Planning standards for terrestrial FM sound broadcasting at VHF
Rec. ITU-R BS.559	Objective measurement of radio-frequency protection ratios in LF, MF, and HF broadcasting
Rec. ITU-R BS.560	Radio-frequency protection ratios in LF, MF, and HF broadcasting
Rec. ITU-R BS.638	Terms and definitions used in frequency planning for sound broadcasting
Rec. ITU-R BS.641	Determination of radio-frequency protection ratios for frequency-modulated sound broadcasting
Rec. ITU-R BT.417	Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service
Rec. ITU-R BT.500	Methodology for the subjective assessment of the quality of television pictures
Rec. ITU-R BT.655	Radio-frequency protection ratios for AM vestigial sideband terrestrial television systems interfered with by unwanted analogue vision signals and their associated sound signals

Rec. ITU-R BT.656	Interfaces for digital component video signals in 525-line and 625-line television systems operating at the 4:2:2 level of Recommendation ITU-R BT.601 (Part A)
Rec. ITU-R BT.2033	Planning criteria, including protection ratios, for second generation of digital terrestrial television broadcasting systems in the VHF/UHF bands
Rec. ITU-R F.240	Signal-to-interference protection ratios for various classes of emission in the fixed service below about 30 MHz
Rec. ITU-R F.1670	Protection of fixed wireless system from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands
Rec. ITU-R M.441	Signal-to-interference ratios and minimum field strengths required in the aeronautical mobile (R) service above 30 MHz
Rec. ITU-R M.589	Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz
Rec. ITU-R M.1767	Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis
Rec. ITU-R P.368	Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz
Rec. ITU-R P.372	Radio noise
Rec. ITU-R P.452	Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.1 GHz
Rec. ITU-R P.453	The radio refraction index: its formula and refractivity data
Rec. ITU-R P.525	Calculation of free-space attenuation
Rec. ITU-R P.526	Propagation by diffraction
Rec. ITU-R P.530	Propagation data and prediction methods required for the design of terrestrial line-of-sight systems
Rec. ITU-R P.531	Ionospheric propagation data and prediction methods required for the design of satellite services and systems
Rec. ITU-R P.533	Method for the prediction of the performance of HF circuits
Rec. ITU-R P.534	Method for calculating sporadic-E field strength
Rec. ITU-R P.581	The concept of “worst month”
Rec. ITU-R P.618	Propagation data and prediction methods required for the design of Earth-space telecommunication systems
Rec. ITU-R P.679	Propagation data required for the design of broadcasting-satellite systems
Rec. ITU-R P.680	Propagation data required for the design of Earth-space maritime mobile telecommunication systems
Rec. ITU-R P.681	Propagation data required for the design of Earth-space land mobile telecommunication systems
Rec. ITU-R P.682	Propagation data required for the design of Earth-space aeronautical mobile telecommunication systems
Rec. ITU-R P.832	World Atlas of Ground Conductivities
Rec. ITU-R P.834	Effects of tropospheric refraction on radiowave propagation
Rec. ITU-R P.836	Water vapour: surface density and total columnar content

Rec. ITU-R P.837	Characteristics of precipitation for propagation modelling
Rec. ITU-R P.838	Specific attenuation model for rain for use in prediction methods
Rec. ITU-R P.841	Conversion of annual statistics to worst-month statistics
Rec. ITU-R P.1147	Prediction of sky-wave field strength at frequencies between about 150 and 1 700 kHz
Rec. ITU-R P.1239	ITU-R Reference ionospheric characteristics
Rec. ITU-R P.1240	ITU-R Methods of basic MUF, operational MUF and ray-path prediction
Rec. ITU-R P.1546	Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz
Rec. ITU-R P.1812	A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands
Rec. ITU-R RA.1031	Protection of the radioastronomy service in frequency bands shared with other services
Rec. ITU-R RA.611	Protection of the radio astronomy service from spurious emission
Rec. ITU-R SM.326	Determination and measurement of the power of amplitude-modulated radio transmitters
Rec. ITU-R SM.328	Spectra and bandwidth of emissions
Rec. ITU-R SM.329	Unwanted emissions in the spurious domain
Rec. ITU-R SM.331	Noise and sensitivity of receivers
Rec. ITU-R SM.332	Selectivity of receivers
Rec. ITU-R SM.337	Frequency and distance separations
Rec. ITU-R SM.851	Sharing between the broadcasting service and the fixed and/or mobile services in the VHF and UHF bands
Rec. ITU-R SM.852	Sensitivity of radio receivers for class of emissions F3E
Rec. ITU-R SM.853	Necessary bandwidth
Rec. ITU-R SM.1009	Compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-137 MHz
Rec. ITU-R SM.1045	Frequency tolerance of transmitters
Rec. ITU-R SM.1055	The use of spread spectrum techniques
Rec. ITU-R SM.1056	Limitation of radiation from industrial, scientific and medical (ISM) equipment
Rec. ITU-R SM.1132	General principles and methods for sharing between radiocommunication services or between radio stations
Rec. ITU-R SM.1134	Intermodulation interference calculations in the land-mobile service
Rec. ITU-R SM.1138	Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions
Rec. ITU-R SM.1140	Test procedures for measuring aeronautical receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-118 MHz
Rec. ITU-R SM.1235	Performance functions for digital modulation systems in an interference environment
Rec. ITU-R SM.1446	Definition and measurement of intermodulation products in transmitter using frequency, phase, or complex modulation techniques

Rec. ITU-R SM.1448	Determination of the coordination area around an earth station in the frequency bands between 100 MHz and 105 GHz
Rec. ITU-R SM.1535	The protection of safety services from unwanted emissions
Rec. ITU-R SM.1539	Variation of the boundary between the out-of-band and spurious domains required for the application of Recommendations ITU-R SM.1541 and ITU-R SM.329
Rec. ITU-R SM.1540	Unwanted emissions in the out-of-band domain falling into adjacent allocated bands
Rec. ITU-R SM.1541	Unwanted emissions in the out-of-band domain
Rec. ITU-R SM.1542	The protection of passive services from unwanted emissions
Rec. ITU-R SM.1633	Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands
Report ITU-R M.2244	Isolation between antennas of IMT base stations in the land mobile service
Report ITU-R SM.2021	Production and mitigation of intermodulation products in the transmitter
Report ITU-R SM.2022	The effect on digital communications systems of interference from other modulation schemes
Report ITU-R SM.2028	Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems
Report ITU-R SM.2153	Technical and operating parameters and spectrum requirements for short-range devices
Report ITU-R SM.2180	Impact of industrial, scientific and medical (ISM) equipment on radiocommunication services

ITU-T Texts

Rec. ITU-T K.52	Guidance on complying with limits for human exposure to electromagnetic fields
Rec. ITU-T K.70	Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations
Rec. ITU-T K.91	Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields

CHAPTER 6

Spectrum economics

Table of Contents

Page

6.1 Introduction

This Chapter addresses issues relating to the financing of a national spectrum management program. It gives some information on the use of tools, based on spectrum economics, to address issues that have arisen in a number of Administrations, mainly in the developed countries, due to the increase in demand for spectrum following the liberalization of telecommunications. The increase in demand is creating problems in frequency assignment that many administrations have found difficult to resolve using the traditional spectrum management tools and which, in turn, has generated an interest in the development and use of new spectrum management tools based on the use of spectrum economics. A number of the ideas that are discussed in Report ITU-R SM.2012 (Economic aspects of spectrum management) are presented below, to avoid taking the theory contained in that report out of context the following text concentrates on the various fee types and spectrum pricing mechanisms. For a detailed analysis of spectrum economics reference should be made to the Report.

A quick guide to the location of fee topics in the Chapter is shown in Table 6-2.

In addition, ITU-D Study Group 2 while addressing Question 21/2 "Calculation of frequency fees", (WTDC-02) finalized its work, which deals with the following:

- Analysis of the various methods, formulas and approaches currently applied by different countries for calculating frequency fees, accompanied by a comparative study clearly highlighting:
  - approaches and principles relating to the calculation of frequency charges;
  - the justifications and reasoning for each approach;
  - how each approach contributes to fostering spectrum management and the effectiveness thereof; and
  - advantages and drawbacks of each approach (socio-economic, technical and other considerations).
- Basic factors that may be taken into account when elaborating new formulas or reviewing existing ones.
- How to bring about consistency and complementarity between spectrum rearrangement processes and economic optimization of frequencies.

The results of this work are available at the ITU-D Study Group 2 website.

6.2 Traditional mechanisms of financing spectrum management

As indicated in other chapters of this Handbook, management of the radio spectrum involves performing many different activities and the extent to which any activity is performed will depend on the requirements of individual administrations. The extent to which spectrum management activities are performed will also depend on the level of resources available and this requires establishing funding mechanisms. While there are a number of different funding mechanisms, (see below), they must always be based on appropriate national law and for many administrations they are frequently based on:

- national budget financing;
- established fees;
- bidding approaches for spectrum.

At some stage in the development of a spectrum management organization most administrations have used one or a combination of these methods to fund all their spectrum management functions.

More examples of basic financing models are presented in ECC Report 53 on "Cost Allocation and Accounting systems used to finance the radio administration in CEPT countries". This report is to be downloaded from http://www.cept.org/ecc/ under deliverables/reports.

6.2.1 National budget financing

This is probably the first method of spectrum management financing to be used by all administrations. In this system a portion of the state's annual budget is allocated to finance spectrum management and no fees are charged to the licensees. The level of funding provided will depend on the priorities of the national government and its total tax resources. When introducing spectrum management in a country, financing it from state funding is probably the easiest method to use. However, as spectrum usage increases the demands on spectrum management also increase with consequent increases in the associated costs and eventually requiring the administration to recover some or all of the costs from licensees.

6.2.2 Spectrum licence and usage fees

Although the use of national budget financing is administratively simple it is fairer to charge radio users an application fee for the issue of a licence, otherwise all taxpayers pay for spectrum management even if they get no benefit from the use of radio[35]. Hence, in many administrations, the cost of providing adequate spectrum management has led to the introduction of charging a once-off fee for the issuing of a licence that assigns the right to use a frequency. The fee may be applied to some or all radio users. The two most common forms of spectrum usage fee for one-off and regular charges are:

– simple fee;

– fee based on cost recovery.

In practice a simple fee might be considered as a variant of a fee based on cost recovery as the administration is setting the price to be paid by the licensee, however a distinction needs to be made as its structure and operation are heavily influenced by national legislative and constitutional requirements. Many countries fund their spectrum management programmes in whole or in part through the use of fees and many also operate some form of cost recovery system.

Examples of the application of frequency fees in many countries, may be found at the ITU-D SG 2 website[36].

A disadvantage of administrative fees is that the fees charged in general do not reflect the value of the spectrum, and as a result can generate false incentives to the licensees with respect to the amount of spectrum they want to acquire or use.

6.2.2.1 Simple fee

In the case of a simple fee, the administration sets a price for a licence and this may be based on a flat rate for all licences, or may vary according to specific criteria. A flat rate fee set at the same level for all licences is easy to use and to operate but does not differentiate between users and so small users of spectrum may be charged the same fee as large users. This can be perceived by certain groups of users as 'arbitrary' and may endanger the trust in the system.

Varying the fee depending on specific criteria such as the quantity of spectrum occupied, or the frequency band used, or the geographic area covered, can provide a more equitable approach.

It is recommended that such fees be developed in an open and transparent process. This fulfils partially the definition of an administrative fee. Administrative fees are subject to a stringent legal framework (see explanation of the cost-coverage principle). If however the fees flow into the general budget of the State then they have to be considered as taxes. Which things (revenues, fortune) and activities are subject to taxes and the height of these taxes is in the entire sovereignty of the State.

6.2.2.2 Cost recovery

The purpose of a cost recovery system is to recover the spectrum management costs incurred by the administration, The charges for frequency usage, and hence the fees for a radio frequency licence, are set according to the costs incurred for issuing the licence and the associated frequency allotment or assignment process (for example: frequency assignment, site clearance, coordination) including any other necessary spectrum management functions (these are once off costs for issuing the licence). Besides these costs a yearly fee is often charged for costs relating to keeping the frequencies free of interference (enforcement costs), see also section 6.2.3.

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[35] On the other hand it can be stated that the economy as a whole benefits from the use of radio. Economic Impact Studies in the UK have shown that the use of radio (direct and indirect effects) generates approximately 2% of UK GDP.

[36] http://www.itu.int/ITU-D/study_groups/SGP_2002-2006/SF-Database/index.asp.

So, licence fees are usually structured on the principle of recovering the costs directly and indirectly attributable to a licence category (broadcasting, mobile, satellite, etc.).

From the point of view of licensees, cost recovery can be a fair system, in that it apportions the cost of managing the spectrum to those that are using it and the charging is transparent. However, cost recovery requires administrative resources to monitor and record the costs of spectrum management. To ensure maximum transparency of the licence fees, it might be useful to produce independently validated accounts i.e. audited by a national auditor, to ensure the costs, on which the licence fees are based, are appropriate and justifiable. Both of these points increases administrative overhead and may require substantial financial systems to be developed so that the costs can be matched to the fee.

It should also be noted that the exact definition and operation of cost recovery could vary according to national spectrum management, legislative and constitutional requirements. These differences may have an impact on the implementation of cost recovery in each country and affect how the costs and fees are justified. There are several reasons for these differences:

a) Cost recovery is interpreted in the way that the sum of the fees charged to beneficiaries of an administrative activity are equal to the sum of the costs arising due to the activity of that sector of the administration. Indeed, from the strictly legal point of view the principle of cost-coverage simply states that the sum of the fees charged to beneficiaries of an administrative activity does not exceed the sum of the costs arising from the activity of that sector of the administration. Accordingly, the executive or legislative authority decisions, as may be modified by the judicial authority, can also provide for only partial recovery of the costs – the difference being financed by the general budget of the State.

b) In some countries a distinction is made between the administration's total income matching or simply approximating to its costs. In the former case the administration is not permitted to subsidize or overcharge the licensee with any excess having to be repaid. In the latter case it is recognized that fees are based on an estimate of the expected costs and therefore the income may exceed or not reach the administrations actual costs. (NOTE – In those countries operating the latter system, strict audit control may still be applied.) Also too high fees can lead to an excess that can be used to reduce fees in subsequent years and vice-versa.

c) The fees set for cost recovery are based on the work performed, directly or indirectly, on an individual licence or the average for that licence category (e.g. the category 'broadcasting').

d) The complexity of the frequency assignment process and the number of spectrum management functions that need to be performed to issue a licence may vary due to:

   – national characteristics – for example the number of users or geographic features requiring the use of a detailed topographic database;

   – international coordination – for example, as a result of bilateral or multilateral treaties, related footnotes in the Radio Regulations or coordination requirements;

   – other related cost (radio studies, participation at radiocommunication conferences, etc.).

The above factors will affect the composition of the licence fee and the mechanisms that an administration may put in place to monitor their income and costs. Differences can also occur in the division between direct and indirect costs, despite general agreement on the definitions, due to different interpretations on the specific costs that should be allocated to each category. In general, the definitions of direct and indirect costs are defined as follows.

– *Direct Costs*

This covers the immediate and identifiable cost of issuing licences for specific applications. For example, they include: the cost of staff time in the frequency assignment process, site clearance, interference analysis when it can be directly associated with a particular class of service – keeping the public news and entertainment channels clear, ITU and Regional international coordination that is specific to a service. In some frequency bands and for some services, or if transmitters are near neighbouring countries, the direct costs will include the cost of relevant international coordination.

– *Indirect Costs*

This covers the cost of the spectrum management functions used to support the administration's frequency assignment process and the overhead of operating the administration's spectrum management procedures. They represent costs that cannot be identified as attributable to specific services or licensees such as general international cooperation, propagation research covering many frequency bands and services, general spectrum monitoring and interference investigations arising from the complaints of rightful users, and the cost of support staff and equipment, as well as for the preparation and participation at the radiocommunication conferences and the follow up actions accordingly.

However in some administrations the definition of direct costs is very restrictive and is limited to the costs incurred for the individual licence applicant and not to the costs of the licence category and some administrations may not charge indirect costs. In the latter case, these indirect costs must be covered by the general budget.

A disadvantage of a system based on cost recovery is that it inhibits charging users a fee based on their proportionate use of the spectrum and the level of spectrum congestion that exists (or 'value' of the spectrum), which can have the effect that large spectrum users benefit to the detriment of the small users. This makes it very difficult to use fees to promote efficient use of spectrum by encouraging users to move to more efficient technologies or to less congested frequency bands. In addition, costs based fees may not take account of the users' ability or willingness to pay, to the detriment of some users (e.g. users in remote rural areas who pay in a cost based regime relatively more than users in congested areas, as the workload to issue a licence is fairly the same). Costs incurred on issuing an individual licence are even more difficult to record.

6.2.3 Other charges

In addition to the costs arising from the issuing of a licence and enforcement of the frequencies involved, there are specific functions of an administration associated with spectrum management activities that must be paid for. Some examples are given below.

– *Type approval or type acceptance fee (not for R&TTE countries)*

This is a fee charged by the administrations for the type approval or type acceptance of terminal or radio equipment. The equipment, once it has been tested in an accredited test laboratory or the equipment specifications are accepted, receives a certificate from the administration or competent authority and thereafter the equipment can be placed on the market. In some regions the conformity assessment is based on manufacturers' self-declaration procedures. Hence the income from these fees may not be significant or non-existent.

– *Accreditation fee*

In some countries testing of terminal and radio equipment is performed by independent accredited test laboratories that form no part of the administration. Fees for testing must be paid directly to the accredited laboratories, and form no part of the income of administrations in that case.

– *Electro-Magnetic Compatibility (EMC) fees and charges*

Regulation of EMC has led to costs for the administrations in the area of market surveillance. Some administrations have therefore chosen to levy an EMC fee on the equipment covered by this type of regulation or to levy a fee on the manufacturers.

– *Inspection fees*

In some cases administrations inspect installations before or after the licence holder has taken the equipment into use. This can be done systematically or randomly. In some cases the fee for the inspection is covered by the normal licence fee, in some cases it is a separate fee.

– *Fees for dealing with interference complaints*

Administrations usually investigate interference complaints from licence holders or other members of the public. In order to inhibit false complaints, or to cover administrative costs, a fee can be charged, either for all cases or only when the complaint turns out to be unjustified.

– *Fees for operators certificates (radio amateurs, maritime examinations)*

In the cases of radio amateurs and maritime users, applicants have to pass an examination in order to receive a certificate before they are allowed to operate their equipment. Administrations may charge a fee for the examination and for the issue of the operator certificate.

6.2.4 Alternative methods of supporting spectrum management activities

Administrations may consider alternatives to the traditional centralized, government operated and funded national spectrum management systems. Though national spectrum management remains a primarily governmental activity, alternative approaches using resources outside the national spectrum manager to perform or fund certain spectrum management functions can enhance the efficiency and effectiveness of the national effort.

A number of administrations have made use of spectrum management resources within the country and outside the national spectrum management process including:

– communication groups with a direct interest in spectrum such as advisory committees, trade associations, professional organizations, and quasi-governmental associations;

– frequency coordinators (and coordination groups) and designated spectrum managers; and

– spectrum management consultants, and support contractors.

These alternatives can be used to support the national spectrum manager. Which approach is used may vary with frequency band, radio service, and/or specific radio application, the capability and resources available within the national spectrum management organization, and the expertise available from other resources. The national spectrum manager can determine the limits of responsibility and authority granted to these groups based on the function to be supported. Administrations may also find that a combination of approaches may be required to perform the overall spectrum management function.

The objectives of using other national entities to assist the national spectrum management process are:

– to save government financial or human resources; however, if spectrum management activities are dealt with by third parties, which are benefit-oriented outside the administration, the problem of financing the spectrum management activities remains as these third parties must be paid for the service they are providing;

– to increase the efficiency of spectrum use;

– to improve the efficiency of the frequency assignment and coordination processes;

– to supplement the expertise of the national spectrum manager.

6.3 Spectrum licencing approaches

Different spectrum licensing approaches are required to deal with the distinct needs of individual radio users and the time period that a frequency band may be open for licensing. If the number of applicants exceeds the available spectrum the “first come-first served” option may not be suitable and mechanisms such as tender procedures, comparative bidding, auctions and lotteries are necessary.

6.3.1 First come-first served

The spectrum assignment mechanism most frequently used by administrations is first come-first served. Spectrum is assigned in the order of receipt of applications and is based on the frequency being available, the appropriate spectrum management functions being completed and the applicant meeting the application criteria. This mechanism is appropriate when there is no shortage of spectrum and it has to be assigned to a potentially large number of users or over a long period of time. This mechanism is most commonly used with national budget financing or spectrum usage fees and is likely to remain the most effective for the foreseeable future, although it may be linked (with or without cost recovery) to methods for regulating demand (e.g. administrative pricing).

6.3.2 Beauty contests

This mechanism is used to determine which applicant should have access to a limited quantity of spectrum and, probably most frequently, for broadcasting or public mobile systems. It is based on the competing applicants submitting their proposals for operating the service; these would then be assessed by the administration. The proposals would typically include information on population coverage, quality of service, speed of implementation, and the operator's business plan. For broadcasting there would be information on programmes: number of hours of children's programmes; educational programming; news services, etc. The proposals are usually prepared in response to criteria established and published by the administration. There is no obligation on the part of the administration to assign spectrum to any of the applicants if no applicant complies with the criteria.

The review of the proposals can be time consuming and resource intensive and the decision making process may not be transparent. The review might be subjective and unless the reasons for the rejection of the losing applicants are clear and they conform to the administrations published criteria, the losing applicants may apply for a judicial review. Any legal challenge can have a significant impact on the administrations timescales for starting the service and may require the administration to repeat the whole tendering process.

Operating a tender procedure can be expensive and time consuming, even without the threat of a legal challenge. This mechanism is only usable when there are a small number of applicants for a limited number of licences. In addition while the tender procedure can take the qualifications of the future licensee into account, and has the objective of issuing the licence to the organization best equipped for fulfilling the licence requirements, it can also lead to a situation where the winning applicant has over enhanced the technical/quality elements to win the bid and then has to develop a service where, for example, the quality or capacity of the system is in excess of operational requirements or, finds later on that it is unable to fulfil its requirements.

6.3.2.1 Beauty contests with a financial bid ('Comparative bidding')

This mechanism is based on the tender procedure, but instead of the administration assigning the spectrum for free, or for a set fee, the applicants are invited to submit a cash bid in addition to meeting the requirements of the administration's published criteria. Thus, the bidders determine the cash value of the spectrum to themselves.

The introduction of the applicants' cash valuation provides a limited indication of the spectrum's value, but it may not be a true market valuation as parts of the applicants' submission, included in response to the administrations published criteria, may have a significant impact on the cash bid. To prevent applicants forming a cartel to reduce the monetary element of their submission, it may be prudent for the government to do research on the spectrum's value in order to set a lower limit ('minimum bid') on the cash element of the submission.

Like the tender procedure, an advantage of comparative bidding is that it can take the qualifications of the future licensee into account and partly take the value of the spectrum into account.

Like tender procedures all submissions are reviewed by the administration. Again there is no obligation on the part of the administration to issue a licence to any of the applicants. The review may be simplified if a number of applicants equal to the number of licences available, clearly present a submission that exceeds all of the administrations criteria and offer the best monetary valuation. However, in most cases the review procedure is more complicated as the cash bid is only one element of the submission and the highest cash bid is not guaranteed to win. In addition the introduction of the monetary element requires a more thorough evaluation of the applicants business and, especially, financial plans. The review process with comparative bidding can be as time consuming and resource intensive as the tender procedure. Unless there are clear winners, it is arguable that the administration's decision might be as subjective as the tender procedure and is even more open to legal challenge, because different elements (financial and other) are evaluated.

6.3.3 Auctions

Auctions represent an assignment mechanism where in the end the applicants determine the amount of money to be paid. In this way the eventual price of spectrum is determined by market forces and the frequencies are assigned to the winning bidder. Mostly administrations set entrance criteria for applicants. These criteria may be similar to the type of entry conditions set in comparative bidding (or lottery, see next paragraph). The main features of auctions, that explain their wide spread adoption all over the world, are:

– in general, auctions promote efficient use of the spectrum by providing the winning applicants with an incentive to use it quickly and maximize its use. Some concerns have been expressed that auctions place a burden on operators at the start of the service, but clearly the bidders should be aware of their cash flow requirements and good business practice should prevent them from 'overbidding';

– in general, auctions are quick and efficient in the assignment of spectrum compared to traditional tender procedures or comparative bidding. Auctions can cope with large numbers of applicants and can be considered as an objective and transparent licensing procedure. As a result auctions reduce the opportunity for favouritism. Transparency of the auction process reduces the possibility of a legal challenge;

– the more criteria and limiting conditions are part of the auction process, the more it will affect the value of the licences (auction price may go down). In some cases, by clearly defining the operational limitations of the licence, administrations may need to develop certain types of spectrum management facilities they had previously considered unnecessary, Examples are specialized monitoring activities, terrain database and automated interference analysis capabilities.

For an auction to go smoothly the rules and procedures of an auction should be known and understood by all participants, prior to the auction's commencement. Any administration planning to implement spectrum auctions would be well-advised to consult the growing body of literature on this subject and to review the experiences of other administrations, to learn, both from the successes and problems that have been encountered with respect to auction design and operation and its impact on the operators, telecommunication manufacturers and end users.

Depending on the complexity of the auction at hand, an automated auction system is desirable. Thus, certain technical infrastructure may be required to hold an auction. As well as, education and training for both spectrum managers and potential bidders is required to ensure a sufficient level of "auction literacy".

Auctions can take a number of forms, some examples are:

– "English" auction

  the auctioneer increases the price until a single bidder is left;

– First-price sealed bid auction

  bidders submit sealed bids and the highest wins;

– Second-price sealed bid auction

  bidders submit sealed bids and the highest bidder wins but pays the second highest amount bid;

– "Dutch" auction

  the auctioneer announces a high price and reduces it until a bidder shouts "mine";

– Simultaneous multiple round auction

  as applied by the Federal Communications Commission in the United States of America, this involves multiple rounds of bidding for a number of lots that are offered simultaneously. The highest bid on each lot is revealed to all bidders before the next round when bids are again accepted on all lots. The identity of the high bidder may or may not be revealed after each round, but is revealed at the auction's close. The process continues until a round occurs in which no new bids are submitted on any lots. This variant is more complex than single-round auctions but offers bidders greater flexibility to combine lots in different ways, and, because it is more open than a sealed bid process, limits the impact of the winner's curse, allowing bidders to bid with more confidence;

– Simultaneous combinatorial multiple round auction.

  this is basically the same method as described under 'simultaneous multiple round auctions', except that in this type of auction the participants can do 'combinatorial' bids. That is that they can place a unique bid on a combination of lots. In case lots have synergies this can be a great advantage for the bidder. A side effect of this possibility is that the auction design gets more complicated and computer assistance and special algorithms are necessary;

– Combinatorial Clock Auction (CCA)

Combinatorial Clock Auctions (CCAs) are rapidly becoming the auction format of choice for many spectrum regulators for licensing all kinds of (mostly mobile) spectrum in the first decade of the 21th century. Examples of countries that have used this format are the UK, the Netherlands, Austria, Switzerland and Denmark. A CCA seeks to solve one of the main disadvantages of the Simultaneous Multiple Round (SMR) auction and the English auction mainly that in these auctions, a new bid by a bidder invalidates every previous bid from the bidder. Additionally, an auction may end with a bidder in a position or at a price they are not happy with. A CCA solves this by making every bid in every round a binding bid (all the bids in all the rounds count), and by giving bidders one last chance to make a bid after the auction ends in the first stage.A CCA is actually a combination of a Clock Auction and a single round sealed bid auction. The first stage of the auction is used to determine the estimated pricing and demand from the bidders ('clock phase'). This is followed by a sealed bid combinatorial supplementary bidding round (second stage) in which bids are constrained by previous behaviour in the first stage. This approach eliminates last round buyer's remorse, and also offers effective price estimates for the bidders. The major downside to this auction format is its incredible complexity, which can be difficult for bidders to figure out. Software is needed to determine the winners in the second stage (combinatorial sealed bid, which also takes into account the bidding behaviour in the first stage of the auction). The bidders must have faith and trust in the auction format and system that when they bid their own true value for the licence(s), they will never pay too much. The algorithms and the system will determine the winners with the highest valuation of the licences. So, there is no incentive to bid 'higher' than your true valuation to win the last bid (as in the English auction or simultaneous multiple round auction). The combinatorial aspect makes it also possible to bid on a package of licences with a unique bid for a certain amount of spectrum.

Advantages of auctions

Auctions have the advantage of awarding licences to those who value them most, while simultaneously generating revenues. But this does not mean that these revenues will be large as the value of bids is dependent on many factors. When auctions are used to assign licences within a given allocation structure, licences are awarded to those who value them the most only within the confines of the allocation structure. For example, if a particular block of spectrum in a particular area is valued most highly by mobile radio but is allocated to broadcasters, revenues and the economic benefits generated from that spectrum will be less than if mobile radio operators were allowed to participate in the auction.

Broadening nationally the range of uses permitted under an auctioned licence also allows spectrum to be used for those services most in demand. However, broadly defining services has the potential disadvantage of increasing the cost of interference coordination between licensees in adjacent spectrum and areas. These arguments regarding allocation structure apply equally to a system of transferable spectrum rights after the initial spectrum assignment. When, in the future, spectrum usage will be more and more converged this negative side effect will be less.

Disadvantages

Auctions are not a universal panacea and are only suitable for specific licences and conditions. They are not suitable if the spectrum rights cannot be defined properly. They are also not suitable for high volume, low value licences (FCFS) nor for application to socially desirable services (military use, public broadcasting, etc.), nor when there is no or limited competition. In fact, the single most important factor for auctioning a licence is that the winning applicants' services should face competition and a prerequisite for auctions is therefore that effective competition legislation exists to ensure the bidders do not form price fixing arrangements.

Auctions may be inefficient or impractical for certain services or situations. One already mentioned case is where there is no competition for spectrum. This could occur, for example, with fixed microwave systems where there are many individual links with narrow beam-widths and very exact locations, or where potential operators see little prospect of achieving a realistic return on their investment within a reasonable timescale. A second case is where providers of socially desirable spectrum-using services, such as national defence or scientific research, may have difficulties in placing a financial value on spectrum. This could lead to those services being under-provided to society if all providers of spectrum-using services faced auctions. That difficulty could be overcome by government bidding for spectrum in a competitive way. The government also buys other goods and services for socially desirable activities via the market, such as police cars and paying rents to hire government buildings.

If auctions to license global or international satellite systems were held in multiple countries, it is likely that potential service providers would have to spend significant resources simply to participate in each auction, and such a cumbersome process could lead to delays in implementing desired services. In addition, sequential auctions would create significant uncertainty for potential service providers because such provider would be unsure that they would win auctions in all countries in which they wished to provide services. If this uncertainty were sufficiently severe, it could impede the provision and the development of international satellite systems. On the other hand, this uncertainty also exists in all other alternative spectrum licensing methods. Also via beauty contests a potential service provider is not certain he could win the license in all the countries he would like to. One might even state that in an auction the service provider has more control over the outcome (highest bid) than in the uncertain process of a beauty contest.

Restrictions of auctions

Should an administration decide to use auctions, it should be aware that, generally, the greater the number of regulations, conditions, or restrictions put on the use of spectrum to be auctioned, the lower will be the amount of money the auction will generate. Hence, depending on their priorities, administrations may wish to consider the trade-offs involved. On a related note, administrations could choose to restrict spectrum supply, which would generally lead to higher auction proceeds. However, there is a trade-off here as well in that a restricted supply of spectrum will lead to a narrower range of consumer services, higher consumer prices, and an overall decrease in economic efficiency.

In order to promote competition, it may be necessary to impose additional safeguards, for auctioned services. For example, in some situations some or all of the potential bidders may be dominant service providers who are endeavouring to strengthen their monopoly or oligopoly (limited number of competitors) positions. Restrictions on eligibility to participate in an auction or limits on the amount of spectrum that any entity may win can alleviate this problem, although this may limit the number of participants.

In general the proceeds of an auction go to the general budget where in a budgetary process will be determined a new purpose for the raised money. In some cases this can be lowering the national debt or investments in new sectors or activities.

6.3.4 Lotteries

This mechanism can cope with a very large number of applicants and is based on selecting the winners at random from the competing applicants. In its simplest form a lottery is simple, quick and transparent but may assign spectrum to someone who does not value it. As there is no subjective decision required to assign the spectrum and no need for any review of the applicants there is little possibility of a legal challenge to the decision. However, unless there is some kind of entry fee the winners are given the spectrum free of charge. Consequently the administration may decide to impose a fee for entry to the lottery and possibly other entry criteria to ensure the winning applicant is capable of providing the service. These additional constraints may restrict the number of applicants and may also recover some of the value of the spectrum. A real disadvantage of lotteries is when the winning lots (licences) represent a real market value. The winners then could make a profit by selling those licences on the secondary market. This could cause problems, as that market value could also have been captured by the public treasury, if a different assignment procedure, such as an auction, would have been chosen. The mechanism of lotteries has in practice not been used much.

6.4 Spectrum pricing

As the radio spectrum is a limited, but reusable, resource it has to be used efficiently and effectively in order to avoid unwanted interference, to maximize the benefits from its use for each administration and to ensure equitable access to the spectrum for all existing and potential users. However, the liberalization of telecommunications and ongoing technological developments have opened the door to a variety of new spectrum applications and these developments, though often making spectrum use more efficient, have spurred greater interest and demand for the limited spectrum resource. As a result in some geographical areas for some services and certain frequency bands, the demand for spectrum has exceeded the available supply. At the same time the increasing tendency for shorter development cycles, has increased the pressure on spectrum managers for quicker decisions on who and which technology should have access to the spectrum.

In these circumstances cost based charging policies and assignment mechanisms not based on market mechanisms, may not be the optimum solution for managing access to the spectrum, as they bear basically no incentives to reach certain management goals. Fees that are described in this section are specifically intended to influence the behaviour of the spectrum users. Well used they:

– by themselves provide a transparent mechanism for promoting efficient use of spectrum;
– prevent users from stockpiling spectrum that they do not really need;
– provide an incentive to move to alternative bands when this would be desirable;
– provide a means of quickly assigning a limited quantity of spectrum, when there is a high level of demand and strong competition between applicants.

In addition some traditional assignment mechanisms are difficult to operate due to the number of applicants and are more prone to legal challenge as the administration's decision making process (especially the comparative process, beauty contest) is not sufficiently transparent.

These concerns have led to the development of additional approaches to spectrum management including, among other things, economic criteria as a spectrum management tool for certain services and as an instrument for calculating licence fee structures. The economic criteria are used, together with other more traditional spectrum management tools, with the aim of improving spectrum management and allowing the radio spectrum to be managed on a more equitable basis for the benefit of all radio users and the general economy.

6.4.1 Incentive spectrum fees

One of the areas affected by consideration of spectrum pricing is the approach to spectrum usage fees, which introduces the concept of the economic value of spectrum in the fee structure.

An incentive fee attempts to use the price in order to achieve spectrum management objectives and hence to provide some incentive to use the spectrum efficiently. Incentive fee formulas have the advantage of representing to some extent the scarcity and differential rents of the spectrum ('economic value'). Hence, in this approach, assignment fees levels are not dependent on cost-based limitations and a fee structure is developed that approximates to the market value of the spectrum. The overall aim of incentive fees is to encourage more efficient spectrum use, with the intention of bringing the demand for spectrum into equilibrium with its supply by:

– encouraging users to start using more spectrally efficient equipment;
– handing back spectrum they do not need;
– moving to a less congested part of the spectrum.

Incentive fee formulas may therefore also provide a mechanism to support a policy on spectrum redeployment.

The fee is developed from a formula that attempts to reflect the scarcity value of the spectrum. Various elements of spectrum usage may be taken into consideration in the development of a formula and different formulae may be required for different frequency bands and services in order to develop a flexible incentive fee structure. Typically a formula may include a number of criteria, for example:

– *Frequency band*

  The amount of the fee charged varies with the frequency used to encourage users to deploy new services in parts of the spectrum under less pressure or to move existing services to bands where there is spare capacity. The administration should however recognize that some services need specific frequencies or specific frequency ranges to function e.g. HF communications, meteorological services.

– *Bandwidth used*

The amount of the fee varies with the amount of spectrum a user occupies. It is used to persuade all users to utilize more spectrally efficient equipment, give up spectrum they do not need and to persuade new users to seek only the minimum they require. This is a method already employed in principle by charging per link in the fixed service or per channel for private mobile radiocommunication (PMR) service.

– *Exclusivity*

This has two aspects. First, with all other criteria of the radio applications identical, the fee for spectrum users with access to an exclusive channel has to be higher than the fees claimed from users satisfying themselves with shared bands. Second, in shared bands, with all other criteria of the radio applications identical, the fee for spectrum users who utilize a large number of radiocommunication equipment has to be higher than the fees claimed from users satisfying themselves with less equipment as the former is more likely to occupy the spectrum than the later (thus excluding the latter from the possibility to use the spectrum).

– *Geographical location*

The fee is higher for operators in highly congested areas (e.g. city centres) and is lower for those in less congested areas (e.g. rural areas). Note: in practice some rural area's spectrum usage can be more congested than some cities and usage will vary with the type of service and the frequency band.

– *Coverage*

The fee varies depending on the transmission coverage area (this refers to the sterilized area, meaning the area that cannot be used by others because of the use by the licence holder and equates to the coverage area plus a buffer zone). Coverage area can also be used in the sense of the number of people reached (potential viewers or listeners).

– *Radio trunking*

There is differentiation of charges between the use of efficient trunking systems and individual radio systems.

The disadvantage of incentive fees is that no formula, however complex, can take into account all the variations of the marketplace.

This requires that considerable care is exercised in setting licence fees if it is the intention to avoid a large discrepancy between the fee and the market value. In addition developing an incentive fee formula may not be a simple task if it is to accurately reflect the variation in spectrum usage across a country. At last, incentive fees may not be suitable for all services.

6.4.1.1 Incentive spectrum fees based on opportunity costs[37]

An often used method to determine the value of a part of spectrum, in case spectrum pricing is introduced, is a fee based on the concept of 'opportunity costs'. An opportunity cost fee tries to simulate the market value of spectrum by calculating the value of *the second best alternative* for that given spectrum. For example the opportunity cost for a taxi PMR license may be a GSM licence subscription. Therefore the value of a PMR licence can be based on the next best alternative for that PMR licence: a GSM subscription. This process may require financial analysis, estimations of demand or market studies to achieve a valuation, and considerable expertise. Opportunity cost fee formulas have the advantage of being directly targeted at the desirable goal of simulating the market value, thus encouraging consideration of alternative means of communication and the return, by existing users, of surplus spectrum.

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[37] See ITU-D 1998 (SG 2) Final report (Document 3).

Just as it is extremely difficult to establish an incentive fee formula that accounts for all relevant variables that influence the price of spectrum in a particular location, it is also extremely difficult to accurately simulate an auction and the effort required to complete the analysis may exceed the costs of an auction. Such a simulation depends upon the evaluation of individual consumer decisions and somehow integrating this information into a usable model. Financial studies or extrapolations may be useful to some extent, but simulating the market will always remain very much an imperfect exercise. Nevertheless, such methods may have advantages over cost based alternatives in terms of managing the spectrum to balance supply and demand and maximizing economic welfare. And also, in comparison with auctions, incentive fees can apply to general licences over a longer period of time, while auctions typically are applied for assigning a certain number of licences on a certain moment, with a particular license duration.

6.4.1.2 Incentive spectrum fees based on users' gross income

Another alternative for a cost based fee can be a fee based on a percentage of the gross income of a company. The value of the gross income used in the fee calculation must be directly related to the company's use of the spectrum to avoid difficulty in the accounting and auditing processes and to relate the gross income to the spectrum activities. The closer the fee based on users' gross income will come to the real economic value of the spectrum, the more the goals will be achieved as mentioned under incentive spectrum fees'.

Table 6-1 presents the positive and negative aspects of traditional cost based and more recently introduced market based fee approaches.

TABLE 6-1

Methods	Advantages	Disadvantages
Simple fees	Can be applied to all users. Can be implemented without lengthy analysis and surveys in view of establishing a fee calculation model and fixing the height of the various fees according to the radiocommunication application. Easy to implement and recovers some or all of the cost of issuing a licence	The fee does not reflect the costs of the administration nor the value the user places on the spectrum. Applied alone it does not promote technical or economic efficiency in spectrum utilization
Cost recovery	Spectrum users are ensured that they pay only for the costs of the spectrum management authority, made for them. Taxes collected from the general tax payers are not employed to finance activities of the administration whose beneficiaries are clearly identifiable	Applied alone it does not promote technical or economic efficiency in spectrum utilization. It is a very complicated process to be able to distribute the total of direct and indirect costs of the spectrum management authority by mean of fee calculation models and tariffs. Due to legal or practical restrictions (for example in the case of licence exemption/ general licence) it may happen that not all activities of the spectrum management authority can be financed with cost recovery fees
Fee based on users' gross income	Links the cost of spectrum to the value of the commercial activities that use it. 'Simple' to calculate	Can only be applied to users whose revenues are directly linked to spectrum utilization. Does not promote spectral efficiency if revenues are not proportional to quantity of spectrum used. Can be seen as an extra tax
Incentive fees	Promotes efficient use of spectrum. Recovers some or all of the cost of issuing a licence, although it is not the objective of such a fee	Can require considerable effort to approximate market values. May not be suitable for all services
Fee based on opportunity cost	Good approximation of the market value of spectrum. Promotes efficient use of spectrum. Is an incentive fee.	Can require a huge amount of data and analysis. Only applicable to limited part of spectrum (account is taken only of users and uses competing for a given frequency band)

6.5 Spectrum rights

Spectrum pricing has led some administrations and licensees to reconsider the rights or permissions associated with a licence: what they include, how they should be defined and whether they should be tradable. In general there is either license exempt spectrum, where there is no need for an individual license, or there is spectrum where a licence is required. Only in the latter case licences can be traded and are given specific spectrum rights such as duration, specific rights to use the frequencies near borders, in some cases roll out obligations etc. Even conditions and obligations can be given to share the licensed spectrum with other users.

6.5.1 How to define spectrum rights

In some respects spectrum is analogous to land in that it can be divided into "lots" that may be conveyed or leased. However, spectrum is not as easily defined or delineated as land since radio propagation is not limited by physical boundaries. In addition, although the "sale of spectrum" is a term that is often used in connection with auctions, it is really only a conceptual idea. In practice, it is the licence that is issued and an auction is a market mechanism used to assign it.

The extent of the spectrum rights that users obtain, depends on the individual licence with associated conditions and exclusions. These rights are granted to the user when the spectrum is assigned. Spectrum rights normally cover details stating the precise technical, or operational characteristics, of the radio system that will be used from a specified location, or within a specified area.

Under traditional licensing mechanisms it has been accepted that the administration has, amongst other things, retained the rights to modify the conditions of the licence, resolve interference complaints and take responsibility for related international spectrum issues. The introduction of spectrum pricing, i.e. through auctions, has induced competing licence applicants to question the extent of the conditions to which they will be subject. These questions have arisen because:

- for the spectrum user, the licence is considered to be an asset[38] (irrespective of the licence duration but the longer the period the greater the value of the licence) that, may be used to finance their development programmes. The fewer restrictions that are imposed on the use of the spectrum the greater the value of the licence and conversely the more restrictions the lower its value;
- each auction normally has a set of criteria specifying the conditions under which the spectrum licence will be put on offer, these may be in addition to a statement of the spectrum rights granted by the licence, and those retained by the administration. If the criteria contradict the statement of spectrum rights, or do not accurately reflect the spectrum rights associated with the licence, then they may:
  - inhibit the operation of the auction, or
  - if at some later date they are the subject of a dispute between the licensee and administration, raise doubts on the value of the licence – this may also result in a legal challenge to the administration or a claim for compensation.

A clear definition of spectrum rights, is very important for the auction and trading process thereafter. A degree of flexibility in the definition of a licensee's spectrum rights is clearly desirable although there are limitations. In particular, the ability of the licensee to change the service they provide may raise problems, particularly where there are a number of countries with many borders, concerning:

- the potential technical and interference problems of having different types of service operating in the same frequency band or on the same frequency;
- the impact of the licensee changing the service they provide (to take advantage of changes in the market conditions) on the users of their existing service.

In the former case, although it may be possible to operate some services in the same frequency band, it needs to be considered on a case-by-case basis. There is also the question of protection from cross border interference that would arise from a national allocation that differs from Article **5** of the RR.

In the latter case, the licensee may face practical problems in changing the provided service as it is likely to be necessary for the licensee to recover any investment in their initial service/system and any change to a new service would need to take this into consideration together with the number of years remaining of the licence. In addition other factors may affect the recovery of investment (both in the existing service and planned for the replacement service), such as the availability of any new equipment for provision of the replacement service, the time required to roll out the replacement service and any new equipment to users. But in a competitive profit maximising environment the licensee itself is best capable of making those decisions.

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[38] In this section asset is not used in its standard accountancy form.

6.5.2 Role of the administration in defining spectrum rights

The spectrum rights retained by an administration are important to it and any applicants competing for spectrum. They are also important to the administration's neighbours[39]. Hence, in providing the licensee with greater rights and perhaps the ability to change aspects of the service they provide or its technical characteristics, the administration needs to ensure that by defining spectrum rights the rights of neighbouring countries are ensured. This also goes for neighbouring frequency users in the country itself. From the international perspective the administration should retain the spectrum rights necessary to:

– provide the international contact point for radiocommunications issues;

– take responsibility for all radio signals originating on its territory;

– meet its obligations under international agreements and treaties (for example the ITU Constitution) and should include the right to reclaim the spectrum before the licence has expired, if it should be necessary to meet, for example, the requirements of an international agreement to reallocate the spectrum on a regional or global basis.

The spectrum rights listed above are likely to be the minimum an administration would wish to retain and in practice there may be additional requirements depending on national legislation, the national spectrum management process structure and organization.

6.5.3 Licence duration

The licence period varies between countries. Normally the licence period lies in the range 1, 5, 10, 15 or even 20 years, although some special licences may be shorter and in some countries licences may be issued for an indefinite period subject to the annual payment of a fee. The annual payment of a fee does not make a licence an annual licence. Longer licence periods do not automatically imply any greater security of tenure, as this is dependent on the conditions attached to the licence. However, annual renewal may make it easier, or more convenient, for the administration to terminate a licence, as opposed to the use of revocation procedures with several years of a licence remaining. But in a regime of auctions, incentive pricing and tradability, in the end, a perpetual licence regime would have the best characteristics, as in an ongoing decentralised market process, the government would want to intervene in that process as little as possible.

6.5.4 Transferable spectrum rights

No assignment mechanism can make allowance for someone coming along at a later date that can make better use of the spectrum and therefore administrations need a mechanism to ensure the spectrum continues to be used efficiently. Two solutions to this issue have been examined in a number of countries.

– *Transferable spectrum rights* – the transfer of a licensee's spectrum rights either in whole or in part, to a third party.

– *Flexible spectrum rights* – the permission for a licensee to modify their spectrum rights and so allow for changes in modulation techniques, population densities, transmission powers, frequencies etc.

Or a combination of those two approaches.

In some countries transferability and, or flexibility of spectrum rights is possible with the permission of the administration under their existing legislation. However, this directly involves the administration in the decision making process, and is likely to introduce delays and constraints.

To avoid unnecessary constraints on the operation of these spectrum rights and to ensure they are completely economically effective, the definition of the spectrum rights should be as clear as possible but also as non-restrictive (flexible) as possible. The least restrictive definition would allow the licensee to choose the end user services they want to provide, as long as it is ensured that no interference is caused to other users of the spectrum. At the other end of the scale, the most restrictive form of spectrum rights limits transferability within a specific allocation and a set of tightly defined technical parameters, but this might not provide sufficient

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[39] In this respect neighbouring countries will depend on propagation distances and may extend up to a 1 000 miles or possibly more depending on frequency and whether the propagation path is over land or sea.

flexibility to achieve economic efficiency. An acceptable solution lies somewhere between these two extremes in achieving an acceptable balance between economic efficiency and restrictive technical parameters and this may be achieved, in some circumstances, by permitting licensees to negotiate their emission rights.

6.5.5 Secondary market

By the introduction of transferable spectrum rights within the given licence conditions and geographical area, a secondary market can be created. It depends on the demand and supply of frequencies and licences in a certain frequency range and the structure of the market in those countries, whether or not this market will be very dynamic or static. A secondary market would clearly need both transferable spectrum rights and a licence with adequate security of tenure and duration to operate. The ability to trade spectrum encourages its efficient use by providing a mechanism for licensees to obtain an economic return on any spectrum they no longer require or can be sold to a higher profit than could be made in their own exploitation of the licence.

Any transfer of rights needs to be registered with the spectrum management authorities in a sort of ‘frequency and owner register’ and like any other market, an ‘anti-trust authority’ is needed to ensure fair competition and avoid dominant market power. In particular there is a need for competition legislation to prevent market power of licensees (monopolies) which could result in hoarding of spectrum and price fixing. When a market in spectrum is developing then it is likely there is a need to establish new organizations to provide frequency resale and, perhaps, spectrum marketing services.

TABLE 6-2

Setting the price of spectrum

Topics	Sub-topics	Paragraph No.
Spectrum Incentive Pricing (“value” of the spectrum)	– “economic variables” to calculate the fee (fee formula): – bandwidth – exclusivity – geographical location – coverage – etc. – fees based on gross income – opportunity cost fees	§ 6.4; § 6.4.1 § 6.4.1b) § 6.4.1a) § 6.4.1c)
Cost-based fees	– based on all kind of cost-allocation systems/calculations	§ 6.2.2.2 § 6.2.3
Simple fees	simple fee for the privilege to use a public resource	§ 6.2.2.1 § 6.3.4
Auctions Bids in “comparative biddings” Bids and beauty contests	winners bidding price	§ 6.4.2 § 6.3.2
Secondary trading	“frequency use rights” transferred following payment by a new user to the former user	§ 6.5.3 § 6.5.1.4 § 6.5.1.5

It should be noted that it is not necessarily a choice *among* the different types of pricing shown above. In one country different kinds of pricing can exist *beside* each other or different elements of pricing can be combined.

6.5.6 Managing a transition in spectrum funding

Whether the level of economic benefits from the use of radio grows or diminishes depends on the spectrum being used efficiently and managed effectively. The implementation of spectrum pricing, and spectrum rights, can have a significant impact on the spectrum management processes.

In fact a spectrum regime of auctions, spectrum pricing and trading is a result of the transformation of a traditional frequency management regime often called ‘command-and-control’ into a regime based on market mechanisms. In the end the central aim of that transition is to let the licensee decide on the type of use and amount of spectrum he or she needs to maximise the profit in a market oriented competitive environment (‘decentralised allocation’). That requires a different way of thinking within administrations and a new culture of reducing the role of administrations and to abandon defining in detail who can use the frequencies under which conditions and circumstances. This new approach and change is considered necessary in a global competitive ICT market where technical developments and innovations go very fast. A more flexible, market oriented, frequency management approach would result in higher economic benefits for society.

6.5.7 Cost of spectrum redeployment (as a method of spectrum management)

Redeployment is a spectrum management tool, which makes it possible to observe the timetable laid down for the availability of frequencies to newcomers. This issue is being studied by Radiocommunication Study Group 1 (see Recommendation ITU-R SM.1603). An example of the spectrum redeployment process is based on the French experience. However, the general principles identified may well apply to other countries (see Annex 2). Also it must be borne in mind, that in a changing regime where tradability is more and more applied, the instrument of spectrum redeployment by the central government could lose some of its relative importance.

ANNEX 1

TO CHAPTER 6

An application of spectrum pricing (New Zealand)

A scheme of spectrum management that draws heavily on free market principles has been established in New Zealand under the Radiocommunications Act of 1989. Nationwide “management rights” for selected frequency bands, valid for 20 years, have been leased by the Ministry of Commerce by auctions. These management rights can be traded, sub-divided or aggregated. A holder of management rights leases “licences rights” of stated duration, to itself or to other would-be users, the licence rights holder being entitled to set up radio transmitters of specified carrier frequency, power and type of emission at specified locations, to be used for whatever purpose the licence rights holder chooses. Licence rights holders pay an annual fee to cover the costs of the Ministry and are responsible for ensuring that radiation beyond the frequency limits of the management rights holder’s lease does not exceed fixed levels. These licences rights are also tradable. Frequency bands, which remain outside this scheme, including bands in which international interference problems are thought likely to be troublesome, continue to be managed by the Ministry of Commerce.

The radical course taken by New Zealand has so far not been followed elsewhere so far. Indeed the geographical isolation of New Zealand probably enables practices to be implemented there, which would not be feasible elsewhere. However, a variety of much more limited spectrum pricing initiatives, linking economic pressures with more conventional methods of spectrum management, have been introduced in several countries, for example, concerning the private radio systems.

ANNEX 2

TO CHAPTER 6

Cost of spectrum redeployment (France)

1 Interests driving the decision to redeploy spectrum

The community as a whole must derive sufficient benefit from redeployment of radio-frequency bands to merit the granting of authorization. This benefit is reflected, in economic terms, through a maximization of the community surplus. In other words, one must reach an equilibrium point such that no other use of the spectrum can improve the community surplus, according to the Pareto optimality criterion.

In seeking this equilibrium point it is useful to compare the preferences (utilities) of the various players involved. Their utility functions are expressed in terms of private value and social value for the community. Private value corresponds to the profits they can derive from the use of the frequency bands, whereas the social value corresponds to the importance of the service to society at large. The calculation of private value is fairly simple, whereas quantifying the social value is relatively complex. It is possible to call on the notion of "opportunity" in trying to evaluate the social value of the service, in other words by calculating what the absence of the service would cost the community.

As regards the process of spectrum redeployment, it is necessary to compare the utilities in terms of private value and social value of the agent being asked to relinquish the frequency bands and of the incoming agent.

Let $U_{outgoer}$ and $U_{incomer}$ denote the respective utilities (comprising the private and social values) of the operator leaving the spectrum and the operator who replaces him. Let $C_{removal}$ denote the spectrum redeployment cost for the outgoer:

If $U_{incomer} > U_{outgoer} + C_{removal}$ then the removal is socially and economically optimal,

If $U_{incomer} < U_{outgoer}$ then the removal is not socially and economically optimal, and

If $U_{outgoer} < U_{incomer} < U_{outgoer} + C_{removal}$ then a choice has to be made.

2 The cost of redeployment

It is assumed that, as the result of spectrum redeployment, the user of a frequency band is obliged to relinquish the band and to pursue his activity in a different frequency band or to use a non-radio solution where this is possible for him. For this user, the obligation to leave the frequency band may induce an additional cost that he would not have incurred in the absence of this obligation. In what follows, this additional cost will be known as the "redeployment cost". The removal cost $C_{removal}$ discussed earlier forms part of the redeployment cost.

In the telecommunications sector in particular, the resale value of the equipment involved in the move is in most cases not known. Investments made in these networks are often so-called "sunk costs" for the users. This means that if the activity ceases, the users cannot recoup their investments. Calculation of the residual value makes it possible to determine the theoretical value of this equipment when it cannot be resold. It is useful to distinguish the residual book value and the residual economic value. For this reason, two methods are envisaged and presented below for the calculation of the redeployment cost:

– calculation using residual book value;
– calculation using residual economic value.

3 Calculation of the redeployment cost using the residual book value

The book value method is applied in particular when the outgoer keeps normal accounts. Moreover, in the case of commercial activity, this method takes into account the tax advantages that the outgoer has enjoyed relating to the depreciation of his equipment.

3.1 Evaluation of the cost incurred by the user on leaving the frequency band

Move to another part of the spectrum or exit from the spectrum

It must first be determined whether the outgoing user is obliged to use radio frequencies, if he is to pursue his activity. If this is the case (as, for example, for an operator of mobile services), the outgoing user is moved to another frequency band and the cost "Cd" of this move to another part of the spectrum is evaluated. If this is not the case (as for example, for an organism owning fixed radio links), the two following hypotheses must be envisaged:

– the user is moved to a different frequency band and the cost Cd is evaluated;

– the user gives up the use of frequencies in favour of an alternative wire-based system and an evaluation is made of the cost Cs, corresponding to the exit from the radio spectrum.

The choice between these two hypotheses, taking only the economic criterion, leads to adopting the less costly of the two.

Let Ci be the cost incurred by the user on leaving the frequency band. Ci is equal either to Cd if the user is obliged to occupy a different frequency band, or to the smaller of Cd and Cs if the user has the possibility of adopting a wire-based solution.

3.2 The residual book value Vcr

This method makes allowance for the age of the outgoing user's equipment, taking the residual book value "Vcr" of this equipment. The usual definition of the residual book value of an item of equipment is obtained as follows:

Vcr = purchase price of the equipment ready for use minus depreciation

Vcr represents the value of the fraction of equipment remaining to be depreciated. If at this stage in the depreciation, its owner can no longer use the equipment, the latter, according to accounting theory, would incur a loss equal to Vcr.

3.3 Renewal costs

Because of technological evolution and the ageing of equipment, the occupier of a frequency band is called upon to renew his equipment even in the absence of any change of band. Let Cr be this cost of renewal of equipment, with identical properties and the same frequency band. Cr in this case represents the cost this occupant would incur even in the absence of any spectrum redeployment.

3.4 Calculation of the redeployment cost

Take the user of a frequency band whose present equipment has a residual book value Vcr and who has to evacuate this band by reason of redeployment. Leaving the band means that he has to spend a sum equal to Ci (see section 3.1) in order to be able to pursue his activities. The fact of evacuating the band will probably mean that it is impossible for him to use his present equipment, hence causing a loss equal to Vcr (see section 3.2). If he were to stay in the band, he would have to spend a sum equal to Cr (see section 3.3). We therefore have the following relationship:

$$\begin{gathered}\textit{Redeployment cost} = \textit{additional cost for the user obliged to leave} \\ \textit{the frequency band} = Ci + Vcr - Cr\end{gathered}$$

Remarks:

– if the calculation results in a negative redeployment cost, this means that the user has an interest in leaving of his own accord the frequency band he currently occupies;

– calculating the redeployment cost of a frequency band requires, in each case, an expert appraisal to establish the actual costs of the existing network and the new network.

The results of the calculation are highly sensitive to the level of depreciation and the architecture of the existing network.

4 Calculation of the redeployment cost using residual economic value

The economic approach makes it possible, among other things, to leave aside the following two aspects:

– the fact that the actual service life of the equipment may be different from the life used for accounting purposes[40] (determined on the basis of depreciation periods);

– the possibility that the outgoing user does not apply a depreciation regime.

Analysis of the value of networks

Once the incomer has recognized his interest in using radio waves to provide his service and when it is established that the value to the incomer is greater than the value to the outgoer plus the cost of moving (in other words $U_{incomer} > U_{outgoer} + C_{removal}$), the outgoer has five options:

– *The outgoer ceases activity*: the outgoer provides a service whose value to society is small, whose technology is obsolete or which no longer has any justification; all these are cases in which it is preferable that the outgoer cease his activity.

– *Sharing frequency bands for a single service*: the existing operator uses frequencies but in an inefficient manner or is unable to justify the quantity at his disposal; in this case, he could, without technical handicap, agree to another operator being installed to provide the same service.

– *Sharing frequency bands between different services*: the incomer may exploit the host frequency band without the existing operator having to move and the latter can also continue exploiting the spectrum without interference from the incomer. This is the solution of sharing frequency bands for the provision of different uses.

– *The outgoer moves his activity to another host frequency band*: the incomer has the exclusive use of the whole frequency band and the existing operator must move his activity to another frequency band.

– *The outgoer moves his activity to a totally different platform*: the incomer wishes to benefit from the exclusive use of the whole frequency band and the existing operator must move his activity. On examination, it turns out that the development cost of the activity of the outgoer on other frequency bands is higher than the development cost of the same activity on a wire-based support (cable, optical fibre, etc.). It is preferable, for an unchanged service, that the outgoer evacuate the frequency bands and move to an alternative platform.

Each of these cases can be tackled by an economic study of the different investment options.

Referring to the work carried out in France on the unbundling of the local loop and the calculation of network costs, the spectrum redeployment cost is examined by comparing different options (again referred to in terms of "configurations"). Take the case of the operator who has to evacuate his frequency band (totally or partially) and move to a different frequency band or a different platform (or simply adjust his use of the frequency band in order to accommodate another operator). The removal of the operator (called the outgoer) must not be to his detriment. The move must involve an incentive for the outgoer. Otherwise, he will not evacuate the frequency band or will try to delay his departure. Equally, the move by the operator must not give rise to the constitution of profits. As a result, an equilibrium point has to be found through the calculation of "fair" compensation. This is done through a comparison between the situation of the outgoer who has to bear the costs of the move and the situation of this same operator if he had not had to move and if he had only incurred the costs of renewing his equipment.

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[40] Depreciation for bookkeeping purposes is different from economic depreciation. Equipment that has been completely depreciated can often go on being used for several years before being replaced. In concrete terms, economic depreciation is the sum of a depreciation term (the loss of nominal value of the equipment in the course of a year) and the term representing the remuneration of fixed capital at discount rate k (or cost of capital). Only the remuneration of that portion of capital that is financed by borrowing (debt) is included in the financial charges recorded in the accounts. As a result, the depreciation for bookkeeping purposes corresponding to the cost of constant use (investment divided by the life of the equipment used in the accounts) and decreasing financial charges, presents a difference in coverage compared with economic depreciation. For the latter, the remuneration is applied to the total capital value of the investment in question, given that part of the financing is in fact obtained internally. It therefore covers both the equivalent of the financial charges and the remuneration of the investment out of own resources (remuneration of shareholders, etc.).

5 The redeployment fund and redeployment procedures

5.1 The redeployment fund

The fund is managed by the body responsible for managing the spectrum (AFNR: Agence Nationale des Fréquences) with a specific budget that is kept strictly separate from the AFNR’s general budget. It can be financed in several ways including contributions from public entities for the requirements of redeployment. So far, the only contributions have come from the Ministry of Finance.

The Ministry of Finance supplies the initial share of the fund, on an annual basis of 3 million euro, increased by an additional amount determined each year on a case-by-case basis in the light of the cases dealt with. From 1997 to 2001 the contributions emanating from the Ministry of Finance have amounted to 65 million euro because of the moves required to accommodate GSM 1800, IMT-2000 and SRD applications (including Blue Tooth). At a later stage, contributions will also come from private persons. Users may be called on to pay their contributions into the fund at the time they obtain the new frequency band. For example, GSM operators will contribute in 2002 for additional frequencies in the 1.8 GHz band and IMT-2000 operators will pay the contribution just after the granting of the authorizations, i.e. in September 2001.

The ministries and the independent authorities (or the entities delegated for the purpose) benefiting from the redeployment fund sign a redeployment convention with the AFNR.

The Board of the ANFR, on which all the ministries and authorities concerned are represented, approves these conventions. The cumulative total of conventions signed as of 30 June 2002 is 59 million euro. The entities that have already benefited from the redeployment fund are mainly the operator France Telecom and the Defence Ministry. Other beneficiaries are notably EDF and SNCF.

5.2 The redeployment procedures

The procedures are launched by the part of the administration responsible for assigning frequencies before the re-attribution of the frequency band. In France the bodies in charge of assigning frequencies are known as “affectataires”.

At their request, the tasks delegated by the State to the ANFR are as follows:

– to prepare the evaluation of the various cost elements and redeployment principles;

– to propose a schedule for the redeployment operation;

– to organize the supervision of the procedure;

– to manage the redeployment fund.

To carry out these tasks, the ANFR relies on a number of commissions within which consensus is sought and found. The commissions involved in the redeployment operation are as follows:

CPF: Commission pour la Planification des Fréquences (The Frequency Planning Board).

This commission receives, examines and coordinates the demands for frequencies emanating from affectataires.

It has the following tasks:

– to draw up and keep up to date the national Table of Frequency Allocations and to harmonize, as necessary, the use of frequency bands;

– to examine all issues relating to the use and allocation of frequencies having national or international implications;

– to issue directives to the CAF: Commission d'Assignation des Fréquences (Frequency Assignment Commission), which is accountable to it and for which it acts as the appeals body.

CSPR: Commission de Synthèse et Prospective des Radiocommunications (Radiocommunications Synthesis and Prospective Analysis Commission).

The CSPR contributes to prospective analyses of the radio-frequency spectrum with a view to optimizing its use by public and private users and makes proposals regarding the rules for electromagnetic compatibility, spectrum engineering and the standards needed to ensure proper use of radio systems.

The CSPR brings together representatives of the departments concerned, as well as those of operators of networks open to the public and the industries concerned.

The CSPR operates with the help of four sub-commissions:

– CCE: Commission de Compatibilité électromagnétique (Electromagnetic Compatibility Commission).

– CVS: Commission de Valorisation du Spectre (Spectrum Value Commission).

– CRDS: Commission des revues du Spectre (Spectrum Review Commission).

– CFRS: Commission du Fonds de Réaménagement du Spectre (Spectrum Redeployment Fund Commission).

Usually, all decisions are taken by consensus. However, when this is not possible, the decision is taken by the ANFR Board, which is the highest decision-making body on matters related to the frequency spectrum. An appeals procedure can then be launched with the Prime Minister's office at the request of a member of the ANFR Board.

To date, all redeployment cases have been handled using the usual procedure, with consensus obtained in the commissions concerned and with full transparency guaranteed.

ANNEX 3

TO CHAPTER 6

Example of Spectrum Auction (Republic of Korea)

1 Introduction

Spectrum auction is a way to determine the frequency assignment price for commercial mobile communication on the market based on competition by applying an auction method to frequency assignment when it is difficult to set a standard price in the market.

In the past, frequency assignment for mobile communications has been conducted by spectrum charge assignment but this could not fully reflect the economic and market value. Thus, the auction as a market based frequency assignment method has been introduced due to an increased demand for limited frequency resources.

It is evaluated that applying spectrum auctions for the mobile carriers is effective when assigning scarce spectrum resources in the market based competition.

The Republic of Korea would like to share its diverse spectrum assignment experience for mobile communication service, which were performed in comparatively short period of time, with other countries

2 History

The plan for revising the Radio Waves Act including the introduction of a spectrum auction system was approved in July 2010 and came into force in January 1, 2011

In the revised Act, frequency assignments on the basis of a price competition, such as an auction became the first priority method. However, it is possible to assign frequencies to mobile carriers not by auction but by spectrum charge assignment in other special circumstances where competitive demand of the relevant frequencies does not exist.

In case of spectrum charge assignment, the economic value of the spectrum which is expected from the value of the frequency band and the bandwidth of the system, should be taken into consideration. Also, the following items should be considered:

- efficiency of radio resource utilization;
- financial capacity of the applicant;
- technical capability of the applicant;
- technical characteristics of the frequencies to be assigned, impact of the corresponding frequency allocation on the telecommunications business and other necessary particulars.

3 The Auction Method

As for selling the three bands: 800 MHz, 1.8 MHz and 2.1 MHz at an auction, the auction for the three bands must go concurrently and the auction method should be simultaneous ascending auction. The method identifies the winner by more than one bidding procedure (round) as described in section 6.4.1.

Minimum bid price means a floor within a range of possibilities for bidding, and it is increased by moving up to the next level round.

The minimum bid price is a reserved price in the first round and from the second round, it is calculated by adding the bid increment to the first bid price of the previous round.

After finishing each round, the highest bid price of each frequency band is noted. Then the minimum bid price of each frequency band in the beginning of the next round is notified to all tendering parties.

4 The Process and Results of Spectrum Auction

4.1 First action for spectrum auction

August, 2011.

4.2 Target of Assignment

The target frequencies were 800 MHz Band (10 MHz Bandwidth), 1.8 GHz Band (20 MHz Bandwidth) and 2.1 GHz Band (20 MHz Bandwidth).

The bandwidth of frequency assignment target is not allowed to exceed 20 MHz per operator.

4.3 Date of Assignment

The 800 MHz band was assigned in July 1, 2012. The 1.8 GHz and 2.1 GHz bands would be assigned on the date of result notice. And the period of frequency usage is 10 years from the date of the frequency assignment notification.

4.4 Minimum Competitive Price

The minimum bid prices were 261 billion KRW for the 800 MHz band, 445.5 billion KRW for the 1.8 GHz band and 445.5 billion KRW for the 2.1 GHz band. The assignment target frequencies and the auction result are summarized in Table 1.

TABLE 1

The Assignment Target Frequencies and Auction Result

Band	Assignment Target Frequency [MHz]		Assignment Date	Assignment Period	Successful Prices Tendered
	Upper	Lower			
800 MHz	819-824	864-869	July 1, 2012	10 Years	261 billion KRW (A Corp)
1.8 GHz	1755-1765	1850-1860	Notice Date	10 Years	995 billion KRW (B Corp)
2.1 GHz	1920-1930	2110-2120	Notice Date	10 Years	445.5 billion KRW (C Corp)

4.5 In Korea, the implementation of the auction system is deemed to be a success and it is also considered as a basis for future commercial frequency assignment policy.

5 Conclusion

After reviewing the auction process and result, the government acknowledged that it has been done in a stable process and has enhanced the fairness and effectiveness of frequency assignment.

BIBLIOGRAPHY

ITU-R texts

Report ITU-R SM.2012 Economic aspects of spectrum management

CEPT texts

ECC Report 53 on "Cost Allocation and Accounting systems used to finance the radio administration in CEPT countries".

CHAPTER 7

Automation for spectrum management activites

Table of Contents

7.1 Introduction

When the amount of data is large and the requirements for analytical studies are complex and diverse, automation techniques become a necessity. Automation can also improve the implementation of limited analysis techniques and databases. Computer systems offer the means to store data in a readily retrievable form, to manipulate the data, to produce reports relating to the data and to perform analytical studies.

Cost effective computer systems that process large amounts of data or perform complex analytical studies have been available for some time. Technological developments have reduced the cost of computer systems, increased computational capabilities and made the application of computer techniques to spectrum management a feasible approach for every administration, including those with relatively small spectrum management requirements or having smaller data bases. The Telecommunication Development Bureau (BDT) has sponsored the development of the spectrum management system for developing countries, SMS4DC, that is now available in multiple languages. Annex 1 to this Chapter provides a summary description of SMS4DC, and an Annex to the ITU Handbook on Computer-Aided Techniques for Spectrum Management provides more detail on SMS4DC.

The Radiocommunication Bureau examines planned frequency assignments and analyses potential interference problems, and, in the case of positive results, records the assignments in the Master International Frequency Register (MIFR) or updates the Plans. It is of paramount importance that individual administrations also pursue similar activities. In particular, standard data files and analysis techniques need to be available for the use of all administrations in order to obtain efficient use of the radio-frequency spectrum.

The purpose of this Chapter is to introduce the subject matter and to refer to the recent documents on this subject. It is not intended to replace the ITU-R Handbook – Computer-Aided Techniques for Spectrum Management (2015) or the Recommendations already prepared by Radiocommunication Study Group 1 concerning this subject.

7.2 Applications to spectrum management activities

Regardless of the size, frequency or complexity of the spectrum management process, computers should be used in part or all of the national spectrum management activities. Spectrum management requirements vary widely from administration to administration and it is important that each administration develops the databases and engineering applications necessary to meet its particular requirements. In determining these requirements, an administration should consider national needs as well as international agreements.

Automation can support various functions of spectrum management. These functions include:

– frequency planning;
– frequency allocations;
– frequency assignment and licensing;
– frequency coordination;
– international notification;
– standards, specifications and equipment authorization;
– monitoring activities;
– storing and maintaining spectrum management data;
– statistical and advanced reporting;
– providing an interface for inquiries;
– fees and automatic notification of renewal; and,
– EMC calculations including propagation.

A very important part of each spectrum management system is a database of various information. Many of these data items are described in the Radiocommunication Data Dictionary (Recommendation ITU-R SM.1413). In the interest of a speedy and economical application of automation to spectrum management, it is advisable that an administration includes only those data elements, data files, and databases that are necessary for it to meet its spectrum management requirements. It is necessary to include the list of the data elements required for international coordination. In the interest of establishing a common approach to data acquisition, maintenance and retrieval, spectrum management data could include the following categories:

– frequency allocation data;
– frequency assignment data;
– licence holder data;
– equipment characteristic data;
– fees;
– geographical terrain data;
– frequency coordination data;
– frequency notification data;
– frequency monitoring data; and
– enforcement data.

7.2.1 When automation of the spectrum management process is needed

The first question that is raised when automation of the spectrum management process of a country is considered must be: "Is it really needed?". The definitive answer in every case is "Yes". However, if an automated spectrum management system is not properly designed, it could be a burden rather than a solution to an administration.

For any automated spectrum management system to be successful, several areas need to be addressed and clearly articulated by the administration proposing such a project. The areas that should be considered and the questions that should be answered include:

– Existence of a regulatory infrastructure for spectrum management. This means that a spectrum management authority and its supporting units are in place and effectively operating. These include, but are not limited to, legislation, regulations and operational policies and procedures;
– Definition of scope and project objectives for applying a computer-aided spectrum management system. Why is automation being considered? Have new directives been issued requiring that resources be redirected to other functions within the administration's mandate? Is automation seen as a tool for coping with an increasing workload? What portions of processes or tasks within each spectrum management unit are to be considered for automation? Are some manual processes better left untouched?;
– Determination of available internal and external resource allocations. An assessment must be made as to what financial and human resources will be required and dedicated to the project. Also, will it be necessary to obtain special funding authority?;
– How is the system to be implemented or developed, by either in-house resources, by contract or by purchasing available software or by a combination of these? Does the administration possess the necessary regulatory and technical experts or will it require assistance?;
– What limits or boundaries, if any, are to be imposed in automation development? Will the magnitude of the project dictate its development over many phases or years?;
– Development of work plans and schedules showing project phases, tasks and status reporting milestones. The use of any graphical illustrations, such as Gantt charts, for the work plan and scheduling should be considered;
– Definition of user specifications. Needs and requirements of the end users must be clearly defined to ensure their proper translation to detailed design specifications. The scope of the spectrum management functions that should be automated and the extent to which each will be automated must be clearly defined. Any contract to be awarded must contain a clear and comprehensive statement of work;

– Identification of operational requirements. Each task or activity contains its own operational requirements that must be easily interpreted into a sequence of steps such as flow charts or pseudo code;
– Establishment of functional and technical specifications. These specifications chart out the development of the system and are the basis of the detailed design;
– Availability of organizational and procedural documentation of existing systems and operations. System developers will need access to this documentation as they will invariably need to become themselves quasi-regulatory/technical experts before the translation of existing operations and procedures can begin;
– If contractors are to be considered, their performance history must be examined. Does the contractor have the requisite skilled or experienced system developers to see the project through to completion and implementation? Previously delivered contracts should be reviewed to determine or assess any related experience that can be applied to the proposed contract.

The items listed above are for the guidance of an administration in considering the decisions on the establishment, design, development and implementation of a computerized spectrum management system.

7.2.2 The benefits of automation of the spectrum management process

Computer-aided techniques have become a common place in Administrations in order for them to be able to manage data and to perform the necessary analytical studies associated with spectrum management. Furthermore, technological developments have led to the continuous reduction in the cost of computer systems, in particular of powerful microcomputers, thus making the application of computer-aided techniques to spectrum management a practical solution.

To maximize the benefits of the introduction of computer-aided solutions for spectrum management, the first step should be to evaluate the application of computer systems to a specific spectrum management situation. The various types of existing computer hardware and software available should be analysed. Their use should be embedded in a clearly defined structure with well-defined functions of national spectrum management.

Once this is done, Administrations may benefit from such an integrated system through timeliness and effectiveness of the following tasks:

– verification of the compliance of frequency assignment requests with the national and international table of frequency allocations and their associated footnotes;
– verification that a set of equipment (transmitter, receiver and antenna) proposed to be used in a certain radio link has previously been submitted and passed the appropriate certification process or meets other mutual recognition agreement standards;
– more accurate and optimized response to frequency assignment requests, through the selection of appropriate channels taking into account fine details such as terrain characteristics;
– automatic and decentralised on-line issue and renewal of licenses with invoices (law must allow for electronic signatures);
– appropriate treatment of radio monitoring data (see ITU-R Handbook – Spectrum Monitoring (Geneva, 2002));
– the establishment of a more expeditious and fully documented, timely billing of customers for their use of the spectrum;
– more accurate preparation and electronic submission of notification forms to be sent to ITU in view of the automatic data validation process which can be implemented; and,
– the availability of electronic exchange of data between Administrations or between an Administration and the ITU (see Recommendation ITU-R SM.668).

The total number of data elements to support all these functions is rather large. The objectives of the national authority largely influence the need for many of the data elements. For example, the amount of data required to achieve meaningful and valid EMC computation grows with the state of congestion of the spectrum. They are related to the density of radiocommunication equipment in use in a country and thus to the infrastructure of the country. This can lead to hundreds of fields of data for all files according to Annex 1 of the ITU-R Handbook – Computer-Aided Techniques for Spectrum Management (Geneva, 2015). However, in many cases, the required data may be reduced to a limited number of basic data elements.

Many ITU activities have been automated. The Radiocommunication Bureau's Terrestrial Analysis System (Terasys) and the Space Network System (SNS) are the computerized tools used by the Bureau to process the frequency assignment notices submitted by the Administrations. The systems also maintain the Master International Frequency Register, as well as the frequency assignment Plans. This data is available in a number of formats, including CD-ROM. The data is thus readily available in the defined format for national use for enquiries or in a database. Also available in electronic form each week is the Radiocommunication Weekly Circular (BR IFIC) with information on notified and recorded assignments on CD.

7.3 Major components of an automated spectrum management system

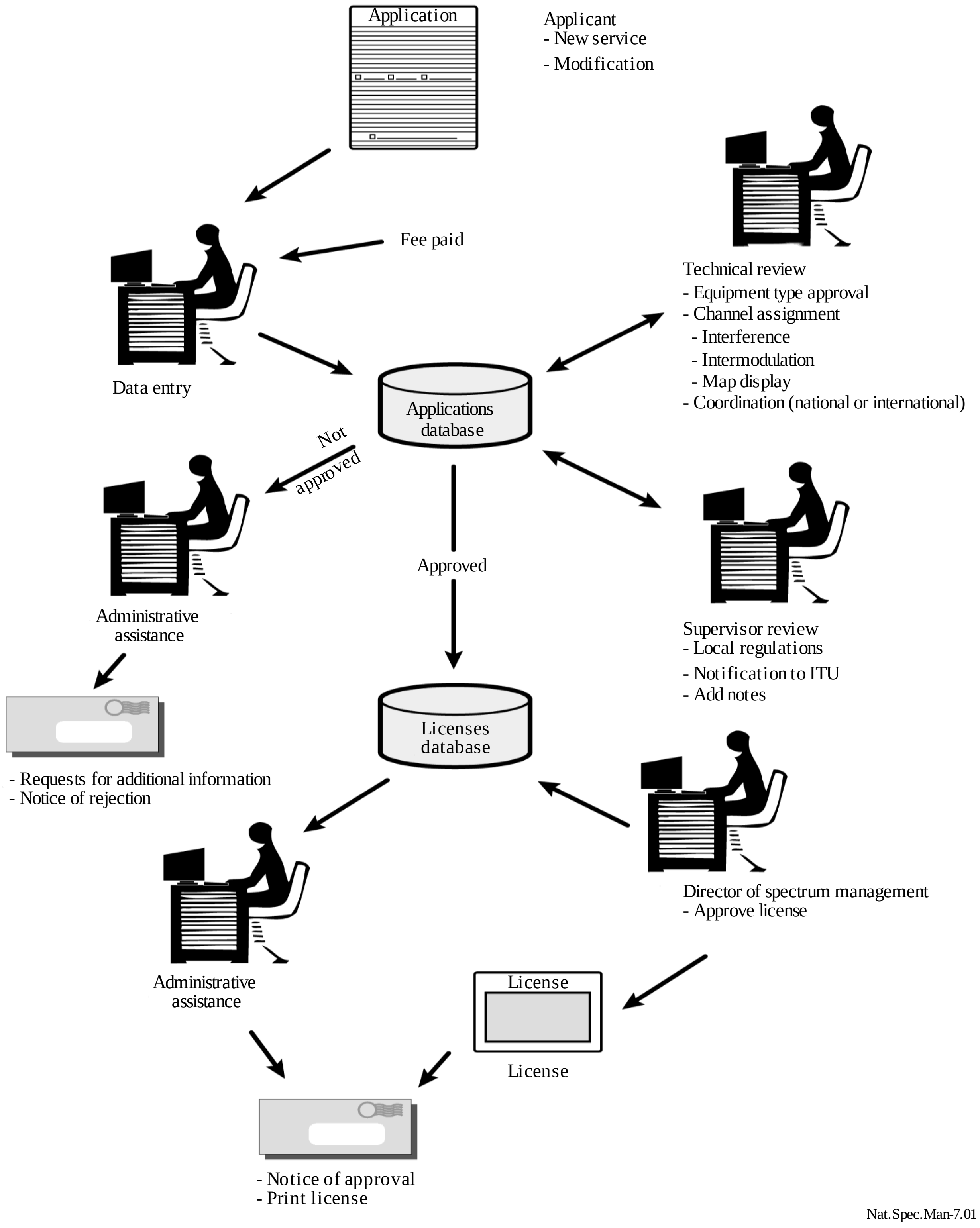
To evaluate the application of computer systems to a specific spectrum management situation, the various types of computer hardware and software available must be analysed. An example of a computerized spectrum management system is shown in Figure 7.1.

The data flow must be well defined (it must be clear where data comes from, what is to be done with it and where it should go). The structure of the data files also has to be defined, as well as the records and fields to be stored in them. The volume of data, the frequency of updates and the updating procedures have to be determined.

Administrations that wish to use specific spectrum engineering models must be careful to ensure that the necessary data to use these models is available and maintained. Careful design of data and databases, including an update methodology, are required to receive usable output from any computerized spectrum engineering modules.

FIGURE 7.1

An example of computer-based processing of application for license



To facilitate the introduction of automation in radio-frequency management, the data elements to be agreed upon should be included in future bilateral or multilateral agreements and arrangements. Therefore, the definition, format and possible coding of the basic data elements should be internationally agreed upon. The data formats must be also coordinated with the Radiocommunication Bureau (see Recommendations ITU-R SM.668 and ITU-R SM.1413). This also means that the list of required data elements can not be final, but has to be adaptable to new findings and requirements. Following this, software applications can be developed, tasks determined and responsibilities specified. It is only then that a set of compatible hardware and software products can be examined and prepared for introduction or adaptation. In this selection process, the availability of maintenance support is another important factor. Furthermore, qualified staff must be available, trained and remain in order to achieve continuity. When all these actions have been completed, a strategy and a plan for the introduction of automation in national spectrum management can be established.

Recommendation ITU-R SM.1370 contains design guidelines for developing automated spectrum management systems. Both private companies and the BDT have developed software which meets the guidelines of SM.1370. As noted above, the software developed by the BDT is named SMS4DC. The BDT has arranged seminars to provide training to Administrations in the effective use of this software.

Specific facilities a regulatory agency should expect from automation include:

1. A system to facilitate processing of applications and licenses.
2. An accounting system to administer fee collection.
3. Engineering analysis tools to allow the analysis to avoid interference where perhaps standardization should be encouraged so that different countries will reach the same conclusion regarding an application for service in the area of a border between them.
4. Geographic maps and a geographic information system for display purposes.
5. A readily available and straightforward interface to spectrum monitoring facilities.

For more details on facilities to be automated, see Recommendation ITU-R SM.1370.

Specific facilities a regulatory agency should not expect from the automation, include:

1. Automatic assignment of frequencies.
2. Automated frequency-site planning.
3. Quality of service of a cellular system.

7.4 Transition from manual to computerized systems

The conversion from manual to automated analysis techniques has numerous advantages and becomes indispensable as the data processed becomes voluminous.

Before starting the transition to an automated system the following factors should be taken into account:

– there is an infrastructure that should be analysed, planned and carried out before starting an automated system. Some of these steps required for this planning are:
  a) a study of the methods that can be used to adapt established manual procedures to an automated system;
  b) the possible acceptance of the new procedures by users;
  c) training of the core of specialized staff for carrying out the automated task;
  d) availability of funds for development and long-term applications;
  e) availability of a computer supplier capable of giving local and long-term support for both equipment (hardware) and programs (software); and
  f) consideration of the trade-off with respect to the level of the data required;
– the changeover from a manual to an automated process will initially create new types of problems;
– the initial period of system development and implementation may be costly. The user should realize that it requires time before he can receive all the advantages and financial benefits of an automated system.

Each administration uses a unique set of documents (licences, application forms, allocation plans, invoices, etc.) in its spectrum management operations. These documents are often manual paper ones, although some now exist in electronic form. In order to effectively transition to an automated spectrum management system, it is absolutely essential that all these existing documents be considered carefully in order to meet the specific needs that the administration has for spectrum management and to provide the requested output formats. A successful transition between the existing and the newly implemented automated system is critically dependent on the scheduling of the transition period and the effort invested in meeting these specific requirements and converting the necessary documents for use by the new system. The state changes in the data currently used by the administration must be fully understood so that they may be successfully replicated by the automated system. These requirements should form part of the contractual framework for the necessary partnership between the administration and the contractor so important for a successful implementation. In any tender process, it is recommended that the administration provide access to potential contractors to the input and output requirements and to current data registers so that the transition effort may be properly estimated and provided for in their offer. The administration should also properly estimate and ensure the availability of its own personnel required as a part of the transition effort. This will allow for a more stringent evaluation of the contractor's capabilities as well as make any guarantees more enforceable.

Many contractual problems have occurred in such projects in the past. Arguments over contractual provisions only leave both parties with bad feelings. It is best to design a transition process that recognizes the significant effort needed by all parties to ensure the process works smoothly. Finger pointing breakdowns do little to move the parties towards a successful conclusion. For these reasons, it is important to adhere to a formal process to document the existing data collection processes and data sources as follows:

1. Identify the type and format of all existing data, including operational and management data, such as general administrative data (department, region codes, fee rules, workflow steps, types of licences, types of equipment certificates, types of holders, …) as well as general technical data (types of services, types of stations, types of equipment, types of mobiles, frequency plans, protection ratios, off-channel rejection curves, …). We can normally define two types of data:
   – Non-repeating data (sometimes called reference data) such as frequency plans, allocations, etc.
   – Repeating data such as administrative and technical data.
2. Define a detailed strategy to migrate the existing data including a list of the data to be migrated, the format the administration will provide the data in, the timetable for delivery of the data by the administration, the timetable for conversion of the data by the contractor, the tests that will be used to verify that the conversion process has been successful and the tests that will be used to verify that the conversion process has been complete.

This shared responsibility should form part of the contracting agreement to avoid misunderstandings. These documents should outline the work to be carried out, the timing of this work and the nature of the responsibilities attributed to each party. The basic data and the operational data will have been defined, the data will be collected in the proper format by the administration, and will be provided to the contractor at the beginning of the transition period. The data provided by the administration should be valid and redundancies should be eliminated. The data from any manual records is often transcribed into an intermediate electronic format (e.g. EXCEL). This data can then be integrated into the new system using scripts provided by the contractor in compliance with the requirements document.

During the data migration process, the administration must rigidly note any modifications made to the original data provided to the contractor since these changes will not be made by the contractor in the migration. The administration will need to use the new system to input these modifications, once the data has been successfully migrated and verified. The process works most effectively if the partnership of the administration and the contractor is well understood and adhered to by all parties.

7.5 Conclusion

As the cost of maintaining manual spectrum management systems increases with the growth in data volume, number of transactions and number and complexity of analytical operations, the use of automated spectrum management systems becomes essential. Computer systems are now available that have the necessary processing capabilities and data storage capabilities to offer substantial performance at reasonable cost.

Recommendation (ITU-R SM.1370) describing Design Guidelines for an Automated Spectrum Management System (ASMS) has been developed by Study Group 1 and should form the basis for tenders issued by Administrations seeking such systems. The software for the spectrum management system for developing countries, SMS4DC, which complies with this Recommendation, is available from the BDT.

Case studies that could assist Administrations considering such automation initiatives are included in Annexes 2 to 9 of this Chapter. It is hoped that these case studies provide useful information to help avoid repeating common errors made when such systems are purchased or developed. No endorsement or criticism of any system included here is expressed or implied. The steps in the processes that ensure or hinder success are the intended highlights rather than the details of the particular systems.

REFERENCES

ITU-R Handbook	Spectrum Monitoring (Geneva, 2011).
ITU-R Handbook	Computer-Aided Techniques for Spectrum Management (Geneva, 2015).

ITU-R texts

Rec. ITU-R SM.668	Electronic exchange of information for spectrum management purposes
Rec. ITU-R SM.1047	National spectrum management
Rec. ITU-R SM.1370	Design guidelines for developing automated spectrum management systems
Rec. ITU-R SM.1413	Radiocommunication Data Dictionary for notification and coordination purposes
Rec. ITU-R SM.1537	Automation and integration of spectrum monitoring systems with automated spectrum management

ANNEX 1

TO CHAPTER 7

ITU computerized spectrum management system (SMS4DC)

1 Introduction

The International Telecommunication Union Telecommunication Development Bureau (ITU-BDT) can supply a computer program to assist the administrations of developing countries to perform their spectrum management responsibilities more effectively. This program is known as the Spectrum Management System for Developing Countries (SMS4DC). SMS4DC is intended to be a low-cost, entry-level spectrum management system; however, it is a very complex software tool with many technical features and functions.

The purpose of the SMS4DC software is to provide developing countries with a tool to efficiently and effectively manage the radio spectrum, primarily for broadcasting, fixed and land mobile radio services and therefore to accelerate the development of wireless technology in these countries.

2 SMS4DC development and features

The first spectrum management software developed by ITU-R and ITU-D, the Basic Automated Spectrum Management System (BASMS), was released in 1995. It used the FoxPro language and operated on a MS-DOS platform. The later (1997) Windows version (WinBASMS) was available free of charge to developing countries. WinBASMS was designed for ease of use and maintenance by a single user and supported most functional requirements defined in the ITU Handbook on National Spectrum Management.

In 2002, Radiocommunication Study Group 1 approved new Recommendation ITU-R SM.1604 calling for improvements/upgrades to WinBASMS. In addition WTDC-02 decided on the further development of the computerized spectrum management system. The SMS4DC is the successor of the WinBASMS which has been developed according to specifications prepared by the ITU Telecommunication Development Bureau (BDT) and the Radiocommunication Bureau (BR) on the basis of former Recommendation ITU-R SM.1048.

The responsibility for assisting, monitoring and reporting on the progress of this aspect of the programme was given to the ITU-R and ITU-D joint group dealing with WTDC-02 Resolution 9. A voluntary group of experts met on several occasions informally in an attempt to draft specifications for this upgrade. Within the framework of this group, a detailed technical specification was prepared which covered the objectives of an enhanced basic system and the essential requirements of an advanced system. The consolidated technical specification was presented to the BDT at the end of 2004 for implementation. Based on these finalized technical specifications, new software, the SMS4DC was developed and released to manage frequency assignments to the Land Mobile, Fixed and Broadcasting services and for frequency coordination of Earth stations (RR Appendix 7 procedures).

The SMS4DC can be used to support most functional requirements defined in the ITU Handbook on National Spectrum Management.

It is emphasized that, for successful installation and operation of SMS4DC, the administration should have in place existing legal, regulatory and technical mechanisms for national spectrum management. Also, while the system automates many of the technical processes, the final choice and decision for the frequency assignment remains with the engineer. Therefore, operating staff must have sufficient knowledge to understand the regulatory and technical processes that are the operational core of SMS4DC and to interpret correctly the results of the algorithms so that they can make good decisions.

The main features of SMS4DC include:

– User-friendly graphical user interface (GUI)

– Incorporating the ITU IDWM

– Installable in networked environments

- Availability of different user access levels
- Employment of digital terrain model (DTM) on server or workstations
- Management of a shared hierarchical administrative database
- Integration of several propagation models
- Demonstration of calculation results on DTM
- Generation of BR electronic notice forms
- Interference calculation
- Frequency assignment
- Consideration of regional/national frequency allocation tables
- Consideration of regional agreements in technical calculations
- Frequency-planning capabilities
- Interface with BR-IFIC databases
- Generation of informative reports
- Employment of ITU modules for coordination contour calculation around Earth stations
- Frequency spectrum billing management
- Link budget calculation
- User log for audit control
- English and French software interface (soon also Spanish)
- Links to Argus (R&S) and Esmeralda (Thales) monitoring software
- Interface to Google™ Earth mapping
- Calculations according to the GE06 Agreement

3 Main functions of the SMS4DC

- *Administrative function*. This function is implemented on a relational database management system that ensures the integrity and consistency of the administrative data. It provides user screens that perform all administrative tasks including: frequency application records, frequency assignment records, licensing records, interference records, frequency measurement records and spectrum fee records. For the time being, the program is available in the English language. In due course, it will be extended to the French, Spanish and Russian languages.
- *Engineering analysis function*. This function provides enhanced analysis tools for processing proposed frequency assignments requested by applicants. It also provides the capability to calculate interference between one or more transmitters and a victim receiver under specified conditions.
- *Graphical user interface*: User friendly interface, displaying of DTM, capability of importing standard mapping formats including Globe map and displaying of geographical maps, providing multiple entry functions, menu items, assigning new stations on map and searching and displaying a station or group of stations on map

Detailed information on SMS4DC is available in the ITU Handbook on Computer aided techniques for spectrum management.

ANNEX 2

TO CHAPTER 7

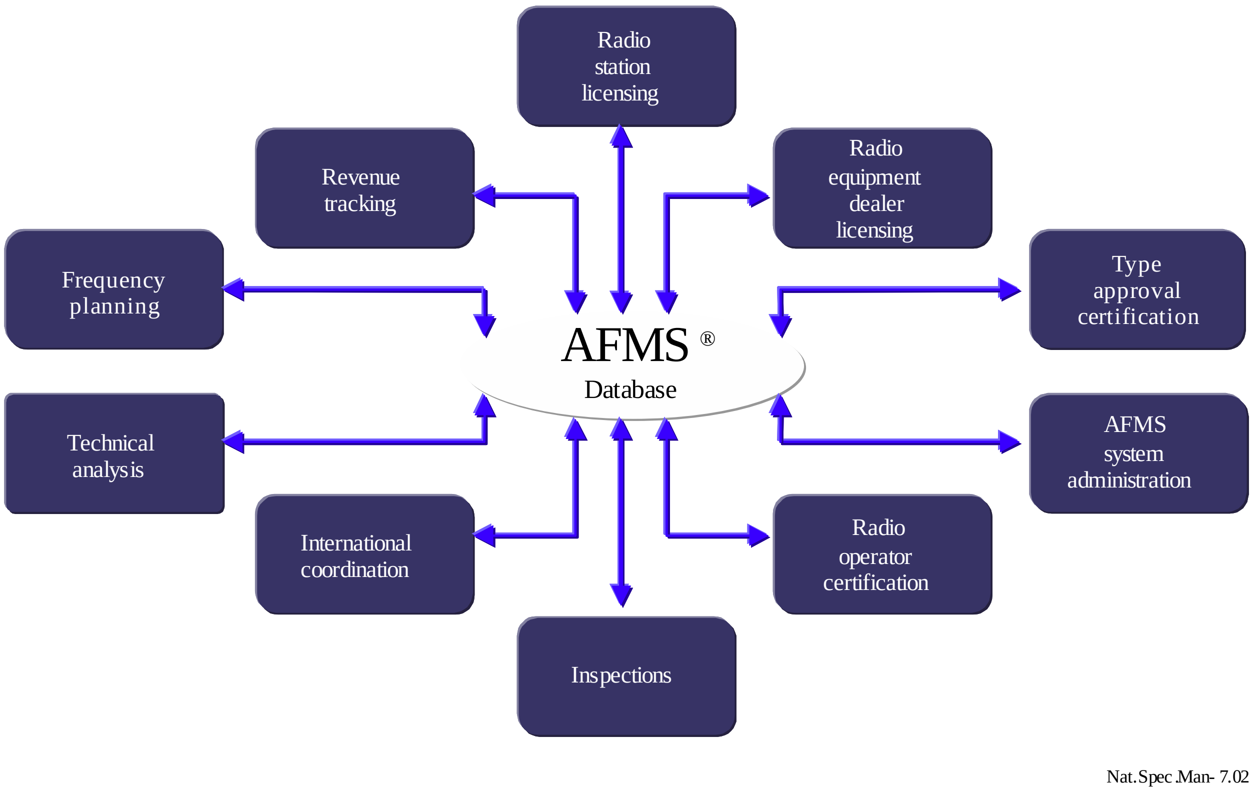
Radio spectrum management in Malaysia
(a case study)

The AFMS is a windows-based computer system and consists of all requirements for managing large amounts of information pertaining to radio station licensing. The AFMS is based on international standards and technical specifications. Included in the system is a data entry module for entering information from a radio station application. As illustrated in Figure 7.2, there are modules for revenue administration and control, frequency planning, technical analysis, frequency coordination and notification, spectrum control, dealer licensing, authorization and automated radio station licence production and renewals. All of the modules work around a frequency assignment and licensing database in an ORACLE database structure.

The Malaysian government contracted for an automated frequency management system based on the Canadian model of spectrum management. The system was custom developed to meet the requirements of Jabatan Telecommunicasi Malaysia (JTM). The system was fully integrated and consisted of a comprehensive spectrum management system operating on a centralized VAX network located in Kuala Lumpur that included a radio monitoring system interface.

FIGURE 7.2

AFMS Modules



Up to the time of installing the AFMS the Malaysian government had maintained all of their frequency assignment records and associated licensing information in a paper-based filing system. Paper files had proven to be inefficient and ineffective. Frequency assignments, revenue and licensing records on paper files had proven to be difficult to control and administer. Harmful interference was becoming a serious issue with wireless operators in Malaysia who were concerned that their operations might eventually become compromised and costly to resolve. With the growing number of radio stations in a rapidly developing society in Malaysia it was clear that automation was essential.

The installation proved to be more difficult than had been anticipated due to the lack of complete and accurate information and inadequately configured frequency assignment channelling. Complete and accurate information is essential in order to establish an effective frequency assignment and licensing database. Although certain information can be defaulted, automated applications require reliable information with which to complete accurate operations.

As with any technology, obsolescence is a reality that needs to be addressed in a progressive administration. Malaysia continued to look for technology upgrades, as well as expert consulting and training over a number of contracts during the 1990s. In 1999, during the ITU sponsored "Telcom '99" in Geneva Switzerland, Malaysia approved a contract to upgrade the computer systems at JTM, which had been reorganized to become the newly established Malaysia Communications and Multimedia Commission (MCMC). Through the foresight of the Malaysian government, the current contract includes a significant provision for spectrum management consulting and training.

As a consequence to establishing an effective frequency assignment and licensing database and an efficient and modern spectrum management operation, licensing revenues in Malaysia have grown significantly as the radio community increases. At the same time, operating costs have been maintained fairly constant. Based on the principle of cost recovery, licence revenues can be used to finance the spectrum management program.

The success of the spectrum management initiative in Malaysia was primarily due to the recognition by the Malaysian government that it was necessary to focus on the transfer of knowledge in addition to technology.

The MCMC website address is http://www.cmc.gov.my.

ANNEX 3

TO CHAPTER 7

Description of spectrum management and monitoring system (SAAGER)

1 Introduction

This Annex outlines the Automated Radioelectric Spectrum Administration and Management System (SAAGER) presently in use by the National Telecommunications Commission (CONATEL) of Venezuela. The SAAGER system is a fully ITU compliant Spectrum Management and Monitoring system and the hardware meets or exceeds the recommendations set forth in the ITU-R Spectrum Management and Spectrum Monitoring Handbooks. The system was supplied by TCI, U.S.A. (www.tcibr.com).

The system allows the Ministry of Infrastructure (MINFRA) acting through CONATEL to effectively utilize the radioelectric spectrum. The system has the following abilities:

Planning and management of the radioelectric spectrum

– Planning of spectrum resources.

– Provides the latest ITU compliant technology that is expandable to permit growth as Venezuela's telecommunications infrastructure grows.

– Enables cooperation with neighbouring countries about frequency assignment needs and interference problems.

Monitoring and technical verification of radioelectric emissions

– Performs all ITU-recommended radioelectric measurements.

– Avoids and resolves interference problems during the installation and operation of critical services such as cellular telephones, terrestrial microwave links, private mobile radio, and wireless local loop.

– Provides the monitoring staff with a list of noncompliant signals and their characteristics.

– Identifies and enables prosecution of illegal operators to collect fines and protect legitimate operators of the spectrum from interference.

Radiolocation of radioelectric emissions

– Determines lines of bearing and locations of interfering, illegal or other noncompliant signals as an aid to enforcement of the Venezuelan radio regulations.

Standardization of telecommunications equipment

– Maintains a type-approved telecommunications equipment database so that only approved equipment is licensed in Venezuela.

The system consists of the following sites and equipment, with quantities indicated in parentheses:

– *National Control Centre (1):* Located in Caracas, acts as the hub of the system, housing the Spectrum Management System Database; generates operational tasks, directs and controls operational activities of the monitoring stations; receives and consolidates the resulting data.

– *Auxiliary Control Centres (5):* Located in Caracas, Maracaibo, Cristobal, San Felipe and Maturin; provides monitoring and technical verification capabilities in the HF/VHF/UHF ranges.

– *Mobile Units (10):* Two per Auxiliary Control Centre provides HF/VHF/UHF monitoring capabilities and HF/VHF/UHF DF (three units) and VHF/UHF DF (seven units) capabilities.

– *Portable Equipment Sets (10):* Provide technical verification capabilities.

The locations of the sites are illustrated in a map of Venezuela which appears in section 3.5 of this Annex.

2 Spectrum Management System

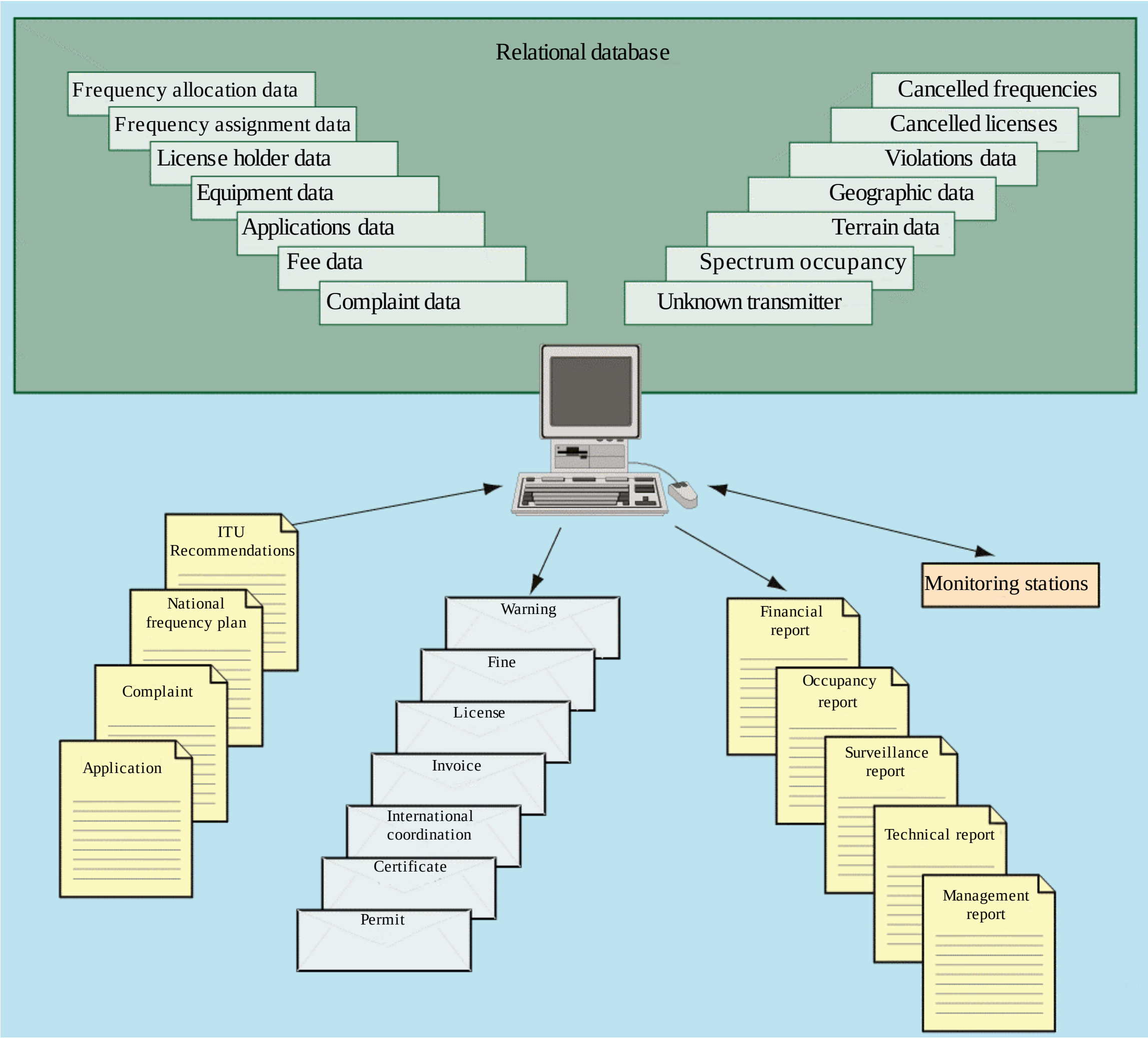
This section provides the functional description of the Spectrum Management System. Figure 7.3 shows the functional flow of the management software.

2.1 Application Processing

A typical example of the processing of an application for a license is illustrated in schematic form in Figure 7.1, including the process of receiving an application and entering it in the system, performing frequency assignment and issuing a license. The system includes built-in data entry forms to help the administration process applications for frequency assignment and licensing. These forms are used for new services as well as changes and modifications to an existing license or a pending application. The input application screen is shown in Figure 7.4.

FIGURE 7.3

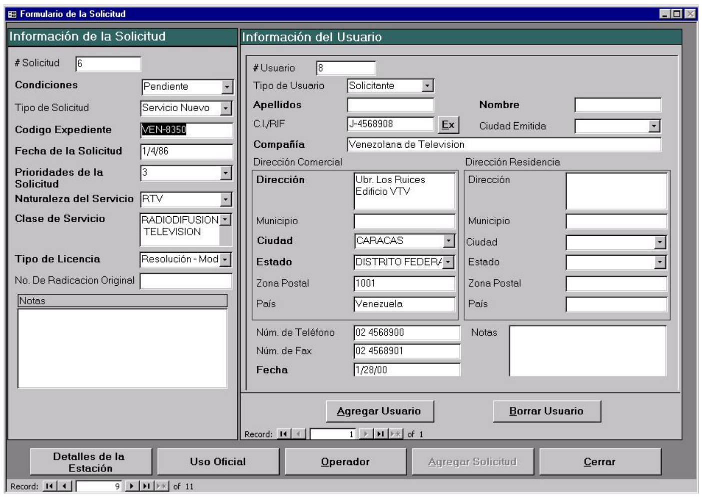
Functional flow through of the management software



Nat.Spec.Man-7.03

FIGURE 7.4

Application form



Nat.Spec.Man-7.04

2.2 Frequency assignment

The operator has access to a variety of built-in functions that help with frequency assignment. These functions:

– show possible channels for a particular equipment and service;

– search the license database for existing assignments and display those for the various possible channels;

– perform interference calculations between the proposed new assignment and existing assignments and

– enter new assignments in the database.

2.2.1 Frequency assignment process

The system supports the automatic assignment of frequencies, including ITU service designations and national service priorities and footnotes. The software is loaded with the ITU Frequency Allocation Plan for Venezuela. An operator can have the system display channels consistent with the Venezuelan National Frequency Allocation Plan, specified equipment types, planned types of services/operations, or operator-specified categories. The system searches its database for existing assignments on these channels and displays them. Interference calculations between existing assignments and a proposed new assignment may be made. The operator may then assign a frequency, which is entered into the database. If it is not possible to find a usable channel in a particular region, one or more of the ASMS spectrum engineering analysis tools can help the operator to locate an available channel based on geographic area or find a frequency within the region that can be shared based on hours of operation.

2.2.2 ITU and National Frequency Allocation Plan

The system operator has the ability to review and update the frequency assignments to each station class. Parameters include frequency range, station class, channel width, and constraints such as co-channel separation distance.

2.2.3 Border coordination

The system contains an International Coordination module that is used by the system managers to process all coordination requests (incoming and outgoing). These requests can be from other countries, the ITU or from another agency inside Venezuela. All licensing information is held on a single database. The module draws the information required from the database for each request. This information includes: date, license number, type of data required, party receiving the communication, and the transmission format (paper or electronic). As part of the coordination inquiries, a permanent record is created and logged into the database.

2.3 Licensing

The majority of the license processing and issuing functions are automated in the system. This allows the system to automatically create a license after the application has been approved. The system provides a form-based interface supporting the following activities:

– renew an existing license for which all conditions of renewal have been satisfied;

– convert a temporary license to a permanent license;

– terminate a license for non-compliance with existing requirements for operation; and

– issue a temporary license or permit.

2.4 Spectrum engineering

Following ITU recommendations the Automated Spectrum Management System was built with a set of powerful engineering analysis tools to assist the operators. These tools are used for the study of the radio spectrum and include Electromagnetic Compatibility (EMC) calculations, radio link performance and station coverage. The analysis tools are used for license applications, coordination requests and interference complaints. Table 7-1 shows the algorithms and models that are resident on the system, and the frequency ranges and types of services they cover.

TABLE 7-1

Engineering analysis module propagation models

Frequency range	Propagation model	Commentary
0.15 to 3 MHz	GRWAVE	GRWAVE computes the electric field strength and path loss with distance for ground wave propagation along a curved, homogenous, smooth Earth. It is also used for the MF band interference analysis
2 to 30 MHz	IONCAP, VOACAP	IONCAP is the name of the original ionospheric analysis program. The most current version, called VOACAP, has been integrated in the Engineering Analysis module. This program can calculate the MUF, LUF and FOT for point-to-point HF communications
30 to 1 000 MHz	TIREM (Version 3.04)	Acronym for Terrain Integrated Rough Earth Model. Developed originally for the U.S. National Telecommunications Information Administration (NTIA) as a part of the Master Propagation System (MPS). MPS is a family of models that stretch from VLF to Millimetre Wave Frequencies
30 to 1 000 MHz	Longley-Rice	U.S. Federal Communications Commission (FCC) Tech Note 101, documents the use of single knife edge and double knife edge diffraction models where prominent terrain features are known for a particular propagation path
Up to 40 GHz	SEAM	Acronym for single-emitter analysis model. Calculates propagation loss and field strength for microwave signals using a free space or smooth Earth propagation model
1 to 40 GHz	Appendix 7	Calculates coordination contours for terrestrial stations and geostationary satellites according to Appendix **7** of the RR
1 to 40 GHz	Appendix 8	Calculates interference between two geostationary satellite networks according to Appendix **8** of the RR

The Engineering analysis tools are integrated with the ArcView mapping program from the ESRI company. This allows the system to display the calculated information over a geographic and topographic map. The mapping program is automatically activated when needed by the system.

The engineering analysis module performs functions including, but not limited to the following:

– base station radial path profiles and coverage diagrams;
– co-channel, adjacent channel and interstitial channel interference analysis;
– multi-signal third order intermodulation analysis;
– receiver desensitization/transmitter noise analysis;
– enables personnel to perform analysis of candidate frequency assignments selected for applications received;
– enables personnel to perform analysis of candidate frequency assignments for incoming coordination requests;
– automatically uses the default algorithm/model for the frequency band and type of service being analysed;
– enables tools to be run on-line;
– enables personnel to update actual system technical records upon completion of an analysis;
– retrieves occupancy data from the monitoring system database;
– allows the system manager to use a different model;
– allows the system manager to update the input data to better represent local conditions; and
– displays the results of propagation analysis over a digitised map incorporated in the system.

2.5 Engineering reports

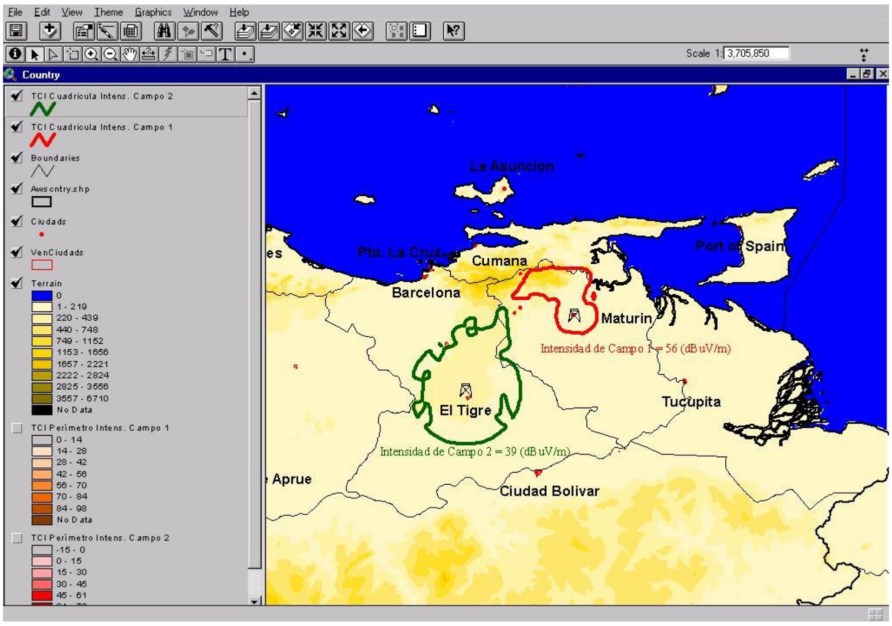
The spectrum engineering analyst accesses the spectrum engineering module to analyze the electromagnetic environment and obtain reports. On selecting a required report, the system presents a screen where the operator enters all the necessary parameters and then may select the format of the report (tabular or graphic). The following reports are available from the system:

– Link analysis and path loss.
– Propagation analysis.
– Field strength contour
– Shadow plot
– Service area analysis
– Interference analysis
– Terrain profile plot.
– Terrain profile plot.
– Intermodulation analysis.
– EMC analysis tool
– Antenna height analysis
– Microwave frequency planning
– Satellite Appendix 7
– Satellite Appendix 8

Figure 7.5 shows a sample report that is available from the system.

FIGURE 7.5

Interference analysis



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3 Spectrum monitoring

The spectrum management system is integrated with a spectrum monitoring system in accordance with Recommendation ITU-R SM.1537. This gives managers the ability to control the frequency spectrum in Venezuela. The fully integrated system can receive taskings from the management system and also send reports back from the monitoring stations. Each of the monitoring stations downloads a copy of the management database on a regular basis. This allows the monitoring stations to have the most up-to-date information on licensed emitters.

The system software runs in a standard Windows NT client-server environment and provides a fully ITU-compliant solution to the administration's spectrum monitoring needs. The monitoring software provides the capability to access, display and save the measurement results produced by the monitoring system. The results can be displayed in alphanumeric or graphic form.

Graphic displays are presented over a map background using the same family of geographic information system software as the management system. The displays include the following information relative to an operator selected monitoring system:

– bearing lines for a signal measured off the air;
– distance and position for a measured signal; and
– locations of licensed transmitters from the database.

The display includes a list of measured signal parameters. The operator has the option to request a hard copy print of the display. The monitoring software provides the facility to access, display and save the measurement results produced by the monitoring systems. The following measurement information is available for each signal monitored off the air:

– measured signal frequency;
– measured field strength;
– measured modulation parameters;
– measured occupied frequency bandwidth; and
– measured direction of arrival.

3.1 Software capabilities

The Software contains the following capabilities:

Metrics: These facilities provide the means to make precise measurements of signal parameters in accordance with ITU recommendations. These facilities are used to verify compliance with license requirements and can be made on a scheduled basis.

Device control: These facilities are used to find, identify and record parameters of specific emitters, usually unlicensed pirate systems or sources of interference. These facilities include extensive direction finding tools to locate the target emitter.

Tools: These tools are used to survey, detect and map the spectrum for the presence of signals. These are basic means to check if the actual electromagnetic environment corresponds to information contained in the management database. The Automatic Violation Detection (AVD) tool will report compliance and discrepancies between the management database and the "real" electromagnetic environment. Spectrum occupancy tools provide statistical checks to verify that the assigned channels are being used in accordance with their licenses.

Diagnostics (BITE): This facility is used to obtain the operational status of a server (fixed, mobile or portable monitoring station).

3.2 Metrics measurements

The metrics contain "Task calendars" and "Task results" that allow the operators to set up the system to make measurements. The software provides a network connection for the "Interactive mode" and another for "Scheduled mode" of performing measurements.

– The interactive mode allows direct interaction with instantaneous feedback, such as monitor receiver tuning, demodulation and spectrum panoramic display selection. (NOTE: Direction finding actions may be "immediate" or "scheduled.")
– The scheduled (Calendar) Mode provides a calendar feature where a client may reserve time slots on a selected server to make requested measurements. A single server is able to handle requests from multiple clients. Note that once the measurement task has been sent to the server, the client may disconnect from the link until it needs to retrieve the results.

As part of the software, the operator has a variety of built in tools that help customize various different tasks. The operator can add additional scheduling requirements that will help with checking interference complaints. If the complainant can give a specific time of the day that interference occurs the operator can task the system to check at those times. The operator can also task the system to run immediately if required. The scheduling tab also allows the operator to schedule how often and how many times the measurements are to be executed. The operator is able to view, print and save a report that summarizes the data that was collected. Measurement results reports contain all information relative to the measurement setup and a summary of its results include the following information: task data, date, time, frequency, bandwidth, identity, requested measurement(s), type, result, and graphical data. One or more of the following parameters may be selected for measurement: occupied bandwidth, modulation, field strength, frequency, and direction.

The measurements are fully compliant with ITU Recommendations and the Handbook on Spectrum Monitoring. These parameters are automatically repeated and averaged according to user selected values. The averaging techniques include linear, RMS and maximum hold techniques.

3.3 Map display and control

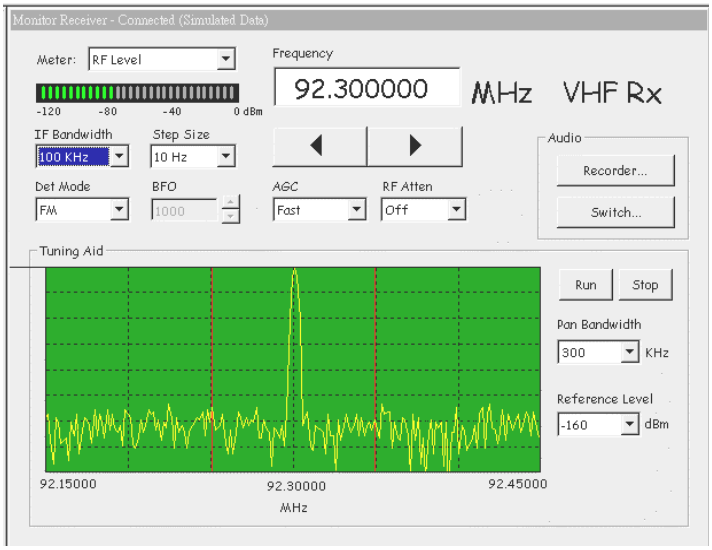
The map window displays the network monitoring stations, results of DF operations, and the locations of emitters (with error ellipses). The system is configured with multiple maps. The operator has the ability to display multiple layers (cities, regions, rivers etc.) of Venezuela by selecting the "Layers" button. The operator can zoom in, zoom out, pan, centre, or do measurement functions.

3.4 Monitor receiver

The operator has control of the built-in monitor receivers through a virtual control panel (VCP) (see Figure 7.6). The VCP has familiar controls associated with typical standalone receivers, providing interactive control of the receiver unit to view the signal being monitored in real-time. Receiver status information and controls for frequency, modulation, and amplitude control are displayed on the same screen. The computer also has a built-in audio switch and sound card. Audio recordings are made digitally as audio files (.wav) and can be transferred between all stations.

FIGURE 7.6

Monitor receiver screen



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The operator has access to a number of displays that allows looking at the frequencies of interest. The spectrum panoramic (or Pan) is one of these displays. It is an X-Y plot of signal amplitude versus frequency and can display up to 10 MHz bandwidth of IF digital data. The operator can use this display to view and identify wideband signals, signal relationships in the radio spectrum, and to investigate sources of interference.

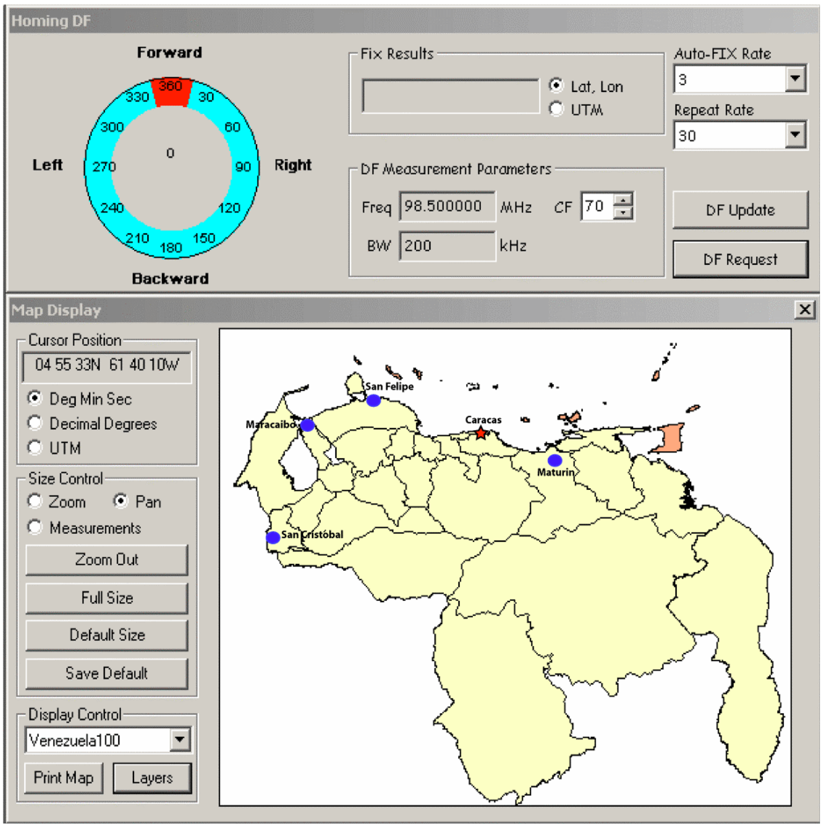
3.5 Direction finding (DF)

The DF system has the ability to quickly and effectively find the location of emitters using the monitoring stations. The system can calculate the results from two or more of the stations as well as use a single mobile station to perform “Drive Down” DF.

“Drive down” DF lets a single mobile monitoring station take successive DF and signal strength measurements while on the move. From these measurements the mobile monitoring station homes in on the location of the transmitter (see Figure 7.7).

FIGURE 7.7

Example of a DF/map display window



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3.6 Monitoring simulation for training

To help train new operators and the keep existing operators up to date the monitoring software has a built-in training module. This training module allows new users to become familiar with scheduling measurements and controlling the receiver without tying up resources or creating/deleting measurements in the operational monitoring database. It also helps existing operators to practice their monitoring assignments and techniques.

The training module is fully interactive and uses the on-line help on a laptop or workstation as well as the supplied hard copy users manual to help a new user become familiar with the interface, graphical displays, and the reports available in the system. The training can be performed without actual monitoring hardware being available on the network.

3.7 Spectrum monitoring system functions

The spectrum monitoring system performs all of the ITU-recommended measurements, including signal parameter measurements (frequency, field strength and power flux-density, modulation, and occupied bandwidth), direction finding and spectrum occupancy. The automatic measurement execution system automates this entire process so that the operators do not have to learn, remember, or spend time observing the various measurement rules.

Spectrum occupancy allows the operator to define the monitored range by specifying the start and stop frequencies of the band to be searched and to specify search parameters, including the time period over which the search may be done.

The monitoring system has, as a central feature, automatic violation detection (AVD). AVD is a powerful tool that allows for the verification of compliance by licensed emitters and detects unlicensed operations. AVD operates in conjunction with the license data (frequency assignments) taken from the management database. AVD determines whether a particular transmission complies with tolerances of assigned center frequency and bandwidth, as specified for the allocated band and service in the Venezuelan National Frequency Plan. It also reports on emitters that are being operated without a corresponding license in the management database. AVD measurements can be performed on a single-frequency or on a range of frequencies specified by the operator. Figure 7.8 illustrates a typical results screen from AVD.

3.8 Reports

Reports of signal parameter, spectrum occupancy and other measurements are available from the system.

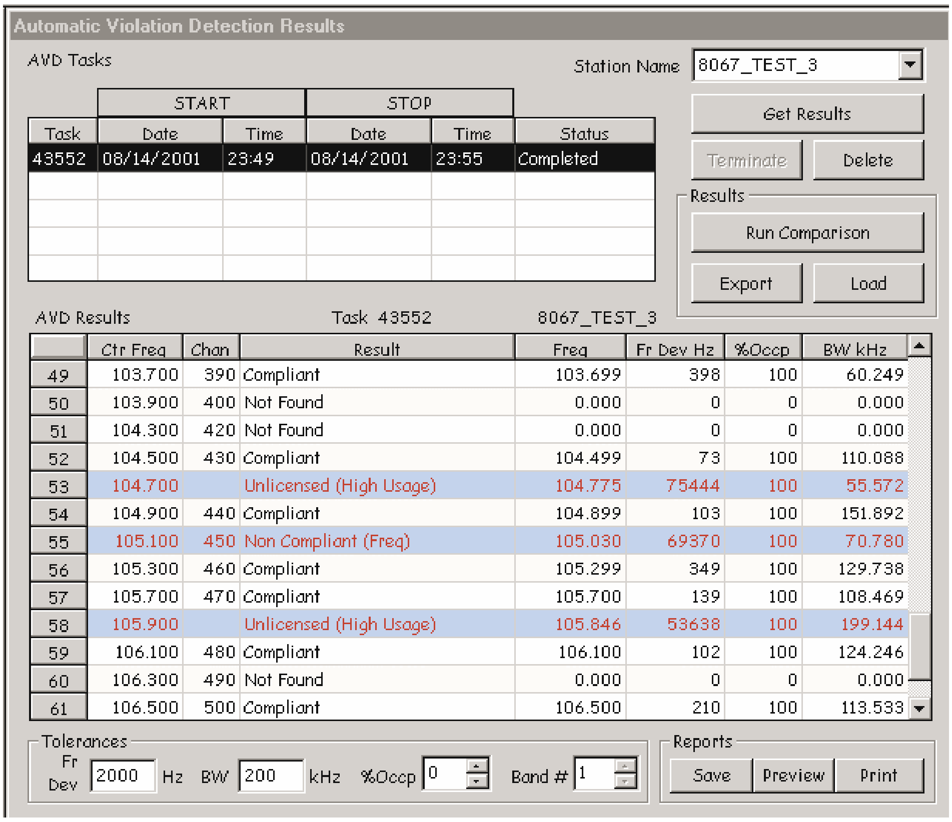
4 CONATEL's use of the system

The introduction of the new integrated spectrum management and monitoring system has fundamentally changed the way CONATEL conducts business. Before the system was introduced licensing and fee processing was a time consuming process that often took weeks to complete. All entries had to be done manually and there was no way to predict how the new emitters would interact with those already in place. Engineering analysis had to be conducted with handheld or portable equipment that had limited capabilities and no integration with the management system.

Since the introduction of the new system the licensing and fee processing can now be done in a matter of hours. With the built-in engineering analysis tools and complete access to the spectrum monitoring capabilities described in this document, the spectrum management system can assign and check each frequency for availability and compatibility with existing emitters.

FIGURE 7.8

Example of automatic violation detection results



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The fully integrated management and monitoring system supplies outstanding control, reporting and data-exchange; it has the ability to use information from both the management system and the monitoring stations to regulate the frequency spectrum. The system uses the AVD abilities of the system to investigate customer complaints and to find emitters that are violating their assigned frequency specifications (bandwidth, power etc.).

4.1 Complaint and violation detection

In the system the main database is used as the central storage point for all complaints. On reception of a complaint from a customer the compliant is checked against the stored list of complaints to see if it is a new complaint or one that has been made before. Once the complaint is determined to be new, the spectrum monitoring software is used to collect frequency measurements from the offending station for further investigation. A wide range of engineering analysis tools were provided as part of the integrated software, and are used to analyse the complaint.

The system includes three forms for working with complaint information: Complaint form, an inspection form, and a violation form:

– The complaint form includes information describing both the incident that caused the complaint and the person making the complaint.

– The inspection form is used to record information about inspections in connections with violations and complaints.

– The violation form is used to record information about violations received in connection with a complaint.

The software allows the operators to collect all pertinent data and the review the complaint. The staff can then either reject the complaint or take some other action, such as fining a license holder or terminating a license.

4.2 Expandibility

The use of the radio spectrum is a constantly evolving process. As more uses are found for the radio spectrum the spectrum management and monitoring system needs to have the capability to expand with these uses. The system was designed with this expandability in mind. The system is modular in design and has a powerful core capability that makes it easily adaptable to future needs. Future expansion possibilities include: upgrade of analysis algorithms for analysis and demodulation of new communication formats, addition of mobile or fixed systems, extending frequency range of mobile stations and adding operator workstations.

5 Experience of others with automated spectrum management system used by CONATEL

5.1 Introduction

The previous sections of this Annex describe the automated spectrum management system in use by CONATEL. The system described above and in References 1 and 2* was supplied by TCI. It is currently being used by several regulatory authorities around the world in addition to CONATEL, including those in Zimbabwe, Colombia, Namibia, Mauritania, Dominican Republic and Uganda. This section summarizes some of the benefits which these users have experienced from the system.

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* References:

WOOLSEY, R. B. [2000] Proc., ITC/USA 2000, Automatic Tools for Telemetry Test Range Spectrum Management. TCI, A Dielectric Company, 47300 Kato Road, Fremont CA 94538-7334.

Spectrum Management Systems, http://www.tcibr.com/PDFs/710webs.pdf

Examples of how this system has automated and improved spectrum management operations for these administrations include:

– One administration used to process 10-20 applications per week, with a backlog of 4-8 weeks for processing and approving a typical application. After the system was installed and the operators trained, the same organization was able to process, assign frequency, and approve 90 applications during the first week of full operation.

– Some administrations have traditionally used separate groups of people to administer broadcast services and telecommunication services, so these administrations never had a unified process for handling and approving licenses. Once they acquired the system described in this Annex they could have a unified database and unified approval and frequency assignment process for all users of the spectrum. They continued to use separate groups of people for different services, but all people used the same system, and all administrative and technical information was stored in a central location.

– These administrations also added to the system database the function of processing, approving and invoicing for permits and licenses for services that did not require use of the spectrum, such as wire based telephony, or value-added services. Traditionally, the administration of these services was handled by small separate spreadsheet programs. The system allowed these administrations to maintain a unified database of all their customers, and all their sources of revenue.

Other examples that apply to specific topics are discussed in the appropriate section below.

5.2 Application processing

The system provides for data entry and processing of applications for service, enabling an administration to perform the frequency assignment and licensing functions described in Chapter 3 of this Handbook. Most users of this system have found it convenient to print paper application forms directly from the system. These forms are then filled out by applicants. Data from these forms is then easily entered into the system.

5.3 Frequency assignment

The system assists the operator with the frequency assignment functions described in Chapter 3 of this Handbook. The administrations using this system have all found the convenience of automatic database searches for other transmitters on a proposed frequency, and the assistance the system provides in assigning frequencies, to be very powerful.

5.4 Spectrum economics

The system includes an integral accounts receivable financial package and administers fee processing, which is a key element of the spectrum economics described in Chapter 6 of this Handbook. Some administrations which use this system had not processed license renewal invoices for years prior to acquiring the system, because renewal processing was too cumbersome with their paper- or simple computer-based filing systems. The system allowed these administrations to easily obtain revenue from license renewals.

5.5 Licensing

The system automates most of the license processing and issuing functions described in Chapter 3 of this Handbook. Some administrations which use this system originally had their licenses in paper form in filing cabinets, where they were not readily available for queries and searches. The data from these paper licenses have been entered into the system and are now part of its database, readily available for computer searches and for use by the system when new frequency assignments are made.

5.6 Spectrum engineering

The system has powerful tools to assist operators perform spectrum engineering functions described in Chapter 5 of this Handbook. Administrations which use this system have found these tools particularly useful for answering “What if” questions, aiding administrations in their spectrum planning activities.

5.7 Spectrum monitoring

The integrated system performs the spectrum monitoring functions described in Chapter 4 of this Handbook. Perhaps the most important advantage of a completely integrated system is automatic violation detection. An integrated system may compare measurements from the monitoring system with license information from the management system to identify frequencies on which there are transmitters that are not included in the license database and to identify transmitters that are not operating within their licensed parameters. Some users of this system specified AVD in their tender documents to be part of the spectrum management and monitoring system, and found it an extremely useful tool to assist operators in detecting unlicensed transmitters and transmitters operating outside their licensed parameters.

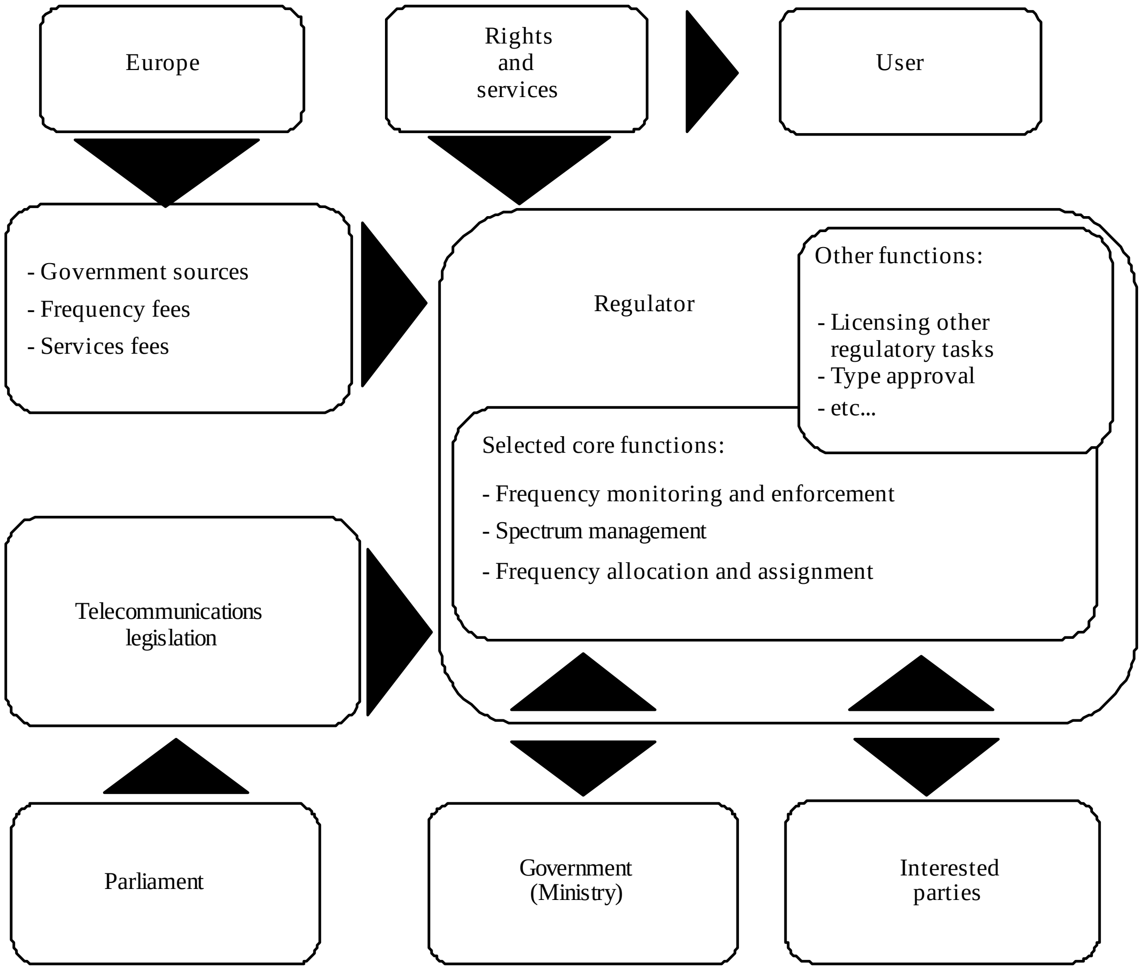
ANNEX 4

TO CHAPTER 7

Software and automation example spectrum management in Central and Eastern Europe

Eleven beneficiary countries of Central and Eastern Europe took part in a major year-long project under the phare multi-country program financing by the European Union to analyse problems and identify solutions concerning spectrum management and frequency monitoring. Despite the specialized technical nature of the subject, much of the project was devoted to examining how to develop regulatory institutions, and to define their tasks, their tools, and their financing options. The rationale for this is to establish the kind of independent National Regulatory Authority (NRA) as public service body in line with practice in the EU Member States.

The regulatory system for radio-based communications, like the overall national telecom regulatory regime itself, is perceived as part of a wider political, legal, and business environment.



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Promoting regulator independence does not mean, however, that the state has to abandon all influence on political issues affecting telecommunications sector development. There is and will remain a political dimension to regulation. What is important is to establish a clear and unambiguous division of responsibilities and tasks between the political level (i.e. the relevant ministry) and the regulatory level (i.e. the NRA).

One the one hand, the political system must provide the legislation and the parliamentary control under which the regulator works. On the other hand, the practical realisation of day-to-day NRA operational independence – if properly arranged – can provide support for the principles of democracy and good governance.

Financial independence is one effective way for the NRA to achieve operational independence. The necessary income for the National Regulatory Authority can be raised by means of user fees and charges. The development of modern regulatory administrations in the CEE countries depends on a number of factors that differ from one country to another. Although the modernization process has started throughout the region, progress by 1998 still varied widely in individual countries.

The project looked at five key issues facing the creation of National Regulatory Authorities and recommended that the priorities be set out as follows:

– Establishment of the legislative basis
– Settling the institutional structure
– Deciding the financial possibilities
– Developing the human resources
– Acquiring the necessary technological tools.

The way each participant country addresses these priorities sets the stage for its approach to modernization. The SMFM (spectrum management and frequency monitoring) project has attempted to investigate these approaches.

The main common observations in the countries indicate that:

– The professional regulatory staff has generally a good knowledge of new targets.
– The process of regulatory change risks getting lost among other change processes.
– The dialogue between different sectors within national administrations can be improved. The dialogue between the regulatory body and the ministry of finance may need strengthening.
– The potential (and current) level of collected fees and charges could in most of the CEE countries seems sufficient to cover the regulator's expenditures (provided the correct allocation and transfer procedures are put in place).

The observations confirm the feasibility of establishing the regulator as a financially independent body, with the realistic possibility of generating a surplus (i.e. a net income for the State). While a lot of attention is focused on the respective rights and obligations of ministries, regulators and telecom operators, the regime whereby the regulator can finance his recurrent costs and investments is underdeveloped in many cases.

The draft plans produced show a modernisation process to be finalised in the different countries between 2000 and 2006. In these plans the first application, according the priorities, has been the implementation of a standard interface for spectrum (P-Interface) between each country allowing administrative exchanges for trans-border cooperation, P-Interface is today working.

P-Interface: a standard interface for spectrum

Despite the different national approaches to spectrum management highlighted in the previous architecture are practical areas where trans-border cooperation is possible and beneficial. The ability to exchange radiocommunications data and frequency management software is one such area. The Phare multi-country common tool described here looked at the development of a standard interface (The P-Interface) as a common tool to exchange data and software between national spectrum management systems. P-Interface is a contribution to the wider goal of facilitating the growth of radio-based services and reducing the risk of harmful radio interference.

The P-Interface software corresponds to a virtual database server that allows its clients access, in a transparent way, to a set of underlying databases. As participants in this 12 months project, 11 countries in Central and Eastern Europe plan to implement the P-Interface layer to exchange data and software among each other. One of the major benefits of the P-Interface is to enable the same compatibility calculation programme to be used by different administrations. Compatibility calculation software developed for one administration is portable to all other administrations. In other words, an administration is able to apply its own compatibility software to data received from a foreign administration and also to run a compatibility software programme received from the foreign administration in its own environment. One example of this common compatibility software is the harmonized calculation method (HCM).

The P-Interface presents a unique application programming interface, allowing the certification of compatibility software. In this way, the software development burden can be shared among participating administrations. Computer assistance ensures that the exchange of radio communications data is complete and consistent. Direct data exchange between administrations is shortening the coordination process with the final objective of facilitating the development of radio-based services and reducing interference risks.

The implanted technology is based on the client/server concept where the relevant data in national spectrum management systems is accessible via server services. With a standard interface to the server, data is seen as being placed in a container with a transparent means of accessing. The internal data structure or the means of data storage therefore become irrelevant and invisible for the client application.

The principles of the P-Interface offer a harmonised approach for the following:

Utilization of a unique data dictionary

One of the main problems in data exchange is the unique identification of data elements. Data elements used by the P-Interface are those defined by the ITU’s Radiocommunication Study Groups. Every administration is able adequately and clearly to identify frequency management information.

Definition of a common radiocommunications database structure

Each data element is allocated as a database attribute to a radiocommunications entry managed by the P-Interface. The database structure integrates the latest results of the ITU Study Groups and can be adapted to take account of the needs of compatibility calculations.

Encapsulation of native database

The P-Interface encapsulates the user's database in a way that the client sees the “Standard P-Database” which contains relevant information for frequency coordination and compatibility calculations; The P-Interface is capable of encapsulating a number of data containers in one database session. In doing so, all legacy applications is preserved.

Utilization of a common map server

Diverging coordinate systems are in use among participating countries. To solve this problem, the P-Interface exposes a common interface to digital terrain data. P-Interface has retained World Geodetic System 1984 (WGS84) as the reference coordinates system. P-Interface offers conversion services between native coordinates systems and WGS84.

Data exchange support

In the proposed concepts, data exchange becomes a simple act of sending a transport container to a foreign administration. Transportation of the container is based on the Internet. A typical scenario is that data is forwarded in the transport container. The container is connected to the user's database. On the client side of the P-Interface, no distinction is made as to whether a particular data element is taken from the transport container or from one of the local containers.

In summary, the problems addressed by this project were complex because of the various environments already existing among participating countries. The scope of the project was multi-disciplinary requiring solutions to problems such as frequency management, advanced computing methods, heterogeneous database access and computer system architectures.

ANNEX 5

TO CHAPTER 7

National frequency management in Turkey

Introduction

As a result of growth in spectrum demand, many countries are faced with the need to more strictly enforce the regulations governing frequency usage. Licensed wireless system operators must be monitored to ensure their networks are not straying from their assigned wavelengths, and rogue television or radio stations must be traced and dealt with.

The government of Turkey has taken an aggressive step to make sure that there are enough frequencies to meet the growing demand. The Telecommunications Authority in Turkey has developed a multi-location National Monitoring System that performs the following functions:

– Supervise radio signals.

– Measure spectrum occupancy.

– Measure radio and TV broadcast transmission.

– Detect frequency infringements.

– Determine and map radio coverage areas.

– Analyse signal interference.

– Locate illegal stations.

– Gather statistics for general frequency management.

A primary element of this system is the National Frequency Management System (NFMS), which includes two key software components that integrate the latest spectrum engineering, propagation modelling and geospatial data viewing techniques to accomplish the objectives of the Authority. The Turkish Telecommunications Authority, which is similar to the U.S. Federal Communications Commission, awarded the NFMS contract to Communications and Spectrum Management Research Center (ISYAM) of Bilkent University in Ankara on the basis of its long-standing involvement in studying spectrum engineering in telecommunications applications, specifically for frequency planning, assignment and usage.

The National Monitoring System (NMS) includes a National Control Centre (NCC) in Ankara and seven Regional Monitoring Centres (RMCs) located in different cities of Turkey. There are fixed and transportable monitoring stations as well as mobile broadcast measuring systems and mobile monitoring vehicles which carry direction finding and monitoring equipments similar to those in the fixed stations. The spectrum monitoring system is what the Authority uses to monitor frequencies, analyze interference between stations, check the compliance of radio station parameters upon licenses and locate illegal emissions. The frequency range of NFMS spans 10 kHz to 40 GHz while the monitoring system covers the frequencies from 10 kHz to 2.5 GHz.

The project was contracted on May 1998. Detailed requirements specification and analysis, followed by system design and development resulted in emerge of the first version of NFMS, which was first put into service at NCC and Ankara RMC. During the following one year, feedback coming from the administrative team of the Authority and the NFMS users has enhanced the system and yielded a fully customized system. In the mean time, existing data of the Authority in electronic form have been transferred into the database of the new system.

System overview

System architecture

NFMS and its components have a modular structure categorized into three layers:

– *a physical layer*, composed of computer hardware and communication network facilities to support infrastructure activities and application systems,

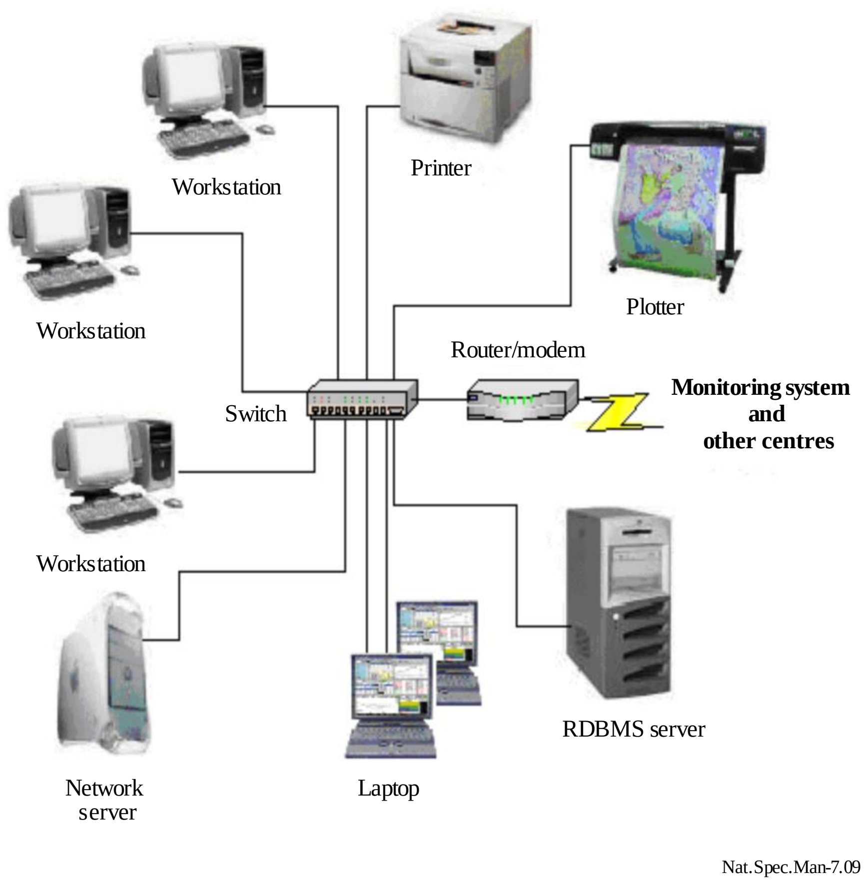
– *a support infrastructure layer*, consisting of operating system, database and database management system, and software tools intended to support application systems,

– *an application system layer*, composed of application specific software and local databases intended to support specific activities and related calculations.

NFMS has been designed in the light of the ITU-R Handbook – Computer-Aided Techniques for Spectrum Management, with further enhancements to operate on multi-regional operation centres. It has a client-server architecture which runs on user workstations connected over a LAN in an operation centre. All administrative and operational data is kept on a local database management server which is also connected to the LAN. Each operation centre can also be connected to other operation centres over a WAN to form a distributed, but integrated operational environment. NFMS system can use any computer resources relying on this infrastructure. The data on each database server in different operation centres are replicated to provide data completeness and coherency. Figure 7.9 shows the system architecture for multi-operation centre approach.

FIGURE 7.9

Multi-operation centre architecture



In order to prevent access and manipulation of NFMS data by unauthorized users, the system provides a four layer security; operating system layer, client workstation layer, database layer and application layer. In addition to these security levels, the system allows security related follow-ups in three forms; audit trial provided by the RDBMS, and record time stamping, login attempt audits and record deletion logs provided by the application layer.

Depending on the administrative policy of the Authority, this architecture can turn into a centralized system where there exists a single central database and clients on remote operation centers can access and manipulate data on this central database.

Design and implemetation methodologies: Keys to success

During the development of NFMS Software, the process defined by the IEEE J-STD Software Development Standard has been followed and under the ISO 9001:1994 certification scope the project has been managed and documented.

Standardization in project development and documentation, and project configuration management have let successful application of software engineering principles to the software life cycle processes, and hence avoiding overlook on any detail in both design and implementation phases, yielding the desired robustness and quality of the software.

Case tools have been used for the analysis and design of the system so that modifications and reengineering can be easily done on system components. NFMS has been designed and implemented as independent of the database management system chosen. Its open system architecture enables addition of new modules and integration with other spectrum management systems. Programming tools specifically tailored for database operations have been used to obtain high level processing performance.

All these together with an excellent project management and coordination with the Telecommunications Authority have yielded a high-performance system beyond the scope of the technical specifications and on-time project completion.

Application software

The two important components in NFMS are its *Spectrum Engineering and Monitoring Support System (BilSpect)* and *Management Information System (MIS)*, which operate integrally by sharing data. These systems provide graphical interfaces with enhanced features such as data validation, on-line help and data look-up, that one would expect from a high-technology application software.

BilSpect

Spectrum Engineering and Monitoring Support System (BilSpect) has been designed as a union of two major components, namely Monitoring Support System (MSS) and Spectrum Engineering System (SES).

Monitoring support system (MSS)

The monitoring support system enables the automation and integration of the National Monitoring System with the National Frequency Management System as described in Recommendation ITU-R SM.1537. MSS controls the automatic measurement functions conducted at various monitoring stations and displays the measurement data gathered by these monitoring activities either in tabular form or graphically.

Using MSS, an operator in a Regional Monitoring Centre can produce automatic measurement tasks such as spectrum occupancy, detecting illegal stations or checking the compliance of radio station parameters upon their licenses in a weekly scheduler for each remote monitoring station. The monitoring stations get these tasks through database and after performing the defined measurements, they transfer the results to the Monitoring Centre for the purpose of statistical analysis or graphical display. The MSS includes the automatic violation detection function to produce alarms while looking for unlicensed signals and looking for signals which are deviating from their licensed parameters.

For example, spectrum occupancy measurement results can be evaluated in three different ways such as frequency band occupancy, single frequency occupancy or busy hour tabular form. Frequency band occupancy diagram shows frequencies along the x-axis and frequency occupancy values (in terms of %) along the y-axis. Single frequency occupancy diagram shows the occupancy values (in terms of %) of a frequency along the y-axis versus time along the x-axis. Busy hour table calculates the sliding one-hour averages of the occupancy values for a frequency starting at each quarter of an hour and shows the hour where the occupancy is at the highest within a 24 h time interval. If the occupancy values of a frequency is available for a period longer than 24 h, then the table shows the busy hours of each day, separately.

In cases where an illegal frequency use is suspected, three direction finding (DF) stations are assigned to make bearing measurements for that frequency using appropriate antennas. If all three stations can identify the direction of source of the signal in question, a simple triangulation technique can find the possible target location, which is also displayed on the map together with the DF stations and their bearings.

Spectrum engineering system (SES)

The spectrum engineering system includes various software modules designed to help operators performing spectrum engineering functions needed for automated frequency management as described in Recommendation ITU-R SM.1370. These modules are used to perform propagation analysis, interference analysis, link analysis, frequency assignment and planning, international coordination calculations, database operations and producing useful reports. The SES is integrated with a Geographic Information System (GIS) software to display the analysis results on screen with user selectable map background as well as utilizing any type of raster or vectorial geospatial data. The system provides the following functionality:

– Propagation prediction using digital terrain elevation data and propagation models recommended by ITU.
– Calculation of the station coverage area and displaying on digital maps.
– Microwave link analysis and calculation of the link availability using the method described in Recommendation ITU-R P.530.
– In terrestrial digital audio and video broadcasting services (T-DAB and DVB-T), calculation of the useful and interfering signal levels, network gain and coverage probability for a single frequency network.
– Intra-service interference analysis in analogue radio/TV and land mobile services.
– Inter-service interference analysis between analogue TV services and T-DAB or DVB-T services.
– Compatibility calculations between the sound broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-137 MHz according to Recommendation ITU-R SM.1009.
– Intermodulation interference and desensitization analyses.
– Frequency planning for analogue radio and TV broadcast services.
– Automatic calculation of candidate frequency assignments for land mobile circuits operating in HF band (2-30 MHz) by using the ICEPAC program developed by the U.S. National Telecommunications Information Administration (NTIA).
– In the border area, finding and displaying the stations on the map that potentially require international coordination.
– Keeping database records for the coordination activities with neighbouring countries.
– Generating ITU notification forms for frequency assignments requiring international coordination, either in paper or electronic format, complete with all the data to be sent to ITU.
– Coordination calculations of radio stations operating in LF/MF band using the method described in the Final Acts of Regional Agreement, Geneva 1975.
– Calculation of the coordination contours for earth stations of geostationary satellites according to ITU Radio Regulations and determination of terrestrial radio stations being inside this contour and sharing the same frequency band.
– Listing, updating and querying of the national and international (i.e. regional and global) frequency allocation tables.
– Database operations such as view, update, query and report on the frequency assignment records.

The SES includes useful analysis tools to assist operators in the frequency assignment process. The system has the following features:

– Once the propagation analysis of a transmitter is performed, any number of user defined field strength contours can be drawn over the map.

– The list of all administrative units (provinces, districts and villages) and their population as well as the total population residing inside a given field strength contour can be produced using census database.

– Signal profile showing the signal level (field strength or received power) versus distance from the transmitter location in any direction can be plotted as well as terrain profile plot.

– Analysis of potential interference between existing and proposed stations assuming that each station involved in an interference analysis can be treated as both source and victim of interference.

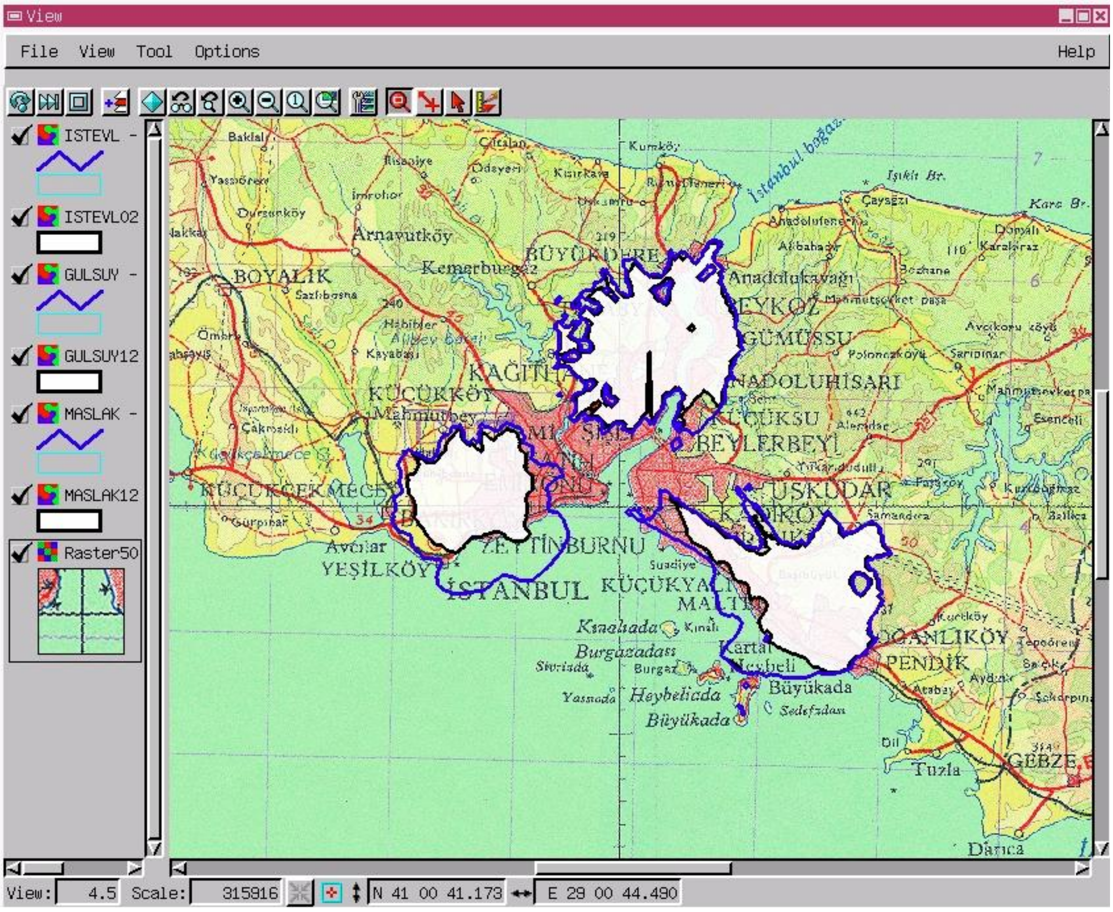
– As a consequence of interference analysis using co-channel and adjacent channel protection ratios, the interference-free coverage area for each station can be calculated and displayed on the map as shown in Figure 7.10.

– Interference-free candidate frequencies for a proposed station can be automatically identified if such a frequency is available.

– The base station coverage and mobile talk-back range is calculated for VHF/UHF land mobile services and the area in which the two-way communication is possible can be displayed on the map.

FIGURE 7.10

Interference-free coverage areas of three base stations in the land mobile service



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Management information system (MIS)

The MIS is an integrated set of sub-systems tailored for automation of all administrative tasks of a Telecommunications Authority. It satisfies administrative data management requirements of the Authority, ranging from data entry to querying and reporting. Supporting the administrative functions listed below in an advanced level it provides a complete, coherent and easy to use turn-key solution to spectrum management activities:

– Application processing
– Licence processing
– Fee processing
– Report processing
– Interference complaint processing
– Security processing
– Frequency assignment.

Establishing a system which satisfies future requirements as well as the existing requirements of an Authority must be an inevitable design policy. Keeping this in mind, the aforementioned functions have been categorized with respect to the nature of the application field in order to fulfil application specific requirements and hence obtain a modular, easy to maintain sub-systems.

Applications for radio licences vary depending on the type of radio stations. For this purpose, two sub-systems, namely *Radio Station Licences Management* and *Amateur Radio Station Licences Management,* have been designed and developed. Additionally, in order to register and follow up citizen band radio certificates, a separate sub-system called *Citizen Band Radio Certificates Management* has been developed.

Some Authorities also provide authorization certificates to individuals for the purpose of operating fixed and mobile radio stations as well as amateur radio stations by conducting exams for candidates. *Radio Operator Certificates Management* and *Amateur Radio Certificates Management* systems have been designed for executing the tasks necessary for these purposes. In order to cope with foreign amateur radio licences issued temporarily for a limited time to be used within the country, *Foreign Amateur Radio Certificates Management* has been developed.

Each aforementioned sub-system has its own associated application processing, licence processing, fee processing, report processing and security processing functionalities.

Interference Complaints Management has been designed as a separate sub-system, but integrated to the other systems, to handle interference complaint applications, sources of interference and its resolution.

Equipment Standards & Authorization Licences Management sub-system handles another major spectrum management activity. It has been designed to record and follow-up equipment test applications, equipment test results, to record and manipulate the equipments approved by the Authority in a form compatible with the ITU norms and recommendations. In addition, this sub-system is used to record, follow-up and prepare authorization licences for import/sell/produce radio equipment, to issue permissions for import/produce of radio equipments and their follow-up, to record vendors and selling of equipments, and to record and prepare conformance certificates for equipments.

For top level management of fees, overdues and fines, *Fee Management* has been designed with more advanced features. Fee Management in fact aims at processing of radio station licence fees and other associated fee payments together with the ability to produce financial statements for the MIS.

As for frequency assignment processing, Radio Station Licences Management interacts with *Spectrum Engineering System (SES)* to complete the required steps of licencing starting from licence application, followed by site inspection, and then frequency assignment and finally ending up with issuing of licence.

Radio stations are visited by the responsible staff of the Authority, periodically or on predefined dates, to control the system and equipment parameters as to the allowed limits and functionalities. These visits, results of controls and even control fees, if exists any, can be recorded and followed up by using *System Control Management* sub-system. Via this sub-system, the user can access all details about the licence, assigned frequencies, station attributes, and dues.

In most cases, Authorities find it useful to follow up the legal states of the unpaid licence fees, overdues and fines by a responsible department within their constitution. *Forensic Follow-up Management* is a sub-system specifically tailored for this purpose which operates in an integrated fashion with the other sub-systems of MIS.

MIS Management Support is another unique sub-system which enables the MIS manager to create user profiles within the organizational structure defined, assign user names and passwords, define access and manipulation rights for a user ranging from limiting the use of a specific sub-system to limiting the functions such as record viewing, record deletion and getting print-out of reports. The manager can in this way control the security of the system and by using monitoring interfaces he or she can keep track of vital user actions such as erasure of records and unauthorized access attempts.

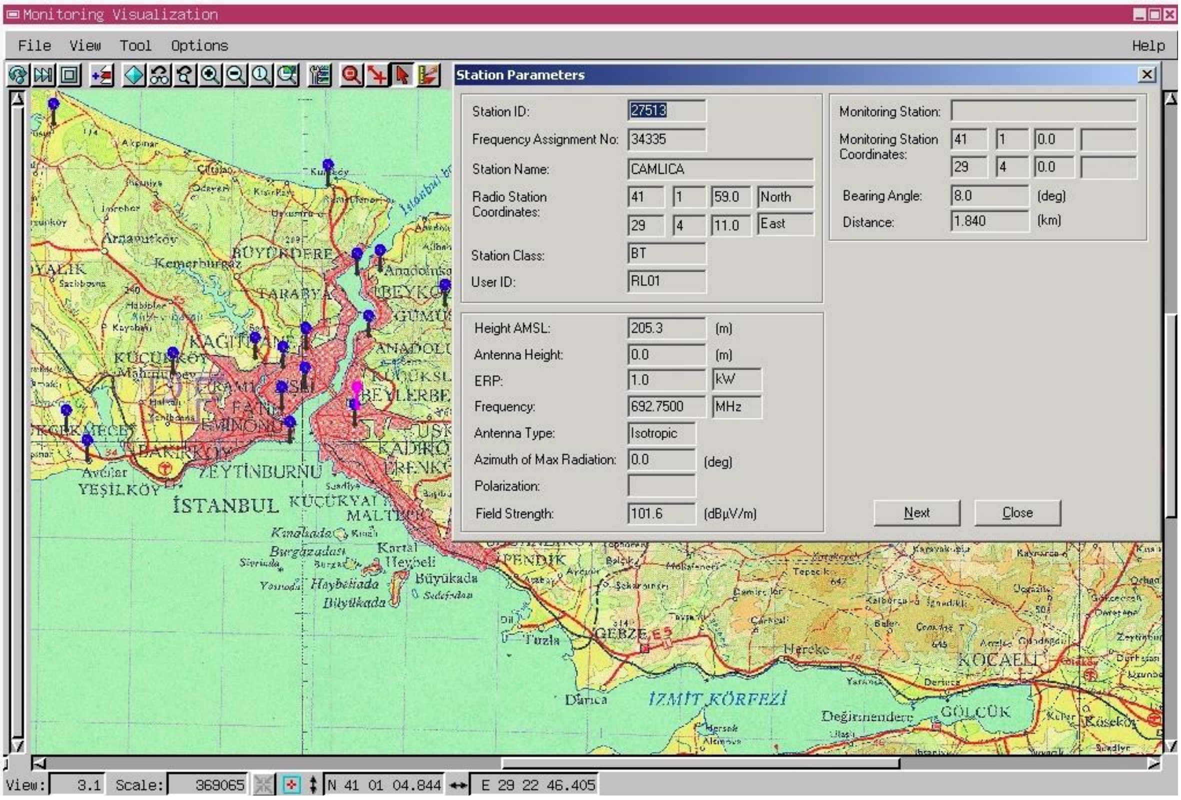
To summarize, NFMS-MIS has the following sub-systems:

– Radio Station Licences Management
– Amateur Radio Station Licences Management
– Amateur Radio Certificates Management
– Radio Operator Certificates Management
– Foreign Amateur Radio Certificates Management
– Citizen Band Radio Certificates Management
– Fee Management
– Interference Complaints Management
– Forensic Follow-up Management
– Equipment Standards and Authorization Licences Management
– System Control Management
– MIS Management Support.

MIS system has also been integrated with *Spectrum Engineering and Monitoring Support System*. By using the database query functions and a Geographic Information System (GIS) mapping software, users can search the database records by frequency, class of station or station location and have the results displayed on the map. For instance, if a user wants to see the radio stations operating in a given frequency range in a geographic area of Turkey, the software accesses the licensing database, finds those stations satisfying the given criteria and displays their locations on the map with user-defined symbols. By pointing and clicking on a radio station symbol on the map, that station’s file is accessed and its contents are displayed in a text box on screen as shown in Figure 7.11.

FIGURE 7.11

Database query results displayed on the map



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NFMS in numbers

Currently, there are millions of files containing the details of all radio stations and equipments used in Turkey that transmit over the airwaves. Radio stations operating in a wide range of services (e.g. broadcast, land mobile, aeronautical services, etc.), microwave links, cell site antennas, airport security systems are all licensed and included in the database. Apparently, the main objective is to build a database that requires data to be entered only once. It should create standard forms for the staff of the Authority to use in issuing licenses. Once the correct information is entered, the database should automatically update itself and divert data into the multiple files where they belong.

Initially, the Authority was keeping data within various sources, ranging from paper documents and MS Excel sheets to a small scale database, but much of the electronic data was out of date and needed correction. During the database development phase of the NFMS project, the existing electronic data have been automatically transferred to the new database by using the transfer programs developed by ISYAM. In this process, syntactic and semantic checks, and data discrimination techniques have been applied on the existing data in order to end up with a consistent and correct database.

NFMS has a fully complete and coherent relational database having a distributed architecture, operationally interconnecting 7 operation centres, namely *Regional Monitoring Centres*, and a *National Control Centre*. The data is replicated on a daily basis among these centres.

Currently there are 365 tables in the NFMS database. It should be noted that the number of records for any field of operation in this table indicates the total number of all records related to that field of operation. For instance, although there are a total of 553 624 records in all tables used for the purpose of “Frequency Assignment and Management”, the number of frequency assignments to licensed stations all over Turkey is 119 228. The record size increases to several more millions in the Monitoring Station Management operation database depending on the type and number of measurement tasks assigned to the monitoring stations.

Preparing for the future

Technology is changing so rapidly that some capabilities are being redesigned as the systems are built. One improvement that is under consideration for the spectrum management system is the utilization of high-resolution building height data and ray-tracing techniques for more precise signal propagation analysis in urban areas. Participants in the project believe the NFMS will have widespread benefits for the years to come.

ANNEX 6

TO CHAPTER 7

Updating the legacy systems for spectrum management

1 Overview

1.1 Introduction

This Annex focuses on the upgrade and development of new software systems in the field of spectrum management. Specifically, we describe here the development process Telcordia followed to deliver a customized advanced spectrum management system[41] (FMS) for one of its clients. A study of modernizing and upgrading of legacy spectrum management systems is particularly interesting because it involves a unique combination of technical, administrative, financial and spatial data processing, numerical algorithms, scientific visualization, report generation and an extensive user interface. The development of the FMS required the integration and upgrade various disparate legacy systems and databases into a comprehensive, unified, and integrated spectrum management system.

2 The challenge

The client requested a review of the operation of their frequency management department and the development of a state-of-the-art integrated advanced frequency management system (FMS) that would comply with their specific requirements and Recommendation ITU-R SM.1370 – Design guidelines for developing advanced automated spectrum management systems.

In general, a spectrum management system incorporates functions in the following generic categories:

– Administrative functions such as record keeping, application processing, report generation, etc.,
– Engineering analyses such as propagation models, interference analysis, link analysis, coverage analysis, etc.,
– Geographic map function to facilitate spectrum planning and interference resolution, and
– Financial functions such fee processing, accounting, collection and billing.

Each of these generic categories includes multiple functions that comprise multiple tasks.

The client was performing Frequency Management using a variety of stand-alone databases and a small set of engineering tools. A number of functions were performed manually. This FMS was designed to integrate database, engineering functions, financial functions, GIS and reporting in a single client-server application. The system had to be flexible, modular, and based on proven database technology.

The following tasks were performed to help the client manage the transition to a new integrated and unified system:

– Analysis of client's operation,
– Development of requirements for the FMS in conjunction with the client,
– Development of the FMS,
– Deployment the FMS on site,
– Operation of the FMS and training of the client before handing him off the FMS software.

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[41] In Chapter 7 the term "spectrum management system" refers to a generic system that automates spectrum management tasks. The term "advanced frequency management system" refers to the particular system developed and described in this Annex.

3 Existing situation

A heterogeneous software and data environment characterized the situation that existed before the introduction of the FMS. The following paragraphs provide a brief description of the environment.

3.1 Heterogeneous software environment

The existing legacy software systems included systems from the client, and from other sources. The list of legacy systems included the following.

– MRSELS-II

  Microwave Radio & Satellite Engineering and Licensing System II (MRSELS-II) provided spectrum analysis and licensing functions for fixed terrestrial and satellite microwave radio systems for 2-40 GHz. Essentially, this was a large database system written in Focus.

– WARE

  Workstation for Advanced Radio Engineering (WARE) provided radio engineering, spectrum analysis and spectrum resolution tools for 150 MHz – 2 GHz. The ultimate engineering capabilities of WARE were geared toward the application of any generic point-to-multipoint radio systems including PCS, BETRS, Mobile and Cellular, etc. WARE was written in C.

– ARC Workstation

  The Advanced Radio Coordination system (ARC) provided Microwave Radio engineering and spectrum resolution tools for 2-40 GHz. ARC was written in C.

– RANEBO

  Telcordia Spectrum Management System for Frequency Coordination between Broadcast and Wireline Services. Ranebo included several propagation and interference models written in FORTRAN.

– Various Fortran programs from the US Government. These included MSAM and REC533 for HF propagation.

– A collection of FORTRAN and C programs from the ITU-R.

– FORTRAN programs provided by the client including satellite coordination.

3.2 Heterogeneous data environment

The data used for spectrum management had several origins

– *Client databases:* The main source of data was the collection of client's normalized databases. Different databases were used for different services.

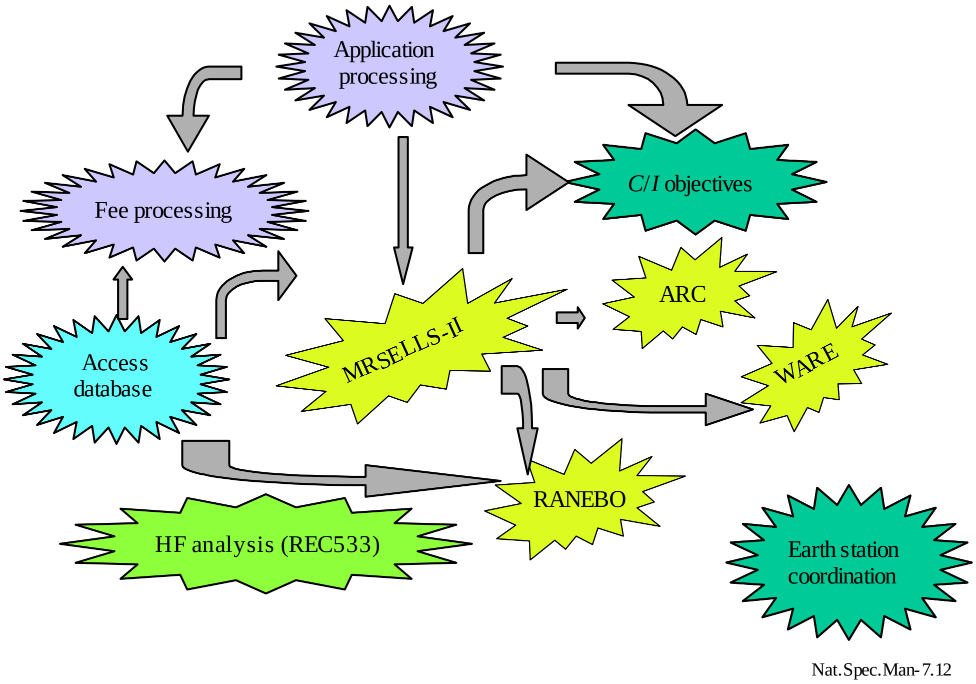
– *ITU-R:* Data pertaining to spectrum allocation, services definitions, etc. was derived from the ITU-R Radio Regulations, the ITU-R International Frequency List (IFL) and other ITU-R sources.

– *GIS Data:* The GIS data including several layers such as roads, political boundaries, and population centres was obtained in ESRI® format.

All systems and data were independent of each another, so if all systems were to be utilized, considerable manual transfers were required. Also, because these systems were based on different platforms, a variety of expertise was needed for system maintenance.

FIGURE 7.12

An illustration of a heterogeneous environment for spectrum management



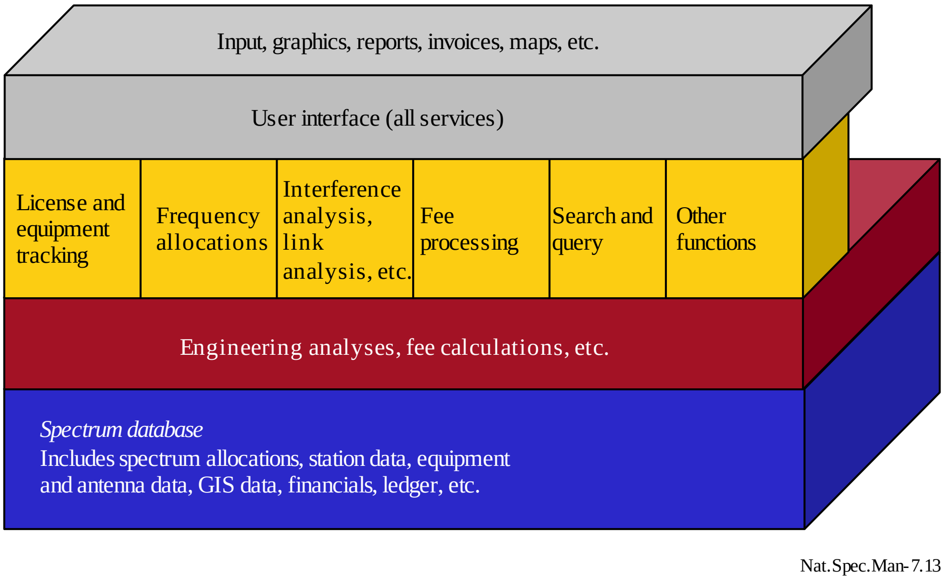
4 Toward a modern unified integrated system

The client was looking for a state-of-the-art system to integrate as many components as possible and to unify the various databases.

Figure 7.13 illustrates an ideal of a unified and integrated spectrum management system. The system is unified because the data for all services and all function resides in a single database. The system is integrated because the data flows automatically from the database to various procedures and among different processes. The system presents a consistent user interface for all services.

FIGURE 7.13

An illustration of a unified and integrated advanced spectrum management system



The advantages of a unified and integrated system are:

– *Reduced maintenance:* Maintaining a single database is less costly than maintaining several.

– *Increased efficiency:* An integrated system provides an efficient means to perform all spectrum management tasks. Instead of re-entering data in many screens to perform various tasks, the data is entered once and automatically populates all required fields for each task.

– *Reduced user errors:* Automated integrated system can provide automated verification and analysis of submitted data.

– *Uniform interface and coding:* Modern object-oriented software engineering techniques facilitate development of a uniform and consistent user interface. Common tasks behave identically for all functions.

– *Upgrading:* An additional advantage of integration is that it provides an opportunity to upgrade and improve existing functions.

The principal disadvantage of tight integration is the up-front cost and complexity of software integration and data migration. Thus, the benefits of integration and replacement must be weighed against the difficulty and expense of doing so. Also, it is desirable to attain a high degree of software reuse, especially, for computational functions that have proven their reliability through an extensive history of use.

The disadvantage of a unified system is that disparate data must be combined in a single database. This requires thorough data modelling to determine a database design that accommodates existing data structures.

The decisions to strive for integration and unification are interconnected yet separate. Integration is largely a matter of programming, while unification also involves data modeling and business practices. In spectrum management systems there is usually sufficient commonality among data elements for different services and functions as well as similarity among spectrum management procedures for various services. As a result, unification is feasible and can result in significant improvement in department operation.

4.1 Platform selection

A key choice in achieving a reliable integrated spectrum management system is architecture and platform selection. The company chose the following platform elements:

– Oracle8i™ was chosen as the Relational Database Management System (RDBMS). Oracle® RDBMS was selected for various technical reasons including platform independence and the ability to integrate with other Oracle applications should the client decide to extend their frequency management system in the future.

– MapInfo Professional® was selected for manipulation of GIS data and MapInfo MapX® components for presentation of data within the application. Oracle® Spatial was selected as the GIS engine. The advantage of this choice is the good integration provided by Oracle Spatial, Oracle and MapInfo between their products.

– Engineering and financial functions were implemented in PL/SQL™, C++ and Fortran. The choice of the RDBMS, the composition of the legacy software, and the goal of achieving object-oriented design dictated this selection.

– The server OS was Microsoft® Windows NT® 4 operating system. The client requested a Windows NT system since the client would administer the system at the end of the project and the projected load on the FMS was moderate. Although, the FMS is based on Windows NT system, platform independence was an important goal for the FMS development. Porting the FMS to Unix should be a straight-forward process.

4.2 Analysis of client's operations

The first step to develop an integrated system was the analysis of client's operation. The client's methods and procedures (M&Ps) were examined with respect to performance of spectrum management functions. A key step in this examination was the investigation of the data flow and the steps involved in various departmental tasks in relation to existing automated system implementation.

The second step was the development of system requirements based on the existing legacy systems, the analysis of M&Ps, the current technical and regulatory requirements, and the projected needs of the department. Development of requirements included such items as construction and revision of a data dictionary and establishing a data model. The development of requirements was dependent in part of the disposition of legacy systems.

Before building the application, the company and the client reviewed the existing software systems to decide which parts to retain, which parts to reuse and which parts to develop.

4.3 Lessons learned building the application

As the application was developed, some of the decisions and rationale with respect to functionality and software reuse were the following.

– The majority of user interfaces were developed anew. The reason is that the art of user interfaces advanced considerably in a short time, so that older user interfaces looked primitive and were difficult to maintain.

– In some areas, such as GIS components, the available components allow for development of interfaces that might have been difficult to develop a few years ago. The company worked with the Oracle GIS group to develop the geographic display integrated with the application.

– Existing C code was reused if technically appropriate. However the majority of the C code was upgraded to C++ to achieve object-oriented design. In certain cases, the existing C code had to be upgraded to include the latest development in spectrum management algorithms (such as changes in propagation models, revised procedures for earth station coordination, etc.).

– Reuse of Fortran code is difficult if it contains a lot of user interface code. In this case, it was more efficient to rewrite the code from scratch or use the application as is without integrating it. If there is no user-interface code or if the original author can extract the numerical portion of the code, then there are three options:

  Option 1: Compile the Fortran program as a library,

  Option 2: Convert to C using an automated tool, such as f2c, or

  Option 3: Convert to C++ manually.

The company employed all three strategies to integrate FORTRAN code depending on the application. However, several FORTRAN programs were not integrated because their frequency of use was too low to justify the investment required for integration.

– Conversion of existing code to C++ (or another modern language such as Java) or rewriting the application provides an opportunity to improve the original application. For example, the client was using several FORTRAN programs to generate power spectrum densities (PSDs) and calculate carrier-to-interference (C/I) objectives. Due to limitation on array allocation in Fortran, these programs used fixed size array with a fixed frequency increments. Telcordia rewrote these programs using SQL tables to store the PSDs and C/Is and C++ programs to compute and manipulate these quantities using variable-length arrays and arbitrary frequency increments. This improved the accuracy, performance and storage requirements of this application.

– Reusing old database code that was developed for a different database technology is impossible. A normalized database schema was developed based on client requirements that included elements from the client's databases, the database and ITU-R fields.

– Reuse of existing reports is often straightforward. The reason is that the reports tend to remain constant through the upgrading process. The format and content of reports, such as application forms, invoices or notification forms, may be dictated by legal requirements or departmental regulations. If the underlying data schema has been preserved through the upgrade, the reports can be used without change. If the underlying schema had been altered, only the data binding have to be changed. Even forms that were previously filled out manually were automated by linking with appropriate data fields. Using this technique, the production of certain forms that were previously generated by hand was automated.

4.4 Converting the data

Another challenge is converting and combining existing data in a single database. This was handled as follows.

– The GIS data was converted from ESRI Shapefiles files to MapInfo format and then uploaded to Oracle Spatial.

– The various ITU-R data was converted using Perl and SQL scripts.

– The Access data was migrated to Oracle by integrating the application with Microsoft® Excel and Access through COM automation. In addition, PL/SQL scripts were developed for data transformation within Oracle.

– A particular challenge in this process is the normalization of data. The final database schema was more highly normalized than the original client data. Also, a greater number of data constraints were used. The higher degree of normalization and extensive data constraints were desired by the client to preserve the integrity of the data.

Enforcement of referential data constraints, such as foreign key and primary key constraints, required the development of automated procedures to locate overlapping or duplicated information and rename, combine or delete records to preserve the integrity of the final database. Enforcement of other constraints was achieved by conversion of data fields to achieve uniformity.

5 Advanced frequency management system

The result of these efforts was the production of an advanced frequency management system (FMS). The system architecture is based on Oracle8i, Oracle Spatial for GIS, PL/SQL and C++ for engineering tools, and MapX for GIS client interface. The system uses HTML for help functions.

FIGURE 7.14

The FMS architecture

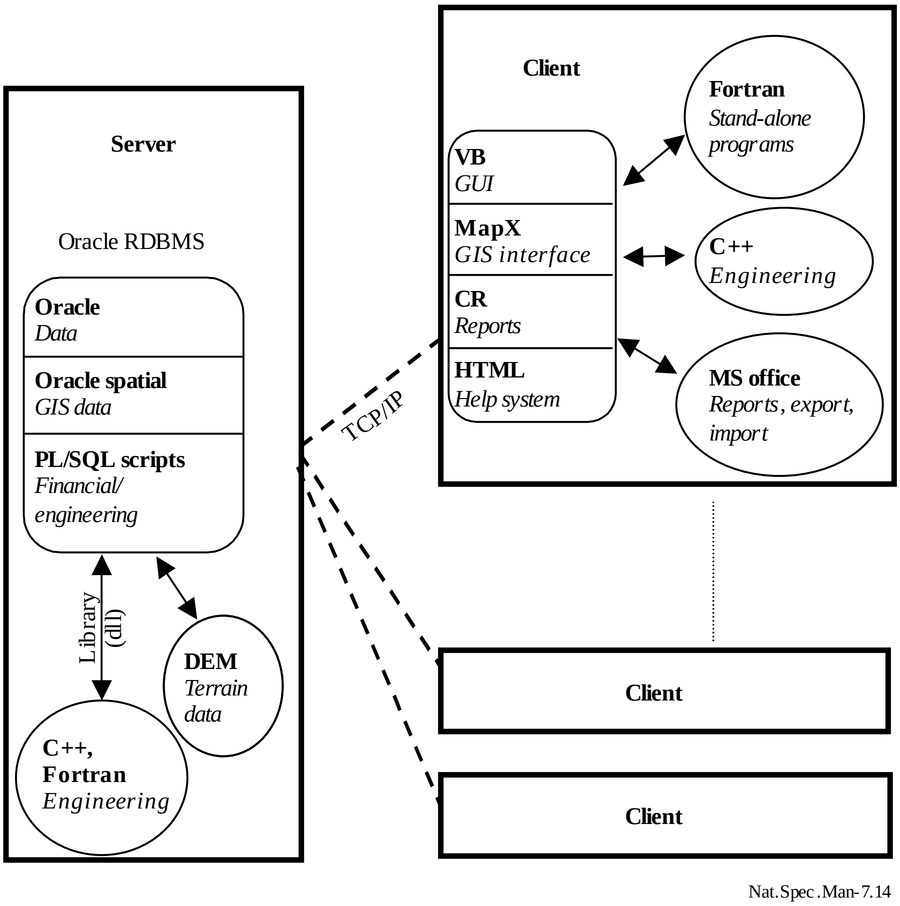


Figure 7.14 shows the architecture of the FMS. This system uses a modular architecture that facilitates customization and upgrading. For example, all numerical procedures are implemented as libraries with a defined application programming interface (API). Thus, Telcordia can update any engineering tool simply by replacing a library. This is important in spectrum management where certain tools, such as earth station coordination, change frequently. Similarly, it is possible to change the user interface or the reports independently of the other components. Another example of the flexibility of this system is the ability to change the terrain database by swapping files.

The FMS is a software system that automates a variety of spectrum management tasks. These include the processes of:

– Assigning new frequencies
– Resolving interference problems
– Calculating and collecting frequency fees
– Performing engineering analyses
– Assuring compliance with international and national regulations
– Evaluating communication link performance
– Performing earth station coordination
– Performing border coordination and notification
– Production of reports, application forms, fee calculations, licenses, and invoices

- Performing queries and searches
- Providing security processing.

The FMS software performs three basic functions:

- The Administrative function includes such features as recording and retrieving assigned frequencies, frequency-user data, equipment data, antenna data, automatic generation of various regulatory forms, data reports and invoices, and spectrum fee calculations. FMS provides an extensive search facility by many technical or administrative parameters. The FMS automatically enforces compliance with the table of frequency allocation and channelling plans. Also, it provides a feature for custom queries. Finally, FMS is integrated with Microsoft Access and Microsoft Excel software for analysis and reporting.
- The Engineering analysis function has the capability to calculate interference between transmitting systems, evaluate coverage area of base stations, and determine the most suitable frequencies for new assignments. All functions are accessed through a user-friendly graphical user interface that includes features such as graphing functions. Engineering capabilities include various propagation models, antenna discrimination model, *C*/*I* analysis (Carrier to Interference), fade analysis, link analysis, RF (radio frequency) human exposure evaluation, satellite angle determination, EMC (electro-magnetic compatibility) analysis (including microwave, land mobile, broadcast, etc.) and many other tools.
- The Geographic Map display function provides detailed interactive map displays required for the understanding of various spectrum management problems. FMS uses an integrated digital terrain databases for performing complex engineering functions.

6 Transition to the FMS

The final step is to hand over system administration of the new system to the client. Although the client intended to administer the new system, there was a transition period during which the company administered the FMS on site. After a period, the administration of the system was shared with client's personnel to enable them to become proficient in system administration.

The department staff was trained on the use and operation of the FMS. The FMS comes with an extensive HTML-based help system. One of the key lessons of this project was the importance of working closely with the client during the design and implementation of the system. The learning curve to use the new system was reduced because the client's staff participated heavily in the design of the user interface.

7 The future

The spectrum management software continues to evolve and be upgraded. A new direction in spectrum management is self-service for certain spectrum management functions over the Web. For example, the spectrum compatibility software to the web has been ported using server-side computing in Java™ programming language. Another exciting possibility is use of electronic data exchange for spectrum management. The FMS can process license applications submitted as Excel tables. Users are able to submit batches of applications by email. Electronic data interchange of antenna data is already well established by National Spectrum Managers Association (NSMA) standards.

A simultaneous trend is the increased importance of the Java language for future spectrum management applications. Java programming language may become the language of choice for Oracle database applications. Java platform allows a single language to be used for server and client-side processing. Also, Java application and applets allow for any portion of the software to be deployed on the web. Porting of existing C++ code to Java is fairly easy, as Telcordia has done for its Spectrum Compatibility software. The downside of the Java platform is reduced performance and inconvenience in implementation of certain numerical procedures. Despite this, as implementation of spectrum management systems begin to resemble e-commerce systems, techniques developed for e-commerce such as the Java platform and XML will become more prominent.

8 Summary

This Annex described the development of an Advanced Frequency Management System (FMS). Development of this system was a challenging task for many reasons, including:

– Close cooperation between the client and the company was needed to define the system requirements including the user interface, engineering tools, database structure, and reports.

– Definition of many FMS features was based on features of existing legacy software or the structure of existing data.

– Client’s expertise and experience were vital for the definition of software interfaces, engineering and financial algorithms, data elements, and report formats.

– The FMS incorporated a large set of legacy code from various sources and in several computer languages directly or in revised form.

– Data manipulation had to be performed to migrate the data into the unified database.

Despite the challenges, a state-of-the-art, unified, and integrated spectrum management system was developed. After operating the system on client’s site, the system was handed over to the client who is using the system productively. By using the FMS, the client improved his efficiency and is able to perform quickly and accurately tasks that were previously laborious.

ANNEX 7

TO CHAPTER 7

National spectrum management and monitoring system in Peru

1 Introduction

This Annex will present the experience of the implementation of the Spectrum Management and Monitoring System for the benefit of the Ministerio de Transportes y Communicaciones (MTC) of Peru (www.mtc.gob.pe). This project was managed by the ITU (www.itu.int) for the benefit of the MTC. The project's Prime Contractor is THALES Communications Corporation (TCC), France (www.thalesgroup.com), where the spectrum monitoring system was provided by TCC and the spectrum management system, ELLIPSE Spectrum, was provided by Cril Telecom Software (CTS), a French Software Editor specializing in providing automated spectrum management systems and software solutions for Telecommunications Operators (www.criltelecom.com).

1.1 System description

The project consisted in the implementation of a complete turn key system to be delivered in Peru for one National Centre in Lima and 6 Regional Centres in the first phase up to 2002, the system may be extended to other regions. Hereafter Figure 7.15 gives the general architecture of the existing network.

The National Centre includes:

The Spectrum Management and Monitoring Software:

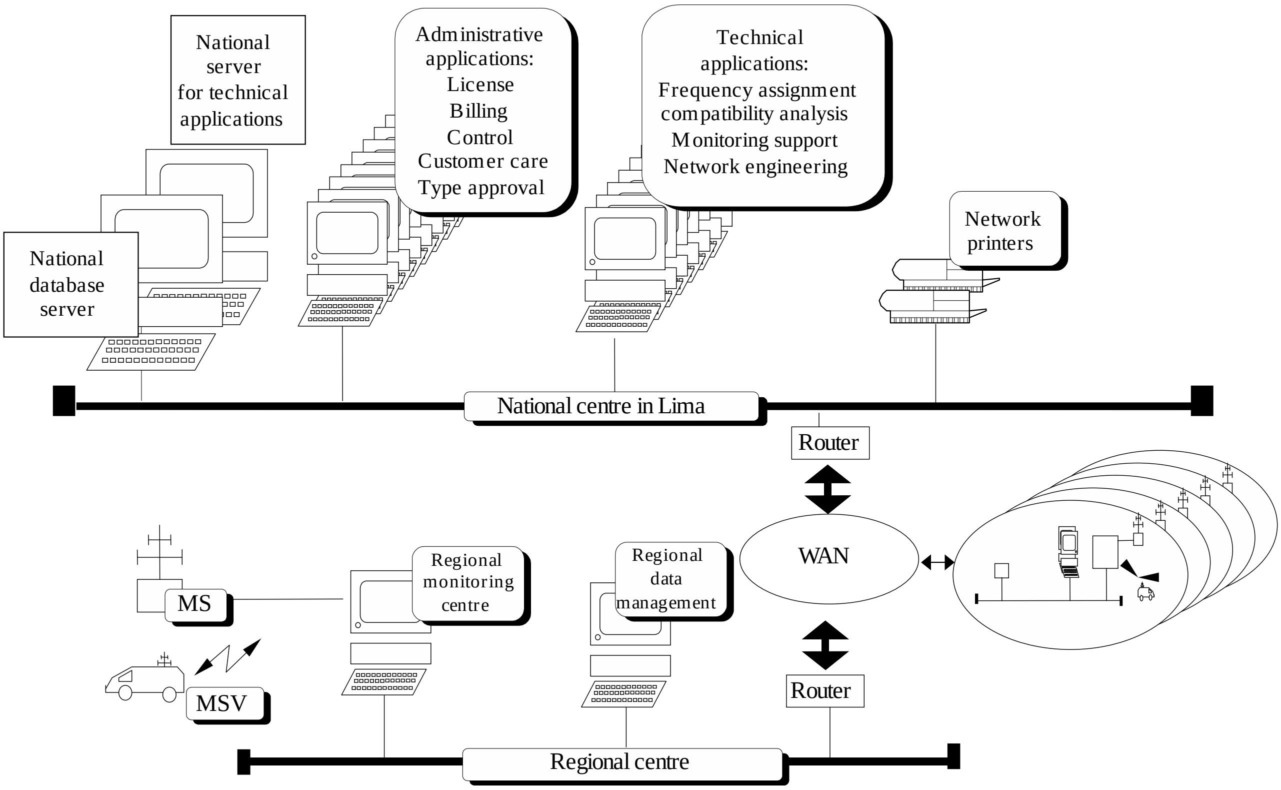
– the national database,
– the technical analysis tools,
– the administrative tools,
– the interface with the monitoring system,
– the national monitoring software.

The Regional Centre include:

– The spectrum management and monitoring software: administrative tools, interface with the monitoring spectrum monitoring software;
– the equipments.

FIGURE 7.15

General architecture of the spectrum management and monitoring system in Peru



1.2 Benefits expected by the Ministerio de Transportes y Communicaciones

With this fully integrated system, the MTC intends to manage and monitor in a very efficient way its national radio spectrum in compliance with the ITU-R Recommandations and in particular with Recommendation ITU-R SM.1537.

Indeed, telecommunications networks have been recognized for a long time as a part of the basic infrastructure which is indispensable for national development and modernization. The radio spectrum constitutes a valuable, scarce and limited resource. A consequence of this fact is that the social, cultural, industrial and economic development of any country is associated with an increasing demand for new telecommunications services and this translates into an increasing need for spectrum space. It is only through judicious use and careful management of the spectrum that these legitimate demands for services can be accommodated. The radio spectrum is also in the core of national security, defence and safety.

Spectrum Management is essential because the radio spectrum has become a vital national resource, as important as more tangible physical resources such as manpower, natural resources, transportation, networks, etc. As the applications using radio waves become more and more extensive, the management of the radio spectrum becomes increasingly complex and difficult. The MTC expects that the provided spectrum management and monitoring system will assist it to satisfy the requirements of spectrum users and administrations.

This system should assist the MTC in the following key activities:

– Policy and regulations

– Coordination of international conferences and meetings

– Frequency planning, allocation and assignment
– Licensing and billing and automatic notification of renewal
– Frequency coordination and notification
– Engineering support (electromagnetic compatibility analyses, *C*/*I* calculation, propagation prediction)
– Inspection, spectrum control, surveillance and monitoring
– Statistics and advanced reporting
– Measurements and location of transmitters in compliance with the ITU-R Handbook on Spectrum Monitoring.

These activities are conducted in the country's capital Lima and some of them in six Regional Centres.

2 Spectrum management system presentation

2.1 Project implementation

The implementation of such a project was planned through different phases. The first phase covered the National Centre in the Capital Lima. The second and third phases included 6 Regional Centres, and additional phases are still planned.

2.2 System description

The automated spectrum management system, ELLIPSE Spectrum, has been designed to help the MTC in its spectrum management tasks in accordance with National Regulations, Radio-communications Regulations and ITU Reports and Recommendations.

Most administrative and technical aspects and activities of spectrum management mainly based on the guidelines of Recommendation ITU-R SM.1370 and related ITU publications are covered and automated.

The following activities are included:

– Workflow management and processing
– Automation of administrative tasks
– Frequency plan definition
– Frequency allocation
– Frequency assignment
– Licensing and permits issuing
– Equipment type approval and certification
– Billing, fees processing and automatic notification of renewal
– International coordination and notification
– Spectrum engineering, coverage prediction, electromagnetic compatibility analyses, *C*/*I* calculation
– Complaints management, inspection scheduling and spectrum control
– Interface between spectrum management and spectrum monitoring systems
– Statistics and advanced reporting.

The main technical features of the system are:

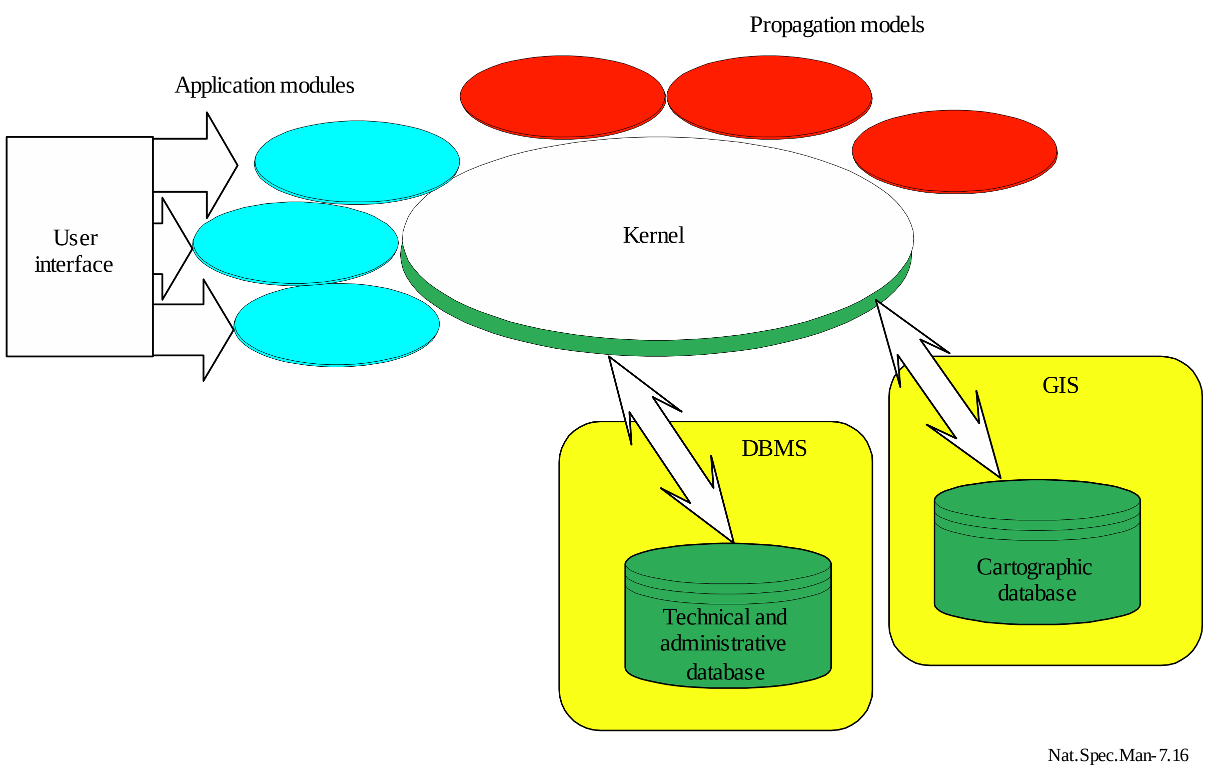
– Integrated spectrum management system with one single software package and one single database for administrative tasks and technical tasks
– Compatibility with ITU Recommendations and Reports
– International coordination agreements
– Several powerful propagation models

– Engineering, electromagnetic compatibility (EMC) and *C*/*I* analyses
– Powerful relational database system (ORACLE)
– Powerful graphical user interface (GUI) system
– Powerful geographical information system (GIS)
– Flexible, easy to use, reliable system
– Multi-users and multitasks system
– Features a multi-language and multi-windowing client-server environment
– Multiple platforms open architecture system.

The System is made up of different functional entities described in the following diagram:

FIGURE 7.16

System functional diagram



The **User Interface** allows the Man/Machine interface.

The **Kernel** is the functional module that manages all the system's shared resources and external resources (hardware, O/S and middleware) and makes them available for the applications.

The **Technical and Administrative Database** uses ORACLE as RDBMS and is used by both the Administrative and Technical Applications.

The **GIS** (geographical information system) uses the **Cartographic Database** to manage the geographical information available.

The **Propagation models** are used to calculate propagation predictions and fields strength. These models may use data parameters extracted from available cartographic data and GIS System.

The **Application modules** are functional entities allocated to a particular task. They use the kernel functions.

The system is multi-user and multitask, and features a multi-language and multi-windowing client-server environment.

The organization of the menus uses a task-based approach, which simplifies and optimizes understanding and use of the application.

2.3 System users administration and security management

The security management was an important point for the MTC for many different reasons among which:

- several persons from different Departments within the MTC may use the System,
- not every user has the rights to carry out all operations available,
- financial records are maintained in the database
- etc.

The system is implemented taking care of these considerations:

- Each user must be defined within the system by the System Administrator.
- An initial level of identification is provided by the operating system of the workstation from which the user may access the system.
- A second level of identification is provided by the application through the RDBMS (ORACLE) access controls.
- The third level is managed by the rights given on data manipulation.

2.4 Administrative functions

The administrative functions provided by the system according to the MTC needs are listed below:

- Data entry interface and data definition
- Spectrum user management
- Workflow management and processing
- International coordination management
- Equipment type approval and certification
- Licensing
- Billing, fees processing and automatic notification of renewal.

2.4.1 Data entry interface and data definition

This interface allows the user to enter the administrative as well as technical data to be used by the technical applications, as well as the reference data: ITU services, frequency plans and bands, libraries values, etc. This interface is intended to facilitate the System's operator's daily tasks.

2.4.2 Spectrum users management

Spectrum users are physical persons or legal entities that hold spectrum user licences or certificates. The system manages all relevant data related to spectrum users.

2.4.3 Workflow management and processing

The system allows defining processes between different MTC departments and entities and related to applications processing, licensing, certification and permits issuing, fees processing and billing, international coordination, notification and engineering, etc.

2.4.4 International coordination management

Radio frequencies are not limited to geo-political boundaries. Therefore, it is essential to coordinate frequency assignments, on the regional and international level. In order to fulfil this task, the MTC should:

– Maintain an accurate frequency management database.
– Be able to perform required Technical Analyses.
– Coordinate frequency assignments with neighbouring countries, either directly (bilateral agreements), or on a regional basis (regional agreements such as through CITEL), or on the international level (through the ITU and other international organizations).
– Negotiate bilateral agreements with neighbouring countries for Frequency-Sharing.

ELLIPSE spectrum allows the MTC operators to apply relevant international coordination Agreements and to generate relevant ITU electronic and paper notification forms required by corresponding services.

2.4.5 Equipment type approval and certification

This module allows managing type approved radio equipment and their certification based on national and international standards. The equipment certificates are printed in the required formats.

2.4.6 Licensing

Licensing and notification procedures should be based on National Policies and Regulations. The MTC should be able to:

– Establish national licensing and notification criteria.
– Establish national licensing and notification procedures and process:
  – Establish licensing procedures and process specific to each type of service (amateur, maritime, aeronautical, land mobile, broadcasting, etc.), station (fixed, mobile, portable, etc.) and user (government, security, private, etc.). The procedure and process comprise the different steps and actions required from submitting an application to the MTC until obtaining the appropriate license.
  – Establish notification procedures and process specific to each type of service, station and user. The procedure and process comprise the different steps and actions required to notify a new assignment, an issuance of a new licence, a renewal of an expiring licence, a modification to an exiting assignment, a cancellation of a licence, etc.
– Maintain an accurate and up-to-date licensing database and notification track record. As mentioned above such database and follow-up should be computerized. Licensing is based on a successful assignment.
– Produce appropriate and required reports and statistics.
– Develop updated licensing application forms and license formats.
– Define, in accordance with the National Radiocommunications Act, a list of license categories, a detailed framework for licensing process and procedures, a detailed licensing fee schedule and structure based on type of service, station, user, coverage, bandwidth, etc.

This module provides complete management of the license allocation process. The type of licence in MTC determines several parameters such as the period of validity, printable template and fees. The licenses are printed in the required formats.

2.4.7 Billing, fees processing and automatic notification of renewal

This feature stores all invoicing information: invoices issued, invoices paid, fees still to be paid, etc. When a licence has been allocated or modified, the invoicing details are stored and the fees are calculated using the parameters stored in the database. Depending on the service, several types of invoices may be issued. The fees may depend on several parameters, such as the number of stations, their power, the number of mobiles, etc. Invoices may then be printed and sent to users.

The system manages the payment arrears charges using the library of penalties and interests, and may calculate customers' debts. The invoices are printed in the required formats.

2.5 Technical analysis tools

The MTC Peru implemented the following Technical modules:

– technical interface data entry,

– engineering, electromagnetic compatibility (EMC) and *C*/*I* analyses,

– frequency assignment.

2.5.1 Technical interface data entry

A user-friendly interface based on GUI concepts and allowing a visual understanding of all elements contained on the screen is provided. The purpose is to allow the system operator to work in an efficient and secure environment. The application menus are usually organized following a job-based approach, e.g. interface data management is used to create and edit sites and stations as well as select them before making simulation calculation, etc.

2.5.2 Engineering, electromagnetic compatibility (EMC) and *C*/*I* analyses

As the administration in charge of frequency management in Peru, the MTC should:

– Set its Policies and Regulations based on technical analyses and planning provided by the engineering support.

– Prepare and coordinate international conferences and meetings based on input and studies from the engineering support.

– Set engineering laboratories with test, maintenance, calibration facilities; research and development; studies; etc.

– Keep an up-to-date listing of type-approved and technically acceptable equipment.

– Coordinate, assign and license frequencies/radio stations based on technical parameters, studies and analyses: EMC and Interference analyses, as well as verification of system engineering.

– The purpose of EMC and Interference analyses is to study the impact of proposed frequency assignments on the environment of existing frequency assignments (on the national and international level). EMC and interference analyses include four main steps:

  – Culling existing assignments according to geographic area around the proposed site and frequency range around the candidate frequency channel.

  – Determination of acceptable levels of interference.

  – Determination of interference levels from each existing assignment to the site under study.

  – Reporting of potential interference cases.

– Prior to performing EMC analyses, system engineering should be performed in order to assess the validity of the minimum requirements for a given network design. Although it is not usually the role of the MTC to perform a complete system design. The purpose of system engineering is to ensure that the technical parameters of the installation are consistent, sufficient and optimal for the type of operation proposed for the site.

– Perform inspection and monitoring activities based on recommendations and guidelines from the engineering support group.

In order to help the MTC achieving the above tasks, ELLIPSE spectrum features different modules such as: station and network coverage calculation, point coverage, route coverage, EMC analyses, intermodulation products calculation, *C*/*I* calculation, etc.

Different Propagation Models are available to the application operator that may be selected for a given analysis, band, region, service, etc. Among those models, a proprietary model developed by CTS is included that may be calibrated using local parameters.

2.5.3 Frequency assignment

The MTC should be able to:

– Maintain an accurate and up-to-date frequency assignment database. With the increasing number of frequency users and radio services, it becomes important to have an electronic database, using state-of-the-art relational database management tools. Frequency assignment is based on national policies and regulations and national frequency planning rules. The National database should include administrative, geographical and technical information on all national frequency assignments.

– Use the EMC analyses, where applicable, to determine if a new assignment is likely to cause or receive harmful interference to or from existing assignments.

– Assign frequencies based on results of frequency coordination and EMC analyses.

– Assign frequencies on shared basis. Indeed, the radio spectrum being a limited resource, the MTC should encourage and apply where applicable frequency sharing principals. Frequency sharing could be obtained if enough space separation is provided, and that is by re-using a frequency if there is enough space separation between the stations locations using the same frequency. The space separation could be controlled by controlling several parameters such as using limited output effective radiated power (ERP), directional antennas, limited bandwidth, appropriate filtering, etc. Frequency sharing could also be obtained through time sharing. In this latter case, the same frequency is assigned to different users on different time slots within a 24 h period.

The system is used to obtain an exact and full analysis of the interference for a given station/frequency. It is based on a modelling of a network using different types of stations and an analysis of the sources of interference. A list of frequencies is offered that optimises Spectrum occupation and minimises interference.

2.6 Interface with the spectrum monitoring system

The Operator in charge of technical spectrum monitoring tasks is able to access the spectrum management system technical data he requires for his day-to-day job. He may as well use monitoring data for updating the spectrum management database.

Information exchange between the management and the monitoring systems is done through electronic files transfer. The system sends to the spectrum monitoring system the lists of parameters to be measured (check list). The spectrum monitoring system returns a list of discrepancy associated with these parameters in an output file (result list), as well as the results of the measurements made where applicable.

Two operating scenarios may be considered:

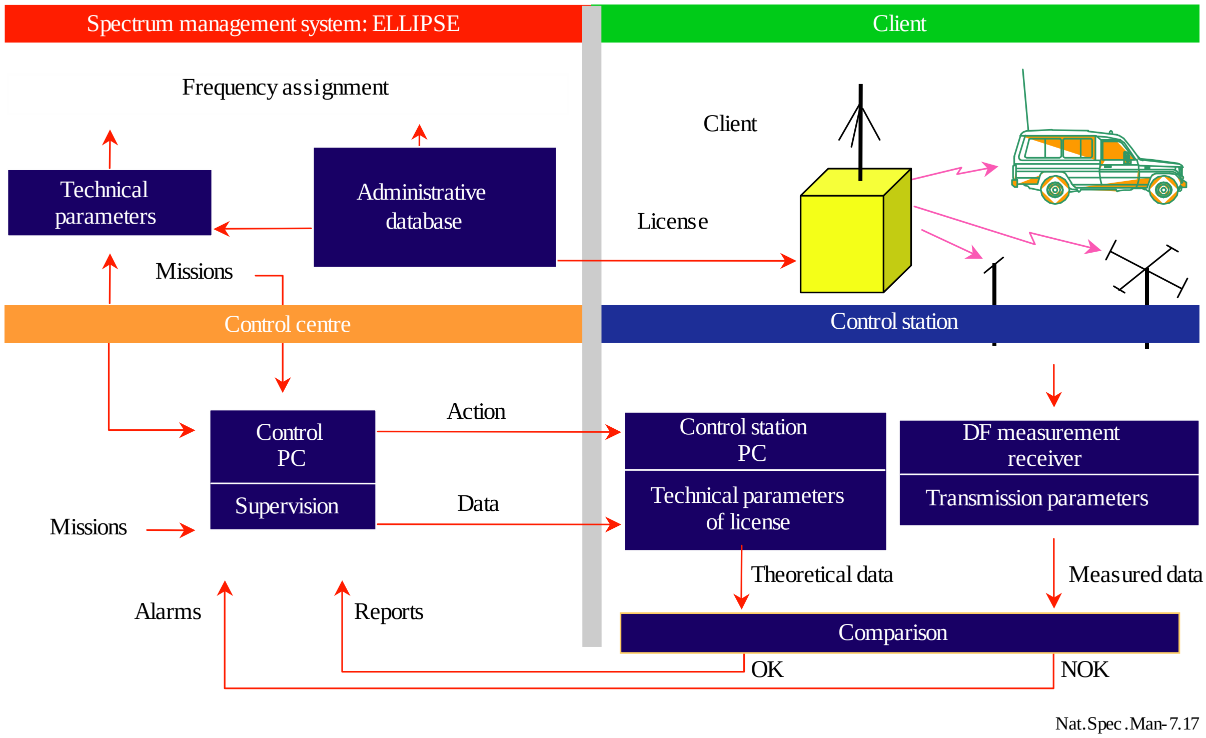
– Technical monitoring session at the initiative of the spectrum management system operator, or

– Technical monitoring session at the initiative of the spectrum monitoring system operator.

These missions may be initialized and launched from the national centre or from each of the regional centres.

FIGURE 7.17

Process and information exchange between the management and the monitoring systems



2.7 Geographical information system (GIS)

2.7.1 GIS tool

The GIS tool has been implemented at MTC Peru in accordance with ITU-R National Spectrum Management Handbook recommendations. The GIS Tool offers a coordinate projection engine and is used to manage all the geo-located geographical data.

The cartographic data is used by the propagation models to predict coverage and EMC calculations. It is also used to display networks topology configuration as well as technical analyses results in a user friendly way.

The different types of data used by the GIS are given below:

– Digital terrain model or DTM (ground level for each location above the sea)
– Digital elevation model or DEM (building heights above the ground level)
– Ground clutter (lakes, forests, buildings, open areas, etc.)
– Planimetry database (administrative boundaries, towns, rivers, roads, etc.)
– Digitised images database (scanned maps and ortho-images)
– ITU IDWM Program Information (e.g. conductivity).

2.7.2 MTC cartographic database configuration

The cartographic data provided for MTC Peru in the framework of this project is as follows:

– A first set of data for the entire country with a low accuracy.
– The second set covers the Capital City of Lima with a very high accuracy.

This configuration was felt as a convenient combination of accuracy vs. cost ratio. Indeed, it allows the MTC to make predictions all over the country, while having precise calculation and analyses for the Capital City of Lima. This cartographic database may be easily upgraded for others major Peruvian cities during upcoming new phases.

2.8 Conclusion

The introduction of a new process within an organization requires usually an adaptation period and close follow-up and assistance to the administration personnel.

This is even more important and sensitive when it consists in the implementation of a computerised system. Indeed, in addition to implementing or adapting to new processes and work methodologies, it is required to provide proper training to the systems operators generally used to paper work, manual processes and/or various non-integrated computerised applications.

Furthermore, a sophisticated computerised system requires a complete and accurate database with validated administrative, technical and geographical information. Therefore, the data gathering and data migration process has been a focus point and a real challenge for both the MTC and TCC/CTS during the implementation and commissioning of the System.

The success of such important and complex project depends really on a major principle: The seriousness and will of all involved parties, the MTC and the ITU in one side and THALES and CTS in the other side to invest the required energy and put the required human, technical and financial means and create the right synergy between all parties and at every level and step of the project implementation and systems operation.

Thanks to the efficiency of such state-of-the-art spectrum management and spectrum monitoring systems, the MTC has now the required means to enhance its daily spectrum management and monitoring tasks and properly fulfill its mandate in compliance with international and national regulations and recommendations. The future planned phases should help in the decentralization of the process.

ANNEX 8

TO CHAPTER 7

National spectrum management and monitoring system in Botswana (Republic of)

1 Introduction

The purpose of this Annex is to describe the spectrum management system in use by the Botswana Communications Regulatory Authority (BOCRA).

The BOCRA is a statutory body established by the Communications Regulatory Act of Botswana. It has a mandate amongst other things, to ensure rational use of the radio frequency spectrum in Botswana by employing proper spectrum management processes. In 2006 BOCRA acquired an Automated Spectrum Management System and this system was developed in line with the existing spectrum management policies. To date the system has undergone several upgrades in order to meet the demands of spectrum management as new technologies are being licenced.

The spectrum management system, illustrated in Figure 7.18, is comprised of:

- One (1) web-enabled, automated spectrum management system (ASMS) located in the BOCRA headquarters, and
- One (1) spectrum monitoring system (SMS) consisting of 16 fixed and 2 mobile monitoring stations located around the country, as well as two TDOA sensors that operate in conjunction with the fixed sites in the capital to provide a hybrid TDOA/AOA capability.

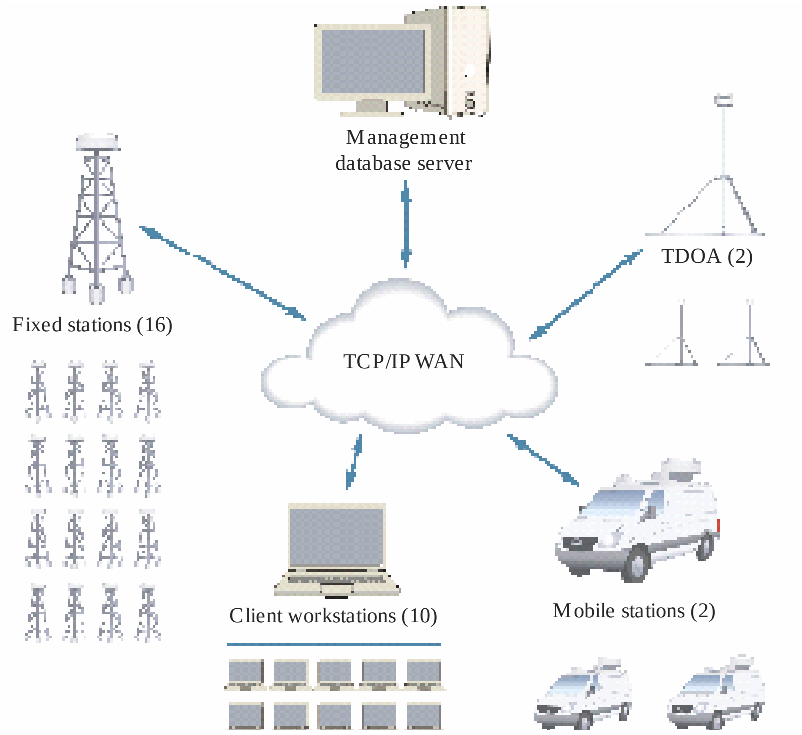
All of the hardware and software is supplied by TCI of the U.S.A., and is designed to work together in accordance with Recommendation ITU-R SM.1537.

The system enables the BOCRA to effectively manage the radio spectrum in Botswana. It does so by:

- Establishing and maintaining a record of the permitted usages for the various radio frequency bands according to the national plan.
- Maintaining a record of all radio equipment for each licensee by serial number and call sign.
- Authorising and maintaining a record of every frequency assignment in accordance with the national plan.
- Analysing proposed frequency assignments for possible interference with authorised users of the spectrum.
- Performing all ITU-recommended radioelectric measurements.
- Detecting non-compliant, unauthorised, or interfering signals and their characteristics.
- Locating the source of non-compliant, unauthorised, or interfering signals, enabling swift resolution of the problem and the protection of the interests of the legitimate users of the spectrum.

FIGURE 7.18

BOCRA System Components



2 Description of the Spectrum Management System

2.1 Overview

The BOCRA's automated spectrum management system (ASMS) is comprised of:

- One (1) ASMS web server connected to the BOCRA's local area network and to the internet. It hosts the BOCRA's online application web site. It also hosts the management system database.
- Ten (10) client workstations, distributed between the administration's central office and the monitoring control centre building. The ASMS client software is installed on each workstation; the optional analysis tools package is installed on several of those workstations.

The purpose of the management system is to aid in planning and managing the use of the radio spectrum resource. At the initial installation of the system BOCRA was responsible for Telecommunications regulation only. BOCRA now has a converged regulatory mandate for Telecommunication, ICT, Broadcasting and Postal Services. The system was upgraded to include licencing of other services. The centralisation has made the overall delivery of the BOCRA mandate easier as the services licences, radio licences, system licences are linked making it possible to have a single view over customers holding separate licences. The system now includes the following functionalities:

- It maintains the national plan of frequency allocations. The plan can be displayed in either table or graphical format.
- It maintains administrative records for all applicants including name, mailing address, and contact information.

- It processes applications for radio licences, systems and services licences, and telecom equipment dealer licences. It records all frequency assignments by user, location, frequency, power, and other technical parameters required by the ITU.
- It calculates the propagation characteristics of transmitting stations and analyses the potential for interference between them.
- It automatically calculates fees for all licences and produces pro forma invoices. It processes payment receipts and synchronises billing and payment information with the BOCRA’s accounting system.
- It manages compliance records such inspections, and violations.
- It produces administrative and technical reports.
- It manages the list of type approved equipment and uses it to fill make/model information in application forms.
- It interfaces with the spectrum monitoring system to help identify non-compliant and non-authorised signals.
- It allows online processing of the following System and Service licenses: PTO (Public Telecommunications Operator), VANS (Value Added Network Services), PTN (Private Telecommunications Network). It also has a provision to save all the softcopy material that was submitted during the application process and any information requested during evaluation.
- It allows filing complaints online such as:
  - Complaints to any of the BOCRA’s licensed operators.
  - Complaints about non licensing issues.
  - Reported violation of license conditions.

It is designed in accordance with the guidelines contained in Recommendation ITU-R SM.1370.

2.2 Architecture

The management system is designed around the client-server computing model. The ASMS web server employs Microsoft® SQL Server® for the database and Microsoft IIS for the website software. The ASMS client software is custom written in a variety of Microsoft languages, and uses components from ESRI™, for the geospatial display of technical analysis results, and Sage™ for interface with the BOCRA’s accounting system.

The ASMS web server and the document printer are housed in the BOCRA headquarters building. The ASMS client workstations connect to the server over the office local area network. The ten workstations are divided between the headquarters and the monitoring centre, which is located in another building in the capital connected by microwave link. Both the ASMS client and SMS client software are installed on every workstation.

The ASMS web server connects to the internet to accept applications submitted from online users. It also connects to the BOCRA’s Simple Mail Transfer Protocol server. It uses this SMTP connection to send approval notices, renewal notices, and general status notifications by email to applicants and administrators, as appropriate.

Multiple layers of security are employed throughout the system including password restricted access, security group memberships, encryption, and techniques to help to secure transmissions over the network and to discourage unauthorised access to the system.

2.3 ASMS Client Software

The ASMS client software provides a friendly user interface to the management system database. It accepts the information contained in licence applications, interference complaints, and other sources and relates that information to data already in the database. The result is the ability to produce a variety of useful output documents, such as invoices, notices, licence certificates and management reports. This is illustrated in Figure 7.19.

The ASMS client application is menu-driven. Each top-level menu provides access to a set of related features and functionality. The top-level menus and the functionality they provide are described in the following sections.

2.3.1 Accounting

The Accounting menu provides access to the administrative details of customers and provides control over the billing features of the system. It allows invoices to be created manually, if needed, and payment receipts to be recorded. The user can update the fixed amounts charged for various services as well as the constants used in fee computations. The double-entry based general ledger used by the ASMS is maintainable from this menu. Lastly, it opens an interface to the BOCRA's accounting system, where the ASMS ledger and the BOCRA's ledger can be synchronised.

2.3.2 Application Processing

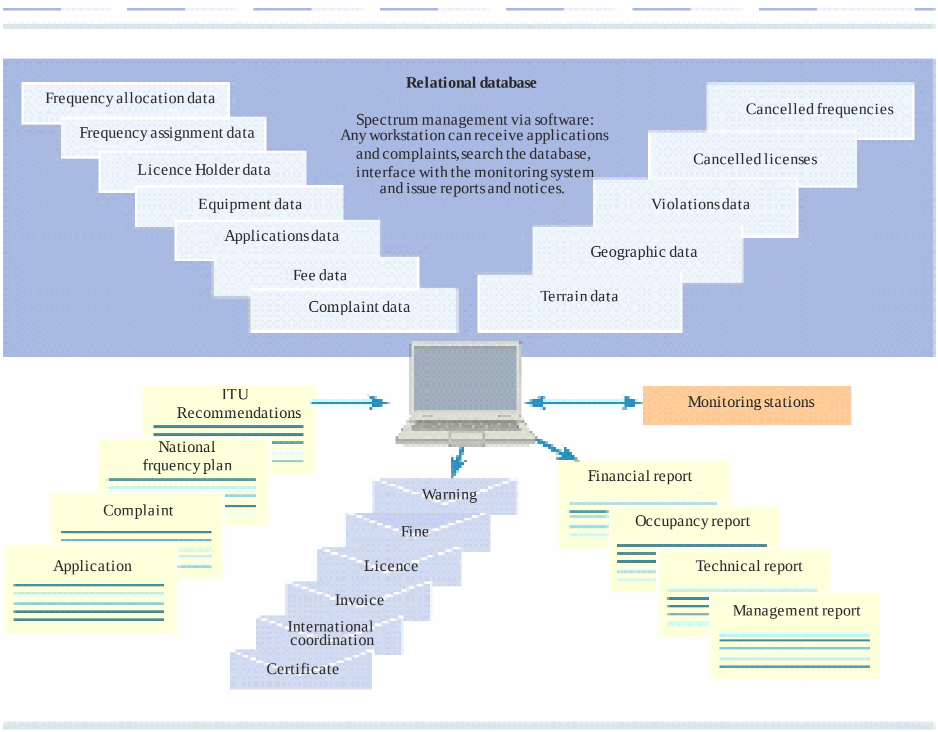
The Application Processing menu allows several types of applications to be entered into the system for review and approval:

- Radio licence (for usage of the radio spectrum).
- Telecom equipment dealer licence (for equipment importers and distributors).
- Telecom equipment type approval (to certify a make/model for use in Botswana).
- Incoming border coordination (to predict interference from proposed foreign stations).
- System and Service (a service-neutral licence for systems providers).

The system assigns a unique reference number to each new application, provides default values in application forms, and auto-completes fields where possible. These features are available to online users of web browsers as well as for users of the ASMS client software.

FIGURE 7.19

Typical ASMS Inputs and Outputs



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2.3.3 Licence Processing

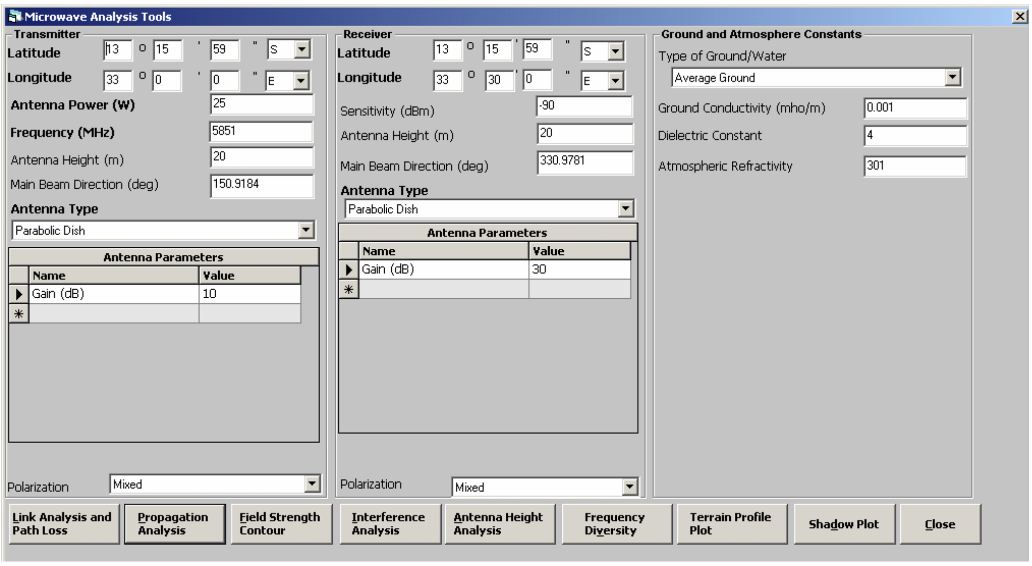
The Licence Processing menu allows various actions to be performed on a licenced application. A brand-new licence can be issued after fees have been paid; licences renewal reminders can be sent by email; licences can be modified, transferred, suspended, or terminated. Extensive search capabilities are also available.

2.3.4 Technical Analysis

The Technical Analysis menu provides access to a suite of tools that predict radio signal propagation over the country’s terrain. The initial conditions for each analysis derive from information contained in a user-selected radio licence application, including station coordinates and the equipment specifications at the station. The user can vary the initial values and recalculate the results without affecting the information stored inside the database. The system also supplies values for certain atmospheric and ground factors are supplied by the system; the user can experiment with those values as well. Some tools provide tabular reports; others display their results graphically on digital terrain maps. The input parameters screen for microwave analysis is shown in Figure 7.20.

FIGURE 7.20

Microwave analysis input parameters



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2.3.5 Frequency

The Frequency menu provides options to query the national frequency allocation plan (or the ITU plan for any region) and to display results in text or graphical format. This menu offers access to several reports and queries related to frequency assignments. It allows existing frequency assignments to be queried and new frequencies to be assigned (subject to application status). It also identifies applications that include stations within coordination distance of neighbouring countries and tracks the status of outgoing requests for border coordination.

2.3.6 Compliance

The Compliance menu provides for the creation, modification, and disposition of complaint reports, violation reports, and station inspection reports. It also exports licenced station details to the spectrum monitoring system (SMS) for use in automatic violation detection (AVD), and displays monitoring measurements obtained from the SMS.

2.3.7 Reports

The Reports menu provides access to eleven text-based reports and fifty-nine custom reports covering wireless stations, applications, licences, complaints and financial queries.

2.3.8 Administrative

The Administrative menu allows administrators to update ASMS system tables, view error logs, manage individual users and define user groups. There are also options to import the latest BR-IFIC terrestrial assignments CD, approve radio licence applications, and print ITU notifications.

2.4 ASMS Web Server Software

The management system database resides on the ASMS Web Server. ASMS workstations connect to this server to process radio license applications, generate reports, and to accomplish most other tasks. The server also hosts the ASMS web customer portal, which allows online applicants to submit applications and other forms electronically over the Internet. The web customer portal allows the following forms to be filled in and submitted:

- Application for radio licence (all types)
- Application for equipment type approval
- Application for radio dealer licence
- Application for systems and services licence
- Complaint

These forms contain all the fields and functionality that appear in the workstation client version of ASMS, including dynamically updated selection lists, auto-filling fields and the ability to electronically attach supporting documents. Online applicants do not see fields reserved for official use, however.

Authorised BOCRA officers can log into the website through the website’s administrator portal. There, they can accept applications and complaints directly into the ASMS database. The elements of online registration and application are shown in Figure 7.21. A web page from the customer application portal appears in Figure 7.22.

FIGURE 7.21

Online registration and application entry

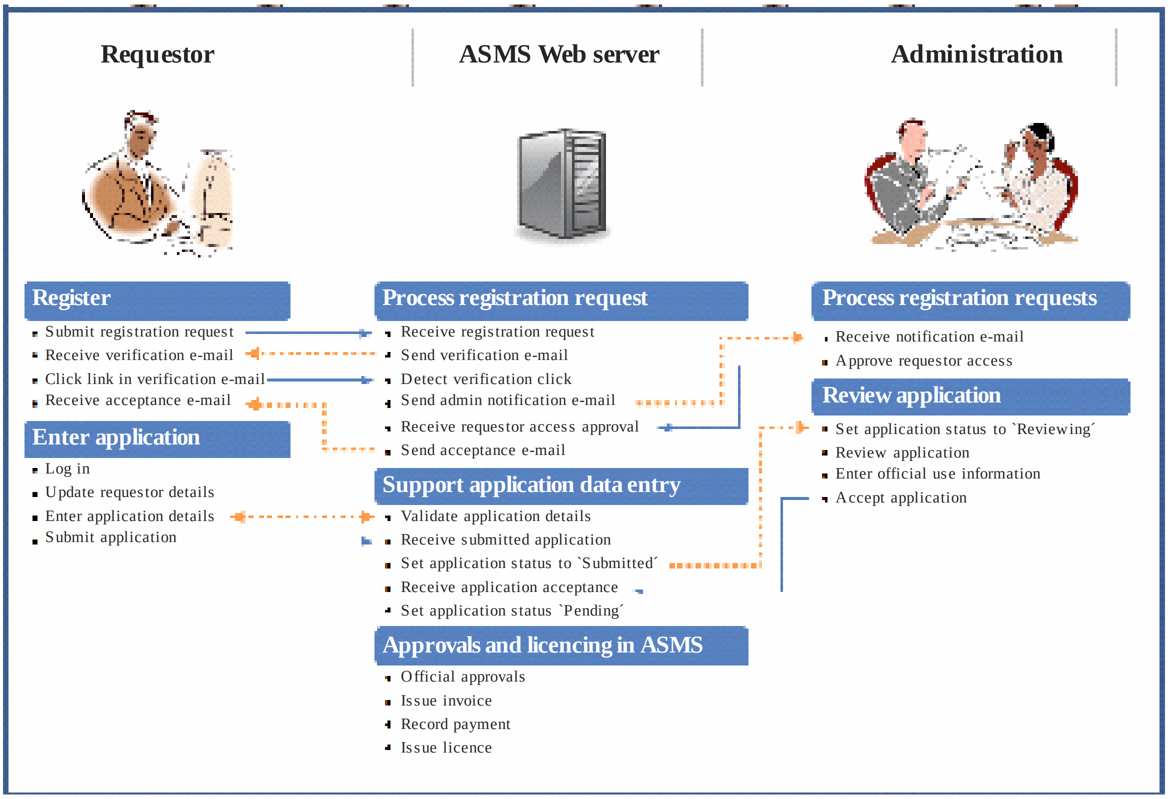

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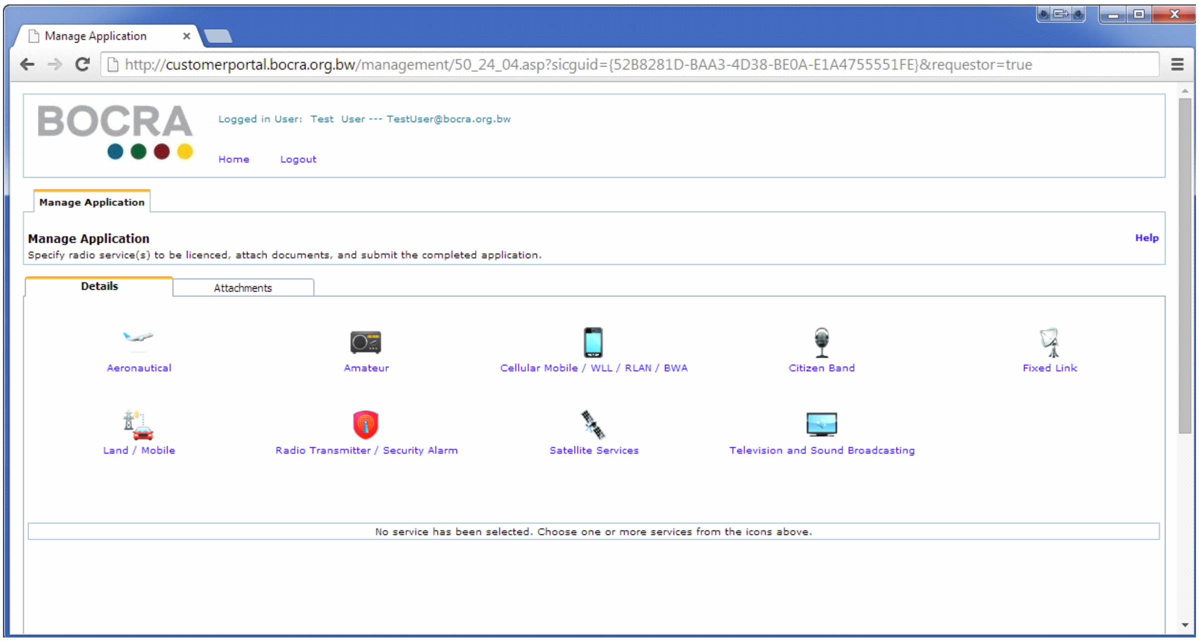
FIGURE 7.22

Online application for radio license



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2.5 Licencing Workflow inside the ASMS

The ASMS implements a centrally-distributed workflow model for the processing of licence applications. The ASMS database attaches a status to each application as it moves through the system. A new licence application or licence modification is considered to be in "Data Entry" while information is being entered. Once the data entry is complete and the system verifies that all required information is present, the application can be promoted to "Pending Approval" status. After the official review and approval is granted from various departments, the system automatically calculates the relevant fees, generates an invoice, and promotes the application status to "Invoiced". As soon as payment in full has been processed, the application can then be promoted to "Licenced" status. Workflow controls ensure that the status of an application cannot be advanced until the current processing is completed.

2.6 Security

Every user of the ASMS Client is assigned to one or more security groups as part of their login profile. Each security group has permission to access a limited portion of the ASMS. Users in the Data Entry group, for example, have permission to view and edit licence applications, but do not have permission to view and edit accounting records. The permissions of each group can be customised. Several levels of access can be set for any control in the user interface, ranging from Not Visible (lowest) to Full Access (highest). When a user belongs to more than one security group and the permissions for an object or control conflict, then the highest permission will take precedence. New security groups can be defined based on existing groups.

3 Description of the Spectrum Monitoring System

The spectrum management system is integrated with a Spectrum Monitoring System (SMS) in accordance with Recommendation ITU-R SM.1537.

3.1 Overview

The primary purpose of the SMS is to:

- Monitor compliance to the assigned emissions as licenced and stored in the management system database.
- Conduct interference investigations; locate unlicenced transmitters or transmitters operating out of their prescribed characteristics.
- Monitor actual usage and the ability to automatically detect violations of licenced technical parameters.

The BOCRA SMS comprises (16) V/UHF fixed monitoring stations distributed around the country. Two major towns are covered by three sites each. Five sites around the country also have HF DF capability. They were strategically chosen to provide country-wide HF DF. All sites collect angle-of-arrival (AOA) measurements which can be combined to obtain a geolocation result.

The system also includes two time-difference-of-arrival (TDOA) sensors installed in the capital city. Their measurements can be combined with the measurements from one other AOA site to provide “hybrid” geolocation capability in the capital.

The system also includes two (2) Mobile Units with HF/VHF/UHF capability. They can perform DF up to 8 GHz.

The monitoring stations are controlled primarily from the monitoring control centre located in the capital city, Phakalane, Gaborone. The ten (10) workstations are divided between the control centre and the BOCRA headquarters. They all run both Scorpio Client (the SMS client application) and the ASMS client software.

The SMS performs all of the ITU-recommended measurements, including signal parameter measurements (frequency, field strength and power flux density, modulation, and occupied bandwidth), direction finding and spectrum occupancy. The Automatic Measurement Execution System automates this entire process so that the operators do not have to learn, remember, or spend time observing the various measurement rules.

3.2 Architecture

The system software runs in a Microsoft® Windows® client-server environment The SMS servers are running on Windows 7 Embedded. The SMS client workstations are running on Windows 7. All measurement servers in the fixed stations are connected to the office network via microwave link. The measurement servers in the mobile vehicles connect via GSM cellular network. The client workstations are divided between the BOCRA headquarters building and the monitoring centre, which is located in another building in the capital connected by microwave link. Both the ASMS client and SMS client are installed on every workstation.

3.3 SMS Client Software

The SMS client software (Scorpio Client) software includes the following capabilities:

3.3.1 Metrics

These facilities provide the means to make precise measurements of signal parameters in accordance with ITU recommendations. These facilities are used to verify compliance with licence requirements and can be made on a scheduled basis.

3.3.2 Device Control

These facilities are used to find, identify and record parameters of specific emitters, usually unlicenced pirate systems or sources of interference. These facilities include extensive direction finding tools to locate the target emitter.

3.3.3 Tools

These tools are used to survey, detect and map the spectrum for the presence of signals. These are basic means to check if the actual electromagnetic environment corresponds to information contained in the management database. The Automatic Violation Detection (AVD) tool will report compliance and discrepancies between the management database and the "real" electromagnetic environment. Spectrum occupancy tools provide statistical checks to verify that the assigned channels are being used in accordance with their licences.

3.3.4 Diagnostics and Maintenance (BIST)

The built-in self-test facility is used to obtain the operational status of a server (fixed, mobile or portable monitoring station).

3.4 Making Metrics Measurements

The metrics tool contains a "Task Calendar" area for setting up measurement tasks. One or more of the following signal parameters may be selected for measurement: frequency, field strength and power flux density, modulation, occupied bandwidth, direction and spectrum occupancy. Measurements are automatically repeated and averaged according to user selected values. The available averaging methods include linear, RMS and maximum hold. All measurements are fully compliant with ITU recommendations and the *Spectrum Monitoring Handbook*. Measurements can be set to execute in any of three modes: interactive, scheduled, and background.

– Interactive mode: Allows direct interaction with various functions that provide instantaneous feedback such as monitor receiver tuning, demodulation selection, real-time DF display, automatic alarm notification and pan-display selection. DF homing to track down a source of interference, and field-strength mapping over a geographical area are important examples of interactive operation. DF and field strength measurements may be commanded in a mobile unit when the unit is either stationary or in motion without the need to assemble/disassemble antennas to make measurements.
– Automatic or scheduled mode: Tasks may be schedule to execute immediately or to be executed at specified times in the future. Functions performed in scheduled mode include technical measurement and analysis, and direction finding.
– Background mode: Used for performing spectrum occupancy, DF Scan and Automatic Violation Detection – tasks where it is desirable to collect data over long periods of time. An operator commands an automatic scan on lists of discrete frequencies or over a range or ranges of frequencies, to run either immediately or at some date/time in the future. The requested measurement results are stored locally in the spectrum processor, and may be recalled by the operator that initiated the task either while the task is still running or after the task has completed. These data may then be used to generate reports and may be combined with licence data in the management system database to perform AVD in order to detect possible licence violations.

The metrics tool also contains a "Task Results" area where the operator is able to view, print and save a report that summarises the data that was collected. Measurement results reports contain all information relative to the measurement setup and a summary of its results include the following information: task data, date, time, frequency, bandwidth, identity, requested measurement(s), type, result, and graphical data.

3.5 Map Display and Control

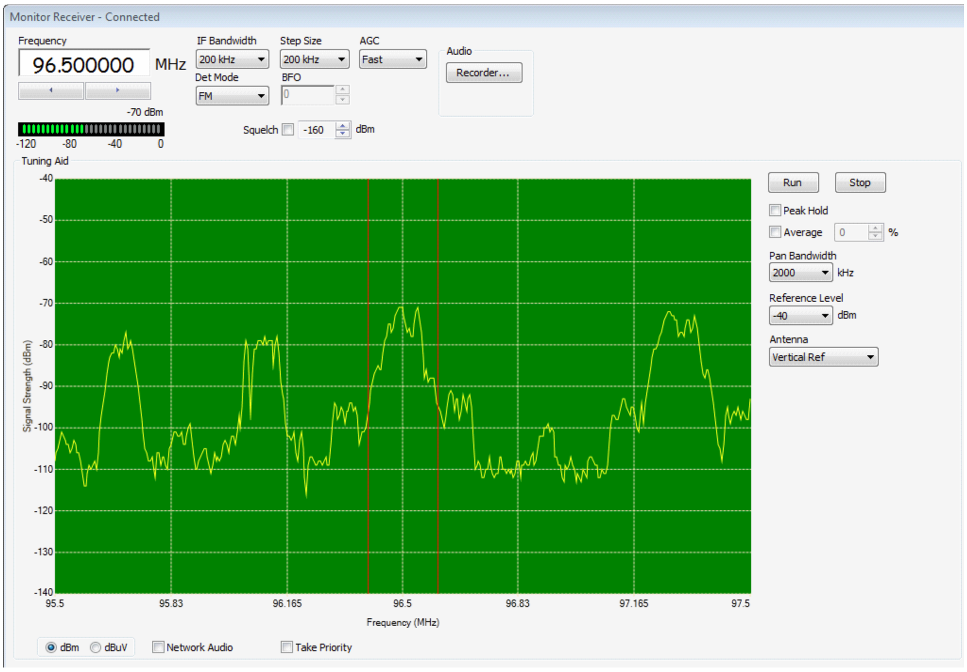
The map window displays the network monitoring stations, DF lines of bearing (LOBs), and the location of emitters using error ellipses at the intersection of LOBs. The system is configured with multiple maps, including Internet maps such as Bing® and OpenStreetMap. The operator has the ability to display multiple layers (cities, regions, rivers etc.) by selecting the "Layers" button. The operator can zoom in, zoom out, pan, centre, or do measurement functions. Built-in and custom annotations can be added to any map. The operator has the option to request a hard copy print of the display.

3.6 Monitor Receiver

The operator has control of the built-in monitor receivers through a Virtual Control Panel (VCP), Figure 7.23. The VCP has familiar controls associated with typical standalone receivers, providing interactive control of the receiver functions to view and listen to the signal being monitored in real-time. Receiver status information and controls for frequency, detection mode, and automatic gain control are displayed on the same screen. Audio recordings are made digitally as audio files (.wav) and can be transferred between all stations. Workstations are equipped with a sound card for audio playback of live and recorded signals.

FIGURE 7.23

Monitor Receiver Screen



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The operator has access to a number of displays that allow looking at the frequencies of interest. The spectrum panoramic (or Pan) is one of these displays. It is an X-Y plot of signal amplitude versus frequency and can display up to 10 MHz bandwidth of IF digital data. The operator can use this display to view and identify wideband signals, signal relationships in the radio spectrum, and to investigate sources of interference.

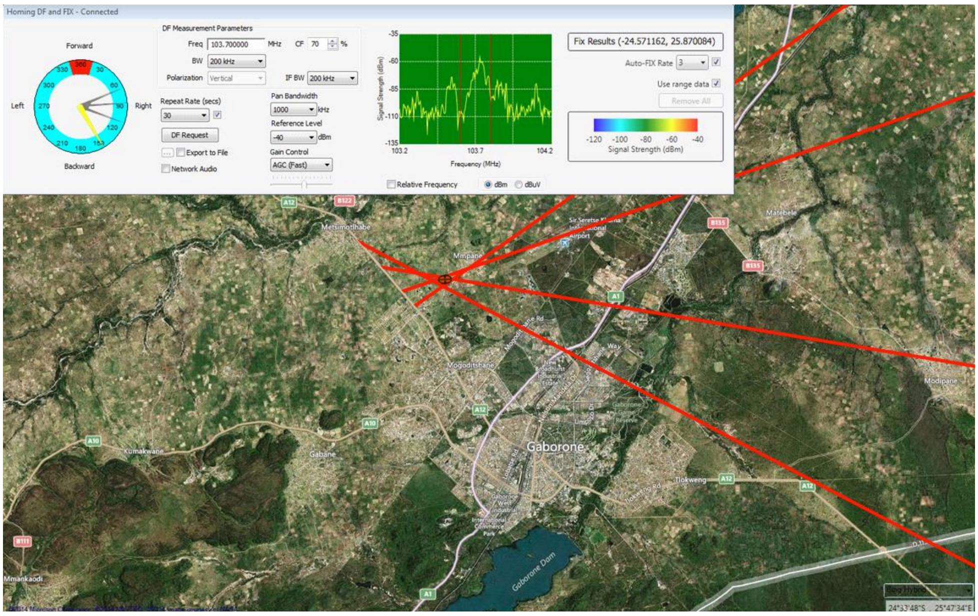
3.7 Direction Finding (DF)

The DF system has the ability to quickly and effectively find the location of emitters using the monitoring stations. The system can calculate the results from two or more of the stations as well as use a single mobile station to perform "Homing" DF.

"Homing" DF lets a single mobile monitoring station take successive DF and signal strength measurements while on the move. From these measurements the mobile monitoring station homes in on the location of the transmitter (Figure 7.24).

FIGURE 7.24

Example of a DF/Map Display Window



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3.8 Occupancy and Automatic Violation Detection

Spectrum occupancy allows the operator to define the monitored range by specifying the start and stop frequencies of the band to be searched and to specify search parameters, including the time period over which the search may be done.

The monitoring system has, as a central feature, Automatic Violation Detection (AVD). AVD is a powerful tool that allows for the verification of compliance by licenced emitters and assists in the detection of unlicenced operations. AVD operates in conjunction with the licence data (frequency assignments) taken from the management database. AVD alerts the operator when transmissions do not comply with tolerances of assigned centre frequency and bandwidth, as specified for the allocated band and service in the Botswana National Frequency Plan. It also reports on emitters that are being operated without a corresponding licence in the management database.

3.9 Reports

Reports of signal parameter, spectrum occupancy and other measurements are available from the system.

3.10 Hybrid AOA/TDOA

The BOCRA now uses a “hybrid” geolocation system to locate emitters in the capital city. It is comprised of two time-difference-of-arrival (TDOA) sensors whose measurements are combined with one or more angle-of-arrival (AOA) stations.

BOCRA upgraded to the hybrid system in order to enhance geolocation accuracy in the most cost effective manner. AOA-only arrangements require fewer sites (2 minimum) and their coverage area is larger, but their accuracy decreases with emitter distance. The accuracy of TDOA-only arrangements does not decrease with emitter distance, but they require more sensors (3 at least, 5 practically) and their usefulness is limited to the area bound by the monitoring sites. Hybrid arrangements, such as the system in use by BOCRA, combine the advantages of AOA and TDOA systems while simultaneously overcoming the limitations of each. Studies undertaken by the system manufacturer indicate that, in general, the hybrid solution requires only half the number of sites compared to a TDOA-only configuration to achieve the same level of geolocation performance. The initial cost of a hybrid system requiring fewer, but more expensive sites versus a TDOA-only system is comparable. However, recurring costs are lower with a hybrid system due to the smaller number of sites.

ANNEX 9

TO CHAPTER 7

Computerized tools and automated harmonized activities used in the CEPT

1 Introduction

The CEPT is using some computerized tools in their spectrum management deliberations:

– SEAMCAT – Spectrum Engineering Advanced Monte Carlo Analysis Tool

– EFIS – ECO Frequency Information System.

2 SEAMCAT

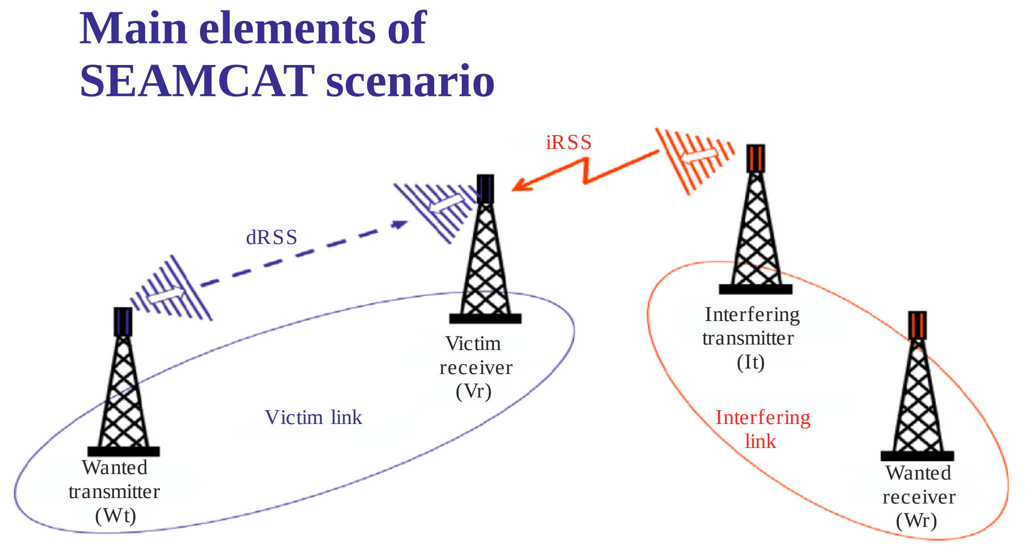
SEAMCAT is a simulation software tool based on the Monte-Carlo simulation method, which is developed within the frame of European Conference of Postal and Telecommunication administrations (CEPT). This tool permits statistical modelling of different radio interference scenarios for performing sharing and compatibility studies between radiocommunications systems (short range devices, GSM, UMTS, LTE, etc.) in the same or adjacent frequency bands.

The software is maintained by ECO (European Communications Office) and is distributed free-of-charge. The SEAMCAT Handbook is available in the public domain as well as an on-line manual and allows the potential user of SEAMCAT to understand how precisely the SEAMCAT software works. The application user interface is MS Windows oriented and XML-files are used for the data exchange.

The SEAMCAT tool can model any type of radio system in terrestrial interference scenarios. Results include inter-alia the quantification of probability of interference between various radio systems, consideration of the required spatial and temporal distributions of the received signals or capacity loss due to interference.

FIGURE 7.25

Main elements of SEAMCAT scenario



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By means of SEAMCAT, the CEPT can develop sharing rules which are important elements of the spectrum use optimisation process. Unless some intelligent interference avoidance is implemented in radio systems, the careful choice of sharing conditions is the only means for achieving successful co-existence and optimal spectrum use.

The SEAMCAT software nowadays is used in most CEPT studies defining the minimum technical requirements for the introduction of new radio services and applications in the spectrum in a spectrum compatible way with the incumbent services and applications. Experts from CEPT administrations rely on the SEAMCAT tool in their spectrum engineering considerations.

The SEAMCAT functions allow automation of repetitive compatibility studies by scheduling several SEAMCAT simulations to be done in one run of the programme. The typical case for this is to study the impact of change of any one (or few) scenario parameters on the probability of interference.

The CEPT SEAMCAT workspace is publicly available. More information including the download of SEAMCAT is found at http://www.cept.org/eco/eco-tools-and-services/seamcat-spectrum-engineering-advanced-monte-carlo-analysis-tool.

SEAMCAT also provides a plug-in (API) that may be used e.g. to model some special system design features such as smart antennas, or to take account for any additional environment features, e.g. terrain/clutter impact. Results can also be exported into external files for signal processing in other tools (Matlab, etc.).

The use of SEAMCAT is also recognized in

– Report ITU-R SM.2028-1 – Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems;
– Recommendation ITU-R M.1634 – Interference protection of terrestrial mobile service systems using Monte Carlo simulation with application to frequency sharing.

3 EFIS

On 31 January 2002 the ECO launched a frequency information system called EFIS. All information in EFIS is available to the public on the Internet. More information including quick search are found at http://www.efis.dk/.

EFIS is the spectrum utilization information database in Europe that ensures the European harmonised availability of information regarding spectrum use in Europe. Nearly all of the 48 CEPT countries (including all EU member states) are represented in EFIS; also, there is an ITU allocation table (Region 1) and the ECA (European Common Allocations) table fully integrated in EFIS.

The EFIS radio application terminology is constantly amended to take into account changes in frequency management such as addition of new applications. ECC Report 180[42] includes guidance on the interpretation of the requirements for administrations when editing information in EFIS.

With this tool the CEPT aims at providing a valuable service to all parties with an interest in spectrum utilisation. EFIS will also contribute to the CEPT policy objectives of harmonisation and transparency as well the European Union policy objectives laid down in Decisions of the Council and European Parliament on Radio Spectrum Policy.

In 2005, the European Commission issued a mandate to CEPT on the feasibility for EFIS to develop into a European portal for spectrum information.

An EC Decision on this issue was published on the 16th of May 2007. EFIS is the tool to fulfill this EC Decision (2007/344/EC) on the harmonized availability of information regarding spectrum use in Europe.

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[42] See: http://www.cept.org/ecc/deliverables.

EFIS has also a role to play in the European Union's spectrum inventory[43], which is part of the programme of initiatives set out in the EU Radio Spectrum Policy Programme (RSPP).

EFIS users can search for and compare spectrum utilisation across Europe as well as related information such as CEPT activities, radio interface specifications according to the R&TTE Directive[44] and other national or international regulations.

EFIS contains the following data types (regulatory information):

– Allocations (ITU RR terminology)
– Applications (agreed European radio application terminology)
– National radio interface information
– Documents (tagged with the applicable application term(s) and frequency range(s)
– Licensing/right of spectrum use

Spectrum management information has featured much more prominently in EFIS since early 2012, with the introduction of a 'non-regulatory' section.

A wide range of information is available in EFIS, mostly in the form of documents linked to the European Table of Frequency Allocations and Applications (the "ECA table" or simply "ECA"); among these CEPT questionnaire summaries for dedicated spectrum inventory purposes, ECC Reports (e.g. compatibility studies) and other useful information about the actual present and future planned spectrum usage, e.g. ECO Report 03 on the licensing information of the public mobile bands or ERC Recommendation 70-03 on SRD (including the national implementation status information of each individual regulatory entry).

Spectrum inventory information includes:

– Relevant information about current usage of one or several frequency bands, or expected future usage;
– ETSI System Reference Documents which include information about the market such as existing spectrum usage, current regulations, forecasted spectrum usage and a proposal for the future spectrum usage as well as regulation;
– EU: relevant information/ECdecisions/reports prepared by CEPT for the European Commission;
– National: national administrations have additional information of a non-regulatory nature on the possible evolution of spectrum use under study in their country they may upload documents under this heading;
– Third Parties: documents with relevant information from CEPT/ECC MoU/LoU partners.

The CEPT Administrations upload their data in EFIS directly. They can use an automated interface between their national spectrum management tools and EFIS by using XML-files.

In basic terms, the EFIS setup consists of a database and a web server, with software applications enabling interaction between database (SQL database) and web server. The system is founded on leading standards within each individual area.

The complete EFIS environment has a production system and a test system with two virtual servers: one for ECO test purposes and one system for administrations (to test, for example, new national software applications/systems before using these in the actual EFIS).

For project management purposes the management and bug/issue tracking system 'Trac' is used.

Details of the EFIS setup are as provided in Figure 7.26 below:

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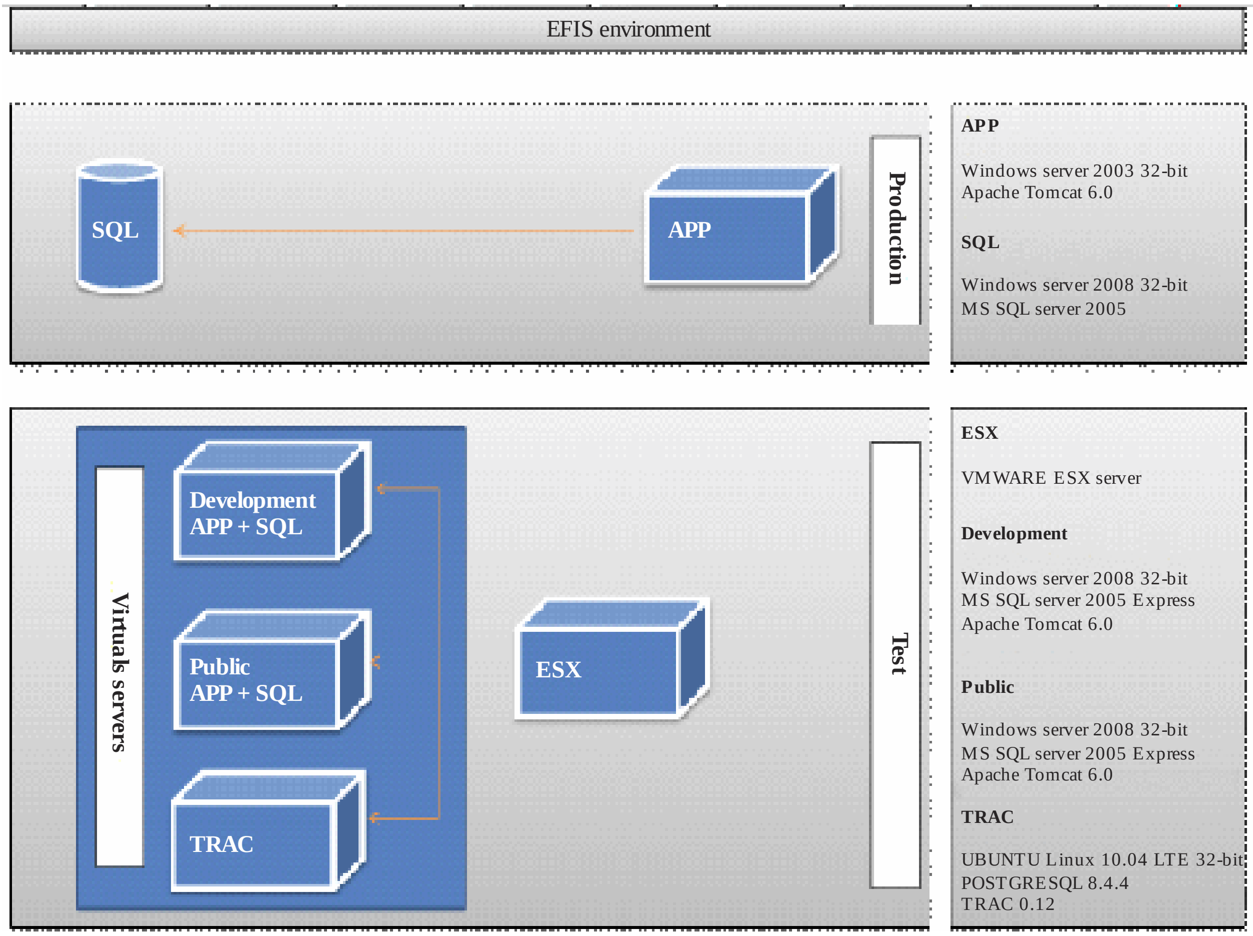
[43] The EU Spectrum Inventory aims at identifying frequency bands in which the efficiency of the current spectrum use can be improved.

[44] This Directive (1999/5/EC) will be replaced in 2014 by the Radio Directive.

FIGURE 7.26

EFIS environment



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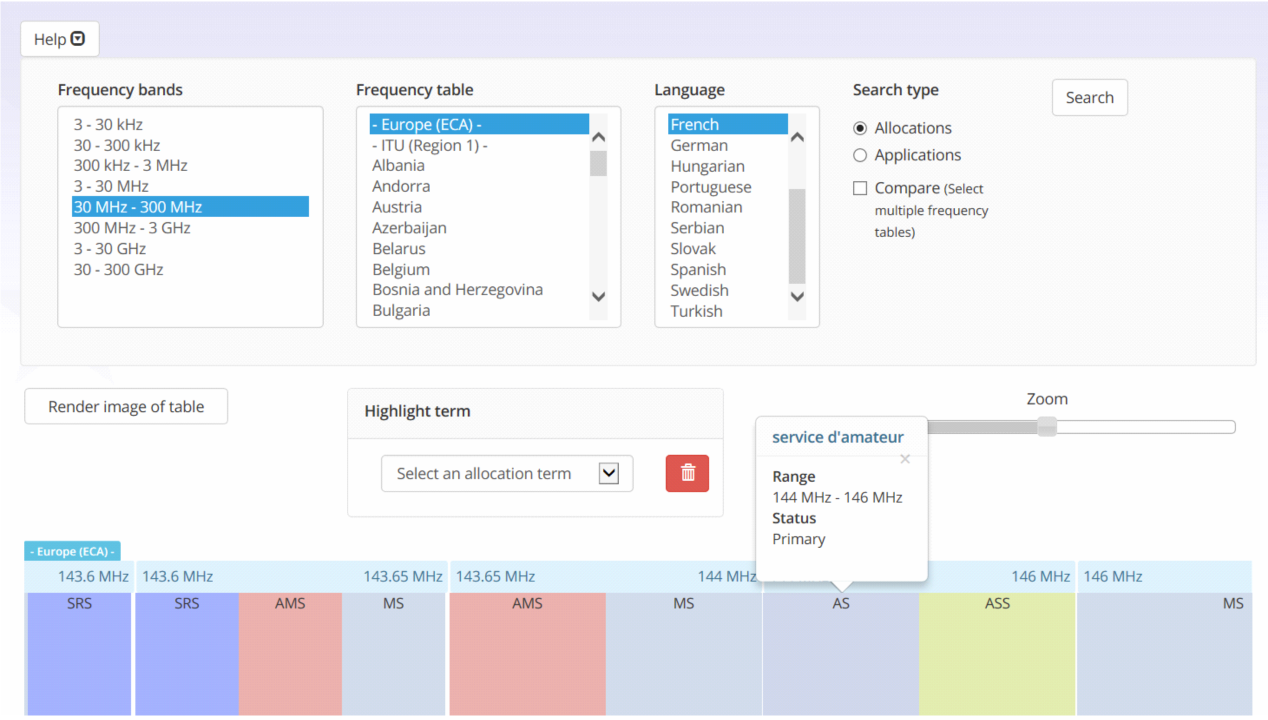
The EFIS database also includes a possibility to use a graphical visualization tool by all those authorities which are interested (also outside of CEPT). National frequency table information, as well as utilization plan information, can be graphically visualized and exported, either as static pictures or by using a link which can be embedded on e.g. a web-side of the external administration. This allows users to retrieve information, compare information in the national language as well as other languages.

FIGURE 7.27

Example of graphical state-of-the-art visualisation of frequency table information



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BIBLIOGRAPHY

ITU-R Texts

Rec. ITU-R SM.1370 Design guidelines for developing automated spectrum management systems

Rec. ITU-R SM.1537 Automation and integration of spectrum monitoring systems with automated spectrum management

CHAPTER 8

Measures of spectrum utilization and spectrum utilization efficiency

Table of Contents

8.1 Introduction

Spectrum utilization efficiency (SUE) is important since the spectrum is a limited resource that has economic and social value, and because demands for spectrum are increasing rapidly in most frequency bands. In recent years, many improved and emerging radio technologies, made possible considerable improvement in the efficient use of the spectrum. The new techniques help in accommodating the growing demands for spectrum allocation and use. The measure of spectrum utilization efficiency is different for different types of systems or services. For example, the calculation of spectrum efficiency for point-to-point systems is different than that for satellite or land mobile systems. Hence the comparison of spectrum efficiency can only be done between similar types of systems and within a specific frequency band or channel. It would also be beneficial to conduct the comparison of spectrum efficiency or utilization of the same system over time to see if there is any improvement in the specific area under study.

It should be noted that although spectrum utilization efficiency is an important factor, it is not the only factor to be considered. Other factors are the selection of technology or of a system, including of the economic impact, the availability of equipment, the compatibility with existing equipment and techniques, the reliability of the system, and other operational factors.

The development of these concepts will first proceed by developing a definition of spectrum utilization, i.e. the amount of the radio spectrum which is being used in a particular situation followed by the description of spectrum utilization efficiency, which is the ratio of the amount of communications achieved per the amount of spectrum used. Since one major use of spectrum utilization efficiency information is to compare the efficiencies of two proposed systems, it is necessary to define a relative spectrum efficiency (RSE). The advantage of determining relative spectrum efficiency directly is that it may be easier to calculate. Examples of calculations on actual systems are given below.

8.2 First method for calculating spectrum utilization

A radio system operates at a particular frequency within a particular bandwidth, at a given location, and at a particular time. At frequencies sufficiently close to the operating frequency, other radio systems may not be able to operate without causing harmful interference or receiving interference. However, the range of a radio system is not infinite; beyond some distance another radio system can operate on the same frequency without causing harmful interference or receiving it. Furthermore, some radio systems are not turned on all of the time. Since they will not cause or receive interference when they are not being used, the spectrum is available to be used by another system. Therefore, there is a time factor associated with the transmitter. In addition to geographical and temporal separation, there are several other means to preclude interference as discussed below.

Spectrum utilization may be defined as the product of the frequency bandwidth, the geometrical (geographic) space, and the time denied to other potential users. According to Recommendation ITU-R SM.1046, the measure is:

$$U = B \times S \times T \qquad (8\text{-}1)$$

where:

U: amount of spectrum space used (Hz × m^3 × s)

B: frequency bandwidth (see Chapter 4)

S: geometric space (desired and denied)

T: time.

8.2.1 Discussion

The general approach to calculating the measure of "U" is to assume that additional transmitters and receivers are to be added to an existing frequency band. Given the technical and operational characteristics of the additional transmitters and receivers, what frequencies, locations, and time slots would be denied to the new system? Spectrum utilization can be calculated considering the spectrum space denied to the new system by the existing equipment. There is no single answer to the measure without a specification for the characteristics of the new system. Equation (8-1) for spectrum utilization is a general conceptual formula that will need more details whenever it is applied to a specific case. There is no obvious set of default values or even “ideal” values that can be used. It can be difficult to apply this concept to a given system, partly because the mathematics become detailed and also because there are a large number of assumptions that must be made.

Transmitters and receivers both use spectrum space. Transmitters use spectrum space by denying the use of that space to certain receivers (other than the intended receiver) that would receive interference from the transmitter. This space is called “transmitter-denied space”, or simply “transmitter space”. Receivers use spectrum space by denying the use of nearby space to additional transmitters (assuming that the receiver is entitled to protection from interference). A transmitter operating in that space would cause interference to the receiver’s intended operation. This space is called “receiver denied-space”, or simply “receiver space”. Note that transmitters do not deny space to other transmitters. The presence of one transmitter in no way prevents another one from transmitting. Similarly, receivers do not deny spectrum space to other receivers. Some models of spectrum utilization compute receiver and transmitter spectrum utilization separately; others combine them.

Each transmitter area of influence may be described in frequency, space, and time (and where applicable, modulation) where that transmitter has denied the nearby frequencies (bandwidth), geographical territories (space) and time from use by other receivers. The transmitter area of interest could be relatively round, or it could be highly directional (because of narrow beam, high-gain receiving or transmitting antennas). Similarly, each receiver is surrounded by an area of interest where other transmitters may not be used without interference. The sum of these bubbles is the amount of spectrum space used by the system. The remainder of the geometric-frequency-time volume remains unused and is available for use by transmitters and receivers of the type specified in the reference system.

“Receiver” space is considered to be the space within which the presence of a hypothetical reference transmitter would cause interference to the receiver. It is presumed that the receiver location is known, along with the rest of the receiver characteristics. But what should be the characteristics of the reference transmitter that must be kept out of the “denied” space? If there is only one type of system using that frequency band, a reasonable choice would be to use the characteristics of the transmitters associated with that system. (When discussing “transmitter characteristics” in this context, included should be all of the characteristics of the general transmitter system, including frequency, bandwidth, power, antenna pattern, antenna pointing angle (if applicable), modulation, operational duty cycles and coding. Some of these characteristics will go into the specification of the “B”, bandwidth term, some in the “S”, space term, and some in the “T”, time term.)

An analysis may be performed to see whether any spectrum remains unused in a given band. Different engineering models could be used, i.e. using a less conservative reference transmitter antenna aimed away from the receiver. An analysis to see how much spectrum that could be used without any engineering at all would use the most conservative model possible (antenna aimed at the receiver). For example, an analysis to discover how much spectrum space would remain for sharing with a planned personal communications system (PCS) would use the characteristics of the PCS system as the reference receiver and transmitter.

There is no simple answer as to how much spectrum is used. It depends on what needs are for existing uses and how difficult it is to find a way to engineer-in a new system use.

Detailed computation

Equation (8-1) separates the calculation into dimensions of frequency, geometrical space, and time. These dimensions suggest what types of factors should be considered. They do not limit consideration of other factors, or suggest that there is a clear separation between the factors.

Frequency space

This factor contains the effect of RF and IF bandpass filters, transmitter modulation including orthogonality, transmitter-occupied bandwidth, off-frequency rejection characteristics, signal processing, and allowable signal-to-interference (S/I) ratios, and coding. Harmonic and other spurious responses are included here. In summary, all of the factors that affect the frequency dependent part of the response of the radio system should be included in this section.

Geometrical space

This factor is intended to contain all of the elements associated with the geometrical space. This includes the physical location of the system components, the pointing angles, and antenna patterns associated with transmitting and receiving antennas. Although the geometric space is always a volume, there are instances where less than three dimensions are interesting. For example, the geometric space of satellite systems may be a cone-shaped volume that is illuminated by either a global or spot beam or, in the case of a 3-dimensional in-building system, where the vertical reuse distance dictates the spectrum requirements. Another example is the space of a terrestrial application area such as for land mobile systems or point-to-point systems. The space of interest may also be an angular sector around a point (as it may be around highly-directional antennas). Antenna polarization isolation should be handled as part of the antenna characteristics.

The geometrical space factor will be affected by the propagation models used to compute the loss of signal as the radio wave travels through the geometrical space. More complex models may require a terrain database as part of the propagation modeling.

Time

The final dimension is time. This includes all duty-cycle related factors and will be important with radar or systems with similar known duty cycles. It may also be easiest to consider a rotating radar antenna as an antenna with an intermittent time response, although the antenna rotation and narrow beam antenna are part of the geometrical factors. The duty-cycle factor of a radar pulse modulation or, of a time division multiple access (TDMA) signal, can be included as a time factor or figured into the frequency factors as part of the allowable S/I protection ratio.

The time factor in a broadcast system, needed to operate all the time, would be “one”. If time is considered, the potential for increased efficiency can be great.

Spectrum occupancy

Closely related to the time factor is the spectrum occupancy of a radio channel. Spectrum occupancy data provides information on the actual level of usage of individual frequency channels. A message consists of a series of base station and mobile transmissions, separated by time gaps.

Since a channel could be unavailable to another user during the entire length of such a message, the occupancy that characterizes the level of utilization of a channel is the message occupancy. This is defined as the percentage of the time that a channel is occupied by such messages, over a given period.

The message occupancy, O_p, of a particular channel is the sum of the base-station transmission occupancy, O_b, mobile transmission occupancy, O_{mt}, and the transmission gaps, O_g. A breakpoint is used to differentiate between transmission gaps and the message time. Spectrum occupancy data provides useful information in assessing spectrum utilization and efficiency of a radio system.

Required databases and models

The calculation of spectrum efficiency and utilization requires a large amount of data, starting with the technical characteristics and locations of all existing transmitters and receivers within the frequency and geographical area of the calculation. This implies the need for detailed and up-to-date frequency management databases. In addition, other information and models will be needed, such as required signal and signal-to-interference models for both the reference system and existing systems in the band. Finally, realistic propagation models will be needed to calculate path loss for the wanted and unwanted signals. Depending on the accuracy needed in the propagation model, a terrain database may be required. This data will be needed over whatever geographical area is chosen to make the calculations.

Overall calculation

The calculation of spectrum utilization can be done for a single transmitter/receiver pair, for a whole system involving many transmitters and receivers, or for the population of a whole frequency band over a moderately large area (a large metropolitan area, for example). If too small an area is selected for analysis, the results may suffer from too much influence from “edge effects”, and from a large likelihood of being statistically non-representative of a larger area. If too large an area is selected, the amount of computer time and the size of the required databases may become too great to make analysis practicable. Whatever area is selected, it is important that realistic assumptions be made with respect to the reference models selected and that attention is given to the receiver and the transmitter areas.

The definition of spectrum utilization, as is defined here, is a single number representing the amount of spectrum space used in the entire area being considered. Since the total will be built up from a sum of answers representing individual grid points, it may be useful to plot contour maps or cumulative distribution graphs showing intermediate results. Examples of such results might include the percentage of frequencies used (denied) or unused (available to the reference system) at each grid location. These plots of intermediate results may be useful in understanding which geographical areas and which parts of the frequency band are crowded, so that special attention can be given to solving problems in those areas. Other types of services may suggest particular intermediate results which should be made available to help give particular insights about the use of that frequency band.

8.3 Second method for calculating spectrum utilization

Spectrum utilization can also be assessed by another means that essentially amounts to a logical extension of the approach set forth in Recommendation ITU-R SM.1599. It is based on a special procedure for re-designating the frequencies of operating radio stations [Kovtunova *et al.*, 1999] and involves the indicator of spectrum utilization that is given by the equation $Z = \Delta F/\Delta F_0$, where ΔF is the minimum necessary frequency band to permit the functioning of the operational facilities in question, and ΔF_0 is the frequency band being analysed, in which are located the actual working frequencies of the operating radio stations. The calculations are based on the determination of ΔF through solving the "travelling salesman" problem by the "nearest neighbour" method. Use of the optimum (or near-optimum) frequency re-designation algorithm will give the lower limit for spectrum utilization. To obtain actual values, ΔF is determined by a separate procedure to select the frequency re-designation algorithm for the frequency assignment data contained in the national frequency register [Zolotov *et al.*, 2001]. The advantage of this method is that it allows comparison of different frequency bands, even if they are being used by radio stations of different services and without requiring any specific standard resources.

8.4 Assessment of economic utilization of spectrum

Economy is one of the important constituents of efficient spectrum utilization. Apart from the technical characteristics of radio stations, economy of spectrum utilization is determined primarily by the degree to which the method used by the planning (or coordinating) authority to assign frequencies to operational systems corresponds to the optimum (or near-optimum) method. It is thus possible to determine the economy of spectrum utilization (or efficiency of implemented frequency assignments) from the ratio $\eta = Z_{opt}/Z_{real}$, where Z_{opt} is the spectrum utilization factor for the operational systems that would be achieved if their frequencies were assigned in accordance with the optimum (or near-optimum) algorithm, and Z_{real} is the spectrum utilization factor for those systems based on the actual frequency assignments. The values of Z_{opt} and Z_{real} may be calculated using either the first method (section 8.2 and Recommendation ITU-R SM.1599), or the second method (section 8.3).

8.5 Applications

There are several ways that the measures of spectrum utilization can be used by administrations [Haines, 1989]. They include:

– maps of spectrum utilization showing areas of spectrum congestion where restrictive standards and intensive coordination are necessary to assure efficient use of the spectrum;

– quantitative comparisons of the intensity of utilization of different bands in each geographical region, aiding spectrum planning for allocations to specific services; and

– periodically calculating spectrum use in each band to reveal trends that can be used for strategic planning.

8.6 Spectrum utilization of satellite systems

Discussions on the orbit-spectrum resource utilization can be found in section 2.3 of ITU-R Handbook on Satellite Communications (Fixed-Satellite Service), Geneva, 2002.

8.7 Measure of spectrum utilization efficiency

The spectrum utilization efficiency is defined as the ratio of information transferred to the amount of spectrum utilization:

$$SUE = M/U = M/(B \times S \times T) \quad (8\text{-}2)$$

where:

M: amount of information transferred

U: amount of spectrum utilization (see equation (8-1)).

The spectrum utilization efficiency is a technical measure of how efficiently one is using the spectrum. The formula for spectrum utilization efficiency is a general, conceptual formula which must have many details added before it can be applied to a specific problem.

The amount of information transferred, M, can be quantified for some systems as a baud rate or units of megabytes/s. This may not be simple as it is difficult to characterize the information rate in an analogue channel, in a radar, or for example, in a standby system that might be used such as a flood warning alarm system. Does the absence of an airplane on a radar screen convey an equal amount of information as the presence of one? How much information is the flood warning alarm transmitting when there is no flood? These questions suggest some difficulty in assigning a numerical value to the amount of information transferred.

According to the principles of information theory [Gallager, 1968], the communication capacity, C_0, (or the amount of information transferred) of a communication channel on which a subscriber or a listener receives a wanted communication, is determined by the relation:

$$C_0 = F_0 \ln (1 + p_0) \quad (8\text{-}3a)$$

where:

F_0 : bandwidth of the wanted communication

p_0 : signal/noise ratio at the receiver output.

If the signal/noise ratio at the receiver input is equal to the protection ratio, p_s, and the bandwidth of the communication channel over which the signals are transmitted is equal to F_m, then the communication capacity (C_p) according to Recommendation ITU-R SM.1046 is:

$$C_p = F_m \ln (1 + p_s) \quad (8\text{-}3b)$$

Alternatively, it may be simpler to leave the answer in terms of number of traffic units such as Erlangs, analogue channels, or radar channels, per unit of spectrum used.

The measure of spectrum utilization efficiency is different for different types of systems or services. For example, the spectrum space, S, in equation (8-1) has different implications for a point-to-point system, a satellite system or a land mobile system. Comparing SUEs of different systems is meaningless since the frame of reference is different. However, equation (8-1) may be adapted to a specific type of system and be used for comparison within that same type of system.

8.7.1 Example of spectrum utilization efficiency calculations

8.7.1.1 Cellular and pico-cellular radio systems

Cellular radio systems with smaller cells can support more traffic overall. The concept of micro-cellular systems with cell sizes on the order of 1 km or less in diameter was introduced in the early 1980s. These systems have overall great traffic carrying capability and are used to support urban personal communications.

Requirements of personal communications in the indoor environment also exist. Because of the smaller coverage area and a lower power requirement, indoor systems could be even smaller in size than micro-cellular systems. These systems can have cell sizes on the order of tens of metres in diameter and could provide much higher overall system capacity than cellular radio systems.

Based on equation (8-1), the spectrum utilization efficiency of a cellular or pico-cellular radio system can be expressed in terms of Erlang bandwidth and area [Hatfield, 1977]:

$$\text{Efficiency} = \frac{\text{Amount of information transferred (E)}}{\text{Bandwidth (Hz)} \times \text{area (m}^2\text{)}} \tag{8-4}$$

where the amount of information transferred represents the total traffic carried by the system, bandwidth is the total amount of spectrum used by the system and area is the total service area of the system.

The unit of traffic amount M is ‘Erl’ for circuit switch (CS) systems, as used in the formula above. However, wireless communication systems are evolving to pure packet switch (PS) systems now. 2G systems mainly rely on CS, while PS is widely adopted in 3G systems for data service. The booming 4G systems will be pure PS systems, and the following 5G systems will probably adhere this feature from 4G systems. The unit of ‘Erl’ is suitable for CS systems, but this will bring large err in measuring the traffic amount in PS domain. ‘Erl’ relies on the assumption that all the data is transmitted under constant rate in each channel, so that the total traffic amount could be calculated by counting the number of used channel. But for PS domain transmission, data is organized to be transmitted with varying rate, and the wireless resource used for each type of data service also varies. Thus ‘Erl’ is not suitable for recording nowadays traffic amount.

‘bit’ (always in low case) is the basic unit for computer networks, and this same unit is widely used in wireless communication systems to record the amount of data. In this way, the unit ‘bit’ is preferred to be used instead of ‘Erl’ in the former formula. Then the formula should be as the following.

$$\text{Efficiency} = \frac{\text{information transmission rate (bit/s)}}{\text{Bandwidth (Hz)} \times \text{area (m}^2\text{)}} \tag{8-5}$$

These considerations for cellular system can be transposed by taking into account the frequency demand, frequency reuse and fading as well as other important conditions. The following illustrates the methodology and parameters to be taken into account for the determination of the spectrum demand.

It is assumed that a cellular planar network is requiring gapless coverage. This can be seen in equations (8-6) and (8-7):

$$\text{Cluster Size} = \text{Frequency Reuse Factor} \tag{8-6}$$

Hence for a planar network:

$$\text{Required nb of channels per BS} = \frac{\text{Total nb of channels of the radio network}}{\text{Cluster Size}} \tag{8-7}$$

Assuming a frequency reuse factor of X, the cluster size becomes Y.

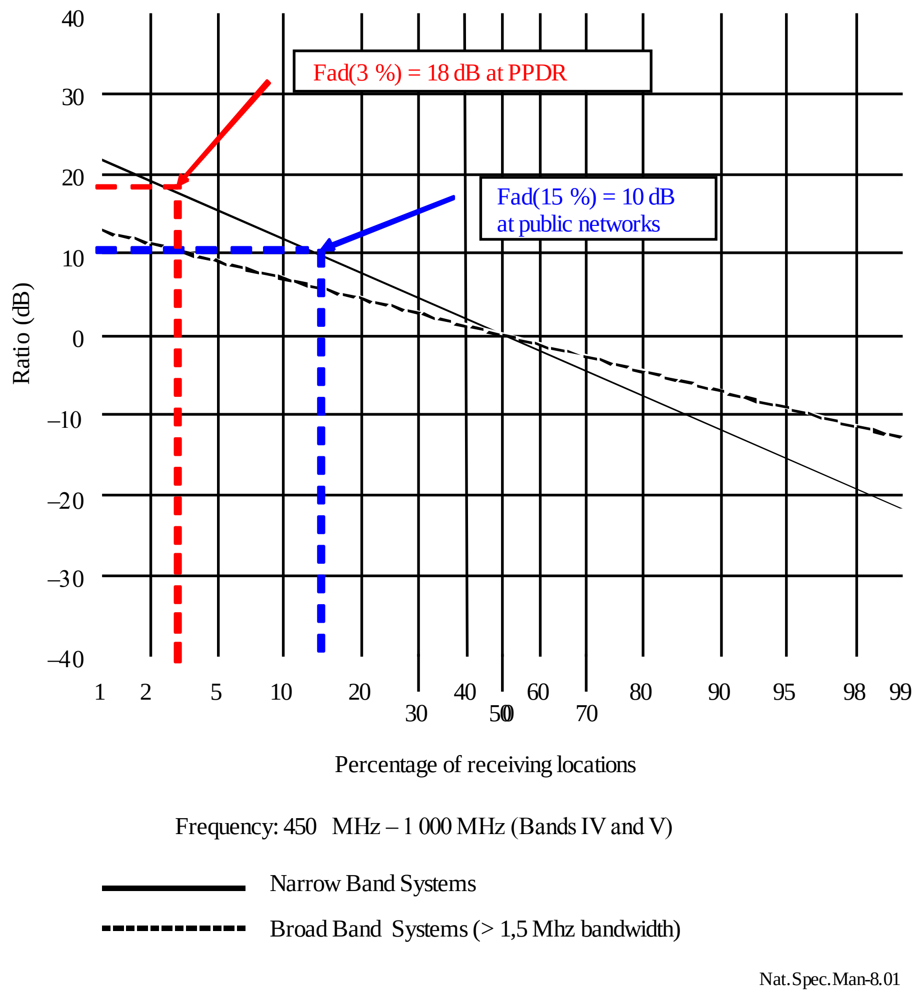
Margins are needed for high density usage scenarios, highly mobile usage (more handovers) and cross-border coordination.

The frequency reuse factor depends mainly on the percentage of receiving locations. This requires itself a specified coverage probability. This means that in each location interval with a specified diameter the measured coverage level has to be verified with a probability value of at least a determined percentage. For an example cellular radio network planning a value of 97 % may be used.

For the evaluation of the values, the former Recommendation ITU-R P.370-7 was used, as shown in Figure 8.1 (since Recommendation ITU-R P.370-7 is suppressed, new evaluations can also use Recommendation ITU-R P.1546).

FIGURE 8.1

Ratio (dB) of the field strength for a given percentage of the receiving locations to the field strength for 50% of the receiving locations



A value of 97% of probability is equal to a value of 3% fading. The consequence of this is that an additional average margin of 18 dB is necessary. Figure 8.1 above includes the two examples for typical public mobile cellular networks and for more robust cellular networks such as for Public Protection and Disaster Relief (PPDR) use. Taking into consideration this margin, the following equations are assumed:

Relation of fading, frequency reuse factor and data loss:

$$F = c - \gamma \cdot \log(d) \tag{8-8}$$

Calculation of the received signal strength depending on the distance and according to the attenuation per decade of the ITU diagram:

$$F_{car} - F_{Int} = c/i_{PPDR\text{-}System} + \sum Fad_{(x\%)} = \gamma \cdot \log\left(\frac{d_{Int}}{d_{car}}\right) = \gamma \cdot \log(\text{Frequency reuse factor}) \quad (8\text{-}9)$$

and the frequency reuse factor is given by:

$$\text{Frequency reuse factor} = 10^{\frac{c/i_{PPDR\text{-}System} + \sum Fad_{(x\%)}}{\gamma}} \quad (8\text{-}10)$$

$$\sum Fad_{(x\%)} = Fad_{(x\%)car} \text{ und } Fad_{(x\%)Int} = Fad_{(x\%)user/interferer} \cdot \sqrt{2} \quad (8\text{-}11)$$

Key to symbols used in the equations:

F	= field strength
F_{car}	= field strength of wanted carrier
F_{Int}	= field strength of interfering signal
c	= constant, includes data of the BS such as transmit power and antenna characteristics
γ	= propagation coefficient (ref. ITU curves for UHF, approximately 50 dB/decade of distance; up to values of 35 dB/decade of distance; the calculations below use 50 dB/decade).
d	=distance
Fad(x%)	=Fading (in dB); there is a relation to the probability of location and hence the data losses, expressed as a percentage
ΣFad	=Fading; single fading events of the wanted and unwanted signals
c/I cellular system	=protection criteria of NB/WB/BB = 9 dB (example).

For robust cellular applications, a specified coverage probability 98%, which is equal to 5% of fading.

According to the formulas above, a frequency reuse factor can be calculated:

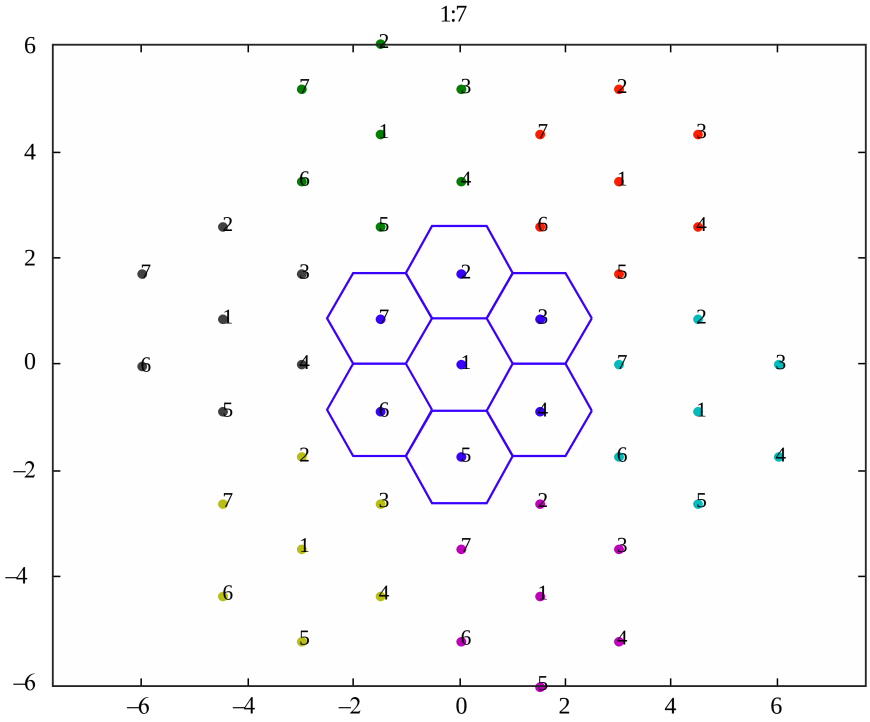
EXAMPLE Case 1: C/I = 9 dB; Fading 2%, which is equal to 19 dB, γ = 50 dB, the frequency reuse factor is calculated 5.24.

SEAMCAT (Monte-Carlo analysis tool, see Report ITU-R SM.2028-1 – Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems, and Recommendation ITU-R M.1634 – Interference protection of terrestrial mobile service systems using Monte Carlo simulation with application to frequency sharing) and/or MCL calculations may be used to calculate probability of co-channel interference as a function of the frequency reuse.

Figure 8.2 illustrates a basic reuse pattern using seven frequency pairs. Each of the cells in the centre (with hexagons) uses a different frequency. The same frequency is then reused in the neighbour "clusters", so that all cells marked with the same number use the same frequency.

FIGURE 8.2

Cluster



The clustering as shown above is typical for GSM systems. Broadband system such as CDMA, UMTS and LTE in general use a frequency re-use of 1.

An alternative "MCL" approach to reuse calculation can be used based on the following formula for the reuse of any technology:

$$N_R = 1/3\ [M\ K\ A\ (C/I)_T]^{2/\alpha} \qquad (8\text{-}12)$$

Where:

- M : slow fading margin
- K : "geometry" factor
- A : system load or activity
- α : exponent from Hata
- $(C/I)_T$: required dynamic co-channel interference ratio.

The MCL method is fast, but seems very dependent on input parameters. Especially the margin *M* can be difficult to set.

Spectrum efficiency considerations based on this method are based on the comparison of the results for NR relative to the bit rate per Hs and the number of frequencies used.

The method can be used as a quick evaluation but the parameter choice should be validated against "real world" experience.

8.7.1.2 Broadcasting and land mobile communications systems

A useful indicator for these systems' spectrum utilization efficiency is the vector variable:

$$\vec{E} = f\,(UEF,\ Z)$$

where:

UEF: factor that gives a measure of the "useful effect" obtained through use of the spectrum by the systems in question

Z: gives the spectrum utilization involved in obtaining that useful effect.

The composition of these two factors for the systems in question is described in [Pastukh *et.al.*, 2002].

Sound and television broadcasting systems

The "useful effect" factor can be taken as the mean number of radio or television channels that can be received by an individual user, k_{mean}. For a geographical area composed of I elementary area components, it may be expressed as follows:

$$UEF = k_{mean} = \frac{1}{N}\sum_{i=1}^{I} n_i k_i$$

where:

n_i: number of individual users in the i-th area element

k_i: number of radio or television channels that can be received within the i-th area element

N: total number of individual users in the geographical area in question.

Land mobile communication systems

The usefulness of a mobile communication system is found in the possibility giving to users to communicate by radio with other users located anywhere within the geographical area. The useful effect can be calculated using the formula:

$$UEF = \left(\frac{N_{sub}}{N}\right)\left(\frac{S_{serv}}{S}\right)$$

where:

N and S: number of individual users living within the geographical area in question and the size of that geographical area, respectively

N_{sub}: number of users (subscribers) of mobile communication systems

S_{serv}: service area covered by those systems.

Additional information on the application of this approach to broadcasting and land mobile systems is presented in [Pastukh *et.al.*, 2002].

8.7.2 Spectrum quality index (SQI) (spectrum utilization relative to demand)

Spectrum utilization efficiency can also be calculated based on actual channel occupancy or the actual traffic carried by the system. This gives a direct measure of the amount of information transferred. The concept of spectrum quality index (SQI) provides a measure of spectrum utilization efficiency of a radio system or service for a given frequency band in a given area by taking into consideration the occupied spectrum, the value of the spectrum, and the denied spectrum.

8.7.2.1 Measure of spectrum quality

Spectrum value factor Γ

Within a specific service, demand on the radio spectrum is not equally distributed throughout a geographic area. For example, in the land mobile service, demands are concentrated in urban areas and the peak of the demand is found in the centre cores of the metropolitan areas. Accordingly, spectrum is more valuable in areas of high demand than those with low demands. Spectrum has no value in an area where it is not required. Denied spectrum is more critical in the areas where the spectrum is in high demand than in deserted areas.

It may not be possible to know the actual demand for some kinds of spectrum in urban areas. A desire for the service provided by the spectrum in question may not be expressed by a license application because the potential user knows that the band is saturated, or because of regulatory restrictions. However, the amount of spectrum units occupied may be taken as a first approximation to the relative demand in an area.

To understand the spectrum value factor Γ, consider a geographic region covered with a volume, *V*. Let *V* be divided into equal-size cubes. The demand in each cube is different and is represented by the number of spectrum units occupied in each cube (product of bandwidth, space, and time). The greater the demand in a cube, the higher the spectrum value factor. This value may be represented mathematically by Γ and has numerical value ranging from 0.0 to 1.0, with the greater number indicating higher spectrum value. Mathematically, the spectrum value factor in cube $\Gamma(n)$ is directly proportional to the number of spectrum units $\beta_t(n)$ demanded in the cube. Accordingly:

$$\Gamma(n) = \beta_t(n) / \beta_{total}$$

where:

β_{total}: total demands in volume *V*.

Spectrum quality index (SQI)

The spectrum quality index is applicable as a relative measure to compare the spectrum utilization efficiency of the same service. It is accordingly given by the relation:

$$\text{SQI} = \frac{\text{Total weighted occupied spectrum}}{\text{Total weighted (occupied + denied) spectrum}} \qquad \text{or}$$

$$\text{SQI} = \frac{\Sigma\, \Gamma(n)\, \beta_t(n)}{\Sigma \Gamma(n) \left\{ \beta_t(n) + D_t(n) \right\}} \tag{8-13}$$

where $D_t(n)$ is the number of spectrum units denied in cube, *n*, in addition to those used for communications. $D_t(n)$ is called the “denied spectrum”.

Accordingly, the inclusion of the spectrum value factor, Γ, into the calculation of SQI effectively reflects relative spectrum demand distribution in the area of interest. This model can therefore provide an indication of how effectively the spectrum is being managed to meet the demand and is useful in assessing spectrum utilization.

Application of SQI

The SQI can be used for absolute as well as comparative measures in a specific area and within a specific service. Absolute measures can be used when all system parameters are known.

In the comparative measure, different schemes or techniques, such as spread spectrum versus FDMA/FM or digital versus analogue modulation, can be compared for a specific service. It is not possible to use SQI to compare a technique used in different services as the models for the two services may be different.

There are a number of factors that can affect spectrum quality such as:

– propagation characteristics;

– demand distributions;

– available technology; and

– performance requirements (grade of service).

8.8 Spectrum efficiency in shared bands (e.g. short range devices)

The following considerations are particularly important in the context of short range devices sharing frequencies with applications of allocated radio services, while short range device applications are always used on a non-protected basis. First, it is important to distinguish between spectrum occupancy and spectrum efficiency. The value of using a particular part of spectrum comes from the utility it provides to users, which is not necessarily the same as the data traffic. A distinction should be made between the concepts of Single system Absolute spectrum Efficiency (SAE), which is based on the raw data transmitted, and Group Spectrum Efficiency (GSE), which is closer to the broader utility or service provided. Spectrum efficiencies can be defined in terms of the GSE in an environment where devices of different and similar nature are present.

Taking the approach in Recommendation ITU-R SM.1046-2, the spectrum utilisation is defined as the product of the frequency bandwidth, the geometric (geographic) space, and the time denied to other potential users:

$$U = B \cdot S \cdot T$$

where:

B: frequency bandwidth

S: geometric space (usually area)

T: time.

It may be noted that *T* is not equal to the transmit time of the device but equal to the time restrictions a device is imposing on all other users. Similar arguments are true for the frequency bandwidth and geometrical space factors. Since all mitigation techniques limit one or more of the three parameters *B*, *S* or *T* to allow others to use the spectrum, a mitigation technique can be therefore considered a spectrum utilisation limiting technique.

Such a mitigation technique may be primitive, simply restricting its spectrum utilisation by a fixed amount and in a fixed manner. It could also be more advanced and include a form of sensing, inducing some sort of dynamic “social behaviour”, often referred to as a politeness protocol.

When a more complex system of sensing and social behaviour is prescribed for a group of devices, one can call such a mitigation technique a “Spectrum Access Mechanism”, not to be confused with a “spectrum access method” which is just describing the behaviour of a single device. The social behaviour may include dynamic changes in nominal frequency, power or timing, or in the amount of frequency space, geometric space or time space used.

E.g. LBT (Listen-Before-Transmit) repositions the transmission in time, rather than stops it; AFA re-positions the transmission in frequency rather than stopping it.

When projecting this on the definition of Spectrum Utilization Efficiency (SUE) expressed by the complex following criterion:

$$SUE = \{M, U\}=\{M, B \cdot S \cdot T\}$$

where:

M: useful effect obtained with the aid of the communication system in question (the definition of this useful effect is up to the user, regulator or manufacturer)

U: spectrum utilization factor for that system.

It can be concluded, also from experience, that some spectrum access or mitigation techniques are inherently “inefficient” because they limit the use of the spectrum while unused spectrum is still available and others are not because they allow the use of all available unused spectrum. It needs to be noted that there may be legitimate reasons for doing so, but it makes no difference for the calculation itself. Also it is not the intention to classify certain methods as better than others.

Considering these basic formulas one could get the impression that for a particular system all parameters in the utilisation formula are exchangeable. This is not always the case, the relation between *B*, *S* and *T* is not always linear and even if the parameters are exchangeable there are other boundaries, caused by, for example, physical receiver parameters.

However, an approach like this provides a more flexible environment for SRD deployment than the current approach of giving each application its own reserved frequency space.

Recommendation ITU-R SM.1046-2 indicates that these calculations of *U* and *SUE* should only be used to compare similar systems. This makes it difficult to apply this concept directly to the SRD bands, where a variety of different applications share the same spectrum. The move to application neutrality in spectrum regulations (e.g. to foster innovations) will make it even more difficult to apply the procedures in Recommendation ITU-R SM.1046-2. CEPT has investigated these challenges in ECC Report 181 in 2012.

8.8.1 Observations and definitions based on the General Approach given in Recommendation ITU-R SM.1046-2

Spectrum efficiency can be described in different ways but the general consensus is that for a system to be efficient some useful information needs to be transmitted. The nature of this information can be very diverse. A standard time or frequency transmitter only sends its identification at regular intervals and a sound broadcasting transmitter sends it information for 100% of the time but both can be considered spectrum efficient. For SRDs that are usually operating in a group the situation is a little more complex. The following spectrum efficiency case definitions are based on common different identifiable scenarios.

Single system Absolute efficiency (SAE)

This is the efficiency of a single system in free space under ideal circumstances:

$$SAE = SUE$$

It is difficult to measure because its efficiency depends on the perception/definition of a person, user or manufacturer. The application requirements dictate the spectrum utilisation in relation to the amount of useful information to be transmitted. For example redundancy or low latency is required for safety critical applications which means the application needs to utilise the spectrum more than needed or it needs to impose restrictions on other users. Both scenarios could be explained as spectrum efficient for that particular application and in the perception of that particular user/application, but this is not necessarily the case for other devices/applications.

Single system Relative efficiency (SRE)

This form of efficiency is easy to recognise and even measure:

$$SRE = SUE_1/SUE_{ref}$$

When for example two transmitters transmit exactly the same information to the same amount of receivers with the same quality of service using different modulation schemes, bandwidth or different power levels, the relative efficiency can be calculated using the spectrum utilisation formula.

This form of efficiency calculation and measurement is easy but not very useful because it assumes an ideal clean and interference free environment which is not the case in shared spectrum situations (‘SRD bands’).

Single system in a group relative efficiency (SGRE)

This form of efficiency is a logical result of the previous two forms and can be measured by taking into account the variation of certain environmental parameters:

$SGRE = SUE_1(condition\ x)/SUE_{ref}\ (condition\ x)$ *Under various environmental conditions*

Some modulation schemes are robust and keep working while others fail in heavy interference or bad propagation situations. A relatively spectrum efficient system can cope with interference while maintaining the same operational parameters while the relatively spectrum inefficient system fails under these interference conditions. The whole digital versus analogue debate falls for example under this category of efficiency.

8.8.2 Modified Approach in Recommendation ITU-R SM.1046-2

Group spectrum efficiency or multiple systems in a group (GSE)

This type of efficiency is calculated as a hybrid of the above methods. The contribution of a single device to the whole group of devices of different nature needs to be determined. How do the other devices react and how is the total spectrum utilised when a single new device is added to the group. The absolute efficiency of a single device cannot be calculated or measured in a meaningful way but the efficient use of the whole environment in which the device operates can be analysed to conclude something about the efficiency of a device. The interesting part is that both the susceptibility of a device to interference from the group and the interference contribution to the group is taken into account.

For each individual SRD the quality of information or quality of service is regulatory irrelevant but the quality of service of the typical SRD, taking all SRDs in a particular environment into account, is an issue.

$GSE = SUE_{total}/SUE_{total\ after\ adding\ new\ device}$

GSE appears an interesting way to define and measure spectrum efficiency because the policy for SRDs is that the functioning of an individual device cannot be guaranteed but it may be possible to do this for the average or typical device in a group[45]. This also leads to an average efficiency for that group. For each device SRE can be calculated but after adding a new device to the group the GSE can also be recalculated for each existing device. The SRD environment becomes dynamic, spectrum efficient technologies may be reassessed and even become inefficient based on technological progress. Grouping or clustering certain technologies or deployment schemes could also lead to overall better GSE.

The GSE approach would, however, require input from new system metrics.

As a principle one can use an equal division of frequency space, in terms of medium utilisation. Further one can use an equal division of possible/available data throughput in the group as a measure of spectrum efficient behaviour of that group. In practice it may be possible to realise this by choosing the technical parameters from a pool of possible combinations of power, bandwidth, geographical distribution, mitigation techniques and spectrum access methods.

If one wants to achieve maximum spectrum efficiency, then each parameter needs to be defined based on the minimum application requirements of all devices in a group (application grouping) by defining border condition for each parameter and as such sacrificing some technology neutrality.

In short, the realisation of this minimum application requirement is much more relevant than the realisation of a certain probability of interference figure. A zero interference figure may not be obtained so the situation of ideal spectrum efficiency is always accompanied by a reference maximum interference figure.

The following describes delay as one of these requirements. Each relevant parameter should be analysed in a similar way.

Probability Distribution of Delay

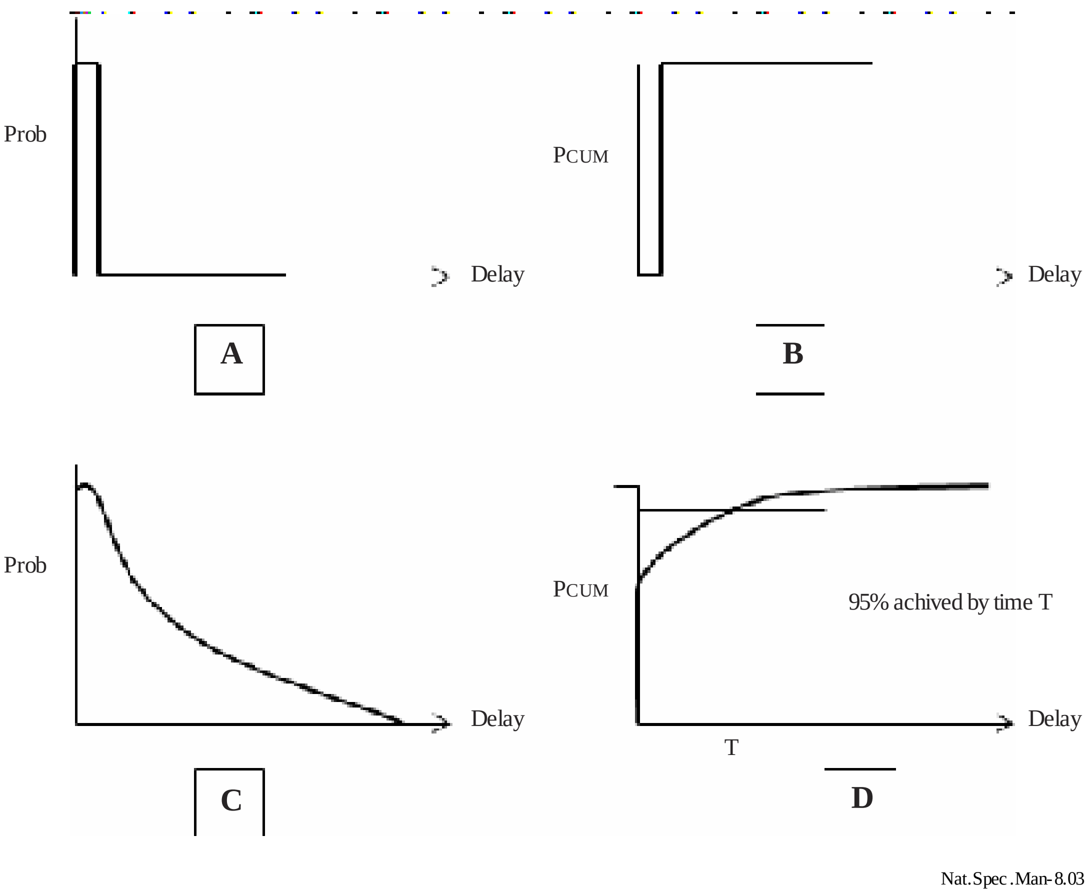
Delay is the time spent waiting on a shared channel until a message can be sent. Although this delay cannot generally be expressed as a single number, it can be analysed in probability terms. In Figure 8.3 graphics A and B show the situation in a clear channel, where no delay is expected. Graphic A is the probability distribution function (pdf) showing the likelihood that a message will be delivered at a given time. Graphic B is the same information as a cumulative probability. This shows the probability that a message will be delivered by (i.e. at or earlier than) a given time. The cumulative probability is found by integrating the probability distribution function. The left hand edge of the plot in A is actually a delta function but is shown expanded for clarity.

Graphics C and D show the effects expected in the presence of other users. Diagram D, the “Cumulative Probability of Delay” is particularly useful.

[45] It is also common practice in CEPT/ECC and ETSI to investigate the impact of a new spectrum user on the existing users. The definition of GSE formalises this common practice.

FIGURE 8.3

Probabilities of delay without (A&B) and with (C&D) shared channel use



When it comes to measure such as latency and reliability, the expectation of a user is often expressed as "X% of messages must be delivered within a time d" and this is easily read from the diagram, whether X is, for instance, 90, 95% or 99% as required by the application.

Calculating Probability of Delay

In some cases, constructing a diagram such as the Cumulative Probability of Delay may require complex analysis. It might be possible to model this in a centrally managed telecommunications system as TDMA (GSM) or Ethernet line, etc. It should be noted that there is a considerable body of work in the field of telecommunications and networks that can be drawn upon, although care must be taken in applying it to wireless systems. But it is unlikely that this probability could be modelled as a general objective for deployment of dispersed non-homogeneous systems such as SRDs in shared bands.

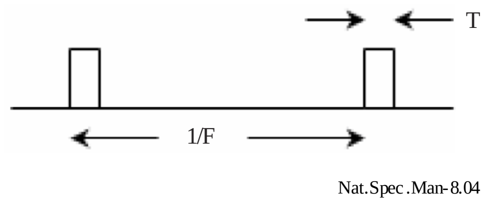
In some cases, however, it is relatively simple to generate a Cumulative Probability of Delay diagram.

Consider the case of a user wishing to send a short message when there is already one other existing user. The existing user sends transmissions of duration T, as illustrated in Figure 8.4, at random times with an average frequency of *F*. In other words, the duty cycle is:

$$\tau = TF$$

FIGURE 8.4

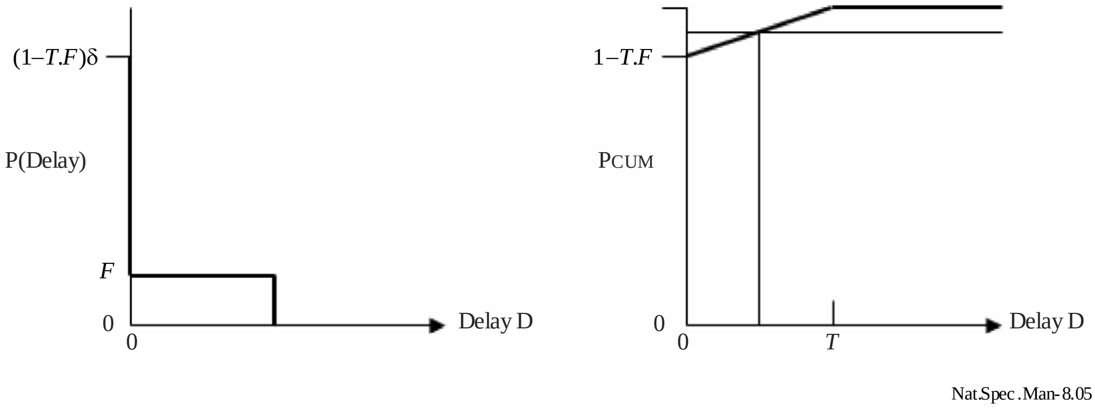
Random transmission of competing signals



The important parameter is the wait time, or delay, until the channel is free. Both the pdf and the cumulative probability of this can be found by inspection, as can be seen in Figure 8.5.

FIGURE 8.5

Probability of delay in case of competing signals/users



Suppose for instance that the transmissions are 1 s every 10 s, so that

$T = 1$ s, $F = 0.1$ Hz, and duty cycle $\tau = TF = 0.1$

The success times for various probabilities are then easily found:

– 90% achieved by d = 0 s

– 95% achieved by d = 0.5 s

– 99% achieved by d = 0.9 s

– 100% achieved by d = 1 s

Consider subsequently the case where the competing user is still at 10% duty cycle, but with transmissions of 10 s duration every 100 s.

$T = 10$ s, $F = 0.01$ Hz, and duty cycle $\tau = TF = 0.1$

The success times are then:

– 90% achieved by d = 0 s

– 95% achieved by d = 5 s

– 99% achieved by d = 9 s

– 100% achieved by d = 10 s

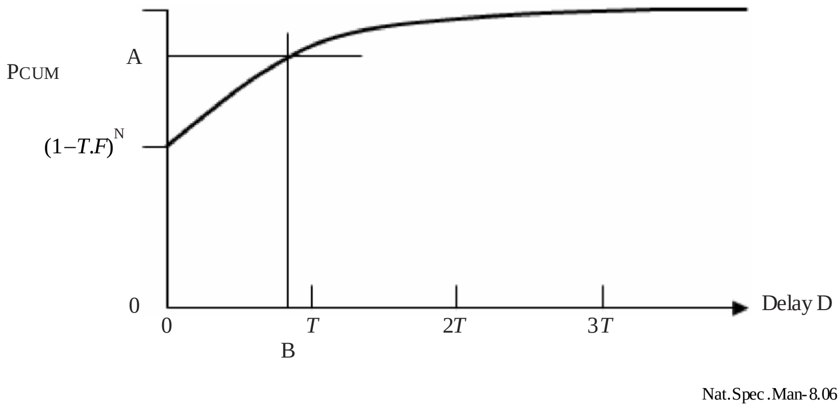
It can be seen that the delay times for a given probability of success are increased by a factor of 10.

This is an important result. In both cases the competing transmission is the same duty cycle; a simple analysis based on probability of interference will come up with the same result. But the cumulative probability of delay shows that from the point of view of a victim, the harm done by one is 10 times greater than the other.

In the case of N such identical interferers, the cumulative probability curve will be of the form in Figure 8.6.

FIGURE 8.6

Cumulative probability of delay in channel with N competing users



The horizontal axis is entirely in terms of T, the duration of the transmissions, rather than the duty cycle TF. Therefore it can be seen that, in any given situation, the delay B at which a given success rate A is achieved is directly proportional to the duration of the interfering transmissions, as their duty cycle is held constant.

Expected Delay

The analysis above shows the general pattern of the delay probability, but does not give us a quantitative result, except for the probability of zero delay.

Queuing theory, however, can be used to make a simple model. Suppose that a number of users are sending packets on a channel, where *T* is the duration of the packets and *F* is the overall frequency (rate of sending summed across all the users).

We can equate *F* to the rate of arrival of objects in a queue and $1/T$ to the rate of clearing. The Expected Delay *D* until a clear slot is then equal to the expected waiting time in the queue.

$$D = \frac{T.F}{1/T - F}$$

This is not a perfect model of queuing with, for instance Aloha or LBT. Nevertheless it is a useful indicative result for the expected wait when using an access mechanism in a shared channel.

The equation above can be re-arranged to show the effect of holding constant *TF*, the aggregate duty cycle:

$$D = \frac{T.(T.F)}{1 - T.F}$$

In this model, therefore, the expected delay is directly proportional to the transmission duration.

Metrics for Latency and Reliability

The traditional metric used in compatibility studies is probability of interference. In many cases, discussed above, this is not adequate, as it will not completely reflect the harm done to various types of victims by different types of interference. In particular it does not take direct account of the need for metrics such as low latency or high link reliability (probability of successful transmission, i.e. including re-transmissions) by many users of the spectrum.

It should be considered that latency and reliability are related. The requirement of the user can be expressed as X% probability of success within maximum delay D. For instance, a user stressing low latency might require 90% within 200 ms; one stressing high reliability might require 99.9% within 3 seconds. In these circumstances, Cumulative Probability of Delay and Expected Delay are useful concepts, although they may be difficult to accurately quantify in actual circumstances.

The above is a simple analysis of a complex mechanism. It assumes that the transmission, that the "victim" is waiting to make, is short compared to the "interferer's" transmissions. It also assumes that the victim has a way of knowing when it is possible to make the transmission. This is the case if the victim employs LBT, but similar results will be obtained e.g. if the victim makes trial transmissions and listens for an acknowledgement. The difference lies in the potential for interference back to the existing user.

The similarity with telecommunications traffic theory and the Erlang distribution and (expressed by Erlang equation) should be also noted, though care should be taken, as it is not directly applicable. There is more than one variation of the Erlang equation, and there are a number of differences to be considered. The most important difference between wireless and wired systems is that not all nodes can necessarily hear each other.

Thus it may be concluded that latency and reliability are useful new metrics that may add value to traditional interference analysis, whenever the considered wireless systems and interference scenarios allow some meaningful deterministic analysis of these phenomena.

It must be recognised that it is not only the technical parameters of the radio signal and the resulting link budget that are important. The modern adaptable packet-switched systems have complex operational patterns through involving not only the physical layer but also higher OSI levels into the picture for overall maintaining of communications stream. Therefore ideally the system designers as well as spectrum managers should endeavour to consider those more sophisticated aspects in order to determine and establish the balance between the levels of operational resilience of considered systems.

One of the most important operational parameters of this category is the latency requirement. This is the maximum acceptable delay in transferring the packet/message and cannot generally be inferred alone from the technical consideration of the useful link budget vis-à-vis the interference instance. Therefore the latency as well as other similar parameters/metrics may need to be considered when pursuing spectrum planning in shared bands.

Another conclusion is that when different applications are mixed, an analysis based on a simple probability of interference does not reveal the full story. Therefore, compatibility analysis in an application neutral environment will require more extensive analysis in the lowest two layers of the OSI model, mainly in the time domain, than is currently done in situations where the applications are defined.

8.9 Ratio of spectrum utilization efficiencies, or relative spectrum efficiency

As described in previous sections, values for *SUE* could be computed for several different systems and could indeed be compared to obtain the relative spectrum efficiencies (RSE) of the systems, a metric that may be used in analysing spectrum use. Such a comparison however would have to be conducted with caution. The quantity of relative spectrum efficiency (RSE) is defined as the ratio of two spectrum utilization efficiencies (SUEs), one of which may be the efficiency of a system used as a standard of comparison.

In this instance:

$$RSE = \frac{SUE}{SUE\ std} \tag{8-14}$$

where:

$SUE\ std$: spectrum utilization efficiency of a "standard" system

SUE: spectrum utilization efficiency of an actual system.

The likely candidates for a standard system are:

– the most efficient system which could be practically built;

– a system which can be easily defined and understood; or

– a system which is widely used, i.e. a *de facto* industry standard.

The RSE is a positive number with values ranging between zero and infinity. If the standard system is chosen to be an ideal or most efficient system, the RSE will typically range between zero and one.

8.9.1 Discussion

The concept of RSE can be used effectively to compare two systems providing the same service, since commensurate choices of parameters can then be made. In this situation, the ratio of the two computed SUEs may be more useful than the numerical values of the two efficiencies. The ratio of two SUEs will show, for example, that System A is twice as efficient (uses only half as much spectrum space or transmits twice the information) as System B.

The major advantage of directly computing the RSE is that it will often be much easier than computing the SUEs. Since the systems provide the same service, they will usually have many factors (sometimes even physical components) in common. This means that many factors will "cancel out" in the calculation before they need to be actually calculated. Often this will greatly reduce the complexity of the calculation.

For example, [Bykhovsky, 1979 and Bykhovsky and Pavliouk, 1986 and 1987] proposed a criterion based on a comparison of the frequency bandwidth (F_c) required to transmit a given volume of information (i.e. to provide a given number of communication or broadcasting channels) in a real radio network with an optimum frequency bandwidth (F_{opt}) of an ideal radio system with the same communication capacity. This criterion for spectrum utilization efficiency (M_u) is defined by the expression $(M_u) = F_{opt}/F_c$. Such an ideal system would make optimum use of the spectrum and possess ideal RF characteristics (from the point of view of unwanted transmitter emissions, non-fundamental receiver reception characteristics, antenna parameters etc.). The characteristics of such an ideal radio system can be expressed on the basis of the equations (8-3a) and (8-3b):

$$P_s = (1 + p_0)^{F_0/F_m} - 1 \tag{8-15}$$

If the RSE factor is reduced to the ratio of a single parameter, there may not be a complete understanding of the concept. For example, the use of higher-level digital modulation in fixed microwave links (256-QAM) allows a considerable bandwidth reduction over lower level modulations (16-QAM) [Hinkle and Farrar, 1989]. A simple comparison of required bandwidth would suggest that the 256-QAM system is about 4 times as efficient as a 16-QAM system. A closer examination, however, shows that the 256-QAM system requires larger S/N ratios and can tolerate less interference. The requirement for more freedom from interference may cancel the advantage from the smaller bandwidth, and a 256-QAM system could actually be less efficient than a 16-QAM system [Hinkle and Farrar, 1989].

The preceding points out the need to evaluate all of the factors which would be needed to calculate an RSE factor, rather than basing an RSE on only a single obvious factor. It may also be important to calculate RSE for an entire frequency band, rather than performing the calculations for only a single link or a single system.

8.9.2 RSE example for the land mobile service

Referring to the definition of RSE in equation (8-14), a reference system using a near optimum assignment strategy can be adopted. The details of this strategy are described [Delfour and DeCouvreur, 1989 and Delfour and Towaij, 1991]. A near optimum assignment strategy (NOAS) could be developed for the land mobile dispatch service. In this service, the typical dispatch users are taxi, police, delivery, etc. These systems consist of base stations with the associated mobiles operating within a specified coverage area. Depending on the number of mobiles, a dispatch service may have to share its channel with other users.

Based on established interference criteria, the near optimum assignment strategy assigns the maximum number of frequencies at predetermined locations within a given geographic area. The assignment strategy not only takes into consideration the traffic demand distribution but also provides reasonable assignment location flexibility.

In this model, the following assumptions are made:

– Future demands are likely to follow present traffic demographic distribution.

– For the purpose of analysis, the geographic area of interest is divided into a grid of equal squares, the size of which is determined by the interference criteria used in the band under consideration.

– The time unit used is directly related to the average peak traffic hours loading.

– The frequency unit used is the value of the bandwidth of a single radio channel used in the band under evaluation.

– Spectrum unit demand, $\beta_t(n)$, within a square is directly related to the total occupancy, $O_t(n)$ (E) within that square, or:

$$\beta_t(n) = C\ O_t(n) \qquad (8\text{-}16)$$

– Spectrum units demanded in the (i)th channel in the (n)th square are approximated by:

$$\beta(n,i) = C\ O(n,i) \qquad (8\text{-}17)$$

where:

C : constant determined by the size of the grid and the channel bandwidth utilized in the band under consideration.

– Different loading factors may be used for public safety services and for other services. Allowances can also be made when several systems share the capacity.

In this model, the equation becomes:

$$\text{RSE} = \frac{\text{Weighted actual occupancy}}{\text{Weighted NOAS occupancy}}$$

8.8.2.1 Discussion

This model employs the concept that a specific geographic area has a spectrum value relative to the total traffic demand in the area. The concept also points out that due to the three dimensional nature of the spectrum (bandwidth, space, and time), there will be denied spectrum users. The amount of denied spectrum is determined by level of interference other systems will receive from operation in the vicinity of the radio system. The model utilizes actual distribution of demands as average peak hour channel loadings.

Based on the model described above, the following observations can be made:

1. Spectrum quality is dominated by urban core communication traffic loading. Effectiveness of spectrum management can be measured by the maximum number of interference free frequencies available in the heaviest traffic cores of major cities.

2. When assigning frequencies outside heavy communication traffic urban cores, care must be taken to avoid pre-empting core assignments.

3. For new and re-planned bands, the near optimum assignment strategy can be used to provide the maximum number of interference-free frequency assignments to meet the demands.

4. The near optimum assignment strategy can result in higher spectrum quality and at the same time simplify the assignment process due to the pre-selected interference-free frequencies throughout the area of interest.

8.10 Conclusions

The above descriptions of measures of spectrum utilization, spectrum utilization efficiency (SUE) and relative spectrum efficiency (RSE) are a starting point for calculations leading eventually to comparisons of one system to another system within the same service. The applications of this theory have taken many approaches when applied to specific cases. Often, these specific applications provide intermediate results giving, for example, additional insight into which locations are already crowded, perhaps in the form of contour maps or graphs of cumulative distributions of geographical area versus percentage of frequencies available for the reference system.

A set of basic measures is suggested, which if implemented within technical and financial resource constraints, will realize available potential for increasing spectrum utilization efficiency:

1. Optimize (when developing new facilities and modernizing radio systems) the electromagnetic system parameters which determine the frequency-space volume with a view to reducing that volume, thereby potentially facilitating frequency sharing by different services and accommodating more networks in a given area.
2. Plan networks with regard to the nominal characteristics of radio systems, in particular reducing unnecessary "margins" in transmitter power, antenna height, received signal field strengths, etc.
3. Use network configuration for radiocommunication and broadcasting services, which are as close as possible theoretically to optimum networks, from the standpoint of spectrum utilization efficiency.
4. Adopt modulation techniques and equipment parameters in view of the efficient use of frequency bands, so as to come as close as possible to the potential limits achieved by a corresponding "ideal radio system".
5. Using the time factor in conjunction with an appropriate system to gain greater spectrum efficiency.

REFERENCES

BYKHOVSKY, M. [1979] Optimalnoe chastotnoe planirovanie odnoproletnykh RRL na selskoi seti (Optimum frequency planning of single section radio-relay links in a rural network). *Electrosvyaz*, 5, p. 47-52.

BYKHOVSKY, M. and PAVLIOUK, A. [1986] Effectivnost ispolzovania radioresursa v sistemah sukhoputnoi svyazi (Spectrum utilization efficiency in land mobile communication systems). Eighth International Wroclaw Symposium on Electromagnetic Compatibility, p. 1103-1111.

BYKHOVSKY, M. and PAVLIOUK, A. [1987] Kritery effectivnosti ispolzovania radioresursa v setyah radiosvyazi i veshchania (Criterion for efficient spectrum use in communication and broadcasting networks). *Radiotekhnika,* 4, p. 34-38.

DELFOUR, M. C. and DECOUVREUR, G. A. [August 1989] Interference-free grids – Part I and Part II. *IEEE Trans. on Electromagn. Compati.*, Vol. 31, **3**.

DELFOUR, M. C. and TOWAIJ, S. J. [May 1991] Spectrum quality indicators for the land mobile systems. IEEE Vehic. Techn. Conference, St. Louis, Missouri, United States of America.

GALLAGER, R. G. [1968] *Information Theory and Reliable Communication.* John Wiley and Sons, New York, London, Sydney, Toronto.

HAINES, R. H. [1989] An innovative technique for quantifying and mapping spectrum use. 1989 IC&C Executive Forum, Washington, D.C., United States of America.

HATFIELD, D. N. [August 1977] Measures of spectral efficiency in land mobile radio. *IEEE Trans. on Electromagn. Compati.*, VOL. EMC-19, **3**, p. 266-268.

HINKLE, R. L. and FARRAR, A. A. [May 1989] Spectrum-Conservation Techniques for Fixed Microwave Systems. NTIA Report TR-89-243.

KOVTUNOVA, I. G., TSVETKOV, S. A. and YAKIMENKO, V. S. [1999] Metodika otsenki zagruzki radiochastotnogo spektra v territorialnom raione (Method of determining utilization of the radio spectrum in a geographical area). *Radiotekhnika,* 6.

PASTUKH, S. Y., KHARITONOV, N. I., TSVETKOV, S. A. and YAKIMENKO, V. S. [2002] Upravleniye radiochastotnym spektrom i otsenka effektivnosti ego ispolzovania (Radio spectrum management and assessment of utilization efficiency). *Elektrosvyaz,* 12.

ZOLOTOV, S. I., KOVTUNOVA, I. G., TSVETKOV, S. A. and YAKIMENKO, V. S. [2001] Metod otsenki effektivnosti sposobov naznacheniya chastot RES v territorialnom raione (Method of assessing the effectiveness of distributing radio frequencies in a geographical area). *Elektrosvyaz*, 9.

BIBLIOGRAPHY

DROZD, A. [2005] *A New Challenge for EMC: Policy Defined Radio.* IEEE EMC, Society Newsletter, Winter 2005.

MAYHER, R. J., HAINES, R. H., LITTS, S. E., BERRY, L. A., HURT, G. F. and WINKLER, C. A. [1988] The SUM data base: A new measure of spectrum use. NTIA Report 88-236, US Dept. of Commerce, Washington, D. C., United States of America.

ITU-R Texts

ITU-R Handbook	Satellite Communications (2002)
ITU-R Handbook	Spectrum Monitoring (2011)
ITU-R Handbook	Computer Aided Techniques (2015)
ITU-R Handbook	Digital Terrestrial Television (2002)
Rec. ITU-R F.699	Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz
Rec. ITU-R S.465	Reference earth-station radiation pattern for use in coordination and interference assessment in the frequency range from 2 to about 30 GHz
Rec. ITU-R S.580	Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites
Rec. ITU-R S.731	Reference earth-station cross-polarized radiation pattern for use in frequency coordination and interference assessment in the frequency range from 2 to about 30 GHz
Rec. ITU-R SM.326	Determination and measurement of the power of amplitude-modulated radio transmitters
Rec. ITU-R SM.328	Spectra and bandwidth of emissions
Rec. ITU-R SM.329	Unwanted emissions in the spurious domain
Rec. ITU-R SM.331	Noise and sensitivity of receivers
Rec. ITU-R SM.332	Selectivity of receivers
Rec. ITU-R SM.337	Frequency and distance separations
Rec. ITU-R SM.377	Accuracy of frequency measurements at stations for international monitoring
Rec. ITU-R SM.378	Field-strength measurements at monitoring stations
Rec. ITU-R SM.443	Bandwidth measurement at monitoring stations
Rec. ITU-R SM.575	Protection of fixed monitoring stations against radio-frequency interference
Rec. ITU-R SM.668	Electronic exchange of information for spectrum management purposes
Rec. ITU-R SM.851	Sharing between the broadcasting service and the fixed and/or mobile services in the VHF and UHF bands
Rec. ITU-R SM.852	Sensitivity of radio receivers for class of emissions F3E
Rec. ITU-R SM.853	Necessary bandwidth
Rec. ITU-R SM.854	Direction finding and location determination at monitoring stations

Rec. ITU-R SM.855	Multi-service telecommunication systems
Rec. ITU-R SM.856	New spectrally efficient techniques and systems
Rec. ITU-R SM.1009	Compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-137 MHz
Rec. ITU-R SM.1045	Frequency tolerance of transmitters
Rec. ITU-R SM.1046	Definition of spectrum use and efficiency of a radio system
Rec. ITU-R SM.1047	National spectrum management
Rec. ITU-R SM.1049	A method of spectrum management to be used for aiding frequency assignment for terrestrial services in border areas
Rec. ITU-R SM.1050	Tasks of a monitoring service
Rec. ITU-R SM.1051	Priority of identifying and eliminating harmful interference in the band 406-406.1 MHz
Rec. ITU-R SM.1053	Methods of improving HF direction-finding accuracy at fixed stations
Rec. ITU-R SM.1054	Monitoring of radio emissions from spacecraft at monitoring stations
Rec. ITU-R SM.1055	The use of spread spectrum techniques
Rec. ITU-R SM.1056	Limitation of radiation from industrial, scientific and medical (ISM) equipment
Rec. ITU-R SM.1131	Factors to consider in allocating spectrum on a worldwide basis
Rec. ITU-R SM.1132	General principles and methods for sharing between radiocommunication services or between radio stations
Rec. ITU-R SM.1133	Spectrum utilization of broadly defined services
Rec. ITU-R SM.1134	Intermodulation interference calculations in the land-mobile service
Rec. ITU-R SM.1135	SINPO and SINPFEMO codes
Rec. ITU-R SM.1138	Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions
Rec. ITU-R SM.1139	International monitoring system
Rec. ITU-R SM.1140	Test procedures for measuring aeronautical receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-118 MHz
Rec. ITU-R SM.1235	Performance functions for digital modulation systems in an interference environment
Rec. ITU-R SM.1265	National alternative allocation methods
Rec. ITU-R SM.1266	Adaptive MF/HF systems
Rec. ITU-R SM.1268	Method of measuring the maximum frequency deviation of FM broadcast emissions at monitoring stations
Rec. ITU-R SM.1270	Additional information for monitoring purposes related to classification and designation of emission
Rec. ITU-R SM.1271	Efficient spectrum utilization using probabilistic methods
Rec. ITU-R SM.1370	Design guidelines for developing advanced automated spectrum management systems
Rec. ITU-R SM.1392	Essential requirements for a spectrum monitoring station for developing countries
Rec. ITU-R SM.1393	Common formats for the exchange of information between monitoring stations

Rec. ITU-R SM.1394	Common format for Memorandum of Understanding between the agreeing countries regarding cooperation in spectrum monitoring matters
Rec. ITU-R SM.1413	Radiocommunication Data Dictionary for notification and coordination purposes
Rec. ITU-R SM.1446	Definition and measurement of intermodulation products in transmitter using frequency, phase, or complex modulation techniques
Rec. ITU-R SM.1447	Monitoring of the radio coverage of land mobile networks to verify compliance with a given licence
Rec. ITU-R SM.1448	Determination of the coordination area around an earth station in the frequency bands between 100 MHz and 105 GHz
Rec. ITU-R SM.1535	The protection of safety services from unwanted emissions
Rec. ITU-R SM.1537	Automation and integration of spectrum monitoring systems with automated spectrum management
Rec. ITU-R SM.1539	Variation of the boundary between the out-of-band and spurious domains required for the application of Recommendations ITU-R SM.1541 and ITU-R SM.329
Rec. ITU-R SM.1540	Unwanted emissions in the out-of-band domain falling into adjacent allocated bands
Rec. ITU-R SM.1541	Unwanted emissions in the out-of-band domain
Rec. ITU-R SM.1542	The protection of passive services from unwanted emissions
Rec. ITU-R SM.1598	Methods of radio direction finding and location on time division multiple access and code division multiple access signals
Rec. ITU-R SM.1599	Determination of the geographical and frequency distribution of the spectrum utilization factor for frequency planning purposes
Rec. ITU-R SM.1600	Technical identification of digital signals
Rec. ITU-R SM.1603	Spectrum redeployment as a method of national spectrum management
Rec. ITU-R SM.1604	Guidelines for an upgraded spectrum management system for developing countries
Rec. ITU-R SM.1633	Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands
Rec. ITU-R M.1634	Interference protection of terrestrial mobile service systems using Monte Carlo simulation with application to frequency sharing
Rec. ITU-R P.1546	Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

ANNEX 1

Spectrum management training

1 Introduction

An automated spectrum management system is a large and potentially complex information system, which includes a large database of applications and licenses, frequency allocations, geographic information, and other data. Training on such a system is an essential element of any administration's spectrum management activities, to prepare staff for their duties. With the rapid evolution of radiocommunication systems, training must be a continuous, on-going process. Spectrum management staff requires a broad knowledge of topics related to the radio-frequency spectrum and radio services. Equipment and computer software is often highly specialized and not used outside the administration. Thus it is necessary to prepare specific training programs and use qualified instructors.

Training courses need to be tailored to the staff to be trained; different categories of staff listed in section 2 require different training courses. These training courses can be composed from standard modules or units, each covering specific topics within spectrum management. Training courses can be divided into three broad categories:

– Basic training (training of new staff)

– On-the-job training

– Professional development training.

These categories are discussed in greater detail in section 3. Furthermore, short introductory courses and/or longer-term, more in-depth training may be needed. Short courses offered in a week or two might provide an overall survey of spectrum management, cover certain specific topics listed in section 3.3, or introduce the trainees to a specific spectrum management system. Longer-term training provides a greater in-depth understanding of specific topics or detailed understanding of the operation of a system.

Training in an automated spectrum management system is generally based on information contained in documentation provided with the system. A manufacturer typically supplies the following documentation with a system:

– Standard equipment and software documentation as provided by the suppliers for basic equipment and computer software.

– System documentation, which serves as a set of reference handbooks, rather than a set of spectrum management procedures.

For each training course a set of training materials, including student materials and instructor guides, should be provided. Each trainee should receive a copy of training materials, including slides, manuals and other training materials. These materials should be retained by the spectrum management agency for permanent reference, especially in those cases of high staff turnover.

This Annex provides a summary of spectrum management training associated with the procurement of automated spectrum management systems. Training for spectrum management and monitoring is also briefly discussed in Recommendation ITU-R SM.1370 – Design guidelines for developing automatic spectrum management systems (latest version), and in more detail in section 2.8 of the ITU Handbook on Spectrum Monitoring, Geneva 2011.

2 Skills required for trainees

The radio spectrum management staff is required to cope a wide range of radio services, systems and administrative procedures. Therefore, a wide variety of personnel possessing a wide variety of skills and experience are required so that a broad range of knowledge and skills are available to the administration. Staff generally includes the following types of personnel:

- *Managers*: Persons in charge of project management and system operation.
- *Technical users*: Engineers, technicians and specialists, charged with radio engineering, technical analysis and frequency assignment (users of radio engineering software tools).
- *Administrative users*: Persons in charge of administrative tasks (i.e. application processing, billing, reporting).
- *Information technology specialists*: Persons in charge of installation, system supervision, data backup, and user management.

The knowledge and skills which these different types of personnel should possess are as follows:

- *Managers*
  - Organization of the regulatory body
  - Objectives, strategy, current and future business of the regulatory body on spectrum management
    - Administrative tasks linked to spectrum management
    - Radio system design and planning
    - Signal processing and information theory
    - Radio propagation
    - Interference analysis
    - Frequency planning
    - Basic knowledge of computer utilization
- *Technical users*
  - Radio propagation
  - Interference analysis
  - Frequency planning
  - Basic knowledge of computer utilization and mastery of relevant application software, e.g. text processing, spread sheet analysis, frequency management software
- *Administrative users*
  - Organization of the regulatory body
  - Administrative tasks linked to spectrum management
  - Basic knowledge of computer utilization including Microsoft Windows
- *Information technology specialists*
  - Operating systems
  - Basic knowledge of application software used by the system
  - Relational database management
  - TCI/IP, LAN and WAN networks.

Some of these skills may be obtained on an as-needed basis through contracting, consultants, or mutual assistance arrangements with other agencies of government. In some cases, spectrum management organizations will not require a high degree of specialized skills in each of these subjects, but will need a clear understanding of the principles involved. To be well qualified for their jobs, some of these personnel, particularly the managers, should have many years of experience in the field of spectrum management.

3 Topics for courses

An administration should develop a training plan that is adequate and suitable for its needs. Training on new systems is obviously required, and is normally provided by the supplier of the system. Regular basic training in introductory subjects for new staff hired to replace those lost to turnover is needed. Long-range plans are needed to provide professional development training for experienced staff in new topics in preparation for advancement.

Suggested topics for a training course are listed in this section. There are differences between countries regarding their legal systems, administrative structures, educational systems and frequency management systems. Also, the skills required of the spectrum monitoring staff depend on their specific tasks. Therefore, the suggested topics for courses given here should be treated as guidelines, and may be adjusted depending on an individual administration’s requirements.

As an example, a training program may devote approximately 3/4 of its schedule to spectrum management and approximately 1/4 of its schedule to spectrum monitoring.

The staff described in section 2 should have the general knowledge and understanding of principles as listed in that section; however, when the administration acquires a new system, these personnel will need specific training on that system.

3.1 Suggested training for the system described in Recommendation ITU-R SM.1370; a useful example of basic training

Recommendation ITU-R SM.1370 describes the elements of an automated spectrum management system (ASMS) to assist administrations with their spectrum management responsibilities. The following list provides suggested training topics for the type of system described in the Recommendation:

Spectrum management applications. Includes an introduction to spectrum management, and understanding the role of a spectrum management system

Understanding the spectrum management system structure. Includes discussions of system structure and subsystem integration.

Understanding and using the spectrum management subsystems. Includes understanding and using subsystems for radio licensing, technical analysis, international coordination/notification, invoicing and payment, radio operator certification, radio vendor (dealer), type acceptance test, inspection, management planning, system administration and monitoring interface. Also includes understanding system reference tables.

Understanding the project and its implementation schedule. Includes understanding project scope and deliverables, how various subsystems are integrated, implementation schedule and its impacts, and responsibilities of the contractor and administration.

Radio licensing subsystem. Includes data entry of license applications, authorizing station operation, invoicing, issuing/modifying/cancelling/renewing licenses, database queries and generating and understanding reports.

Understanding/performing the technical analysis process. Includes introduction to technical analysis and detailed instruction in performing technical analyses.

Understanding/performing international and regional coordination. Includes notification and registration of frequencies, performing international coordination, queries and reports.

Understanding the user management process. Includes definition of vendors, understanding certification and registration process, and understanding vendor licensing fees.

Understanding the equipment type acceptance process. Includes understanding the type acceptance function and process.

System administration. Includes understanding and performing system and network configuration, backup and recovery, and database administration, and understanding system access and security.

The inspection system. Comprises understanding and uses of the inspection subsystem.

Maintaining and using licensing system reference tables and codes. Describes the different types of codes, and the use of each of the code tables.

Understanding the monitoring and direction finding function. Introduces monitoring and direction finding systems, and describes the interface between the monitoring and licensing systems, the role of monitoring in spectrum management, fixed and mobile monitoring systems, monitoring reports, operation of fixed and mobile monitoring systems, and spectrum measurement techniques.

3.2 On-the-job training

After basic training the new staff member is assigned a role and task in the organization and posted in a department for a certain job. To effectively perform the desired tasks, on-the-job training is the most effective and frequently used form of training for new staff. It is a key method to preserve the know-how of the department. Yet it is not enough simply to assign new members of staff to an experienced colleague and trust that all will be well. It is the responsibility of the manager to plan on-the-job training just as he or she would a course, and to monitor progress. This training focuses on the particular assignment of the staff.

3.3 Detailed training; Professional development training

Professional development training provides detailed technical information to employees in preparation for advancement, change in assignment or grooming their technical knowledge. There are a variety of topics which should be covered in a spectrum management professional development training course. The topics given in a particular course should be chosen according to the skills and jobs of the personnel to be trained. The topics to be given in a spectrum management training course should generally be chosen from the following topics:

1. General principles of spectrum management
2. Understanding and using automated spectrum management systems
3. Radio licensing
4. Understanding/performing spectrum assignment
5. Understanding/performing technical analysis
6. Understanding/performing international coordination
7. Understanding the equipment type approval process
8. Accounting system, including fee calculation and invoicing
9. Applications to the administration’s system

a) Using and operating the system
b) Understanding and performing network configuration
c) System access considerations
d) Understanding and performing system back-up and recovery
e) Understanding system security considerations
f) Understanding and performing database operations

10. Data entry
11. Spectrum monitoring
12. Administration of spectrum management systems.

Managers should receive training in all of the topics listed above. Technical users should generally receive training in all topics except 8, 9b), and 9d). Administrative users should typically receive training in topics 2, 8, 9 a), 9 f) and 10. System administrators should receive training in topics 2, 9 and 12, including specialized courses in administration of software systems and databases.

In addition to formal training courses, a complete program of professional development training should include experiences of other administrations and involvement with activities at the ITU, such as:

– active participation in ITU study groups and conferences;
– active participation at regional forums and standardization organizations;
– exchange of ideas and information with other administrations. Coordination meetings and visits of other administrations enrich the experience; and
– attending seminars/workshops on new technology issues.

4 Training facilities

Training in radio spectrum management and monitoring is available from a variety of sources around the world, including the following:

– Training is provided by the ITU. Both the ITU Telecommunication Development Bureau (BDT) and Radiocommunication Bureau (BR) provide training opportunities as described below, and the BDT can provide guidance to developing countries regarding specific courses and possible sources of funding to attend those courses, including sources of funding for both training costs and travel/living expenses.
– The Administrations of Germany (Federal Republic of), Australia, Canada, China (People’s Republic of), Korea (Republic of), the United States of America, France, Israel (State of), Italy, Japan, Portugal and the United Kingdom of Great Britain and Northern Ireland offered in Resolution ITU-R 23-2 (RA-12) to receive monitoring officials from other administrations to train them in techniques of monitoring and direction finding. All of this training is tuition-free.
– Training is also available from organizations and universities in certain countries, as described in the following subsections. Some of these courses are tuition-free and some require payment of tuition.
– Manufacturers such as TCI, an SPX Company (USA); Elbit Systems (Israel), LS telcom (Germany), ATDI (France), Rohde & Schwarz (Germany), Thales (France) and Agilent Technologies (USA), offer training, including training on the systems they provide. The training programs of these manufacturers are described in Attachments to this Annex. Those who have signed Partnership Agreements with the BDT will not charge a tuition

fee for their courses and/or provide lecturers free of charge to workshops and seminars organized by BDT Centres of Excellence; others may charge for training.

The training facility information presented in this section was obtained largely in response to the call for descriptions of available training courses and facilities in response to the ITU-R Circular Letter 1/LCCE/54, and from the BDT. The training described in this section is available on various general topics within spectrum management, and on specific equipment and computer software which may be specific to individual Administrations.

4.1 Training resources available through the ITU

The ITU is committed to human resources development. The World Telecommunication Development Conferences approve programmes, including for human capacity building and other special programmes for developing countries. These programmes provide for transfer of knowledge, sharing of experiences and know-how, and dissemination of information, and include resources such as the Spectrum Management Training Program, Centres of Excellence and Virtual Training Centre described below. In addition, the Radiocommunication Seminars facilitate training.

4.1.1 Spectrum management training program (SMTP)

The SMTP is a full package of high level training materials in all areas of Spectrum Management and is being developed by experts drawn from within and outside ITU. This Programme covers a full range of topics on Spectrum Management. The SMTP will offer a solid means for staff training in the theory and practice of modern Spectrum Management. It will establish itself as the global “golden standard” for Spectrum Management.

Overview. The SMTP is designed for Member States and Sector Members of ITU. In particular, it will serve the capacity building needs of operators, regulators and policymakers. It will also be a resource pool for members of the Academia and ITU Centres of Excellence (CoEs) network. However, beyond these target groups, the SMTP will also be available to anyone who would like to enhance and broaden their professional knowledge while working in the field of Spectrum Management. As such, students entering the SMTP may be from different institutional levels, from technical to managerial, and with different backgrounds (engineering, legal, economic, etc.).

The SMTP comprises of two levels: Basic and Advanced. The Basic Level of the SMTP is more technical oriented, while the Advanced Level is associated also with non-technical subjects and skills.

The *Basic Level* of the SMTP comprises of the following modules:

1. Obligatory Module 1 “Legal Basis and Regulatory Framework of Spectrum Management”;
2. Obligatory Module 2 “Spectrum Engineering Fundamentals”;
3. Obligatory Module 3 “Wireless Telecommunications Technologies”;
4. Elective Module 1:
   – Option 1: “Spectrum Monitoring”;
   – Option 2: “Enforcement and Type Approval of Equipment”;
   – Option 3: “SM for Satellite Systems”;
   – Option 4: “SM for HF Systems, Science, Maritime and Amateur Services”;
   – Option 5: “SM for Aeronautical and Radio Determination Services and Military Systems”;
   – Option 6: “Computer-aided Spectrum Management”.

The *Advanced Level* of the SMTP comprises of the following modules:

1. Obligatory Module 4 “Economic and Market Tools of Spectrum Management”;
2. Obligatory Module 5 “Strategic Planning and Policies for Wireless Innovation”;
3. Elective Module 2:
   - Option 1 (Legal Specialization): “Advanced Spectrum Authorization Regimes”;
   - Option 2 (Legal Specialization):“Socio-Economic Impact of Spectrum Regulation; Competition and Consumer Protection”;
   - Option 3 (Technical Specialization): “Terrestrial TV Broadcasting Planning and Digital Transition”;
   - Option 4 (Technical Specialization): “Opportunistic Spectrum Access and Cognitive Radio”.

For detailed information see**: http://academy.itu.int/news/item/1077/**.

4.1.2 The World Radiocommunication Seminar

The Radiocommunication Bureau organizes on alternate years (generally in November), at ITU Headquarters in Geneva, a seminar (five days) which deals with the use of the radio-frequency spectrum and the satellite orbits, and, in particular, with the application of the provisions of the ITU Radio Regulations. The seminar covers the international frequency management aspects of the Terrestrial and Space Services, including related work of the ITU-R Study Groups. Special attention is given to the Radio Regulations procedures adopted by WRCs. Demonstrations and workshops are also organized to enable the participants to get hands-on experience with ITU notification procedures as well as with some of the software and electronic publications made available by the Radiocommunication Bureau to the Administrations of Member States and to Radiocommunication Sector Members. The lectures and discussions during the seminar are held in the six working languages of the ITU with simultaneous interpretation facilities. The documentation is posted on the ITU-R website (http://www.itu.int/en/ITU-R/seminars/Pages/default.aspx) and can be made available after the seminar upon request, for training purposes within administrations. Such seminars are also occasionally planned in different regions.

4.1.3 Centres of Excellence

The BDT maintains several Centres of Excellence in Telecommunications at various locations around the world for the benefit of developing countries which perform the following training functions:

- serve as focal points for training, professional development, research and information on matters related to telecommunications in various regions;
- train policy makers and regulators in the development of national sector policies and regulations;
- train high level corporate managers in the management of telecommunications networks and services;
- train frequency managers in the management of frequency spectrum in its policy, regulatory and technical aspects;
- provide training on selected issues of advanced telecommunication and information technology, telecommunication financing and multilateral trade agreements;
- provide capability for the development and harmonization of telecommunications standards, including support for participation in world telecommunication standardization forums;

– serve as focal points for regional and global information society initiatives;
– provide capability to formulate and implement pilot projects demonstrating the application of information and communication technology in specific fields of importance to various regions;
– provide consultancy to governments and private sector interests;
– provide facilities for conferences, seminars and colloquia to discuss and disseminate information on telecommunications issues.

There are six Centres of Excellence, as follows:

1. Centre of Excellence for African French speaking countries (Major Node: Dakar)
2. Centre of Excellence for African English speaking countries (Major Node: Nairobi)
3. Centre of Excellence for Asia Pacific (Major Node: Bangkok)
4. Centre of Excellence for Americas (Major Nodes: Costa Rica, Ecuador, Venezuela, Peru, Colombia, Argentina, Chile and Honduras)
5. Centre of Excellence for the Arab Region (Leading Countries: Syria, Egypt, Jordan, Tunisia and Sudan)
6. Centre of Excellence for Eastern Europe and CIS Countries (Leading Countries: Russia, Ukraine, Belarus, Slovakia, Poland and Bulgaria).

The centres are governed by Governing Councils or Steering Committees, which establish management structures and academic programmes to achieve the training objectives of the Centres.

Further information on the activities at these centers is available from the ITU website (http://www.itu.int/ITU-D/hrd/coe/~index.html).

4.1.4 Virtual Training Centre

The BDT has created a virtual training centre. The training centre website (http://www.itu.int/ITU-D) has a library, which contains training-oriented material.

One of the topics contained in training programmes is "Spectrum Management". ITU has also entered into partnership programmes with private sector, regional and international agencies, governments, academia and training organizations to build synergies and mobilize additional resources for capacity building initiatives. This programme has three main approaches for contributing to development: establishing a training agreement (by waiving training fees), contributing to BDT yearly action plan, and/or joining existing regional projects based on public-private sector partnerships focused on long term self-sustainability.

4.2 Training provided by administrations and organizations

4.2.1 Training facilities in the United States of America

Within the United States of America, the United States Telecommunications Training Institute (USTTI, http://www.ustti.org) has been offering training opportunities in radio spectrum management since 1983 after the Institute was launched at the ITU Plenipotentiary Conference in Nairobi, Kenya. The USTTI courses are sponsored by U.S. companies and/or government agencies. Each year the USTTI offers a number of courses directly related to radio spectrum management:

1. Training in Radio Spectrum Management and Regulatory Policy Matters (each spring, given jointly by the Federal Communications Commission and the USTTI)
2. Radio Frequency Spectrum Management (each spring, given jointly by the National Telecommunications and Information Administration (NTIA) and Comsearch).

3. Spectrum Management in the Civil Sector (each spring, given jointly by the U.S. Federal Communications Commission and Comsearch).
4. Radio Spectrum Monitoring and Measuring (each spring, given by the U.S. Federal Communications Commission (FCC) and by L-3/Apcom, Inc).
5. Practical Applications of Spectrum Management and Spectrum Monitoring (each spring, given by TCI).
6. Radio Spectrum Monitoring Techniques and Procedures (twice a year, once each spring and once again in the summer, given by the FCC).
7. Laboratory Techniques in Support of Equipment Authorization Programs (each fall, given by the FCC).

In addition to these opportunities, U.S. companies sponsor USTTI wireless radiocommunication courses, which may contain elements of spectrum management. Details of these are available in the USTTI course catalogue, published yearly.

Training under the aegis of the USTTI is tuition-free. Applicants should seek funding from their own organizations or governments or from other organizations for their international and domestic U.S. travel, and for living expenses during training.

4.2.2 Australian Communications Authority International Training Program

The International Training Program has been developed by the ACA (http://www.aca.gov.au/) in response to an increasing number of requests from international organizations for individual training and work-study programs. It aims to provide an overview of Australia's fully liberalized telecommunications and radiocommunications environments from a regulatory perspective. The training program has three streams covering radiocommunications and telecommunications issues. All the training sessions are conducted in English.

The International Training Program provides those countries that are in the process of introducing a competitive environment, along with those who may be considering introducing competition, a change to learn from Australia's experiences. It also has the added benefit of providing participants with a unique opportunity to network with individuals from organizations and countries in a similar position to their own, as well as those countries further along the path to open competition.

The ACA provides all training free of charge, however, participants are required to meet all the accommodation, travel and sustenance costs.

4.2.3 Training at the United Kingdom Telecommunications Academy (UKTA)

The United Kingdom Telecommunications Academy (http://www.ukta.co.uk/) offers a range of communications training free of all tuition charges to applicants from countries seeking to develop their communications expertise.

The Academy is a joint venture between some of the leading communications companies and selected universities in the UK, making use of their combined training capabilities to provide a portfolio of high quality training events. Places on these events are being offered to the managers and technical operatives from countries having a less developed communications environment. Successful applicants are likely to be contributing (or aspiring to contribute) in a significant way to the development of the communications infrastructure and capabilities within their own countries.

The Academy is supported by the United Kingdom Government, Department of Trade and Industry and has been created to provide training opportunities for delegates from those countries wishing to share in the knowledge and expertise of the UK communications industry.

The training covers a wide range of communications related knowledge, expertise and activities, including management, commercial, technical, and personal development. Individual courses range from 1 day to 2 years in duration. There are no specific courses titled Spectrum Management but technology oriented courses, which may contain aspects of spectrum management. Applicants may select a combination of courses from this brochure to form a consecutive programme appropriate to their personal needs. All training is in English.

4.2.4 Israeli National Spectrum Management Course

Israel (http://www.moc.gov.il/sip_storage/FILES/5/1725.pdf) conducts NSM courses to train engineers, lawyers and economists who serve in the Ministry of Communications, or to teach other experts who are connected to NSM. This website-link provides the content and timetable of the five-days training. The course has been conducted in Israel, Nepal and part of it in more than 28 countries, including ITU-D Distance Learning courses to Pacific Asia and Latin America. The course is based on Spectrum Management activities in the International, Regional and National levels, including the development of several National Spectrum Management programs.

In the framework of this course the fundamentals of wireless wireless-communications are provided; receivers, antennas and wave propagation are highlighted. The main wireless services are presented and detailed; emphasis on broadcasting, land mobile (mainly cellular) fixed services, satellites, Short Range Devices and radars. RF Human Hazards, RF Regulation, EMC and RFI are discussed. The 14 topics are public domain (satellite communications will be added); the detailed content of the course is bolded and web hyperlinked.

Meetings	Topics	Details
1.	Introduction	End-to-end Wireless Communication and the RF spectrum
		Radio Frequency (RF) Engineering
2.	Propagation1: equations	Maxwell Equations; Friis equation and free-space propagation loss, Elements Influencing Propagation Loss; Radar free-space equation; Far-Field, Near-Field; Doppler effect Fresnel zones
3.	Propagation2: Radio Horizon & HF	Radio Horizon as a Function of Ant Height; Snell's law; Effective Radius of the Earth; Attenuation due to atmospheric gases; ducting; HF propagation; Ionosphere regions, layers and hops
4.	Antennas: Fundamental Parameters	Antenna aperture and beamwidths, practical formulas; 3-dimensional antenna pattern; impedance, return loss and vswr; MIMO
5.	Transmitters and Receivers	Tx and Rx schematics; Transmitters unwanted emissions & masks; receiving conditions; sensitivity, selectivity; noise figure, thermal noise
		Radio Frequency (RF) Services
6.	Broadcasting: Video, Audio and Data	Broadcasting network, technical parameters of TV systems; RF bands; multipath; RF Digital Dividend; coexistence TV and cellular
7.	Land Mobile: mainly cellular	Mobile standards, basic cellular mobile reference network; frequency/ code/ time division multiple access; OFDM/OFDMA; IMT interfaces and evolution; GSM/UMTS/LTE structures; LTE bands; Wi-Fi offload; networking
8.	Fixed Service	Evolution & current state of fixed services technology; deployment topologies; LoS and NLoS FS links; applications and examples; channel arrangements (CA) and blocks; Link budget point-to-point logarithmically and numerically
9.	Satellite Communications	Definitions: ITU Radio Regulations; Satellite Orbits and Services; Satellite Equipment; Regulating Satellite Communications

Meetings	Topics	Details
10.	Short Range Devices	Definitions; new multiplexing, spreading & modulation techniques; typical applications; RFID technology; RF for global or regional harmonization; 3 case studies
11.	Radar Systems	Applications; Radar friis basic transmission loss; detection probabilities; Doppler effect; radar parameters; Moving Target Indication
RF: Regulation, RFI and Human Hazards		
12.	RF Regulation and Standardisation	What to regulate; role of regulation and standardization; international, regional and national organisations, RF monitoring; compare and contrast Europe vs. America
13.	EMC and RFI	RFI: Antenna to Antenna Coupling, Interference Types and Modes; mitigation, Intra-system and Inter-system RFI; Receiver Susceptibility Characteristics; unwanted signals; Linear Carrier-to- Interference ratio; S/N protection criterion
14.	RF Human Hazards	RF exposure and hypersensitivity; technical quantities; power density at the far field (from base station) and SAR at the near field (handset); ICNIRP guidelines for limiting exposures; reference levels around the world; exposure from multiple-antenna emissions. RF Hazards limits & their impact on cellular network planning

4.3 Training provided by Universities

Some universities also offer short courses in regulatory and spectrum management either as modules of post graduate programs or independent short trainings. It is beyond the scope to cover all the relevant courses by all the universities. Therefore, as an example two courses conducted at two universities are given below. These courses have a tuition fee in addition to the other charges, which are borne by the administration, including travel, accommodation and sustenance charges.

4.3.1 Courses at the University of York

The Department of Electronics (http://www.elec.york.ac.uk/contedu/welcome.html) at the University of York provides one-week modules for the part-time Modular Postgraduate Courses in EMC and in RF Communications, which can also be taken as short courses. One of the offered courses is "Radio Spectrum Management and the Radio Regulatory Environment" (five days). This course approaches the radio spectrum as a finite resource and overviews the tools, techniques and administration required to ensure efficient spectrum utilization.

4.3.2 Courses at the George Washington University Centre for Professional Development

The George Washington University Centre for Professional Development has a "Customized Education and International Program" (http://www.gwu.edu/~cpd/ceip) to stimulate personal and professional growth in business, industry, government and non-profit entities. The centre also offers to create customized curriculum to meet the organization's specific learning goals. One of the offered courses is "CWTC 551 Radio Frequency Spectrum Management" (five days). This course examines the technical, regulatory, and legal intricacies of radio-frequency spectrum management, how they impact developing technologies, and how they relate to strategic planning.

REFERENCES

ITU-R Texts

ITU Handbook on Spectrum Monitoring (Geneva, 2011).

Recommendation ITU-R SM.1370: Design guidelines for developing automated spectrum management systems.

Resolution ITU-R 23-2: Extension of the International Monitoring System to a worldwide scale.

ATTACHMENT 1

TO ANNEX 1

Spectrum management and monitoring training*

1 Training program

TCI is the only supplier of automated spectrum management and monitoring systems to design, fabricate and install complete, integrated systems internally, without major subcontractors, and as such, the Company is uniquely positioned to supply integrated spectrum management and monitoring systems and the training for those systems. In-depth training is essential to assure successful implementation of a spectrum management and monitoring system. The Company offers a training program which has been tailored to the integrated nature of the system. This training program provides the personnel of an administration with the knowledge and ability to successfully operate and maintain the automated spectrum management and monitoring system.

Training is provided for the following administration personnel:

– Spectrum management, technical and administrative staff responsible for the operation of the management system

– Operators of the monitoring system

– Engineers and technicians responsible for maintenance of the system.

The courses are conducted using appropriate training methods, including instructor lecture, laboratory, and other hands-on training. Course instructors have extensive background and experience with radio monitoring, direction finding, and spectrum management concepts.

For each training course, teaching resources and audiovisual material are provided, including a set of reproducible training materials for use by the instructor and students in the course. These training materials contain block diagrams, illustrations, and system schematics, and enable the administration to establish a comparable, on-going training program. The training materials include scenario-based exercises to enable the user to thoroughly understand and efficiently perform user-specific tasks.

2 Course Duration

Although training courses of shorter or longer duration can be provided, the duration of the Company’s standard training course is four weeks, during which three sequential courses are offered: spectrum management course, monitoring operation course and maintenance course. a four-week training period allows plenty of time for comprehensive training on a modern automated spectrum management and monitoring system. a four-week course rather than a longer course is offered as the company’s standard training course because:

– With a Windows®-based system, operation is intuitive and therefore easy to learn.

– Context-sensitive help allows users to obtain information on the currently active window at the push of a button.

– A training simulator (described in Annex 3 of Chapter 7) provided as part of the system facilitates on-the-job training.

* This Attachment is provided by TCI (www.tcibr.com).

– Sophisticated, integrated monitoring systems consist of much less hardware than older systems, and therefore less operation and maintenance training is required.

3 Courses

Management Frequency Assignment and Licensing Course. For operation of the Management System, a 10-day management system operation course is conducted, typically for up to ten administration personnel. Topics covered in this course include:

- Spectrum Management:
  - General principles of Spectrum Management.
  - Overview of the Automated Spectrum Management System (ASMS) Software.
  - Operation of the system, including typical workflow.
  - Allocation of frequency spectrum for use in various commercial and consumer requirements.
- Data Entry:
  - The data entry process used in the ASMS.
  - Combination of lecture and hands-on use of the system and processing of applications.
- Licensing and Administration:
  - How to evaluate a license application for approval, handle license modifications, renewals, terminations, etc., and manage complaint resolution.
  - Thorough understanding of the application and licensing process and conformance with required procedures.
- Frequency Assignment, Technical and Engineering Analysis:
  - The frequency assignment process and the use of the engineering analysis tools in assignment of frequencies and resolution of complaints.
  - Practical uses of frequency assignment and engineering analysis tools provided with the management system, including generation of reports.
- Fee Calculation:
  - The fee calculation process and other accounting functions.
  - Lecture and hands-on processing of required fees and use of accounting package.
- System Management and Administration:
  - Standard software maintenance by System Managers
  - Familiarization with the following tools and standard software: RDBMS Tools; Data Recovery Software.
  - Data Backup; Computer User Account Creation and Management; Security Management; Database Maintenance; Network Administration; Procedures.

Monitoring Operation Course. For operation of the monitoring stations, a five-day operation course is given on the fixed and mobile sites, typically for up to eight personnel. A description of this course is fiven in the following table:

Operations Training

Title	Objective	Content
Monitoring Operation Training	To enable operators to effectively perform daily monitoring assignments	System Overview (Hardware)
		Block Diagram of Stations
		Spectrum Monitoring Software
		Terminology and Concepts
		Monitoring Techniques
		The Operating System
		The Client/Server-based System
		Starting the Software
		The Basics
		Exploring the Software
		Overview of Measurements
		Scheduling
		Evaluating Monitoring Results
		Reports and Data Presentations
		Diagnosing and Reporting Problems
		Direction Finding
		Digitized Maps
		Measurements

Maintenance Course. For maintenance of the system, a five-day course is given, typically for up to eight technicians. A description of this course is given in the following table:

Maintenance Training

Title	Objective	Content
Maintenance Training	To enable technicians/ engineers to troubleshoot and repair the system	Block Diagram
		Cabling, Wiring and Interconnect Diagrams
		Overview of Calibration, Diagnostics and Error Messages
		Diagnostics and Error Messages
		Calibration
		Trouble Shooting
		Field Replaceable Unit Repair and Replace
		Preventive Maintenance

ATTACHMENT 2

TO ANNEX 1

LS telcom training programs*

1 Training program

LS telcom AG, Germany offers a wide variety of training courses, professional workshops and seminars that address all aspects of Spectrum Management and Spectrum Engineering.

To enhance and formalize the training services to developing nations, the Company works in partnership with the International Telecommunication Union (ITU) at the ITU Centres of Excellence in Africa, Asia, the Caribbean and the Arab region, where the collective goal is to assist developing nations in undertaking more effective management of the issues associated with liberalization and privatization of their telecommunications networks.

2 Courses

The following courses are readily available to be presented either in Germany, or in a third country chosen by the client.

The trainings offer not only theoretical basics by using practical examples, but a range of challenging hands-on computer exercises, too.

Our Training Calendar gives more detailed descriptions for each course.

Spectrum management

– Principles of Radio Spectrum Management
– Technical Issues of Radio Spectrum Management
– Spectrum Monitoring Measurements

Broadcasting

– Broadcast Planning Basics (FM/TV,T-DAB/DVB-T)
– Broadcast Planning Advanced (FM/TV,T-DAB/DVB-T)
– Digital Radio Mondial (DRM)

Fixed networks

– Basics of Microwave Link & Fixed Service Planning and Coordination
– Radio Link Calculation and Coordination (WLL, PtP)
– Satellite Coordination and Notification

Mobile communications

– Radio Planning Basics for Mobile Networks
– Professional Mobile Radio PMR (TETRA and TETRAPOL)
– Frequency Selection and Coordination for Land Mobile

* This Attachment is provided by LS telcom, Germany (www.lstelcom.com).

- GSM – Technical Principles and Radio Network Planning
- UMTS – Technical Principles and Radio Network Planning

Others

- Digital TerrainData: Requirements, Production & Usage
- Spectrum Pricing
- Spectrum Auctions
- Crystal Reports.

ATTACHMENT 3

TO ANNEX 1

Spectrum management training*

1 Training principles

THALES is a worldwide company present in the five continents with numerous Spectrum Management and Monitoring Systems in operation, and belongs to the three ITU Sectors.

This Company provides a fully integrated Spectrum Management and Monitoring System. The Spectrum Management System as well as the Spectrum Monitoring Interface Module are usually provided by CTS (Cril Telecom Software), a French software editor specializing in providing Automated Spectrum Management Systems and software solutions for telecommunications operators. Spectrum management training is usually handled by CTS.

Projects handled by both Companies are usually turn-key projects that include systems and platform supply as well as required services, such as installation, commissioning, data migration and integration, and training. Thanks to their long experience in systems implementation worldwide, both companies gained valuable expertise while tailoring training programs.

Training is a major component during project implementation. Indeed, without proper training, potential systems operators may not have the required skills to take full advantage of the supplied systems. Spectrum management training in the Companies' ELLIPSE system complies with Recommendation ITU-R SM.1370 while addressing each administration's specific needs and requirements in terms of contents and duration. Training may be carried out at clients sites or at company's sites in France. Technical assistance should be carried out at clients sites as it consists in hands-on/on-the-job training and assistance while the operators are performing their day-to-day spectrum management tasks.

The automated spectrum management system is a computerized information system that addresses the administrative and technical tasks to be handled by the administration in charge of spectrum management. It usually integrates a geographical information system as well.

Therefore, training addresses the following topics:

– Spectrum management tasks
– Application software
– Computerized system platform and software
– Database and system administration.

It consists of theoretical training, application theoretical training with hands-on practice, followed by on-the-job training and technical assistance during day-to-day use of the system.

Training documentation consists of the spectrum users manual as well as specific training documentation (e.g. handouts, power-point documentation, practical examples).

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* This Attachment is provided by Thales (www.thalesgroup.com) and Cril Telecom Software (CTS) (www.criltelecom.com).

2 Training programs

This section details the complete training programs that companies could propose to the administration when installing a turnkey spectrum management solution. They are composed of standard modules that are selected according to the profiles of trainees:

- *Managers*: Persons in charge of project management and system commissioning.
- *Technical Users*: Engineers in charge of Spectrum Engineering and Electromagnetic Compatibility (EMC) studies, as well as frequency assignment (users of radio engineering software tools).
- *Administrative Users*: Persons in charge of administrative tasks (e.g. application processing, billing, reporting).
- *System's Administrators*: Persons in charge of installation, system supervision, data back up, and user management.

Details are presented in the following sub-sections.

2.1 Administration managers training courses

- Trainees pre-requisite: Trainees shall have skills in the following domains:
  - Organization of the regulatory body and objectives, strategy, current and future business of the regulatory body on spectrum management.
  - Administrative tasks linked to spectrum management.
  - Radio propagation, interference analysis, frequency planning,
  - Basic knowledge of computer utilization, including MS Windows O/S.
- Recommended training modules
  - Basic concepts: working database; reference database, memory mode, site, stations networks.
  - Basic component: launching spectrum system; multi layer display; selection of databases; updating of the working database with the reference database; manipulation of technical entities, configuration of the models; coverage; printing; results export; updating of the reference database with the working database.
  - Management of services; frequency plans; equipment.
  - License creation; type approval; invoicing; account follow up.
  - Creation of agreements; creation of coordination forms; issue and integration of electronic files.
  - Measurement campaign; results exploitation. Utilization of reports program: Interface with spectrum relational database; report preparation; data protection rules.

2.2 Technical operators training courses

- Trainees pre-requisite: Trainees shall have operational skills in the following domains:
  - Organization of the regulatory body, administrative tasks linked to spectrum management.
  - Radio propagation, interference analysis, frequency planning.
  - Basic knowledge of computer utilization, including Windows, RDBMS.

- Training Modules
  - Basic concepts: working database; reference database, memory mode, site, stations networks launching spectrum system; multi-layer display; selection of databases; updating of the working database with the reference database; manipulation of technical entities configuration.
  - *C*/*I* Intermodulation products; propagation models; tuning of models; frequency assignment for land mobile service. Creation of networks; creation of ground earth stations; link clearance; link budget. Interference analysis MW-MW & MV-GES.
  - Menus; request forms; creation of agreements; creation of coordination forms; Issue and integration of electronic files.
  - Management of services; frequency plans; equipment; license creation; type approval; invoicing; account follow up.
  - Measurement campaign; results exploitation. Utilization of reports program: Interface with spectrum relational database; report preparation; data protection rules.

2.3 Administrative operators training courses

- Trainees pre-requisite: Trainees shall have operational skills in the following domains:
  - Organization of the regulatory body.
  - Administrative tasks linked to spectrum management.
  - Basic knowledge of computer utilization, including Windows, RDBMS.
- Training modules
  - Menus; request forms; creation of folders; follow-up process.
  - Management of services; frequency plans; equipment.
  - License creation; type approval; invoicing; account follow up.
  - Creation of agreements; creation of coordination forms; issue and integration of electronic files.
  - Measurement campaign; results exploitation. Utilization of reports program: Interface with spectrum relational database; report preparation; data protection rules.

2.4 System's Administrators training courses

- Trainees pre-requisite: Trainees shall have operational skills in the following domains:
  - Operating systems and Windows.
  - Relational Database Management System (RDBMS).
  - TCP/IP, LAN WAN Networks.
- Training modules
  - Menus; request forms.
  - Basic concepts of the operating system, of database, access through SQL in system framework.
  - System administration: back-up, restore; access right management. Usage of Crystal Report: Interface with system FMS Data base; report preparation; data protection rules.

ANNEX 2

SRD Regulatory Approach in CEPT

1 Introduction

Short Range Devices (SRD) are playing an increasing role in the economy and in the daily life of citizens. SRDs cover a very wide range of applications such as data collection with auto identification systems or item management in warehousing, retail and logistic systems, baby monitors, garage door openers, wireless home data telemetry and/or security systems, keyless automobile entry systems and hundreds of other types of common electronic equipment relying on such transmitters to function. At any time of the day, most people are within a few meters of consumer products that use SRDs. Because of this diversity, the short range device market is not a single entity because it comprises of a number of markets for a wide range of applications that provide real economic value to industry and to citizens worldwide in terms of efficiency and quality of life.

SRDs operate on a variety of frequencies and are generally exempted from individual authorization requirements. Unlike clearly defined radio services which benefit from allocated frequency bands, an SRD frequency band doesn't exist and therefore SRDs must share the operating frequencies with other radio applications without causing harmful interference to, nor claiming protection from any application or service. This should be ensured by defining an appropriate regulatory framework which should also provide an efficient use of the spectrum.

Noting this context, it seems important to consider all the specific aspects attached to the SRD approach in order to define a strategy to elaborate the most appropriate regulation which will grant sufficient confidence to SRD industries and that will also guaranty an appropriate protection to radio services.

2 The SRD Context

SRD applications are not identified as a radio service. This means that SRDs do not have a specific spectrum allocation and they can therefore operate everywhere in the frequency spectrum under the following conditions:

1) SRDs operate in shared bands and are not permitted to cause harmful interference to radio services;

2) SRDs cannot claim protection from radio services.

These conditions, associated with the fact that SRDs are most usually authorized under a general authorizations regime, fix the rational to define the appropriate regulatory framework.

These specific conditions create some complexity in defining the appropriate regulation. In the following part of this document, issues and impacts related to each of the features are described.

Shared use of the spectrum and related issues

For shared spectrum considerations, it is important to distinguish between spectrum occupancy and spectrum efficiency. The value of using a particular part of spectrum comes from the utility it provides to users, which is not necessarily the same as the data traffic. A distinction should be made between the concepts of Single system Absolute Spectrum Efficiency (SAE), which is based on the raw data transmitted, and Group Spectrum Efficiency (GSE), which is closer to the broader utility or service provided. Spectrum efficiencies can be defined in terms of the GSE in an environment where devices of different and similar nature are present (ECC Report 181 [5]).

In SRD deployment it is not possible to give each application its own reserved frequency range.

For shared spectrum considerations it must be recognised that it is not only the technical parameters of the radio signal and the resulting link budget that are important. The modern adaptable packet-switched systems have complex operational patterns through involving not only the physical layer but also higher OSI levels into the picture for overall maintenance of communications stream. Therefore ideally the system designers, as well as spectrum managers, should endeavour considering those more sophisticated aspects in order to determine and establish the balance between the levels of operational resilience of considered systems.

One of the most important operational parameters of this category is the latency requirement. This is the maximum acceptable delay in transferring the packet/message and cannot generally be inferred alone from the technical consideration of the useful link budget vis-à-vis the interference instance. Therefore the latency as well as other similar parameters/metrics may need to be considered when pursuing spectrum planning in shared bands.

Another conclusion is that when different applications are mixed, an analysis based on a simple probability of interference does not reveal the full story. Therefore, compatibility analysis in an application neutral environment will require more extensive analysis in the lowest two layers of the OSI model, mainly in the time domain, than is currently done in situations where the applications are defined.

Recommendation ITU-R SM.1046-2 [9] indicates a methodology that should be used to compare similar systems. This makes it difficult to apply this concept directly to the SRD bands, where a variety of different applications share the same spectrum. The move to application neutrality in spectrum regulations (e.g. to foster innovations) will make it even more difficult to apply the procedures in Recommendation ITU-R SM.1046-2. CEPT has investigated these challenges in ECC Report 181 [5] in 2012.

General authorization regime and related issues

Applying a general authorization regime for SRD applications means that normally no coordination is required, that administrations do not have to spend efforts in awarding individual licenses to SRD and it is also not intended to limit the number of users. However, one immediate consequence is that the regulator has no exact information about the precise locations of use and real usage densities. This implies that the introduction of new restrictions, whether it is additional technical restrictions or other authorization conditions at a later stage (e.g. after the occurrence of interference problems), may be difficult. New technical requirements for SRD equipment, to overcome such interference problems, may be introduced in international standards but the real effect on the markets will only appear after some years and the existing equipment population, already in use on the market, is not concerned by changes in later version of such standards.

Finally, it has to be noted that short range devices may be mass-market and/or portable products which can easily be taken and used across borders; differences in spectrum access conditions therefore prevent their free movement, increase their production costs and create risks of harmful interference to other radio applications and services.

3 European scheme to define SRD regulation

Cooperative framework based on European Commission, ETSI, CEPT/ECC relationship

The European Commission, ETSI and the Electronic Communications Committee (ECC) of CEPT are involved in the cooperation process dealing with spectrum management decisions by setting standards as well as regulatory decisions.

The MoU between CEPT and ETSI describes the cooperative process applying to the development of harmonized European standards and of ECC Decisions (or other ECC deliverables). This process aims to facilitate access to spectrum for new applications envisaged by ETSI. According to the MoU between CEPT and ETSI, any modification of the harmonized European standard which would require a modification of ECC deliverables should lead to a coordination process between the two bodies. The same would apply if ECC envisages a change in its regulation which would require a modification of harmonized European standards.

Harmonized European standards are agreed by a consensus amongst administrations and industry, and are adopted by a public vote managed via National Standards Organizations. Once adopted the Commission cites them in the OJEU (Official Journal of the European Union) without further intervention, except in exceptional cases.

CEPT/ECC deliverables may be adopted voluntarily by CEPT member administrations after public consultation. In addition, when the harmonization measure is covered by a Commission mandate, a CEPT Report is submitted to the European Commission which proposes harmonization measures based on the Spectrum Decision process. The implementation of harmonization measures based on Decisions of the European Commission is mandatory for EU Member States.

Role of ETSI in SRD regulation

The ETSI is responsible for producing harmonized European standards for telecommunications and radiocommunications equipment. These standards which are used for regulative purposes are known as European Norms (prefixed with EN).

Harmonized standards for radio equipment contain requirements relating to the effective use of the spectrum and avoidance of harmful interference. These can be used by manufacturers as part of the conformity assessment process. The application of harmonized European standards developed by ETSI is not mandatory, however where they are not applied, a notified body must be consulted. The national standardization organizations of EU Member States are obliged by EU law to transpose European Standards for Telecommunications (ETSs or ENs) into national standards, and to withdraw any conflicting national standards.

With regard to SRDs, ETSI developed four generic standards (EN 300 220; EN 300 330, EN 300 440 and EN 305 550) and a number of specific standards covering specific applications.

CEPT SRD Regulation in Europe

The CEPT ERC Recommendation 70-03 and also the EC Decision 2006/771/CE (and subsequent amendments) on SRDs provide both a list of the available bands for SRD applications with associated usage conditions. Alongside a list of the bands and conditions, definitions of the relevant applications are also provided within these documents.

Based on a permanent Mandate from the European Commission, the CEPT is tasked with regularly updating of the technical Annex of EC Decision 2006/771/EC.

The work in CEPT ensures that sufficient information for compatibility studies has been made available by stakeholders and ETSI. System reference documents from ETSI (SRdoc) normally trigger the process or contribute to this process by providing valuable information for identifying input parameter for these studies. In addition, ETSI Specialist Task Forces (STFs) also can contribute new information. In general, this establishes a process of co-regulation in which administrations, industry and operators/users participate to find the best suitable regulatory approach for SRD applications.

- *Recommendation CEPT/ERC/REC 70-03 – Relating to the use of short range devices (SRD)*

This Recommendation (http://www.erodocdb.dk/Docs/doc98/official/pdf/REC7003E.PDF) sets out the general position on common spectrum allocations for SRDs for CEPT member countries. It is also intended to be used as a reference document by the CEPT member countries when preparing their national regulations. The Recommendation describes the spectrum management requirements and technical specifications for SRDs. It also includes links to all applicable reference documentation such as CEPT/ECC Reports, CEPT/ECC and EC Decisions, and harmonized European Standards.

This particular approach with CEPT/ERC/REC 70-03 provides a good example of the CEPT use of 'soft harmonization', where existing services remain protected to the extent that national administrations deem it necessary, yet providing the opportunity for the harmonized development of new services in the majority of European countries. The success of the ERC Recommendation 70-03 owes much to its 'soft harmonization' approach, which is quicker to set up than a more rigid, centralized harmonization process for SRD applications, where the measures needed to deal with important but limited incumbent interest can block or delay the process of introducing SRD spectrum usage opportunities.

- *European SRD information in EFIS*

The ERC Recommendation 70-03 (including the national implementation information) is available in data format in the ECO Frequency Information System (www.efis.dk);

SRD related information can be found under the link: EFIS SRD Regulations. The information can be exported in csv (excel) format.

The European Common Allocations table is also integrated in EFIS and can be downloaded (just select ECA in the EFIS database). It contains all the SRD related ECC harmonization measures and applicable ETSI Harmonized European Standards.

General procedure

A clear procedure is established in order to define a new SRD regulation starting from formal requests for consideration by the CEPT. These requests can originate in industry, often through ETSI via a System Reference Document, or from Administrations that have identified a specific need for a new application.

A 'System Reference Document' is usually produced for a new SRD application or change of an existing SRD regulation. It should include a technical description information on the market and spectrum sharing which can be used by CEPT countries in their deliberations on spectrum compatibility and regulatory issues. Such requests are considered in CEPT for any necessary compatibility and regulatory assessment and for a recommendation on any required further action. Any recommendation for modification of ERC/REC 70-03 that is provisionally agreed proceeds to a public consultation process with subsequent resolution of comments before final approval for publication.

In parallel with the CEPT process outlined above, ETSI generally develops a harmonized European standard (HEN) for the relevant SRD application. During this process ETSI will liaise with CEPT for information relating to appropriate operating conditions to ensure compatibility with existing services.

The benefits of this regulatory process include:

1) Defined entry points into the process for industry;
2) Following neutral studies:
   - compatibility with existing users;
   - maximum/efficient use of the spectrum;
   - reliable operation of new applications by defining appropriate operating conditions;
3) Public consultation intended to ease the process of national implementation.

ECC Policy Goal aims to increase the efficiency of the regulatory process, particularly the compatibility studies, and to provide a rapid frequency designation process and to give a higher degree of certainty for industry. A key element of this is to encourage the industry to provide initial spectrum studies to support its proposals.

When fine-tuning the regulatory process in practice, the following aspects should be considered:

1) The overall process is time-consuming and therefore, deadlines for work items of the regulatory approach should be defined. Otherwise, the approach may not align with the short life-cycle of some SRD products. Micro-management of individual SRD applications and/or very small frequency bands should be avoided. Bundling of similar requests/similar SRD applications will also help to avoid frequency band fragmentation.
2) Any extensive and unnecessary emphasis should be avoided on providing protection for existing SRD applications. A balanced approach between incumbent and new SRD applications in a frequency band should be pursued and the basic rule should be 'equal access to the spectrum';
3) 'Lowest common denominator' compromises between the stakeholders should be avoided which tend to make everybody equally unhappy. The regulatory solution should fit to the SRD application needs. If required, different frequency bands should be considered because of negative spectrum compatibility results.

4 Principles and strategy of developing SRD regulations in CEPT

The SRD concept is investigated following a defined common process.

The principles and strategy have been set out in the CEPT in CEPT Reports 14 and 44 [2, 3] and ECC Report 11 [4].

All SRD application requests should be subject to a detailed description.

Defining sharing conditions for the efficient use of spectrum for a certain frequency band and application usually requires comprehensive compatibility studies so as to ensure that such new collective usage (see [7]) will not be detrimental to licensed users. Therefore, all new requests for an SRD application are subject to compatibility studies to define a sharing scheme and a licensing regime. The regulatory environment for SRD application should provide clear directions regarding the obligations and behavior (politeness) of the devices.

Two types of applications could be investigated under an SRD approach:

a) Generic application;
b) Specific application.

The advantage of the generic approach is that the regulation will be as open as much as possible to new SRD application developments. This fosters innovation.

On the other hand, using the specific SRD application approach to the band has the advantage that the number of devices may be better estimated and interference scenarios may be more reliably predicted. Typically where higher power levels than those typically employed for generic SRD applications are required.

One challenge of this approach is to accurately define the category of SRD application in order to ensure that the overall SRD usage density in the frequency band is under control.

Technical approach

The technical layout of complete radio systems can be chosen with maximum freedom. The choice of modulation systems, error correction protocols and link establishment choices for robustness and latency and the application are all the choice of the manufacturer. However, when defining the appropriate operating frequency band, administrations need to consider grouping different SRD application in order to foster the collective and the efficient use of the spectrum.

Neutrality Principles

It is likely that for the same reason of technology neutrality there will be a trend towards grouping users not by application but more by the type of signal transmitted. This also supports the principle of "commons" segments of spectrum not specifically designed for one application but available for those users obeying common access rules, e.g. access to a frequency sub-band will depend on a combination of parameters such as power, duty cycle, length of transmission, spectrum access method.

Applications referring to SRD categories or types of SRD devices performing a specific task with a particular installed base are described by one or more system reference documents (including the usage scenario of these types of devices) and/or application specific harmonized standards.

As such it is defined as a field or scope of application in terms of usage application such as non-specific SRD applications (i.e. all usage fields) or specific applications, i.e. specific usage fields for which specific usage scenarios and usage densities were assumed in the respective spectrum compatibility studies. The term application should not be misunderstood as a specific field of technology.

The principle of application neutrality means the end of segregation by application where sub–bands were designated exclusively to a particular SRD application (described in CEPT Report 44 [3]). In order to preserve technical efficiency, a suitable replacement could be partitioning of the bands based on technical objectives – e.g. sub-bands for high reliability, for low latency, for high throughput. However, this may lead to more detailed definition needed in describing the technical spectrum access requirements and this may lead to a reduction in technology neutrality if not performed properly.

However, the relationship between spectrum access and perceived functionality is different for different applications, even though the signal parameters are identical. Therefore this approach can only be achieved if the proper technology, in terms of latency, reliability or data bandwidth is described for all application types in the same environment. Full application neutrality may not be an achievable objective and should be used with caution.

Technology neutrality

Technology neutrality has different definitions in different areas of technology and is in electronic communication usually described as "the rules should neither require nor assume a particular technology". As one can see for SRD technology this reads in two parts "require" as in regulation and "assume" as in standards.

The principle of technology neutrality is more difficult to realise and therefore may not always be realised by regulation without sacrificing spectrum use efficiency. It should be still possible to frame regulations so that, for instance, either analogue or digital modulation is allowed or a range of bandwidths is possible. In most cases, however, it is necessary to set specific technical conditions to allow successful sharing, so technology neutrality is at odds with spectrum efficiency. In order to assist the emergence of new technologies, the principle of technology neutrality should be applied as far as possible.

Technology neutrality is a desirable aim, but similarly, is only truly achievable when applications have equal access and equal requirements. In addition, spectrum efficiency and technology neutrality are in direct conflict with each other if no mandatory technical border conditions for all devices in a certain environment are defined.

Predictable sharing environment

This addresses a second-level of compatibility (i.e. intra-SRD sharing) which needs to be established to ensure that SRDs do have equal access to bands and therefore have to protect each other (instead of being protected by regulators). The sharing rules mandated in spectrum regulation then become the level playing field on which SRDs would have to operate. As such, there could therefore be the case for having different playing fields for different categories of SRDs. Appropriate spectrum access rules facilitate predictable sharing arrangements.

Predictable Sharing Environment is assumed to be defined as common behaviour for communication equipment and systems, common rules with common well defined technical parameters and mitigation techniques to provide better defined sharing conditions within a specified frequency band.

From the spectrum requirements presented by industry, it is clear that some new services and functions, such as safety related applications, may require a more predictable sharing environment than that provided by traditional mitigation techniques. Different scenarios for combining services requiring a predictable sharing environment should be considered during compatibility studies in order to determine an acceptable solution.

Alternatively, by carefully specifying the technical parameters and mitigation techniques, it may be possible to create a predictable sharing environment for the whole band that could apply to all SRDs.

Mitigation techniques considerations

In order to ensure an efficient use of the spectrum by considering different SRD applications in a same frequency band, mitigation techniques are systematically considered. This includes e.g. specific duty cycle restrictions, listen-before-transmit requirements, frequency adaptation and detect-and-avoid mechanisms. Other more sophisticated technologies can also be considered such as common co-existence specifications which are implemented by different SRD sectors/categories for having equal access to the spectrum. Most mitigation techniques would require clear specifications in international standards, so administrations can use them in their regulatory approach.

Adapting the individual authorization regime in specific cases

SRDs are usually associated with general authorizations. However, individual authorizations could also fall within the SRD approach. This may be particularly relevant in relation to 'light licensing regimes' where, for example, there may be a need to coordinate with an incumbent user; or 'private commons' where an individual (and licensed) user sets the conditions for access.

A drawback of the licencing regime of the SRD approach is that while individually licensed users, through the regulator, have means to deal with harmful interference, the SRD user is unlikely to have any such recourse, neither through the manufacturer nor the regulator (unless the interference is caused by illegal transmissions).

Such a regime could only be applied to specific and well-defined SRD applications.

Responsibility of the manufacturers

It needs to be emphasized that it is ultimately the responsibility of manufacturers to build short range devices in a way to protect such devices against harmful interference to the extent possible and to minimize the risk of interference from radiocommunication services as well as from other short range devices sharing the same medium. This should be noted in particular for such SRD devices where the users claim to have high requirements in terms of e.g. latency, throughput, predictability or reliability of the wireless communications link. In such cases, the implementation of adaptive techniques to "escape" from interference or the definition of special frequency band conditions may provide solutions.

REFERENCES

[1] Recommendation ERC/REC/70-03, Relating to the Use of Short Range Devices (SRD), Tromsø 1997 and Subsequent amendments.

[2] CEPT Report 014, "Report from CEPT to the European Commission in response to the Mandate to Develop a strategy to improve the effectiveness and flexibility of spectrum availability for Short Range Devices (SRDs)", July 2006.

[3] CEPT Report 44, "In response to the EC Permanent Mandate on the Annual update of the technical annex of the Commission Decision on the technical harmonisation of radio spectrum for use by short range devices", Report approved on 8 March 2013 by the ECC.

[4] ECC Report 011, "Strategic plans for the future use of the frequency bands 862-870 MHz and 2400-2483.5 MHz for short range devices", Helsinki, May 2002.

[5] ECC Report 181, "Improving spectrum efficiency in the SRD bands", September 2012.

[6] Radio Spectrum Policy Group Opinion on "streamlining the regulatory environment for the use of spectrum", 19 November 2008.

[7] Radio Spectrum Policy Group, "Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches", November 2011.

[8] COMMISSION DECISION 2006/771/EC of 9 November 2006 on harmonisation of the radio spectrum for use by short-range devices and subsequent amendments (2009/812/EC, 2010/368/EU, 2013/752/EU).

[9] Recommendation ITU-R SM.1046-2 – Definition of spectrum use and efficiency of a radio system.

ANNEX 3

Best practices for National Spectrum Management

Introduction

With due regard to the ITU Constitution and Convention, this Annex addresses Best Practices for national spectrum management activities. International practices are not included. However, some of the Best Practices contained below are intended to interface with, or transition to international practices, e.g. those relating either to collaboration with colleagues in other countries, or to coordination, such as that which would occur at a bilateral or multilateral consultation preceding a World Radiocommunication Conference, or at an international satellite coordination meeting. These practices are further intended to harmonize global spectrum management policies, to the extent practicable, by harmonizing practices among national administrations.

Practices:

1. Establishing and maintaining a national spectrum management organization, either independent or part of the telecommunication regulatory authority responsible for managing the radio spectrum in the public interest
2. Promoting transparent, fair, economically efficient, and effective spectrum management policies, i.e. regulating the efficient and adequate use of the spectrum, taking into due account the need to avoid harmful interference and the possibility of imposing technical restrictions in order to safeguard the public interest
3. Making public, wherever practicable, national frequency allocation plans and frequency assignment data to encourage openness, and to facilitate development of new radio systems, i.e. carrying out public consultations on proposed changes to national frequency allocation plans and on spectrum management decisions likely to affect service providers, to allow interested parties to participate in the decision-making process
4. Maintaining a stable decision-making process that permits consideration of the public interest in managing the radio frequency spectrum, i.e. providing legal certainty by having fair and transparent processes for granting licenses for the use of spectrum, using competitive mechanisms, when necessary
5. Providing in the national process, in special cases where adequately justified, for exceptions or waivers to spectrum management decisions
6. Having a process for reconsideration of spectrum management decisions
7. Minimizing unnecessary regulations
8. Encouraging radiocommunication policies that lead to flexible spectrum use, to the extent practicable, so as to allow for the evolution of services[46] and technologies using clearly-defined methods, i.e.:
   a) eliminating regulatory barriers and allocating frequencies in a manner to facilitate entry into the market of new competitors,

[46] Whenever the term “services” is used in this Handbook, it means applications and recognized radiocommunication services.

b) encouraging efficiency in the use of spectrum by reducing or removing unnecessary restrictions on spectrum use, thereby encouraging competition and bringing benefits to consumers, and

c) promoting innovation and the introduction of new radio applications and technologies

9. Assuring open and fair competition in the marketplaces for equipment and services, and removing any barriers that arise to open and fair competition

10. Harmonizing, as far as practicable, effective domestic and international spectrum policies, including of radio-frequency use and, for space services, for any associated orbital position in the geostationary-satellite orbit or of any associated characteristics of satellites in other orbits

11. Working in collaboration with regional and other international colleagues to develop coordinated regulatory practices, i.e. working in collaboration with regulatory authorities of other regions and countries to avoid harmful interference

12. Removing any regulatory barriers to free circulation and global roaming of mobile terminals and similar radiocommunication equipment

13. Using internationally recommended data formats and data elements for exchange of data and coordination purposes, e.g. as in the RR Appendix **4**, and in the ITU-R Radio-communication Data Dictionary (Recommendation ITU-R SM.1413)

14. Using "milestone" management steps and phases to monitor and control lengthy radiocommunication system implementation

15. Adopting decisions that are technologically neutral and which allow for evolution to new radio applications

16. Facilitating timely introduction of appropriate new applications and technology while protecting existing services from harmful interference including, when appropriate, the provision of a mechanism to allow compensation for systems that must redeploy for new spectrum needs

17. Considering effective policies to mitigate harm to users of existing services when reallocating spectrum

18. Where spectrum is scarce, promoting spectrum sharing using available techniques (frequency, temporal, spatial, modulation coding, processing, etc.), including using interference mitigation techniques and economic incentives, to the extent practicable

19. Using enforcement mechanisms, as appropriate, i.e., applying sanctions for non-compliance with obligations and for inefficient use of radio-frequency spectrum under relevant appeal processes

20. Utilizing regional and international standards whenever possible, and where appropriate, reflecting them in national standards

21. Relying to the extent possible on industry standards including those that are included in ITU Recommendations, in lieu of national regulations.

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