International Telecommunication Union

HANDBOOK

National Spectrum Management

Edition 2005

Radiocommunication Bureau

v.1.01

International Telecommunication Union

THE RADIOCOMMUNICATION SECTOR OF ITU

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Inquiries about radiocommunication matters

Please contact:

ITU
Radiocommunication Bureau
Place des Nations
CH-1211 Geneva 20
Switzerland

Telephone:	+41 22 730 5800
Fax:	+41 22 730 5785
E-mail:	brmail@itu.int
Web:	www.itu.int/itu-r

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This edition includes the modifications introduced by the Corrigendum dated 28 April 2006.

FOREWORD

This revision of the Handbook on National Spectrum Management involved a major update and expansion of the 1995 edition. It was developed by a Rapporteur Group established for this purpose by Radiocommunication Study Group 1. Mr. Robert J. Mayher, former Chairman of Study Group 1 served as Rapporteur of the group, assisted by the Counsellor, Mr. Dusan Schuster. Members responsible for revisions to the chapters included Mr. Steven Bond, Mr. Dave Barrett, Mr. Howard Del Monte, Mr. William Luther, Mr. Philippe Mège, Mr. Alexandre Pavliouk, Mr. Thomas Racine, Mr. Jan Verduijn and Mr. Roy Woolsey.

Valery Timofeev
Director, Radiocommunication Bureau

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CHAPTER 1

SPECTRUM MANAGEMENT FUNDAMENTALS

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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 not two administrations would manage the spectrum in exactly the same manner, the basic processes are essential to all national approaches.

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

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-range spectrum plan. 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 and amateur radio activities.

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

– 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; and

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

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. 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.

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. 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.

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. 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 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[2], specifications, and equipment authorization;

h) Spectrum monitoring;

i) Spectrum regulation enforcement;

- inspections;
- investigations;

j) Spectrum management support functions including;

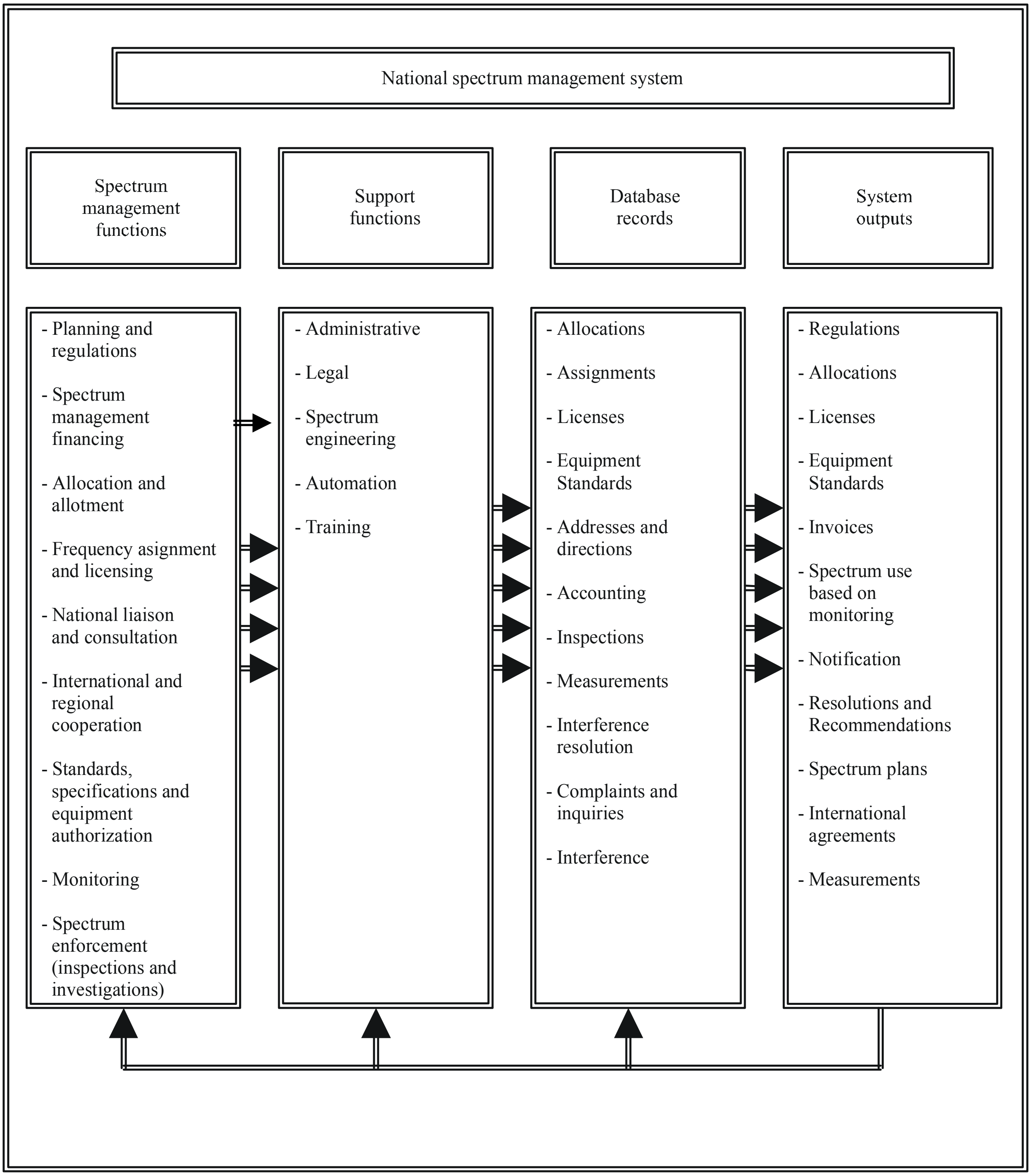
- administrative and legal;
- computer automation;
- spectrum engineering;
- training.

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.

2 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[3], 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

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[3] "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)."

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;

– 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 and as such 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), many of whom are ITU Sector Members, including ARIB, ETRI, CSA, T1A, ETSI and many others.

Within an increasingly international context, the ITU finds itself in an environment that includes many other players:

– Relevant Intergovernmental Standardization Organizations (ISO/IEC and CISPR)

– Internet Engineering Task Force (IETF)

– Partnership Projects (3GPP)

– National and regional telecommunications standards making bodies (CITEL, TIA, ETSI, ARIB)

– Standards-making fora

– Operator and vendor associations (ETNO, GSM-A, ECTA, EICTA)

– Non-telecommunications centred standards-making bodies (CENELEC, CEN)

– Users and consumers groups.

ETSI began in 1988 with 126 members as a European regional standards body that establishes electronic telecommunication standards. Since then, it has evolved into an international group of more than 850 members in 54 countries. It has produced many standards in the areas of mobile (e.g., GSM), radio access (e.g., DECT), broadcasting (e.g., DAB), fixed network protocols (e.g., ISDN), system architecture and electromagnetic compatibility.

These relationships are both direct (via formal agreements), and indirect (via cross-industry memberships and participation) links among the standard making bodies. Formal relationships developed between different organizations include:

– ITU has improved the formal means through which its Recommendations can reference publications by other bodies (see Resolution ITU-R 9).

– ETSI has a well-defined set of cooperation agreements with many peer organizations.

– Partnership Projects can be created to let experts from different standardization bodies work together to define common solutions to technical problems, to be submitted later in many cases for ITU-R consideration.

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 Monitoring

Spectrum monitoring serves as the eyes and ears of the spectrum management process and supports its functions through verification of planning. 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 effort 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, comparison can be made between the theoretical planning and actual use. This comparison can be used to adjust planning.

Monitoring is also used to support the enforcement function. In providing data on actual use, the enforcement activity can use this data to approach the ideal of interference-free, properly authorized and harmonized use of the spectrum.

Monitoring is closely associated with inspection and compliance functions in that it enables the identification and measurement of interfering signals, the verification of proper technical and operational characteristics of radiated signals, and detection and identification of illegal transmitters.

Monitoring information is necessary because authorizations do not ensure that the spectrum is being 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 systems and the introduction of unintentional radiators, such as computers, which may cause local interference.

Few administrations have chosen to use monitoring in place of licence records. This approach often requires a great deal of manpower to review and interpret data, and may not, depending on the circumstances, fully reflect spectrum use. Reliance solely on monitoring for records of frequency use is *not* recommended.

1.6.7 Spectrum enforcement

Effective management of the spectrum depends on the spectrum manager’s ability to control its use through enforcement of relevant regulations. However, the purpose of enforcement inspections and monitoring is to strengthen the spectrum management process and should directly support it. Therefore, they should always be linked to the spectrum management authority and subject to the overall priorities of the management program. Enforcement inspection and monitoring are covered in detail in Chapter 4.

Spectrum managers should be granted the authority to enforce spectrum use regulations and set appropriate penalties. For instance, 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 and should not cover the content of the information being transmitted.

Authority to grant a frequency assignment should include determination of compliance with terms of the assignment. The spectrum management department should work closely with the monitoring, assignment and licensing units in collecting information. The enforcement inspection function may depend on monitoring input, and could include the following:

– investigating interference complaints;

– investigating illegal operation, and operation not in keeping with the terms of the radio station licence;

– collecting information for legal prosecution or otherwise assisting law enforcement agencies;

– ensuring that radio station operators comply with national and international statutory and regulatory requirements; and

– taking technical measurements, such as output noise power, distortion and power level measurements at the transmitter site.

1.6.8 International cooperation

1.6.8.1 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.

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.

1.6.8.2 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. A group of spectrum management experts from developed and developing countries meet regularly to coordinate and progress the work. The work has been organized in stages using questionnaires to obtain detailed information on national spectrum practices and the use of the spectrum in frequency ranges identified as having particular interest to developing countries. A report of the first stage of activity was published during 2002, with a second report in 2004. A database of information on methods administrations are using to calculate spectrum fees was established on the ITU website[4] in response to Question ITU-D 21/2 (associated with Resolution 9) by WTDC-02. Further information, including the responses to questionnaires, can be obtained from the ITU-D Study Group 2 website, following the links to Resolution 9.

The following summarizes the spectrum management needs of developing countries as taken from the responses to Resolution 9:

– *Assistance in raising the awareness of national policy-makers as to the importance of effective spectrum management for a country's economic and social development*

  With the restructuring of the telecommunication sector, the emergence of competition, and the high demand for frequencies from operators, effective spectrum management has become indispensable for states. The ITU should play a key role in raising the awareness of policy-makers by organizing seminars designed specifically for them.

– *Training and dissemination of available ITU documentation*

  Spectrum management must be in accordance with the provisions of the RR, with regional agreements to which administrations are parties, and with national regulations. Spectrum managers must be able to provide frequency users with relevant information. In order to help frequency managers gain a thorough knowledge of those provisions, and of ITU-R Recommendations, (both of which are constantly evolving), developing countries would like to see intensive training provided in the form of specific ITU seminars. Through its regional offices, ITU could set up an effective real-time system to provide frequency managers with information on existing and future publications.

– *Assistance in developing methodologies for establishing national tables of frequency allocations*

  These tables form the mainstay of spectrum management. They identify the services available and their category of use. ITU could foster access by government administrations to information available in other countries.

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4 http://www.itu.int/ITU-D/study_groups/SGP_2002-2006/SF-Database/index.asp.

– *Assistance in the setting up of computerized frequency management and monitoring systems*

These systems facilitate routine spectrum management tasks. They must be capable of taking local features into account. The establishment of operational structures also enables the smooth execution of administrative tasks, frequency allocation, spectrum analysis and monitoring. According to the specific requirements of individual countries, the ITU can provide expert help in identifying the technical means, operational procedures and human resources needed for effective spectrum management.

– *Economic and financial aspects of spectrum management*

ITU could set up a mechanism enabling developing countries to:

- identify financial resources to be allocated to the operational and investment budgets for spectrum management; and
- assist in defining a policy on fees which takes into account the specific features of each country and which contributes to satisfactory national economic development.

– *Assistance with preparations for WRCs and RRCs and with follow-up on respective decisions*

The submission of joint conference proposals is a way of guaranteeing that regional characteristics are taken into account. Along with regional organizations, the ITU could give impetus to the establishment and running of regional and sub-regional preparatory structures for Conferences. Considerable resources are needed for the implementation of decisions taken by Conferences, and the ITU could contribute to establishing a follow-up mechanism for such decisions at national and regional levels.

– *Participation in the work of ITU study groups and of their working parties*

The study groups play a key role in the drafting of recommendations that affect the entire radiocommunication community. It is essential that developing countries participate in their work in order to ensure that their specific needs are taken into account. In order to ensure that those countries participate effectively, ITU could, through its regional offices, assist in running a sub-regional network organized around coordinators responsible for the questions under study, as well as providing financial assistance in order for the coordinators to participate in study group meetings.

1.6.9 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 a 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 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.

1.6.10 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.

1.6.11 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 then 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 Fig. 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 1-1 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 1-1

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

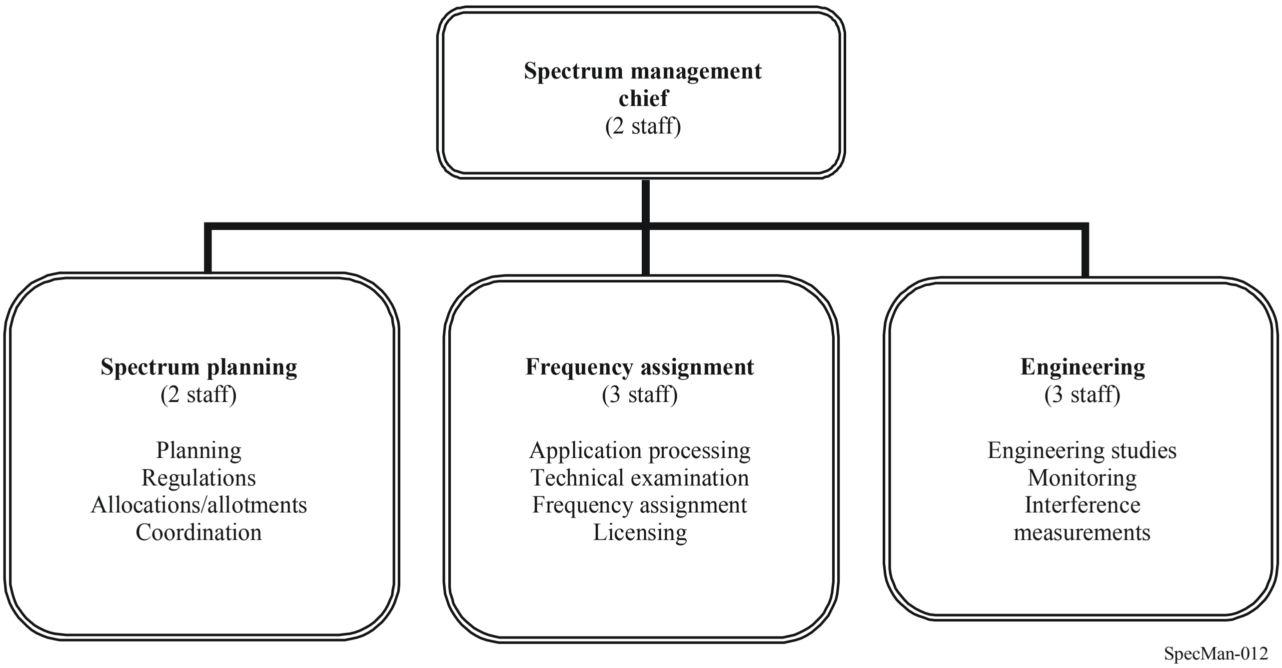
The typical range of main actions is a function of the number of licenses/frequency assignments per week that are processed, or of the changes made to a parameter(s) of an existing license. Staff size also depends on the expertise, education and technical background of the staff.

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.

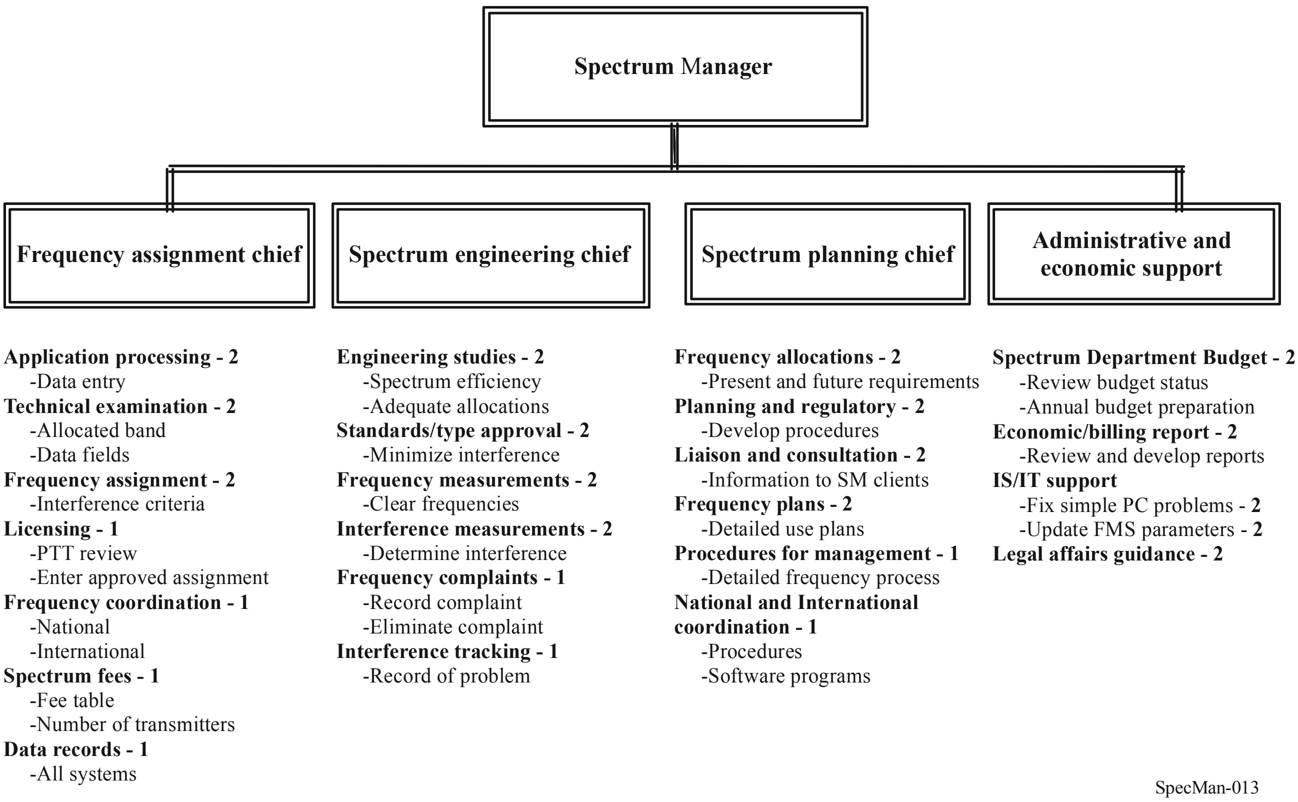
– The Spectrum Engineering Division ensures that the radio systems employed are efficient and effective. The Division normally uses an automated spectrum management system, augmented with measurements. The outputs support the Frequency Assignment and Spectrum Planning Divisions, and assist the Spectrum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



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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.

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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.

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 (46) meet 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/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, 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 years 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, the Arab Group, 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-160H), 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.

At present, there are seven (7) Study Groups:

– Study Group 1 Spectrum management

– Study Group 3 Radiowave propagation

– Study Group 4 Fixed-satellite service

– Study Group 6 Broadcasting service (terrestrial and satellite)

– Study Group 7 Science services

– Study Group 8 Mobile, radiodetermination, amateur and related satellite services

– Study Group 9 Fixed service.

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

– SC Special Committee On Regulatory/Procedural Matters

– CCV Coordination Committee For Vocabulary

– CPM Conference Preparatory Meeting.

The 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. Regulatory and procedural matters are addressed in a Special Committee, if so decided by WRC, 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.

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 channelling plans

– Chapter 7: Applications for frequency use

– Chapter 8: Licensing procedures

– Chapter 9: Regulations applicable to special radio services:

  – Amateur radio service

  – Experimental stations

  – Industrial, scientific, and medical (ISM)

  – Low-power devices

– 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.

CHAPTER 2

SPECTRUM PLANNING

Table of Contents

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, well 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[5], 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.

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.

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[5] 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.

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 defense 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 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 on-going 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.

2.4 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 based on 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.

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 § 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 the possibility of 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.

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;

– 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 time frame. It also leads to:

– revision of the national table of frequency allocations;

– the 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 time frame.

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 recompensation, 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 principals 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 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.

2.12 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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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
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CHAPTER 3

FREQUENCY ASSIGNMENT AND LICENSING

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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.

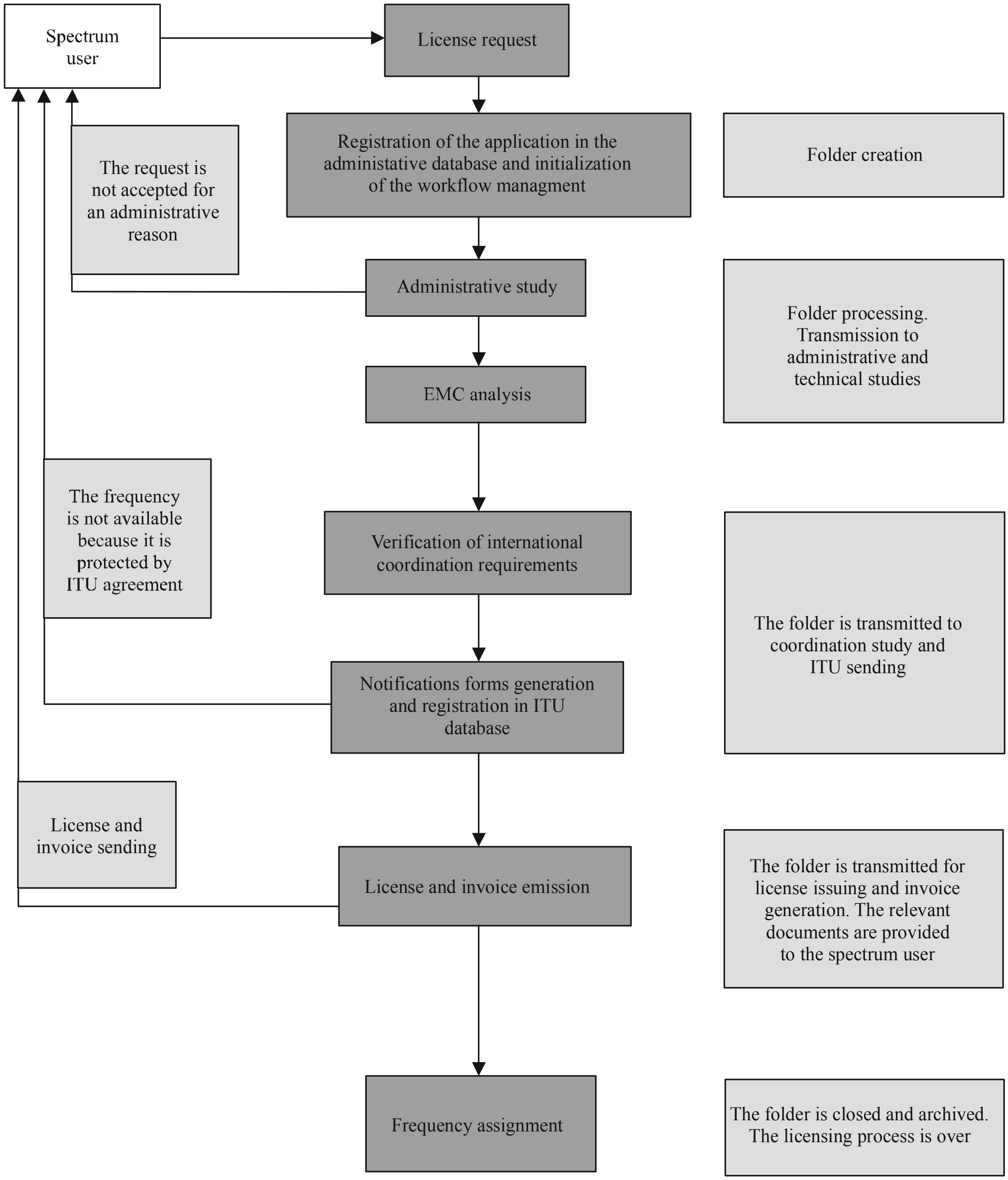
The assignment process includes the analysis of requirements for proposed radio services together with any relevant studies, and the assignment of frequencies in accordance with a national frequency allocation plan. This plan may also include references to related actions necessary to protect the country’s 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



SpecMan-031

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 Fig. 3.2) presents examples of the possible different entities of the database and the links between each entity.

In Fig. 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

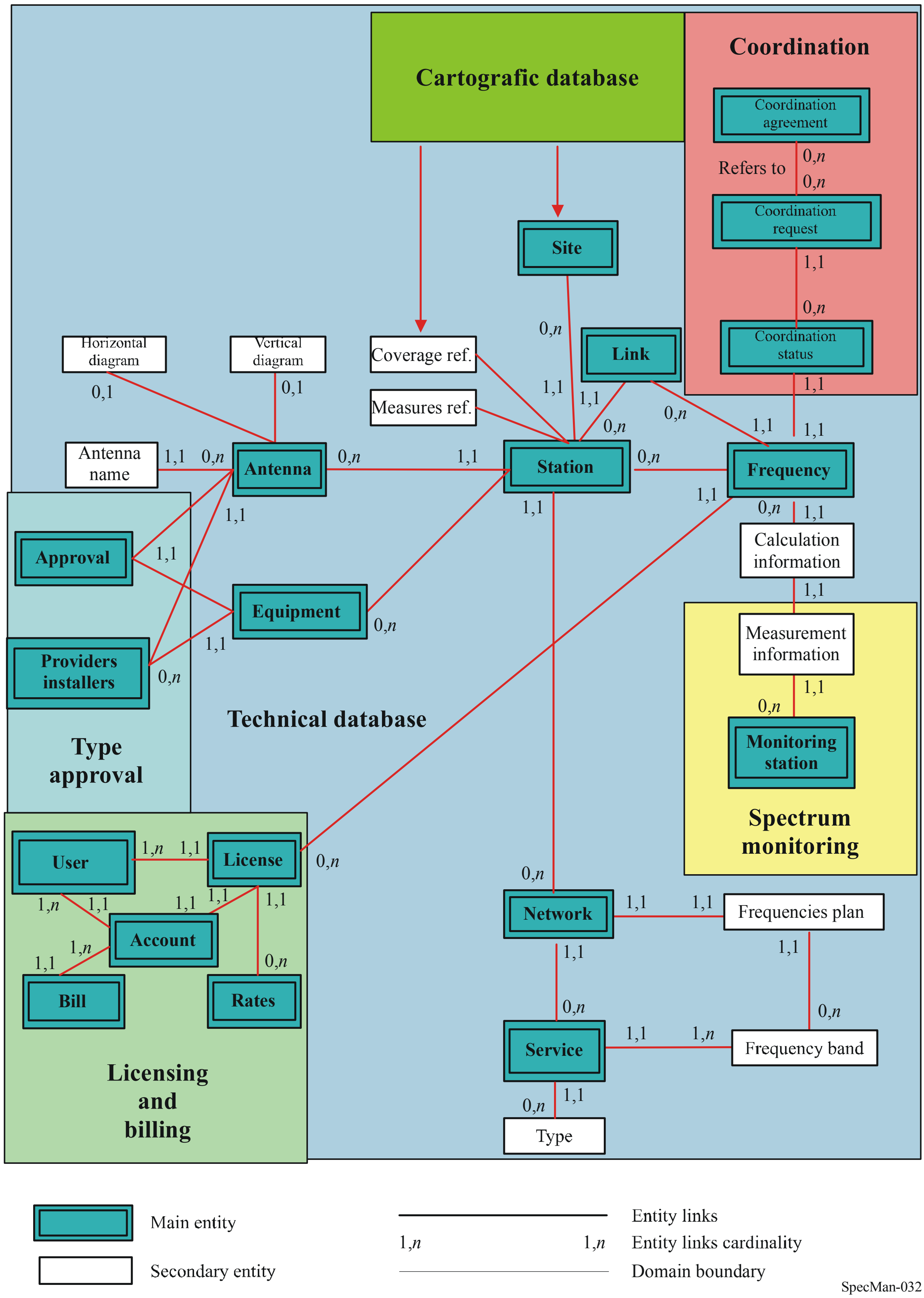
– the administrative extensions: coordination, licensing and billing, equipment approval, and activity statistics.

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 Fig. 3.2, with different status of a relevant data set (see Recommendations ITU-R SM.1048, 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, 2005)).

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 Fig. 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[6] 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

6 Since 2001 the Vienna Agreement of 2000 is also referred to as the Berlin Agreement.

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[7].

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.

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.

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[7] 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.

3.2.2 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:* 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: 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).

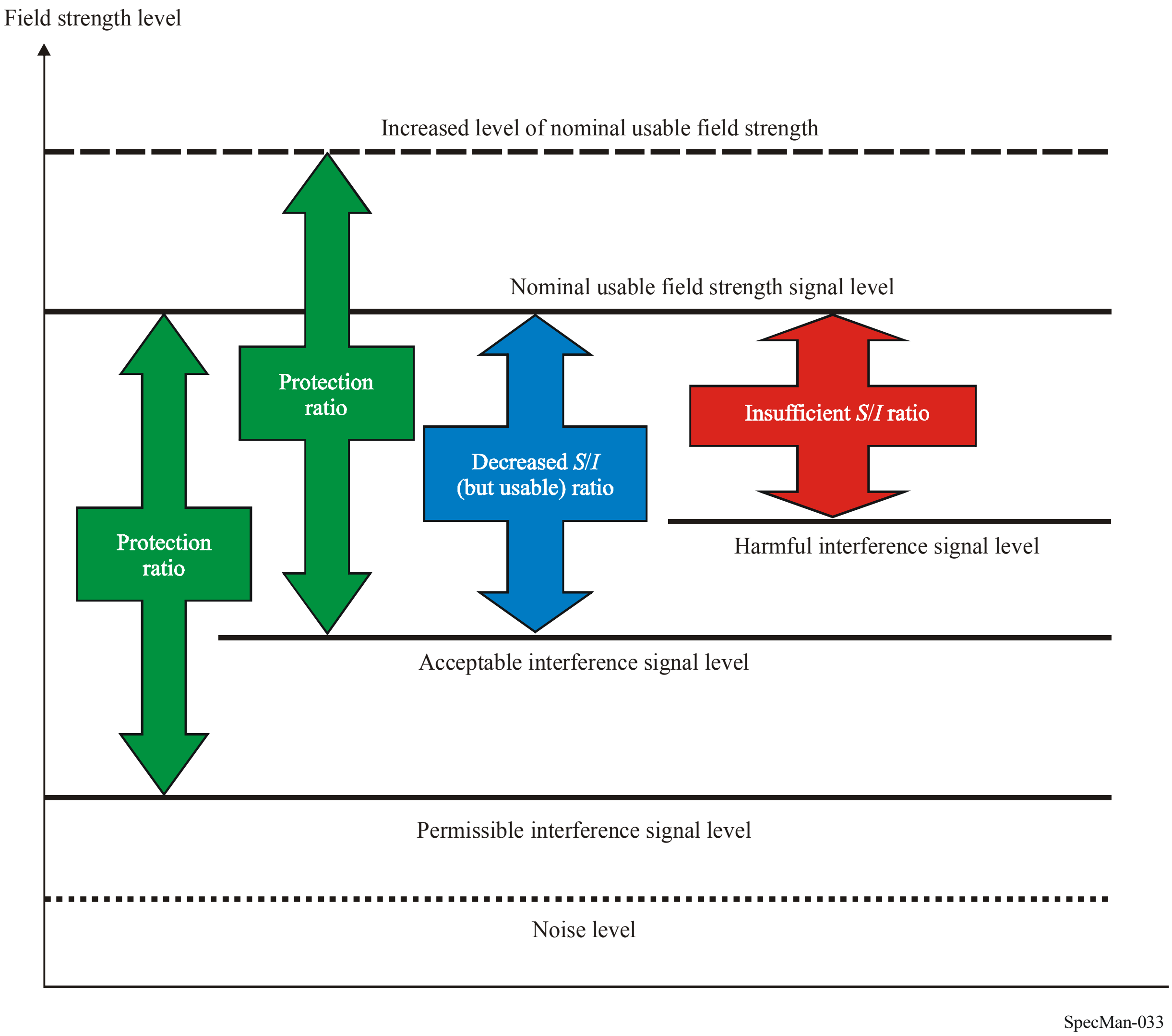
No. 1.170 *protection ratio* (R.F.)*:* The minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels, at the receiver input, determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output.

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 Fig. 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 Fig. 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 Fig. 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 Fig. 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” (see, for example, § 3.3.3). 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.

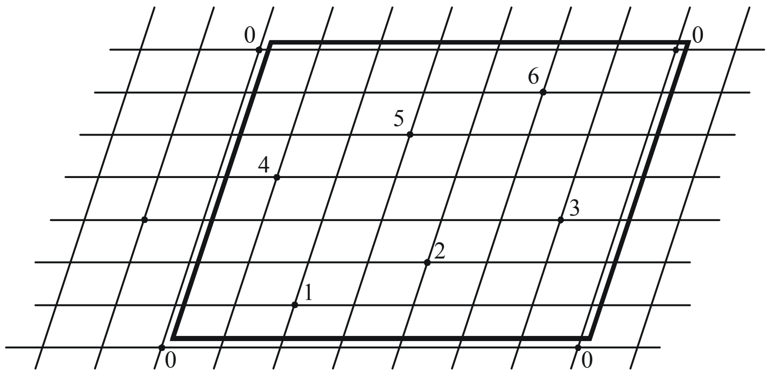
Under the above assumptions, the boundary of a service area for each transmitter is a circle, the radius of which depends on the type of service (sound or television broadcasting, mobile, etc.), and the propagation characteristics in the frequency range under consideration.

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



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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 Fig. 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;

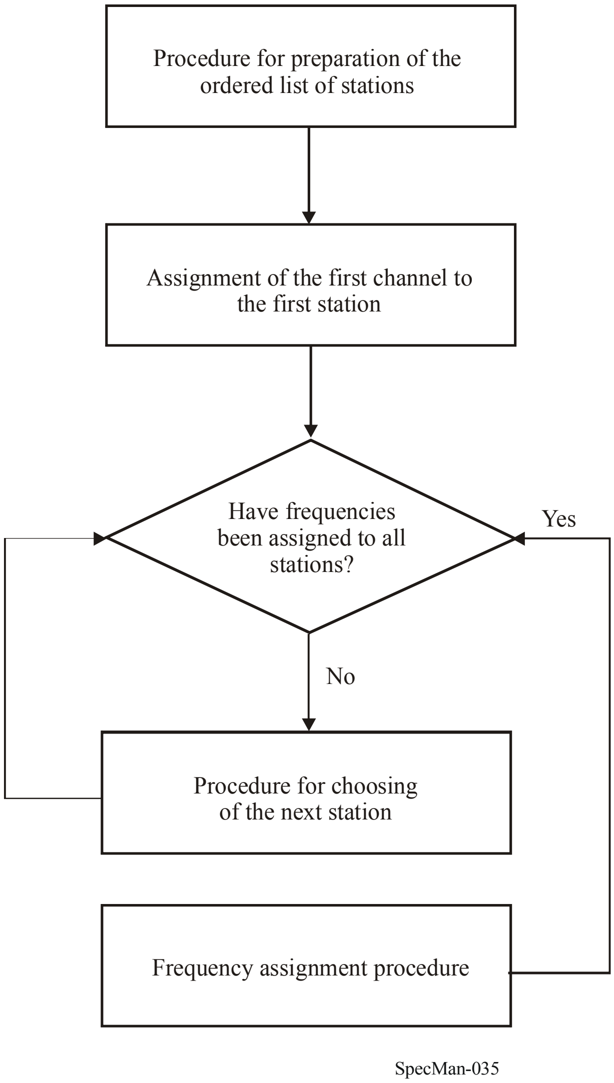
b) a list of available frequency channels; and

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.

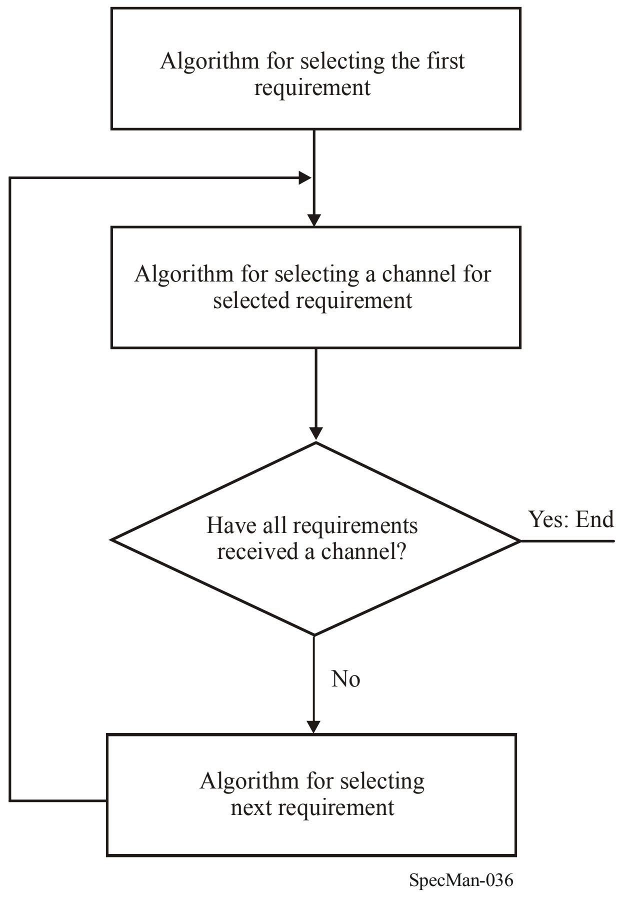
In practice, a problem sometimes arises with designating frequencies for new radio stations. These stations must be accommodated within the existing network assignments. For example, it can become complex for a television system which needs a number of low-power repeaters covering small service areas (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 Fig. 3.6.

FIGURE 3.6

General flowchart of sequential frequency-synthesis planning



3.3.3 "Interference-free" assignment grids

A method developed for the land mobile service in Canada [Delfour and De Couvreur, 1989] is the application of "interference-free" assignment grids.

This method is a computer-based system that starts with the established, assumed interference equations for co-channel and adjacent channel sharing, desensitization, and receiver and transmitter intermodulation interference. A high capacity assignment grid is constructed taking into account the possible use of bandpass filters. The decisions left to the spectrum manager are for co-channel conditions, specifically distance separation. This method reduces decision variables. Assignment grids provide an efficient use of the spectrum and a uniform quality of service. With a computer system, the grids can be modified to accommodate changes in demand, different terrain, and different areas as population grows or migrates.

3.3.4 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.

3.3.5 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.

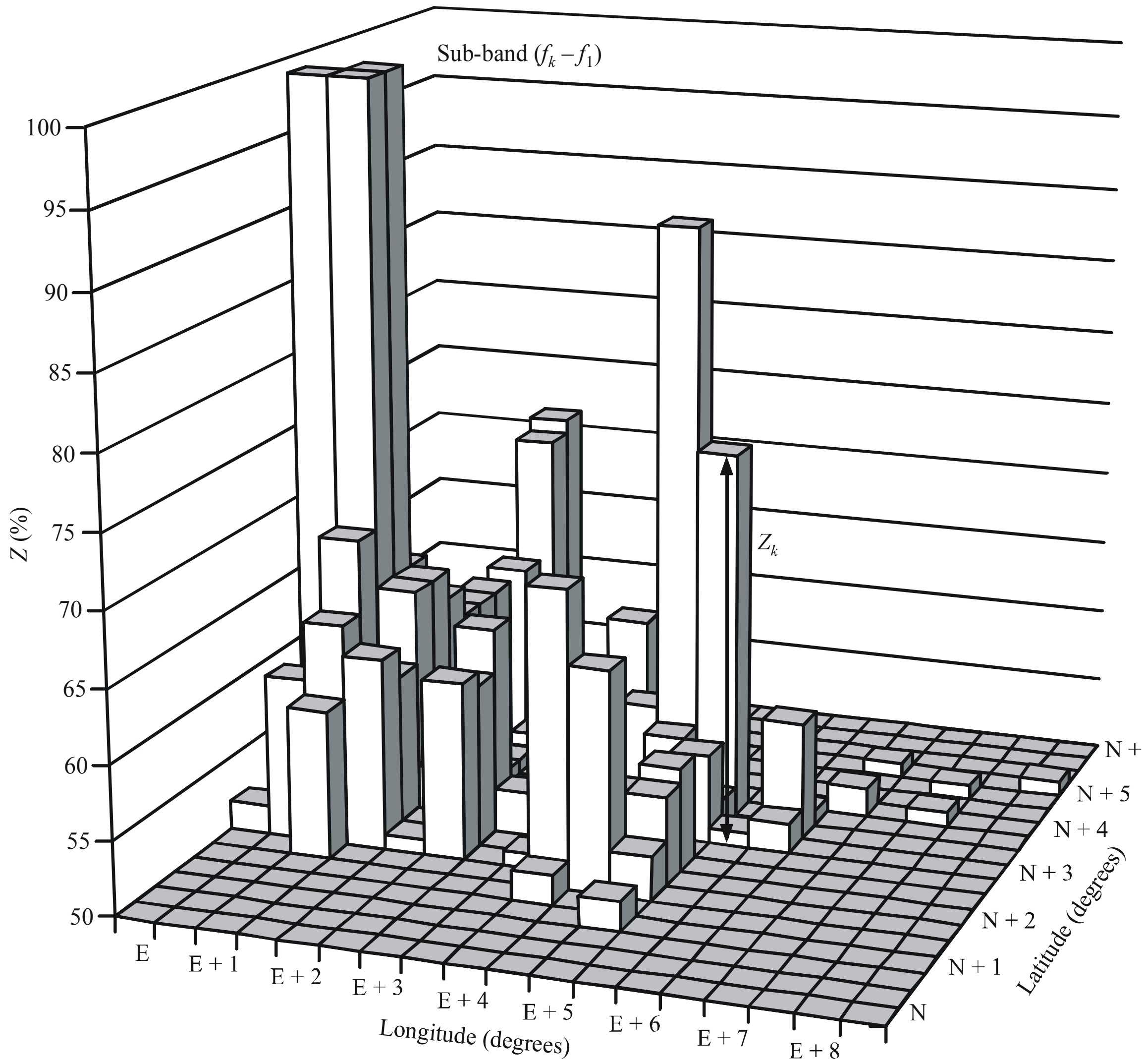
For example, Fig. 3.7 shows distribution of a spectrum utilization factor, Z, (defined in Recommendation ITU-R SM.1046-1) in one sub-band ($f_k - f_1$) among territory cells of dimension $1° \times 1°$ within a total region of about $8° \times 8°$. It is seen for which cells the sub-band, Z_k, is suitable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



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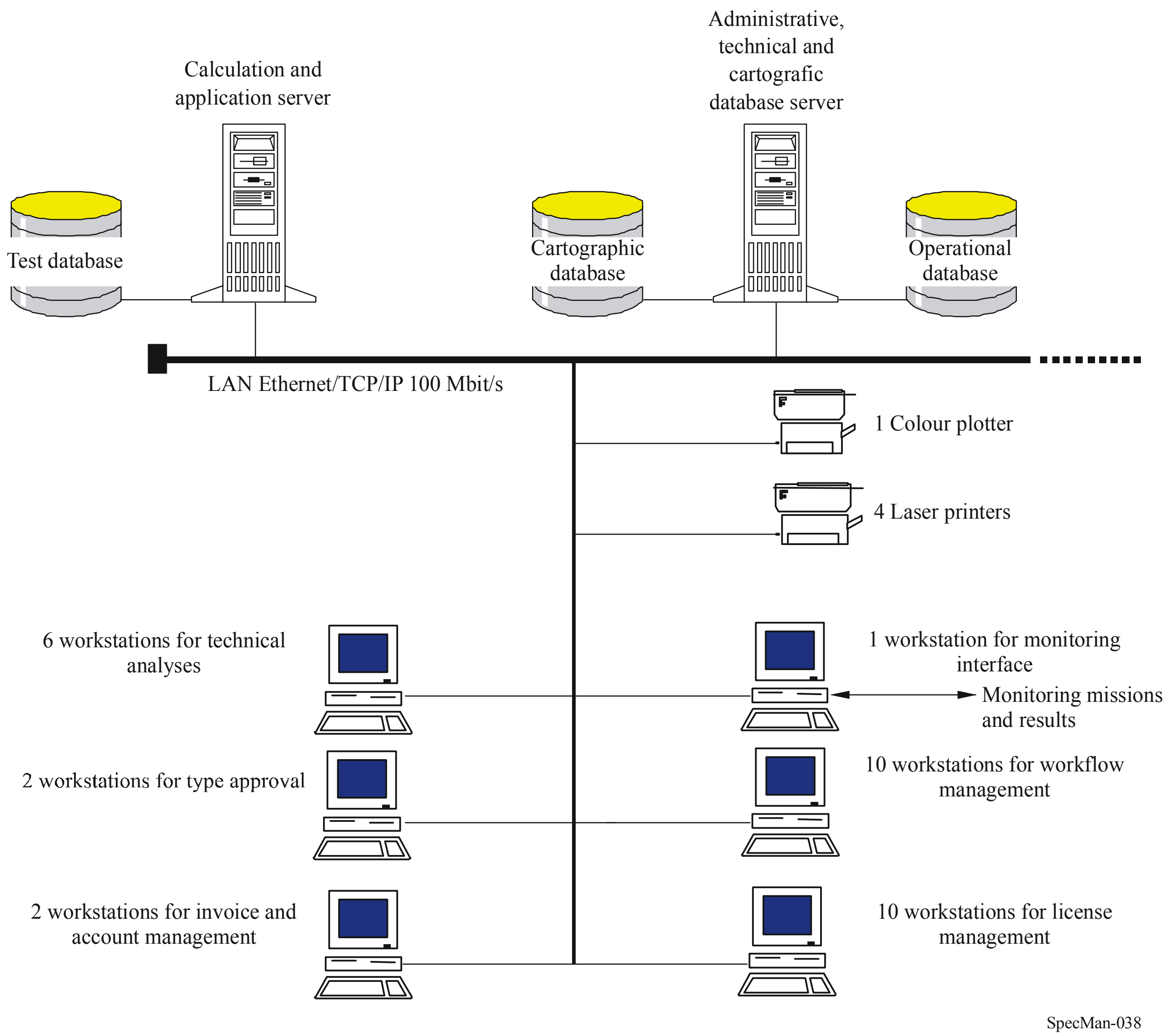
In many countries there are common automatic spectrum management systems covering radio facilities in all radio services [Bare, 1990 and Bykhovsky *et al.*, 2002] Automatic, local systems intended for individual services such as television and VHF sound broadcasting, land mobile and fixed services, etc.,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

An operational configuration example of a model SMS is given in Fig. 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 Recommendation ITU-R SM.1538 – Technical and operating parameters and spectrum requirements for short-range radiocommunication 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 to 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 2.4 of the Handbook for Computer Aided Techniques for Spectrum Management, Geneva, 2005).

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Rec. ITU-R F.385	Radio-frequency channel arrangements for radio-relay systems operating in the 7 GHz band
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Rec. ITU-R F.595	Radio-frequency channel arrangements for fixed wireless systems operating in the 18 GHz frequency band
Rec. ITU-R F.635	Radio-frequency channel arrangements based on a homogeneous pattern for radio-relay systems operating in the 4 GHz band
Rec. ITU-R F.636	Radio-frequency channel arrangements for radio-relay systems operating in the 15 GHz band
Rec. ITU-R F.701	Radio-frequency channel arrangements for analogue and 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)
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Rec. ITU-R F.747	Radio-frequency channel arrangements for fixed wireless systems operating in the 10 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 radio-relay systems in the 38 GHz band
Rec. ITU-R F.1098	Radio-frequency channel arrangements for fixed wireless systems in the 1 900-2 300 MHz band
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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

CHAPTER 4

SPECTRUM MONITORING, SPECTRUM INSPECTION AND INVESTIGATION

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4.1 Introduction

Radiocommunications have become an increasingly vital part of the telecommunications infrastructure and consequently economy of a country and economic approaches to national spectrum management are becoming essential. These approaches promote economic, technical, and administrative efficiency, and help ensure that radio services are able to operate on a non-interference basis.

Theoretical planning is not sufficient any more. Knowledge of the actual use of the spectrum is needed before decisions can be made on frequency assignments and even frequency allotments.

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.

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

In supporting the spectrum management process, monitoring, inspection and investigation are handled in this Chapter in two parts: Part A – Spectrum monitoring and Part B – Spectrum inspections and investigations. An innovative solution is presented in Annex 1 to this Chapter.

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 ensure that it is being 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 on a continuous 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 one 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 WRC 2003.

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;

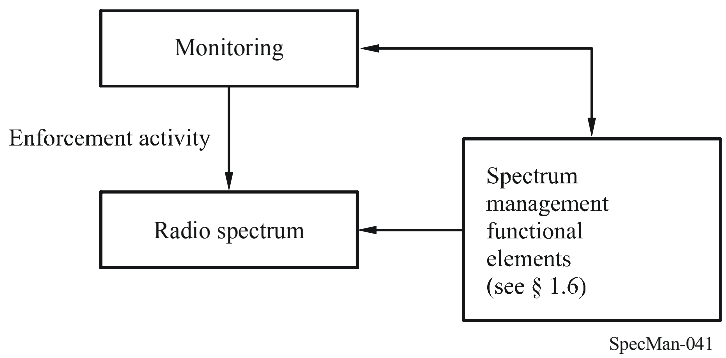
– provide valuable monitoring information for programmes organized by the ITU Radiocommunication Bureau, for example in preparing reports to radiocommunication conferences, in seeking special assistance of administrations in eliminating harmful interference, in clearing out-of-band operations, or in 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 graph is shown in Fig. 4.1.

FIGURE 4.1

Monitoring in the spectrum management process



Note 1 – The spectrum is used for all kinds of radio transmissions. The spectrum management elements (e.g. frequency allocation, assignment, licensing, 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.

Note 2 – 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.

Note 3 – In observing the radio spectrum, monitoring can also provide information to elements of spectrum management on (hitherto) unforeseen use of the radio spectrum. When spectrum management sets up an experiment for new services before a policy (regulations) on that new service has been developed, monitoring can observe the experiment and advise on it.

Note 4 – Monitoring can also address radio spectrum users directly in case of interference or technical infringements of national (or international) regulations. The monitoring operators can give guidelines to the users to avoid interference, etc. This is called enforcement activity.

4.3 Spectrum inspection and investigation as elements of the spectrum management process

Effective management of the spectrum depends on the spectrum manager's ability to control spectrum use through enforcement of relevant regulations. This control is primarily built on inspections and investigations, both being part of the enforcement function. However, the purpose of inspections and investigations is to strengthen the spectrum management process. This will directly support spectrum management and spectrum-use goals.

With the authority to grant a frequency assignment must come the authority to determine compliance. An organizational unit, provided with the inspection equipment and mobility, is usually needed to enforce the national and international regulations and regulatory requirements of frequency management. It works closely with the monitoring section, and the assignment and licensing unit in collecting information, all of which contribute statistics and information analysis to policy units. Also, the role of the investigating unit is important. Getting unauthorized transmissions off of the air and being able to take appropriate sanctions for related equipment is essential, particularly when a part of the spectrum is granted to public operators who invest significant resources to offer services to the public.

The inspection and investigation function (also via monitoring input) can include the following:

– investigating interference complaints;

– investigating illegal operation, and operations not in keeping with the terms of the radio station licenses;

– providing guidance on remedial measures for compliance with license and other regulatory requirements;

– collecting information for prosecution cases and assisting law enforcement agencies in confiscating illegal equipment;

– ensuring that radio station operators comply with national and international regulations;

– taking measurements, e.g., output power, distortion etc., at the transmitter.

PART A

Spectrum monitoring

4.4 Monitoring to assist frequency assignment

Spectrum monitoring supports the overall spectrum management effort by providing a general measure of channel usage and band usage (discussed in more detail in § 4.5), including channel availability statistics This provides information for the frequency 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 assignment process:

An aid to new assignments and planning: Licensing data can be used to predict the levels of use with some degree of success depending on the sophistication of the prediction model and the accuracy of the data. As the volume of radiocommunication increases, the current data will become progressively less adequate in identifying the least-used channels. New monitoring data from the area of the proposed assignment is invaluable in identifying a frequency most suited to new assignment.

An aid to sharing: The demand on the spectrum is now such that services are expected to share, except in certain limited cases. Some service types are clearly incompatible, but often the matter is a borderline and trials will have to be mounted to determine the true degree of compatibility. Monitoring the conduct of the trial will give information, such as relative signal levels, to aid analysis of the system users' perceptions.

An aid to developing better EMC models: In analysing the use of the spectrum, the monitoring service is able to compare the outcome of this analysis with the EMC model used. If necessary, this can lead to a modification of the model itself.

Monitoring data may be impractical to utilize for all assignments. Areas of the country where there is little use of the radio spectrum are quite adequately served by modelling based on licensing data. Monitoring data collected in the busier areas can be compared to the levels predicted by analytical methods and the results used to identify suspect licensing data or refine the method so that it best fits the total picture. By this means the applicability of the method can be enhanced and monitoring better targeted to those areas most in need of assistance.

An aid to database verification and improvement: Accuracy and currentness of spectrum management databases are of prime interest. Monitoring data can be utilized to help verify the accuracy of these databases and to help bring them up to date. Also, the monitoring capability, with the potential to check the database, helps provide some added motivation for the maintenance of an accurate and current database.

An aid to recognizing anomalous propagation effects: The VHF and UHF bands are not immune to the effects of anomalous propagation. High atmospheric pressure areas over the waters separating two countries 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. The result is interference from distant services 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 services can be judged. It may well be that only a few services are affected by only a few distant transmitters. The appropriate cure will be case-specific and good monitoring data will greatly aid identifying the causes of the problem.

An aid to international and regional coordination: Monitoring is useful to obtain technical information to incorporate in the international coordination process as well as in bilateral or multilateral activities, for example, HF propagation prediction for broadcasting stations.

4.5 Monitoring to assess spectrum occupancy

Good spectrum management can only satisfactorily proceed if the planners are adequately informed on the current usage of the spectrum and the changing trends in demand. While much data is collected from prospective users on licence application or renewal forms, it only indicates that the use of a frequency is authorized, but may not give adequate information on whether the frequency is actually used. Therefore a frequency band that appears crowded on the basis of frequency assignment records may or may not in fact be crowded.

Care should be taken in evaluating frequency bands used for safety or emergency communications. Though frequencies are required for these activities, spectrum occupancy will usually be low.

In spectrum planning and policy development it is important to know the level of utilization of the various assignment bands. It can be expected that the demand for "private mobile radio" – for taxis, courier services and other domestic service providers – will continue to increase with concentrations in the major cities. It can also be expected that the demand for cellular telephone service will continue to increase. Planning to make more spectrum available, by for example moving fixed services to higher frequencies, is a long term process. Adequate warning of the need will avoid inabilities to issue new assignments or the quality of service deteriorating below acceptable levels.

Standards of use relating to channel occupancy to perceived quality of service need to be established for reference purposes for each of the service categories involved.

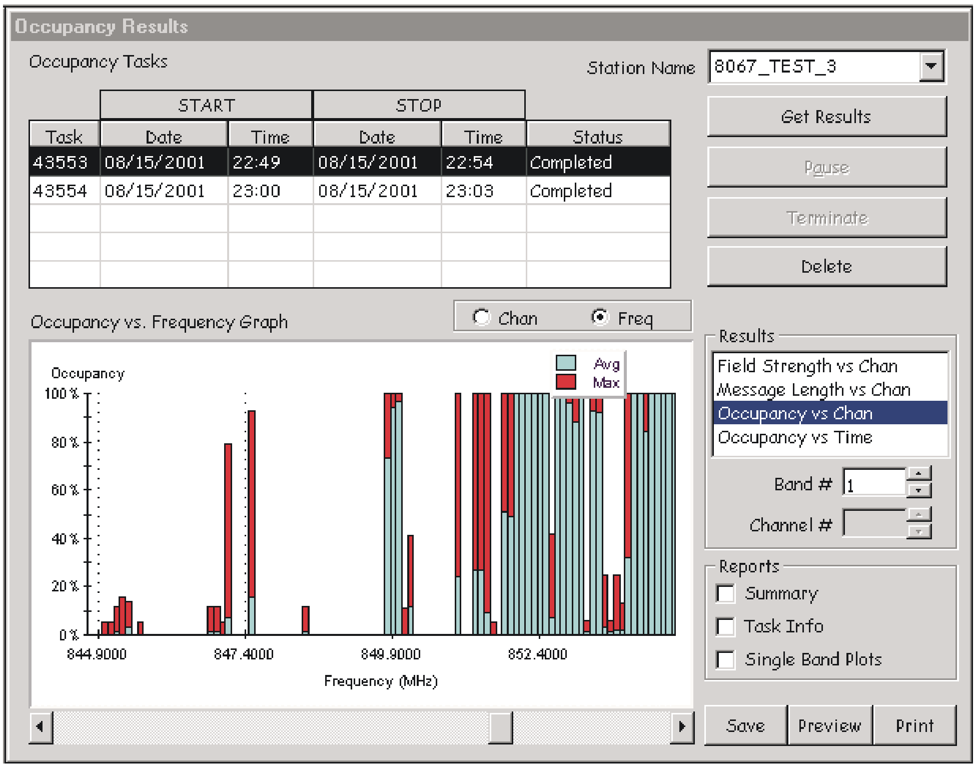
A modern receiver covering the requisite bands, processing each channel to record the occupancy can rapidly give a picture of the usage of the band. Analysis of this data will then show the proportion of the time for which each channel is occupied and can also show for each scan the occupancy of the entire band.

Data may be displayed graphically for easy visualization by the user. There are a number of methods of presenting results. Figure 4.2 shows a summary of a cellular network band in frequency order with the level of occupancy of each channel expressed as a percentage. Channels can typically be referenced either by frequency or channel number, and occupancy may be given in terms of average and maximum occupancy. Other displays may give the data sorted by occupancy order rather than by frequency or channel, to give the user a clearer visualization of the number of channels with differing levels of occupancy, and may show the ratio between busy hour loading and daily averages. Bar graphs or pie charts can be presented showing the number of channels falling into set occupancy percentages.

While these various methods of data presentation can show different aspects of channel loading, they are only suitable as management summaries showing average levels and the degree of uniformity across the band. Detailed results need to be presented in tables so that information can be accurately extracted. Better still the information can be digitally provided directly to frequency assignment and management computer facilities.

FIGURE 4.2

Example of channel occupancy – cellular network band



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In addition to the verification of usage associated with assignment, monitoring data can support other related spectrum management applications.

With the availability of new calculation methods of assessing spectrum utilization (see Chapter 3) and the possibility of using the resulting data to assist frequency planning, the role played by monitoring can be expanded considerably to make it into a new, effective mechanism for spectrum utilization management. Such a new role is possible in connection with more precise (measurement-based) processing of the basic data to support calculation of the degree of spectrum utilization. Among the basic data that are indispensable for performing a quantitative assessment of spectrum utilization are the signal-to-interference protection ratio and the amount of frequency and spatial separation required between radio stations (see Recommendation ITU-R SM.1050 – Tasks of a monitoring service). To this end it will be necessary to conduct monitoring operations on a regular basis, systematically storing the information obtained in the databases of the spectrum utilization management system.

4.6 Monitoring for compliance with national rules and regulations

The enforcement responsibilities of the spectrum regulatory authority include the identification of transmissions that do not conform to national rules and regulations either because the transmission is unauthorized or because of some technical defect in the transmission. There are a number of reasons for this type of work:

– an unauthorized or defective transmission causes other users poor service through interference;

– unauthorized transmissions represent loss of license income to the administration and a disincentive for other users to seek licenses;

– planning can only effectively proceed in a known and coordinated environment.

The extent to which investigation and enforcement work is complaint-driven or pro-active in seeking out infringements is largely a matter of administrative policy and overall cost. The cost is not just that of running the enforcement service but the time devoted to the planning and assignment departments must be considered along with the costs to the authorized users in running their services. Equally, the balance between eliminating unauthorized use through administrative or technical assistance or through legal means is also a matter of local policy and judgment. If considerable assistance is rendered, consideration may also be given to some form of cost recovery.

Much of the process of verification of compliance with national rules and regulations can be automated, as described in § 4.10.1.

Monitoring for compliance with national rules and regulations consists of detection and identification of unauthorized transmissions and verification of technical and operational parameters.

4.6.1 Detection and identification of unauthorized transmissions

Spectrum monitoring may detect the presence of unauthorized transmitters which may cause interference and represent a loss of licence revenue. Unauthorized transmissions may be suspected as the cause of interference, and there is the need to be able to detect and identify them. However, it can be difficult to separate the unauthorized signals from authorized signals sharing the same, often crowded, band. Monitoring may also detect unintended emissions.

4.6.2 Verification of technical and operational parameters

Monitoring is used to obtain detailed information on the technical and operational characteristics of radio systems. This might typically include measurements of the frequency, power and emission spectrum of a transmitter. Licence compliance can be verified and the measurements will aid an EMC or interference analysis in specific cases. In some cases, this verification goes beyond monitoring to actual site inspections described in Part B of this Chapter.

4.7 Monitoring to identify the source of, and, resolve interference

The spectrum manager's monitoring capability is often called on to help in the resolution of interference complaints. 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 on the part of the spectrum authority to make such determination. In coordination with the complainant and knowing the frequency of receiver operation, direction finding or homing equipment can often be used to locate the interfering signal source.

As congestion grows the users usually become less satisfied with the service available. By being able to monitor in areas attracting disproportionately large numbers of complaints the true nature of the problem can be ascertained and the best remedial action devised. It may also help to substantiate or refute a complainant's allegations regarding the perceived interference.

4.8 Monitoring facilities

The monitoring facilities chosen by each administration can vary widely and this concise summary only attempts to outline the major facilities that will be of interest to the spectrum manager (for more details consult the ITU-R Handbook on Spectrum Monitoring). These facilities can be both fixed and mobile. Mobile facilities may be more economical, particularly in the higher frequency bands, and with the compact size and minimum power consumption of modern equipment, mobile stations can come close to performing the same functions as fixed stations.

4.8.1 Facilities below 30 MHz

If there are reasons to monitor the radio spectrum below 30 MHz, e.g. if an administration is responsible for having HF transmitters, and due to the nature of propagation below 30 MHz, an administration will need at least one fixed monitoring facility to service its needs. For HF-direction finding at least three fixed facilities are needed, which may include by collaboration with other administrations. The key equipment at such facilities is summarized in § 4.9.2.

A mobile or transportable system may be useful in resolving local interference EMC issues. The key requirements here being a calibrated receiver and antenna for field strength measurements and a spectrum analyser or an integrated system as described in § 4.9.2. This facility may be part of the overall spectrum management function or part of an enforcement unit.

To lower the investments for a fixed facility, administrations may consider sharing an fixed facility. This idea is especially recommended for those geographical areas where no HF monitoring facilities are available.

4.8.2 Facilities above 30 MHz

The selection of monitoring resources needed in these frequency bands is dependent on the propagation range and the purpose of the monitoring exercise. The propagation range is dependant on the heights of the antennas, obstacles such as hills and urban clutter. Typically this will be a few tens of kilometres.

The aims of monitoring may be divided into three broad categories:

– local observations or measurements for a limited period, usually for a very specific purpose such as enforcement;

– measurements centred on highly populated areas to obtain usage and occupancy statistics;

– extended or nearly permanent observations over a wide area for general spectrum occupancy statistics and related spectrum management decisions.

Much monitoring equipment that operates above 30 MHz is used in a mobile or transportable mode. Fixed monitoring systems in urban areas are also widely used.

Typical mobile and transportable systems are employed for signal tracking and homing or spectrum occupancy measurement and include antenna and other equipment described in § 4.9.2.

A mobile and transportable system generally includes direction finding, voice recording and spectrum analysis capability. Such a system can also be used to monitor fixed links, including trunked systems. Facilities for monitoring fixed links and multiplexed systems may also apply since the level of occupancy of multi-channel links is a valid quest for the monitoring service.

Mobile and transportable systems can be left in an area of interest for long periods of time (weeks or longer). Data can be stored at the monitoring site or transferred from the remote location via a temporary dial-up telephone modem connection. In some cases, fixed remote facilities can be established to meet a long term monitoring requirement. If a few areas have a particularly high density of use, it may be effective to set up a permanent remote monitoring facility. It may also be desirable to extend this to cover most of the country.

Mobile and transportable facilities would have receivers normally scanning the relevant bands, recording occupancy data to a local computer/controller, with either a dedicated or dial-up line to a control centre. Facilities may also exist for demodulation and direction finding depending on the administration's wishes. A control centre could seek to identify transmissions and validate these against national files, with the ability to target mobile resources to areas of particular interest. Such a facility, especially if covering much of the country, would be a substantial undertaking, requiring much planning and assessment of its cost benefits. Nonetheless, many countries are embarking on this route in an attempt to control ever-increasing congestion in bands allocated to mobile services.

4.8.3 Space monitoring

A monitoring service responsible for the enforcement of domestic laws and regulations and engaged in international monitoring, pursuant to RR Article 16, may participate in the monitoring of emissions from space stations as a normal and necessary extension of regular monitoring facilities, techniques and operations.

In principle, other than position determination or orbit characteristics, the tasks carried out by a radio monitoring station for space services do not differ from those of a radio monitoring station for terrestrial services. The use of relatively more complex measuring equipment, such as more complex antenna systems, is, however, necessary for the performance of these tasks. Different monitoring and measurement procedures are also necessary. This is due to the fact that a space station is located on board a satellite in space and that its position may therefore, be dependent on time. Basic knowledge of the orbit characteristics of the satellite is an important pre-requisite for any kind of satellite observations and measurements.

Both the measurement techniques to be used and the specific terms of reference result in the differentiation between "terrestrial monitoring" and "space monitoring" and to the creation of the term "monitoring station for space radiocommunication services". The functions of such a station can be outlined as follows:

– regular and systematic observation of the RF spectrum with the aim of detecting and identifying space station emissions;

– determination of occupancy and percentage use of transponders or space station transmitters;

– measurement and recording of the characteristics of space station emissions;

– investigation and elimination of harmful interference caused by space station emissions – if appropriate, in cooperation with terrestrial and other monitoring stations for space services;

– investigation and elimination of harmful interference to the frequencies used by a space station caused by the emissions of terrestrial stations, unknown earth stations, or other satellites, e.g. by observing and measuring a transponder, interfering signal in a similar manner as for legitimate space station emissions;

– confirming geostationary orbit positions or characteristics of other orbits;

– undertaking of measurements and recordings for technical and scientific projects;

– detection of illicit use of transponders and identification of the source;

– using special satellite techniques to locate emitters on Earth.

If all types of spacecraft are to be observed, it is necessary for the antenna system to be capable of tracking "low and eccentric orbit" satellites, as well as being able to point accurately at any geostationary satellite in the visible segment of the arc.

There are a number of factors involved in the provision of the above-mentioned facilities which must be balanced against cost: frequency coverage, system sensitivity, antenna slewing rate, antenna pointing accuracy, ease of changing antenna feed hardware if necessary, receiving bandwidth capability, degree of sophistication of signal analysis instrumentation and degree of automation of measurements. A highly automated and sophisticated spacecraft monitoring system, fully steerable, with continuous frequency coverage across the 1-60 GHz spectrum, for example, and sensitive enough to give carrier-to-noise ratios of at least 26 dB on all signals of interest would be ideal. However, it soon becomes clear, for example, that the cost increase in order to improve sensitivity by a few decibels is almost exponential. Each administration must, therefore, analyse its own priorities and internal needs with regard to spectrum management and decide priorities for monitoring of space services.

4.9 Automation of monitoring

Where possible spectrum monitoring systems should be automated (see Recommendation ITU-R SM.1537). Automation, through the use of computers, modern client/server or other architectures and remote communications, simplifies many of the duties and responsibilities of administration of the radio spectrum. Computerized equipment provides a means to perform mundane or repetitive measurement tasks rapidly and accurately, freeing personnel for data analysis and other more complex tasks.

4.9.1 Automation of routine measurements

The monitoring measurements recommended by the ITU are mostly repetitive tasks which lend themselves to automation. These tasks include signal parameter measurements (frequency, level and field strength, bandwidth and modulation parameter measurements), spectrum occupancy, and radio direction finding. Signal analysis and station identification (through location or signal analysis) can be automated to a significant extent. The statistical nature of spectrum use lends itself to automated analysis. Results of automated measurements are recorded in a measurement database for use and review by operators.

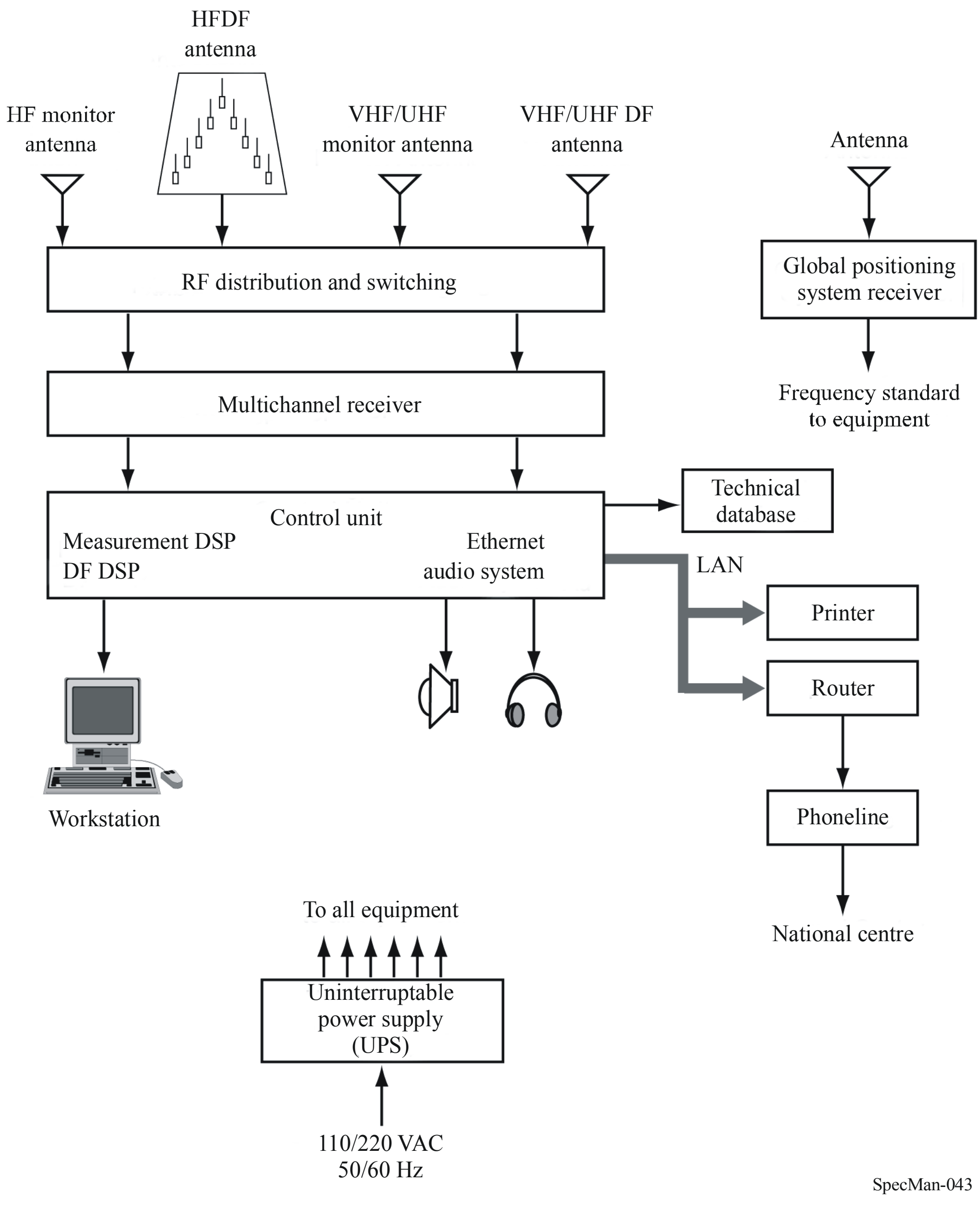
4.9.2 Equipment to automate monitoring

An automated monitoring station includes a measurement server, with a small set of sophisticated measurement equipment modules including digital receivers operated by a computer, and client workstations, which provide the operator interface and contain computer software to make the system easy to use and maintain. A fully automated HF/VHF/UHF station typically has the architecture illustrated in Fig. 4.3.

The station includes antennas, RF distribution, receiver(s), a processing/control unit and a technical database of licensing and measurement information, which comprise the measurement server. The equipment also includes one or more workstations and network equipment for local and remote client control. The measurement server is generally a compact, high speed bus unit containing processors, receivers and other electronics. An alternate configuration for the measurement server is to serve a group of separate but highly integrated units including digital receivers, direction finders and processors.

FIGURE 4.3

Example of a block diagram of an automated, integrated HF/VHF/UHF monitoring station



Functional requirements for the equipment includes the following:

– reception for frequency measurement and class of emission. Receivers and other measurement equipment will typically be synchronized to run from a stable "clock" or reference frequency and will contain a variety of demodulation facilities to allow the nature of the signal to be determined by audible and technical means;

– very broad (10 MHz) instantaneous bandwidth, with a high dynamic range in order to scan the spectrum at very fast scan rates and effectively acquire and measure intermittent, broadband and frequency agile signals that may range from weak to strong levels;

– calibration of antenna and receiver for field strength measurements;

– direction finding to identify the direction of arrival of radio signals;

– spectrum analysis to check the characteristics of individual signals and also to record the occupancy of a band of frequencies. This will be invaluable in identifying vacant "slots" for proposed new services;

– demodulation and digital recording.

Whereas older systems typically had separate equipment to perform each of these functions, present-day systems are comprised of integrated equipment where all of these functions are performed by an integrated receiver/processing/measurement system.

4.9.3 Computer software for automation

Automated systems include computer software operating on the measurement server, which performs the monitoring and measurement functions, and software operating on the client workstations, which provides the user interface. The software typically provides for several modes of operation, including an interactive mode, automatic or scheduled mode, and background mode.

Interactive mode allows direct interaction with functions that provide instantaneous feedback, such as monitor receiver tuning, demodulation selection and panoramic display selection. These functions are controlled from "virtual control panels" on the client workstations. Synthetic panoramic and spectrum displays are created on the operator workstation. DF tracking and homing is an example of interactive operation, where DF is commanded in a mobile unit as the unit is in motion. DF results may be presented with respect to the front of the vehicle, and allow the driver to decide in which direction to take to approach the desired signal transmitter.

Automated or scheduled mode allows technical measurement and direction finding tasks to be scheduled for immediate or future execution. Background mode is used for performing tasks such as spectrum occupancy, and automatic violation detection described below, where it is desirable to collect data over long periods of time. Wideband scanning for occupancy, or DF combined with occupancy (DF scan), may be specified over a particular frequencies or ranges of frequencies. In DF scan, the system performs DF on many frequencies simultaneously and provides azimuth versus frequency displays, which are useful for intercepting modern digital modulations, since DF results on the same azimuth from many different frequencies are the signature of a frequency hopping signal.

Results of measurements are displayed in convenient, often graphical, formats and printed reports may be generated. Sophisticated client/server systems can be designed to be easier to use than systems with separate or stand-alone equipment such as receivers and spectrum analysers. With task icons and toolbars on the computer screen which the operator can access via pointing and clicking on a computer screen, these systems can be very intuitive, and easy to learn and operate.

4.10 Integration of monitoring sub-system with automated spectrum management system

Automated spectrum monitoring systems should be integrated with an automated spectrum management system (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 very useful features, including automatic violation detection and remote access to system resources.

4.10.1 Automatic violation detection

An integrated, automated spectrum management and monitoring system can perform measurements, such as occupancy, technical parameters such as 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 unlicensed signals, and licensed signals, which are deviating from their authorized parameters.

The user typically specifies start and stop frequencies for the band(s) to be scanned, as well as scan parameters including bandwidth and time period over which the search is done. The system performs the specified scan and then accesses the license database to determine which signals in the measured spectrum are not in the license database, and automatically provides a list of frequencies which are being used which are not in the database. The system also checks signal parameters, such as bandwidth, over-modulation and not being within licensed frequency tolerance, and issues reports where violations are found.

A system requires a valid, complete license database in order to successfully perform automatic violation detection. Some administrations, particularly when first converting to automated spectrum management and monitoring systems, have difficulty providing an accurate license database, and may need to expend considerable effort validating available data and providing missing data in order for the automatic validation detection function to perform as desired.

4.10.2 Remote access to system resources

Automated, integrated spectrum management and monitoring systems typically use local and wide area networks to link all computers together in a network, so that all of the computers at a spectrum management centre as well as computers at all spectrum monitoring stations are part of a nationwide network. These systems include computer software so that a client at any station can access the resources of any or all of the measurement servers and the management system database server. Thus all of the resources of a multi-station network are available to any given operator, provided he has the proper authorization to access all of those resources.

The monitoring stations may be controlled remotely from a workstation at a spectrum monitoring or spectrum management centre, and monitoring results may be reported back to the requesting workstation. Communication links only need to be available between stations when a client is issuing tasking to remote servers, and later when the client requests results of his tasking. As long as communication links are available when the tasks is issued, if the links then become unavailable, measurements results are not lost, but are retained on the measurement server until requested.

PART B

Spectrum inspections and investigations

4.11 Inspections and investigations for compliance with national rules and Regulations

Efficient management of the spectrum depends on how effective is the spectrum manager's ability to control use of spectrum through enforcement of regulations. This control is primarily built on inspections of radio installations and investigations of spectrum use/interference, both being part of the enforcement function. However, the purpose of inspections and investigations is to strengthen the spectrum management process, and they should directly support effective spectrum management and efficient spectrum use goals.

To emphasize the role of enforcement it is of importance to also define what enforcement means:

Enforcement can be described as "The range of actions and sanctions that can be used to enhance national law and regulations for the purpose of achieving the best possible quality of (radio) communications for the legitimate users of the radio frequency spectrum." [CEPT/ECC 2002].

This includes taking action against real and potential sources of interference or unauthorized use, and may include appropriate judicial measures.

Radio equipment generally must be installed and used in accordance with either licence or license-exempt conditions. These may specify, for example, frequency assignment, transmitter power, antenna characteristics, height of the external antenna, frequency deviation and occupied bandwidth. National authorities carry out inspections and measurements of radio stations in accordance with their own guidelines and procedures.

The use of radio equipment continues to expand rapidly. This applies to business, telecommunication, broadcasting, amateur and leisure activities. Unauthorized use of radio equipment may cause interference to legitimate users.

Safety of life and property may be put at risk if, for example, radio equipment used by emergency services suffers from interference. The successful running of a business can be adversely affected by radio interference. Domestic viewers and listeners can be prevented by interference from enjoying services such as broadcasting.

4.12 Verification of technical and operational parameters

Based on national planning scenarios, a transmitter, licensed to operate, is normally subject to a number of technical and operational parameters.

Before a transmitter comes into operation, an on-site inspection may be carried out to check whether or not its radio equipment complies with the general/individual licence and/or permitted conditions.

All types of radio systems can be checked, but the investigation of radio equipment in some countries is only carried out in cases of reported interference. For any radio system inspection a check should be made of the number of mobiles and hand-portables in a radio network available for use. Prior "off air" monitoring may sometimes provide an idea of the size of the operation and the number of mobiles or hand-portables involved.

The technical part of inspection of radio equipment should include at least the verification of:

– location of the radio base station and the external antenna position;

– frequency and tolerance;

– harmonics and spurious emissions;

– transmitter power;

– occupied bandwidth or frequency deviation;

– type of antenna, height of the antenna, etc. depending on the type of installation;

– conformity to other licence conditions.

The radio base station should be confirmed as being located at the address shown on the licence. Such matters need to be resolved before proceeding with the station inspection. If a radio base station has moved a short distance, so that the coverage area is little changed, the licensee should be instructed, subject to national administration policy, to regularize the licensing provisions. This is preferable to the administration closing down the station.

The operational parameters, if indicated in the license, should be checked when the transmitter is in normal operation. The type of communications (e.g., business-like conversation versus citizen band like conversation), can be checked or using the transmitter outside the allowed working area around a base station may be verified.

4.13 Detection and identification of unauthorized transmissions

It is essential for the success of spectrum management to create a spectrum available for those who are granted to use the spectrum as intended.

Getting non-authorized transmissions off the air may be essential before a new service can become operational in a specific part of the spectrum.

This is of major importance when a part of the spectrum is granted where safety of life or property is at risk or to public operators who often having invested considerable resources to offer services to the public.

4.14 Inspections to identify the source of, and, resolve interference

An administration has a responsibility to ensure that harmful interference is avoided, and so an inspection may draw attention to a licence discrepancy (either accidental or deliberate) before any serious interference problems arise.

A radio station inspection may be necessary when a radio station in question is identified as being responsible as a specific source of interference. An inspection, can be carried out as part of the work programme of an administration, or in response to a specific interference complaint, is designed to ensure that the installation conforms to conditions for its use, and that the radio equipment operates in a manner that is not likely to cause harmful interference.

Administrations may wish to consider the possibility of initiating a procedure whereby radio system installers can register as an “approved installer”. The intention is to enhance the quality of installations and thus reduce the discrepancy rate.

4.15 Investigation to identify the source of, and, resolve interference

To keep the spectrum free of unauthorized use and consequently usable for the intended users, investigation may be needed to identify possible sources of interference. Pro-active investigations help in realizing this goal.

Monitoring and frequency assignment data, providing registrations of regular and un-regular emissions, is critical to set priorities in the working programme of the investigation section. On the basis of the monitoring data, actions to sweep unauthorized emissions out of the spectrum is an effective way of organizing the work.

4.16 Equipment for inspections

The selection of inspection resources needed is dependent on the level of inspection defined by the administration. This can differ from country to country. Many administrations will only carry out inspection in cases of reported interference. Some administrations will only carry out routine inspections.

Essential equipment used for inspections are:

– frequency counter;

– power meter.

In addition the following equipment may be used for more detailed assessment:

– portable test-receiver;

– tone-generator;

– dummy antennas;

- decoding equipment;
- spectrum analyser if needed;
- GPS receiver.

In more enhanced situations, a transmitter may be used, e.g. to check the sub-audio system of duplex networks.

4.17 Equipment for investigations

In general equipment of mobile monitoring units, including direction finding or homing equipment, is sufficient for investigating activities. Additional recording equipment is useful.

Portable equipment (receiver and antenna) is used in case the transmitter is to be located somewhere in an apartment building.

In some cases there will be a need to use covert vehicle installations in order to be able to work in close proximity to the site of a transmitter, without drawing undue attention of the unlicensed user.

4.18 Remote access to system resources

For carrying out inspections and investigations it is of major importance that the staff dealing with inspections and investigations are updated with the latest information contained in the various databases. Consequently a direct (remote) link to the national allocation license database is needed.

ANNEX 1

TO CHAPTER 4

Concession of radio monitoring service; The case of Argentina: an innovative solution

1 Introduction

In 1936, Argentina inaugurated its first radio monitoring station, thereby becoming only the second country in the Americas and the first in South America to equip itself with a proper system of this sort.

In 1974, the Argentine Administration installed two new monitoring stations employing the latest technology available at the time, one in the city of Pilar in the province of Córdoba and the other in the city of Don Bosco in the province of Buenos Aires. This brought to four the number of monitoring stations covering the country, but owing to the swift pace of technological change and the lack of investment in the necessary maintenance and upgrading, these facilities and their equipment gradually grew obsolete.

By the 1990s, the situation became such that the stations were operating by manual means only, without any computer support. Spectrum management tasks were done on paper. The monitoring instruments for the various measurements were operated mechanically, using switches on the front panel of the receivers, and emissions were identified using headphones.

The Government's difficulties in administering and managing the spectrum efficiently became such that it was practically impossible for this task to be performed in accordance with the requirements of the new regime of telecommunication enterprises, particularly given the speed with which the technology was evolving.

It was then that the regulatory authority for the communications sector – that is, the Comisión Nacional de Comunicaciones (CNC) – and the Argentine Government realized that major changes were needed if the basic tools required for administering the radio spectrum, this limited natural resource requiring such close attention, were to be made available.

2 International call for tenders

In late 1996, Argentina's regulatory authority, after spending several years developing a number of proposals and overcoming a variety of problems and stumbling-blocks, approved the bid documents for an international call for tenders for the concession of the radio monitoring service throughout the country.

That call for tenders introduced a new concept: on the one hand, the Government would retain its role as regulator and administrator of the radio spectrum, with functions that could not be delegated (enforcement power, frequency assignment, spectrum planning, licensing, collection of charges and levying of fees, etc.); whilst on the other hand assistance was sought from a private firm having broad international experience in the production of monitoring equipment and systems, which would be responsible for making the necessary investments to install, operate and maintain a nationwide monitoring network, and for adapting and providing the technical analysis and administrative software necessary in accordance with Argentine specifications. The concession-holder would also undertake to train the Government administration's personnel in the use of these new computer tools.

The call for tenders provided that the concession-holder would be compensated for its investments solely by receiving a percentage of the charges that it itself would have to bill to users. For collection purposes, the concession-holder would have to establish a single bank account that could be used from any city or town of significant size anywhere in the country. The bank selected to handle collections would, moreover, be responsible for separating the monies received between the Government's accounts and the company's accounts according to the percentages stipulated in the contract.

In addition, the concession-holder was obliged to follow up on the collection of tariffs established for spectrum users, and in the specific case of public institutions and agencies was to abide by the instructions given by CNC in that regard.

Implicitly, the call for bids required bidders to provide for designing a new network of fixed and mobile monitoring stations, with modern equipment, which would have to be kept technologically up to date during the lifetime of the contract. In addition, the company winning the bid had to provide training in the operation of the new technology for the technical personnel of the old government-owned stations that the company undertook the obligation to absorb, and hire the necessary personnel to operate the service on the terms laid down by the Government in the call for tenders.

Using the network of stations thus established, it had to be possible to observe and measure all the parameters of telecommunication services assigned in the country up to that date, in any part of the spectrum; and it had to be possible to continue to perform that function in the future, with provision for the emergence of new technologies and, for example, services that might require higher frequencies.

The bid documents also stipulated that the concession-holder would have to develop and install a computer system to administer and manage the spectrum which would make it possible for CNC to perform this task more efficiently and more accurately, given that, as noted above, these were not among the responsibilities to be delegated. Several things needed to be done in order to meet this objective. Most important, a single electronic database of spectrum users had to be established, because the information in CNC's possession was up to that time either paper-based only or held in a variety of separate small databases belonging to different organizational units. In addition, digitized maps of the whole country on a variety of scales had to be provided, together with the software for carrying out the relevant technical calculations.

Another key point set out in the bid documents concerned restrictions to be imposed on the concession-holder in regard to the monitoring of frequencies belonging to the country's military and security forces, for the purpose of maintaining the confidentiality of classified government information. Consequently, the scanning function carried out by the instruments had to be programmed in such a way that, when the scanner reached a frequency that the concession-holder was not permitted to monitor, its measuring function would be deactivated so that no data could be recorded for that frequency. The concession-holder was also required to set up a control post connected to the monitoring network, which military and security forces personnel could use to verify compliance with that provision and carry out their own work using equipment installed there.

The contract-award process required bidders to submit three envelopes, containing:

– background information on the bidder;

– the technical bid;

– the financial bid.

The three envelopes were assessed in successive elimination stages for the purpose of selecting the successful bidder.

3 Implementation

The work covered by the tender – which, *inter alia*, required the purchase of the necessary land on which the regional centres and remote stations were to be built – commenced in July 1997. Also at that time the importing of instruments, equipment, antennas and vehicles began, until eventually a total of six control centres and twenty automated remote stations (remote-controlled via satellite) were established. In addition, ten mobile monitoring stations and ten support and measurement vehicles were provided, all of which constituted the necessary operating capacity for performing the technical monitoring functions required.

Thanks to this network of stations, approximately 60% of the country's population (some 20 million inhabitants) and over 90% of its radio traffic can be covered.

Lastly, the successful bidder's commitment to the Argentine Government included the provision, installation and maintenance of an aid-to-navigation station at the Marambio scientific base in Antarctica and training in the operation thereof.

Once the contract was awarded, the concession-holder's role vis-à-vis CNC consisted in particular of performing two types of task:

– Those tasks carried out according to requirements previously established in the contract with respect to services having to be monitored, in certain cities and at certain regular intervals. To carry them out, the concession-holder was required to prepare and submit for approval by CNC an annual programme of work which took into consideration operational requirements requested of it from time to time and the experience gained in previous periods.

– Those tasks carried out upon request and arising without forewarning for whatever reason, such as interference problems or technical field studies.

To perform these tasks efficiently, the concession-holder has established a voice and data satellite communication network linking the five regional centres, the remote stations operating under their control and the National Control Centre in Buenos Aires.

In addition, the concession-holder works with CNC on an ongoing basis in a variety of situations, such as working to clear the spectrum at times of major special events or in proximity to certain airports where air aid-to-navigation systems could be affected, or in tasks undertaken on behalf of CNC for the purpose of establishing with certainty the occupancy of frequencies in specific geographical areas as well as in connection with services to be sold at auction.

The new monitoring network as it is today is shown in Fig. 4.4.

As the new installations have been brought into service, this has freed up resources for use elsewhere. In the time the new monitoring system has been in operation, the substantial increase it offers in operating capacity has made it possible for more than 6 000 specific CNC requests of various kinds to be attended to, beyond the yearly level of activity planned. All these requests have been dealt with to CNC's entire satisfaction.

In addition, a vast amount of information on the occupancy of the spectrum in the most common frequencies and services has been compiled, which has given CNC a full picture of the true state of affairs regarding radio operations in the country's major centres and enabled it make appropriate management and planning decisions.

4 Conclusion

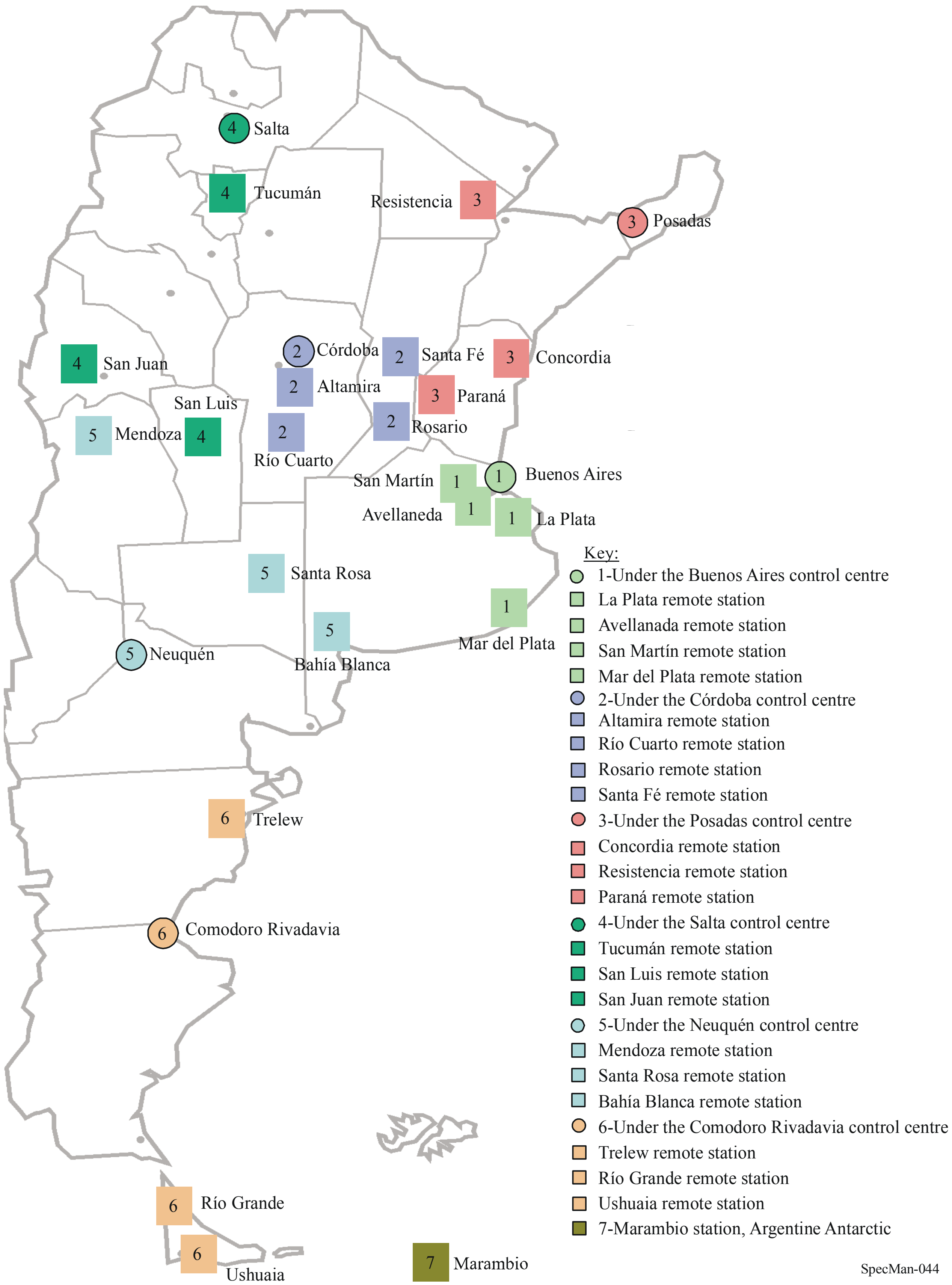
The system put in place supports the development of Argentina's telecommunication infrastructure with a view to achieving the country's strategic economic and social growth objectives. Moreover, the mechanisms that have been established in regard to spectrum management and monitoring make it possible for Argentina to fulfil its responsibilities more effectively at the regional and international levels and to safeguard this national resource.

In addition, the technology utilized has allowed the gradual regularization of the administrative and technical management of the spectrum, at the same time as it has set a long-term global planning process in train.

Indeed, the structural changes that have been introduced allow the authorities to gain access to new frequency bands in order to implement services developed using new technologies; and this renewal process has in turn made it possible to provide users with frequencies that are free of interference, improve the quality of public radiocommunication services and set about optimizing the use of this national resource.

FIGURE 4.4

Current national emission monitoring system for the Argentine Republic



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ITU-R Texts

ITU-R Handbook – Spectrum Monitoring (edition 2002).

Rec. ITU-R SM.182	Automatic monitoring of occupancy of the radio-frequency spectrum
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.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.853	Necessary bandwidth
Rec. ITU-R SM.854	Direction finding and location determination at monitoring stations of signals below 30 MHz
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.1052	Automatic identification of radio stations
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.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.1267	Collection and publication of monitoring data to assist frequency assignment for geostationary satellite systems
Rec. ITU-R SM.1268	Method of measuring the maximum frequency deviation of FM broadcast emissions at monitoring stations
Rec. ITU-R SM.1269	Classification of direction finding bearings
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.1447	Monitoring of the radio coverage of land mobile networks to verify compliance with a given licence
Rec. ITU-R SM.1536	Frequency channel occupancy measurements
Rec. ITU-R SM.1537	Automation and integration of spectrum monitoring systems with automated spectrum management
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.1600	Technical identification of digital signals

CHAPTER 5

SPECTRUM ENGINEERING PRACTICES

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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 v. 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

No. 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 SM.853 provides a method to calculate the necessary bandwidth for multi-channel FDM systems, and Recommendation 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."

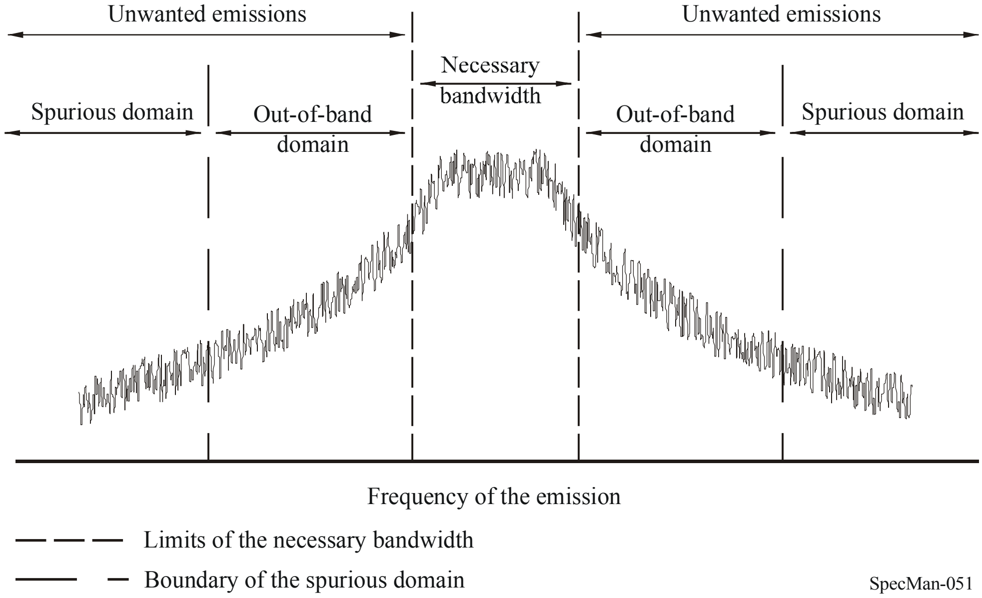
Further guidance on the bandwidth of specific emissions can be found in Recommendation ITU-R SM.328, furthermore the ITU-R Handbook – Spectrum Monitoring provides further guidance on practical measurement of bandwidth.

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

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

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 (Recommendation 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 give estimates for different radio services, frequency bands, regions of the world and antenna heights that may be applicable for a particular situation being considered.

– Propagation over a specific terrain profile. When necessary, a detailed calculation may be made for propagation over a terrain profile obtained from a topographic database. The computer algorithms would be based on the methods described in Recommendation ITU-R P.526.

– Okumura-Hata. This model is now covered by Recommendation ITU-R P.1546 and uses the Okumura-Hata formula that calculates the attenuation depending on the distance and equivalent height of the transmitting antenna. This attenuation is corrected depending on the percentage of buildings around the reception location, on the type of the path (land, sea or mixed).

– Longley-Rice (ITS). The ITS model of radio propagation for frequencies between 20 MHz and 20 GHz (the Longley-Rice model) is a general purpose model that can be applied to a large variety of engineering problems. The model, 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.

– ITM. The Irregular Terrain Model was originally developed for the US National Telecommunications Information Administration. It is available free of charge from http://elbert.its.bldrdoc.gov/itm.html.

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 Recommendation 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.

5.4 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 analog 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:

$$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f) \qquad (1)$$

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:

$$I = I_1 + I_2 + ... + I_K \qquad (2)$$

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 § 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:

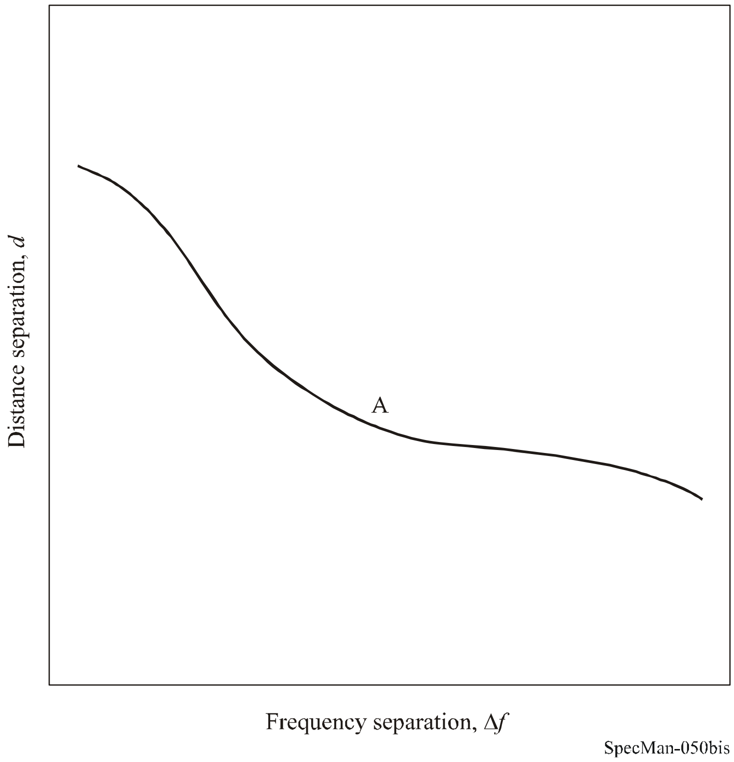
$$L_b(d) + FDR(\Delta f) \geq P_t + G_t + G_r - I_M \qquad (3)$$

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:

$$L_b(d) + FDR(\Delta f) = \xi \qquad (4)$$

Above the curve is the region of acceptable receiver performance. Below the curve is the region of non-acceptable receiver performance.

Separations in frequency and distance. The equation describing curve A is L_b (*d*) + *FDR* (Δ*f*) = ξ. 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*(Δ*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,…) 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;

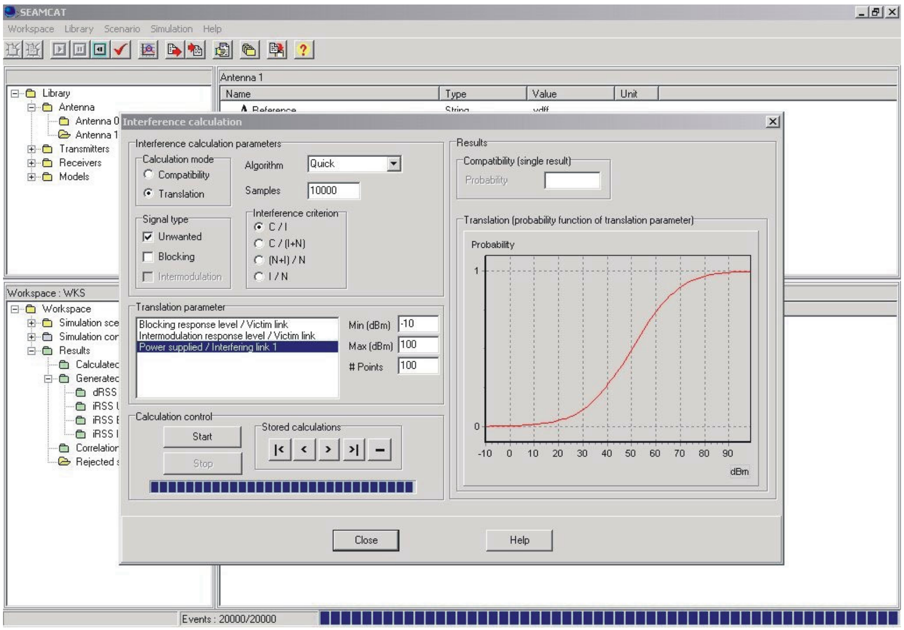
– compatibility study for ultra wideband systems and other radio systems operating in this frequency bands.

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 Radiocommunications Office (ERO) and may be downloaded directly from their web-site: www.ero.dk.

SEAMCAT provides all the functionality described previously in this section via an easy to use graphic user interface. A sample result is shown in Figs. 5.2 and 5.3.

FIGURE 5.2

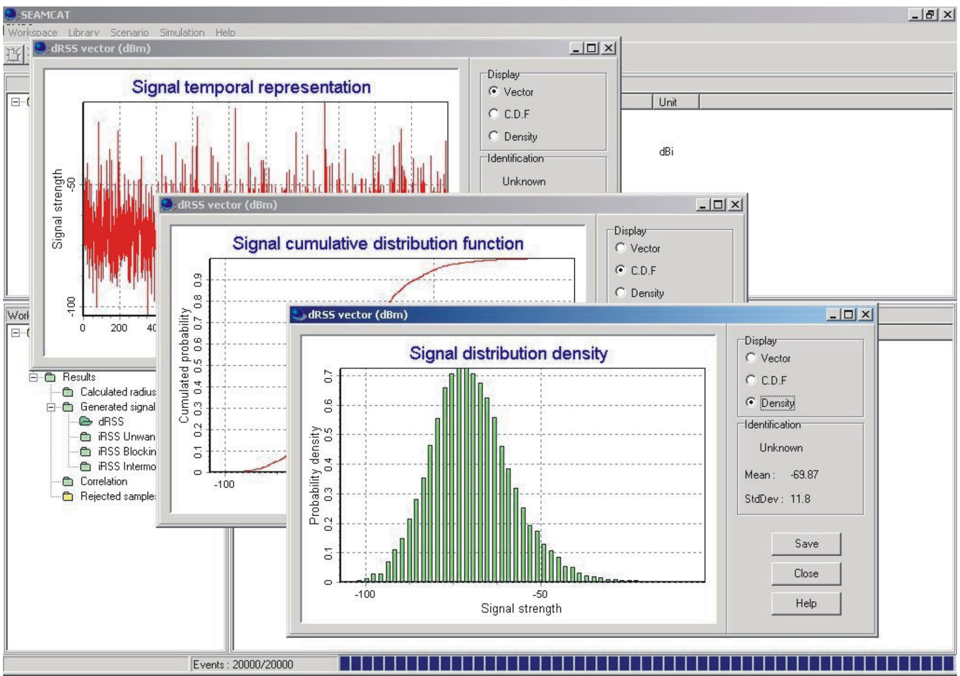
Example of SEAMCAT graphic user interface



SpecMan-052

FIGURE 5.3

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 5-3 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 5-3. 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 5-3

Methods to facilitate sharing

Frequency separation	Spatial separation	Time separation	Signal separation[1]
Channelling plans Band segmentation Frequency agile systems Dynamic sharing: – dynamic real-time frequency assignment[2] FDMA Control of emission spectrum characteristics Dynamic variable partitioning Frequency tolerance limitation Demand assignment multiple access (DAMA) Frequency diversity	Geographical shared allocations Site separation Antenna system characteristics: – Adaptive antenna (smart antenna) – Antenna polarization discrimination – Antenna pattern discrimination – Space diversity – Antenna angle or pattern diversity Space division multiple access (SDMA) Physical barriers and site shielding	Duty cycle control Dynamic real-time[1] frequency assignment TDMA	Signal coding and processing FEC Interference rejection CDMA Spread spectrum: – direct sequence – frequency hopping – pulsed FM Interference power/bandwidth adjustments: – co-channel – dynamic transmitter level control – pfd limitation and power spectral density (psd) limitation (energy dispersal) Modulation complexity Coded modulation Adaptive signal processing Antenna polarization

(1) These techniques for signal separation may also be applied to frequency, space and time separation technology.

(2) Dynamic real-time frequency assignment facilitates sharing by simultaneously using frequency and time domains. Therefore, this method is shown in both columns.

Within Table 5-3 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 so 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 the following section, 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 broadcasting service in the VHF and UHF band is described in Recommendation ITU-R SM.851. To allow satisfactory operation of the two services, maximum interference field strengths at the receivers are specified.

For the protection of 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 5-4

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:

$$F_i = E\,(50,T) + A + B.\,E\,(50,T) \qquad (5)$$

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 Recommendation ITU-R P.370. A (dB) is the required protection ratio for television broadcasting and is described in more detail in § 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 5-5

Field strength for protection of land mobile service

Frequency band (MHz)	Field strength (μV/m)	
	Annoying interference (Grade 3)	Noticable 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:

$$P_r \text{ (dBm)} = E - 20 \log F - L_c + G_r - 77.2 \qquad (6)$$

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 Recommendation ITU-R P.370. 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 landmobile 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 5-6

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

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.

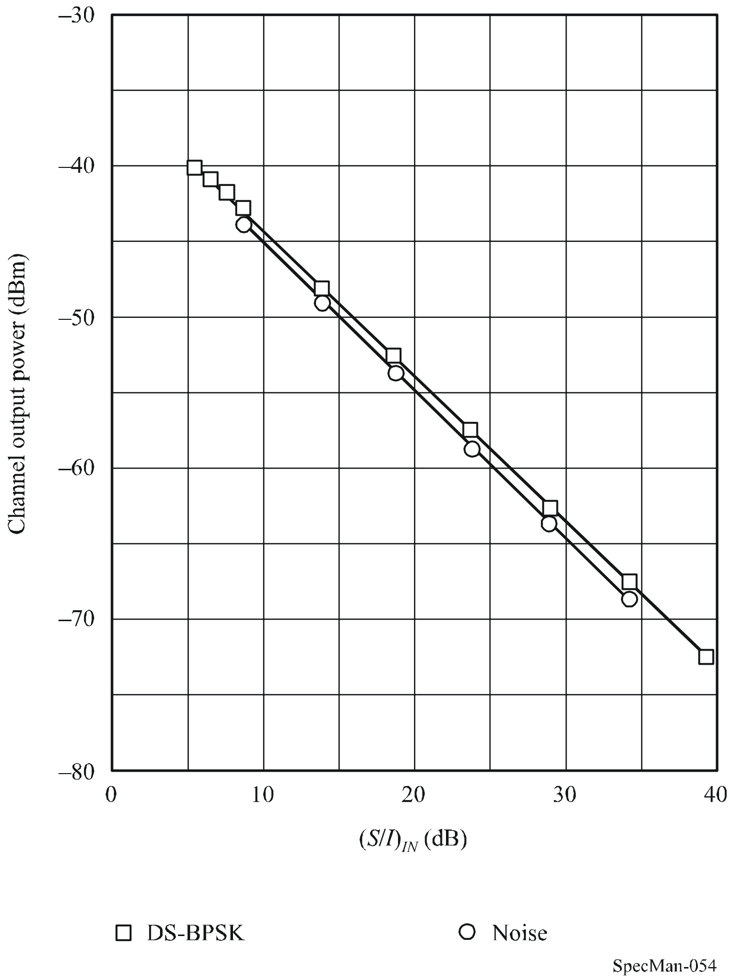
5.5.5 Sharing using spread spectrum techniques

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 5.4 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 5.4

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 5-7

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.

5.5.6 Summary of ITU-R Recommendations on sharing between services

TABLE 5-8

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.1236 SA.1258 SA.1277 SA.1278 F.1502	M.1469 M.1472 M.1473 M.1474	SF.355 SF.1005 SF.1006 SF.1481 SF.1486				
Mobile	SM.851	F.1402		SA.1154 SA.1236 SA.1277 SA.1278						
EESS/SR/SO		F.761 F.1247 SA.1277 SA.1278	SA.1154 SA.1277 SA.1278			S.1069 SA.1071 SA.1277 SA.1449		SA.516	SA.1277	SA.1278
MSS				SA.1277					SA.1264	
FSS		SF.355 SF.1005 SF.1006 SF.1481 SF.1486	S.1426 S.1427 M.1454	SA.1277			S.1068 S.1151 S.1340			
Radio-navigation					S.1341	S.1151				
Radiolocation				SA.516						
Met-sat/Met-aids					SA.1158 SA.1264					
Inter-satellite				SA.1278						
RNSS				SA.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 5-9 is extracted from Recommendation ITU-R SM.669 and 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 5-9 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 5-9

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_t = 1			m_t = 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 $(S/N)_t$ = 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 $(S/N)_t$ = 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 Δf = 0.5 kHz m_s = 0.3 $(S/N)_t$ = 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 Δf = 0.5 kHz $(S/N)_t$ = 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 $(S/N)_t$ = 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 $(S/N)_t$ = 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 $(S/N)_t$ = 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 Δf = 0.5 kHz De-emphasis $(S/N)_t$ = 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 Δf = 44.5 kHz $(S/N)_t$ = 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.

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* ex-CCIR Recommendations 240, 339, 500 and 600.

TABLE 5-10

Protection ratio references from other Radiocommunication Study Groups

VOLUME (ex-CCIR)	Recommendation(1)	Notes
III	ITU-R F.240	Many PRs including fading
VIII	ITU-R M.589	Radionavigation PR
VIII	ITU-R M.631	Phased radionavigation PR
VIII	ITU-R M.441	Aero. mobile (R) (ICAO An.10)
X-1	ITU-R BS.638	Sound RF/AF PRs
X-1	ITU-R BS.560	Sound, LF, MF, HF PRs
X-1	ITU-R BS.641	FM sound PRs
X-1	ITU-R BS.412	FM sound/VHF PRs
X/XI-2	ITU-R BO.566	Broadcast PR definitions
XI-1	ITU-R BT.655	AM TV PRs
XI-1	ITU-R BT.565	625 TV/RN, 582-606 MHz 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 Figs 5.5 and 5.6, 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 5.5

F_a versus frequency (10^4 to 10^8 Hz)

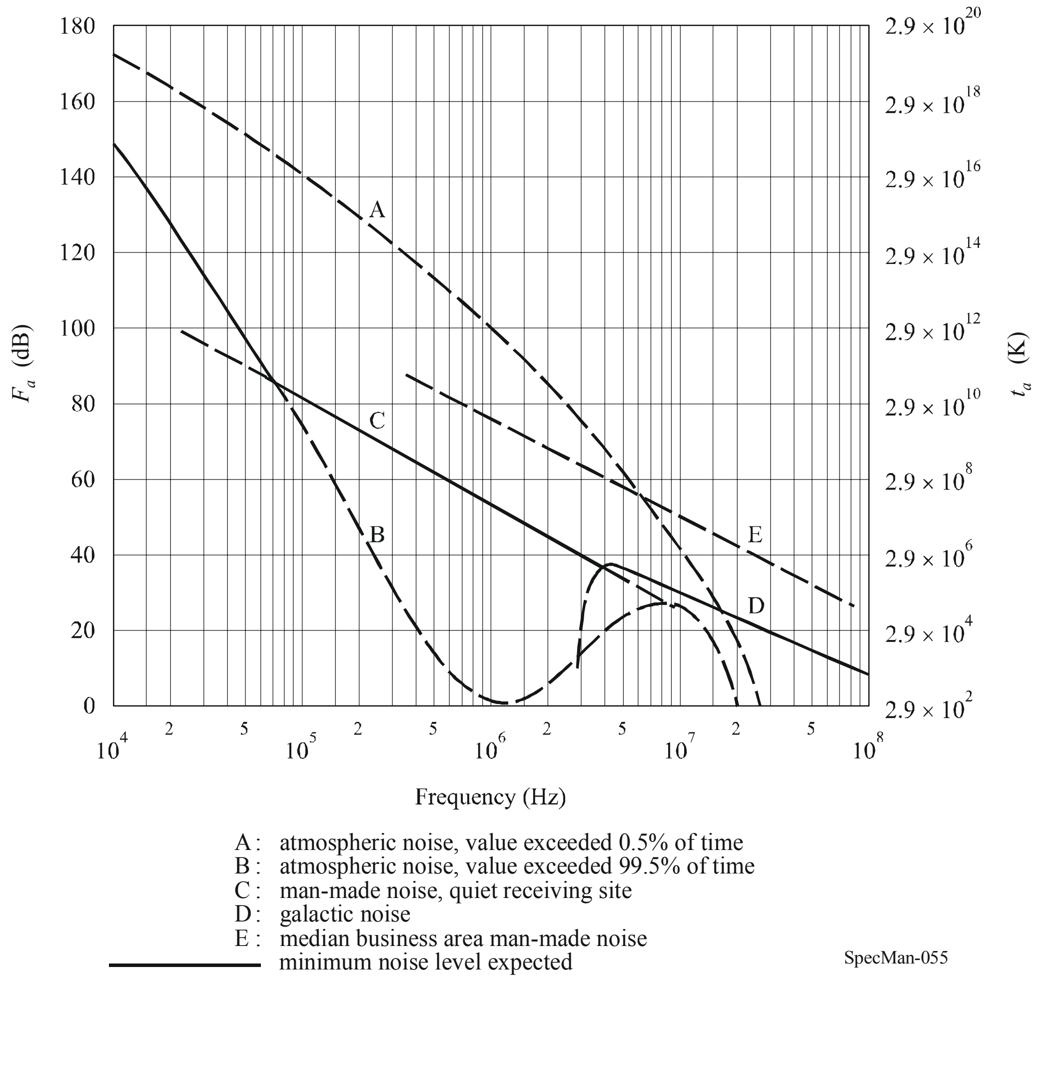
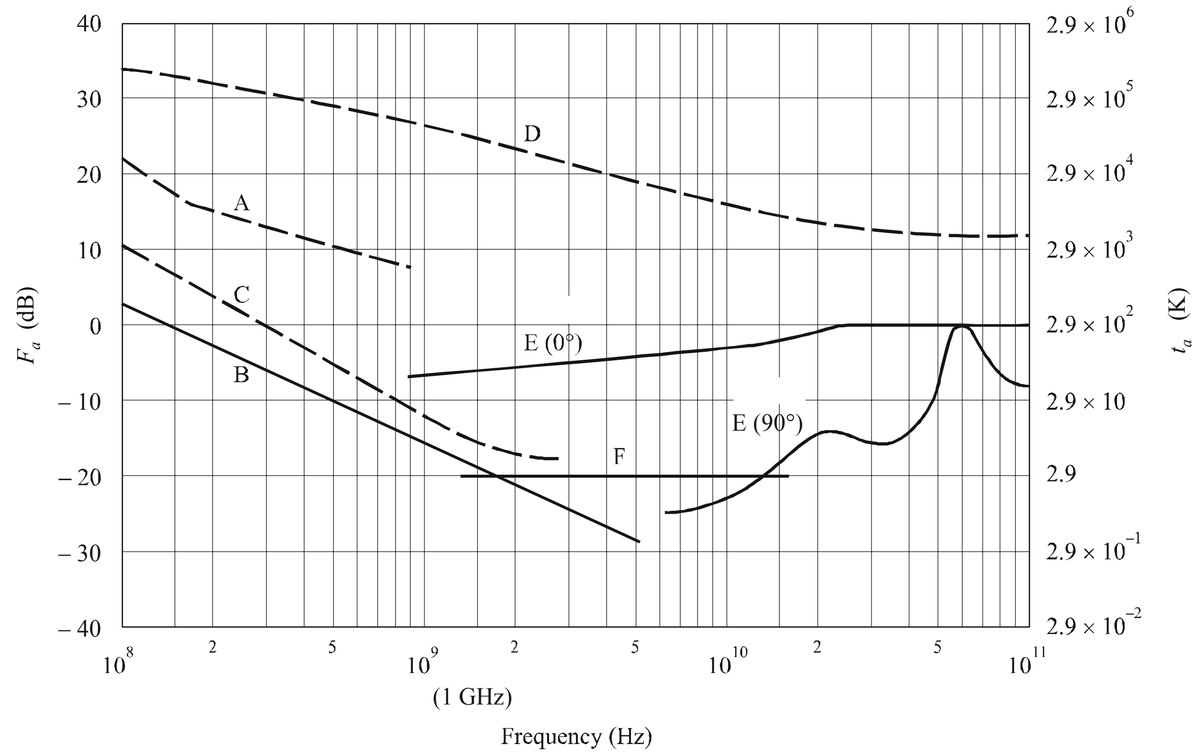


FIGURE 5.6

F_a versus frequency (10^8 to 10^{11} Hz)



A: estimated median business area man-made noise
B: galactic noise
C: galactic noise (toward galactic centre with infinitely narrow beamwidth)
D: quiet Sun (½° beamwidth directed at Sun)
E: sky noise due to oxygen and water vapour (very narrow beam antenna); upper curve, 0° elevation angle; lower curve, 90° elevation angle
F: black body (cosmic background), 2.7 K
——— minimum noise level expected

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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 5-9 and 5-10. 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.

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 equipments 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.

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), Geneva. Telephone (41 22) 791 2532, Fax (41 22) 791 4858, or 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.

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-2000).

– 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-2000 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.

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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 F.240	Signal-to-interference protection ratios for various classes of emission in the fixed service below about 30 MHz
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.631	Use of hyperbolic maritime radionavigation systems in the band 283.5-315 kHz
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 0.7 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 propogation data and prediction methods required for the design of satellite services and systems
Rec. ITU-R P.533	HF propagation prediction method
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
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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 RA.1031	Protection of the radioastronomy service in frequency bands shared with other services
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.669	Protection ratios for spectrum sharing investigations
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
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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.1538	Technical and operating parameters and spectrum requirements for short-range radiocommunication devices
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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 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

CHAPTER 6

SPECTRUM ECONOMICS

Table of Contents

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 new 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 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.2012-2 (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 dealing 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 that 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 www.ero.dk 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 licensee. The level of funding provided will depend on the priorities of the national government and its total tax resources. When introducing spectrum management to 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[8]. 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. There are two most common forms of spectrum usage fee for initial and ongoing charges and they are:

– simple fee;

– fee based on cost recovery.

In practice cost recovery might be considered as a variant of a simple fee 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.

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[8] Otherwise 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.

Examples of the application of frequency fees in many countries, may be found at the ITU-D SG 2 website[9].

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. Varying the fee depending on specific criteria like the quantity of spectrum occupied, or the frequency band used, or the geographic area covered, can provide a more equitable approach.

A disadvantage of simple fees is that the fee charged may not reflect the costs of the administration and so the fees recovered may be greater or less than the administration's costs and there is the potential, if the fee is too high, that it may dissuade use of the spectrum. In addition fees based on specified criteria may not be based on the value of the spectrum, nor on any management costs, hence their introduction reduces the transparency of the charging system and can make the application of fees to different users purely arbitrary. 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 objects (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, but with the aim to avoid overcharging the licensee and to avoid using the national budget to subsidize spectrum management. The charges for frequency usage, and hence the fees for a radio frequency licence, are set according to the costs incurred in 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 one 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 § 6.2.3. Licence fees are usually structured on the principle of recovering the costs directly and indirectly attributable to a licence category.

From the point of view of licensees, cost recovery can be a fairer 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

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[9] http://www.itu.int/ITU-D/study_groups/SGP_2002-2006/SF-Database/index.asp.

overheads 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 a case of the cost-coverage principle 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 due to 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 recovery from the beneficiaries of an administrative activity by mean of fees of the costs of a sector of the administration is not complete but only partial – 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 a fee 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 may be based on the work performed, directly or indirectly, on an individual licence or the average for that licence category.

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.).

e) How the costs of the individual spectrum management functions are attributed to a particular licence category may be different due to:

   – the interpretation of whether the cost should be the responsibility of the licensee, should attract a fixed fee or should be the responsibility of the state (paid from the state budget);

   – their allocation between direct and indirect costs, (see below).

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 consultation 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 consultation.

– *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 consultation, 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 make any charge for indirect costs.

A disadvantage of 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, 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 on licence categories may not take account of users' ability to pay, to the detriment of some users (e.g. users in remote rural areas) while other users do not have sufficient incentive to use the spectrum efficiently. Costs incurred on issuing an individual licence are even more difficult to record and again offer no incentive to use the spectrum efficiently.

6.2.3 Other charges

In addition to the income and costs arising from the issuing of licences there are other functions of an administration associated with spectrum management activities that generate costs and income. These charges may be based on a simple fee that may or may not recover the cost of the function, or on a cost recovery basis. Some examples are given below.

– *Type approval or type acceptance fee*

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 certificate applies in a number of countries and the equipment is covered by the manufacturers' self-declaration procedures. Hence the income from these fees may not be significant.

– *Accreditation fee*

In some countries testing of terminal and radio equipment is performed by the administration, while in others it is performed by independent accredited test laboratories that form no part of the administration, and even in some cases where the laboratories are still part of the administration, fees are collected for the accreditation of the laboratories. Note, if it is performed by accredited bodies then administrations cannot charge a fee for it unless indirectly 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.

– *Annual fee*

A fee to help recover the regulatory authority costs that are not recovered by the above-mentioned fees.

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 effort, 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 resident 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 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 licencing 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 licencing . If the number of applicants exceeds the available spectrum and particularly if they have to be assigned in a short time period the "first come-first served" option may not be suitable and mechanisms like tender procedures, comparative bidding 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. 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.

6.3.3 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 is not unusual for the Government, having taken an administrative decision on the spectrum's value, to set a lower limit 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.

6.3.4 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 a service. These additional constraints may restrict the number of applicants and also recover some of the value of the spectrum.

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 the charging policies and most assignment mechanisms, as described above, 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 any 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) is not sufficiently transparent.

These concerns have led to the development of new approaches to spectrum management including, among other things, economic criteria as a new 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 Spectrum fees

One of the areas affected by consideration of spectrum pricing is the approach to spectrum usage fees, which has been extensively examined in order to introduce some concept of the economic value of spectrum in the fee structure. Examples of these fee mechanisms are listed below.

a) *Spectrum fees based on users' gross income*

A fee can be charged 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.

b) *Incentive spectrum fees*

An incentive fee attempts to use price 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. 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[10] of the spectrum. The overall aim of incentive fees

[10] The market value of spectrum should be defined.

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 move to 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 also 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 equipments has to be higher than the fees claimed from users satisfying themselves with a lesser number of equipments as the former is more likely to occupy the spectrum than the later (thus excluding him 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*[11]

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. Incentive fees may not be suitable for all services.

c) *Opportunity cost fees*[12]

An opportunity cost fee tries to simulate the market value of the spectrum. 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. Note: this can be seen as an example of a method to calculate the incentive fee.

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, so too it is 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 evaluating 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. Nonetheless, such methods may have advantages over cost based alternatives in terms of managing the spectrum to balance supply and demand and maximizing economic welfare. Also, incentive fees can apply to general licences over a longer period of time, while auctions typically apply for assigning licences on a certain moment.

Table 6-1 presents the positive and negative aspects of traditional and market based fee approaches.

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[11] See ITU-R Study Group 9 for definition.

[12] See ITU-D 1998 (SG 2) Final report (Document 3).

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	For spectrum users they are ensured that they pay only for the costs generated by them with the spectrum management authority. 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 restrictions 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 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	Requires 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)

6.4.2 Auctions as part of bidding approaches

Auctions represent a new form of assignment mechanism where the applicants determine the value to be charged. In this way the price of spectrum is determined fully by market forces and the frequencies allotted to the winning bidder. An auction may be based purely on the price bid or the administration may set criteria that form the entrance conditions applicants have to meet to take part in the auction and the administration may also set a reserve price. These criteria may be similar to the type of entry conditions set in comparative bidding (or lottery), except in the auction and lottery environment they are not used in determining the winner.

– Auctions may 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 ensure that this is taken into consideration in the size of their bid.

– Auctions can be quick and efficient in the assignment of spectrum compared to traditional tender procedures or comparative bidding. Auctions can cope with large numbers of applicants, which is particularly useful when there is limited spectrum available for assignment. In particular, as the operation of auctions reduce the opportunity for favoritism and corruption on the part of the administration making the spectrum assignment, they are considered to be transparent and reduce the possibility of a legal challenge. However, the more criteria and conditions that are applied to an auction the greater possibility of reducing the value of the spectrum and possibly the level of competition. In some cases, to clearly define the operational limitations of the license, administrations may need to develop the type of spectrum management facilities they had previously considered unnecessary, e.g. monitoring, terrain databases, automated interference analysis capabilities.

For an auction to progress smoothly the rules and procedures of an auction should be known and clearly 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 spectrum auction "pioneers", 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 in question, an automated auction system may be desirable. Thus, certain technical infrastructure may be required to hold an auction. As well, education and training for both spectrum managers and potential bidders may be 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 pioneered 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.

Advantages

Auctions have the advantage of awarding licences to those who value them most highly, 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 broadcasters but is allocated to mobile radio, revenues and the economic benefits generated from that spectrum will be less than if broadcasters 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.

Disadvantages

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.

Auctions are not a universal panacea and are only suitable for specific licences and conditions. They are not suitable if the spectrum right cannot be defined properly. They are also not suitable for high volume, low value licences nor for application to socially desirable services 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 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 defense or scientific research may have difficulties in placing a financial value on spectrum, which could lead to those services being under-provided to society if all providers of spectrum-using services faced auctions.

If auctions to license global or international satellite systems were held in multiple countries, it is likely that potential service providers would have to expend 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 providers would be unsure that they would win auctions in all countries in which they wish to provide service. If this uncertainty were sufficiently severe, it could impede the provision and the development of international satellite systems.

Restrictions

Should an administration decide to utilize 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 auction financial income, 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 income; 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 endeavoring 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.

Decisions on the use of auction income are a national determination.

6.5 Spectrum rights[13]

6.5.1 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, mainly in the OECD countries. There are two alternatives; one a licence to use equipment, the other spectrum rights. In practice there are many permutations of spectrum pricing/traditional charging policies, spectrum right/equipment licence but some are unlikely in practice.

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[13] Spectrum rights need a clear definition by ITU, in particular as it relates to the satellite 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 kinds 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 below. In one country different kinds of pricing can exist *beside* each other or different elements of pricing can be combined in the total.

6.5.1.1 Spectrum rights obtained by the licensee

In some respects spectrum may be 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 or political 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 user obtains, depends on the individual licence with associated conditions and exclusions. These “conditions and exclusions” have no influence on the nature of the rights! Only on their extent. These rights are conferred on 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. They may also include requirements on, for example, the periods of operation or frequency sharing.

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 led 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[14] (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.

If an administration proposes to introduce spectrum rights, their definition and the legal basis for the trading process are very important. 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 does raise problems, particularly where there are a number of countries with many close 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 differed from Article 5 of the RR.

In the latter case, the licensee may face practical problems in changing the service they provide 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

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[14] In this section asset is not used in its standard accountancy form.

years remaining on the licence. In addition other factors may affect the recovery of investment (both in the existing service and planned for the replacement service), like 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. Jurisdiction on rights would be according to the national laws.

6.5.1.2 Spectrum rights retained by an administration

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[15]. 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 they retain adequate control of the spectrum and have the capability of recovering it should the necessity arise. 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. The additional requirements could vary for different licensees as they may include, amongst other things, different levels of spectrum management responsibility between licensees, control of the service, the type of radio system, its coverage area, frequency band, exclusive or shared use and how the radio system will be used.

6.5.1.3 Licence duration

The licence period varies between countries. Normally the licence period lies in the range 1, 5 or 10 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.

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[15] 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.

6.5.1.4 Transferable or flexible 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, non-mutually exclusive, 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.

In some countries some form of transferability or flexibility of spectrum rights may be 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 needs to be flexible. The least restrictive definition would allow the licensee to choose the end user services they provide, but this is incompatible with protecting existing end users and ensuring 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 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.

6.5.1.5 Secondary market

The existence of a secondary market is a pre-condition of the introduction of transferable spectrum rights within the given licence conditions and geographical area. If a secondary market does not exist, then small users with transferable spectrum rights could find it difficult to attain the current market value for their spectrum and may be at a disadvantage compared to large users. At present, most frequency licences throughout the world are not transferable and 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 would encourage its efficient use by providing a mechanism for licensees to obtain an economic return on any spectrum they no longer require.

Any transfer of rights would need to be registered with the spectrum management authorities and the spectrum market, like any other market, would need to be regulated to avoid abuses. In particular there would be a need for competition legislation to prevent hoarding of spectrum and price fixing. If a market in spectrum were to develop then it is likely there would be a need to help establish new organizations to provide frequency resale and, perhaps, spectrum marketing services.

6.5.2 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. As implementation of spectrum pricing, or spectrum rights, can have a significant impact on spectrum management processes it is advisable that change should be managed due to the potential implications for the economy, the licensing process, industry and radio users. In particular it is necessary to consider the impact of any change in the existing level of spectrum management funding, both in the short and long term. The type of implications that may arise will depend on the:

– administration's spectrum management operation and its organizational structure;

– the extent and type of radiocommunication and telecommunication services in the country;

– the type and extent of the proposed changes;

– the national legislation.

6.5.3 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).

ANNEX 1

TO CHAPTER 6

An application of spectrum pricing

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 been not followed elsewhere so far Indeed the geographical isolation of New Zealand probably enables practices to be implemented there 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

1 Interests driving the decision to redeploy spectrum

The community as a whole must derive sufficient benefit from a 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 § 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 § 3.2). If he were to stay in the band, he would have to spend a sum equal to Cr (see § 3.3). We therefore have the following relationship:

Redeployment cost = additional cost for the user obliged to leave
the frequency band = Ci + Vcr – Cr

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[16] (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.

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[16] 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.).

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.

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 Defense 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.

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CHAPTER 7

AUTOMATION FOR SPECTRUM MANAGEMENT ACTIVITES

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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 provided two such computer hardware systems to each of the least developed administrations. They have also sponsored the development of basic spectrum management software (WinBASMS) that is now available in four languages. This system will soon be upgraded and be named 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 (2005) 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, 2005). 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

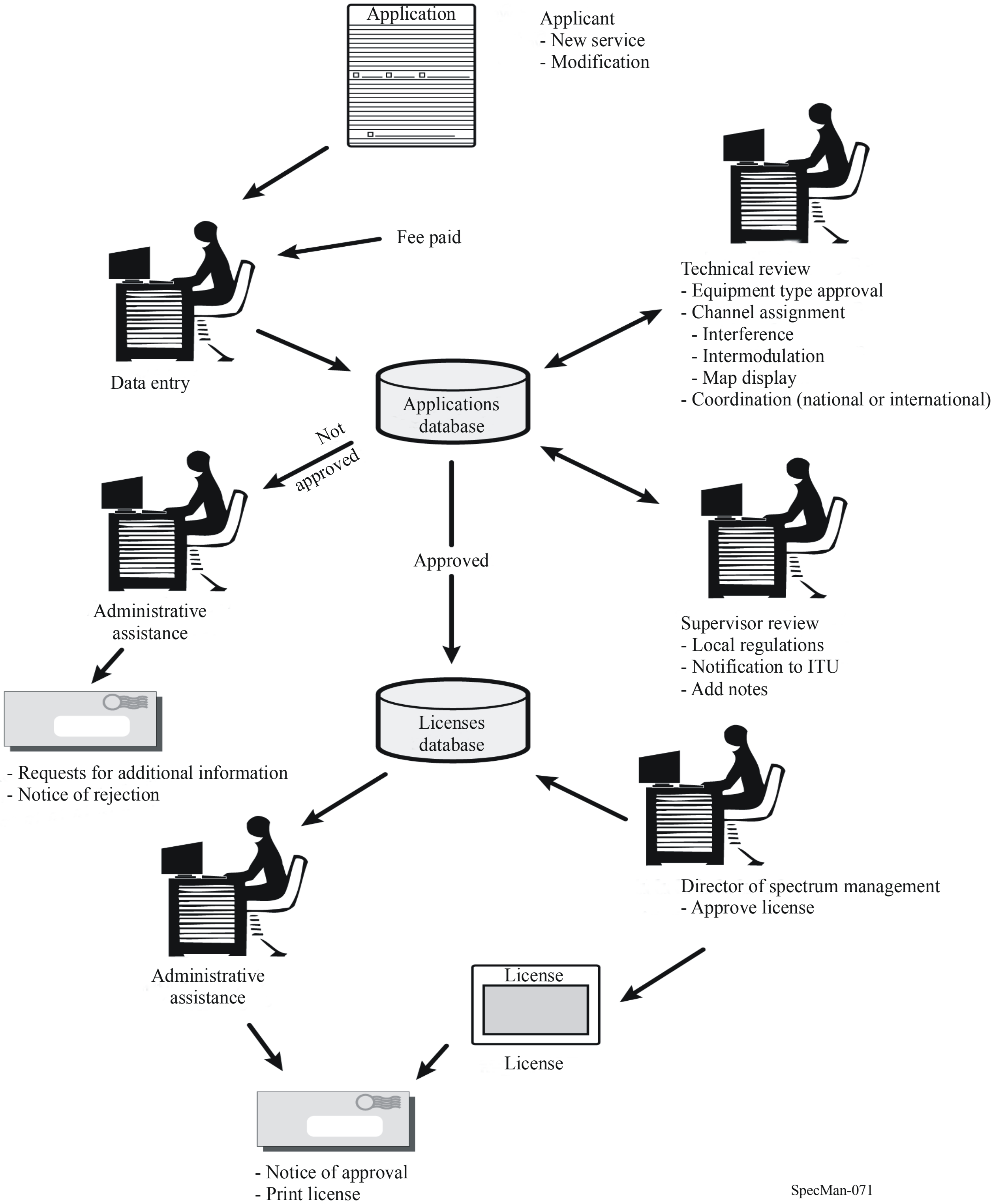
To evaluate the application of computer systems to a specific spectrum management situation, the various types of computer hardware and software available must be analysed. An example of a computerized spectrum management system is shown in Fig. 7.1.

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 Recommendation 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.1048 contains design guidelines for a basic automated spectrum management system (BASMS). The software for this system has been developed, mainly for developing countries, and is now available free of charge from the BDT. The latest version (WinBASMS 2.1) operates in a Windows environment (3.1, 95, 98, NT4, W2000, Me, XP) in three languages (English, French or Spanish). A Russian version (2.0) is also available. The BDT has arranged seminars in the past to provide training to Administrations in the effective use of this software. Recommendation ITU-R SM.1604 called on the ITU to update this software. The BDT currently has a project underway to do this and the software will be renamed SMS4DC.

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.

In accordance with Recommendation ITU-R SM.1048, the Basic Automated Spectrum Management System (BASMS) has been developed jointly by the ITU-R and the ITU-D for developing countries for the major radio services and for a single user (see Annex 1 to this Chapter). The software for this system now is available from the BDT but is not supported and will soon be replaced by the SMS4DC in accordance with Recommendation ITU-R SM.1604.

A new Recommendation (ITU-R SM.1370) describing Design Guidelines for an Advanced Automated Spectrum Management System (AASMS) has been developed by Study Group 1 and should form the basis for tenders issued by Administrations seeking such systems.

Case studies that could assist Administrations considering such automation initiatives are included at Annexes 2 to 7 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, 2002).

ITU-R Handbook – Computer-Aided Techniques for Spectrum Management (Geneva, 2005).

ITU-R texts

Rec. ITU-R SM.182 Automatic monitoring of occupancy of the radio-frequency spectrum

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.1048 Design guidelines for a basic automated spectrum management system (BASMS)

Rec. ITU-R SM.1370 Design guidelines for developing advanced 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

Rec. ITU-R SM.1604 Guidelines for an upgraded spectrum management system for developing countries

ANNEX 1

TO CHAPTER 7

Development and implementation of computerized spectrum management systems by the International Telecommunication Union

1 Introduction

The Basic Automated Spectrum Management System (BASMS) and its Windows version WinBASMS are the first computerized spectrum management systems developed by the ITU jointly by the ITU-R and ITU-D Sectors and particularly by the Telecommunication Development Bureau (BDT) of the ITU-D. This is an excellent example of cooperation between these two ITU Sectors. Throughout the years, the centre of related activities moved in turn between the Sectors.

The development of a computerized spectrum management system began in 1992 with the development of the general guidelines for the BASMS. This took three international meetings for a group of Radiocommunication Study Group (SG) 1 and BDT specialists devoted to this task which ended with the approval of Recommendation ITU-R SM.1048.

The Group of Experts (GOE) established by the BDT developed the necessary specifications and supervized the creation, testing and implementation of the relevant software. Implementation of the first DOS version (BASMS) of the system was initiated in 1995, in 1997 the system was amended to be supported by Windows platform (WinBASMS) and its user interface was translated from English to French, Russian and Spanish. WinBASMS has already been implemented by a number of countries.

Based on experience gained, Radiocommunication SG 1 in 1998 developed Recommendation ITU-R SM.1370 concerning major requirements of Advanced Automated Spectrum Management Systems (AASMS). Currently the GOE is in the process of developing specifications for modernization of the WinBASMS and for creation relevant software for new SMS4DC (Spectrum Management System For Developing Countries).

1.1 WinBASMS development and features

The purpose of the WinBASMS software is to give developing countries a tool to efficiently and effectively manage the radio spectrum primarily for broadcasting, fixed and mobile radio services and therefore to accelerate the development of wireless technology in countries.

BASMS consists of a data base management system and a number of basic engineering tools for spectrum management purposes.

It is interesting, in retrospect, that under development of Recommendation ITU-R SM.1048 much discussion was held concerning how complicated the BASMS should be. It was finally decided to limit the system to the basic tools necessary for spectrum management since it was expected that the majority of the countries that would be using the system would have relatively small number of frequency assignments to manage and did not require complex engineering tools.

Recommendation ITU-R SM.1048 was then used as a guide by the BDT and GOE to implement the BASMS software. A request for proposal (RFP) was developed by the GOE and advertised in 1994. A contract was awarded to a US company, Applied Spectrum Research, in 1994 to develop the BASMS software. The software was completed in 1995 after going through Alpha testing review by the GOE. The first Beta test and BASMS training was conducted in Geneva in August 1995.

In 1996 it became apparent that there was a great interest in converting BASMS from the DOS to Window platform and in expanding its capabilities and in particular the number of languages to cover French and Spanish for other countries. The GOE examined this amendment along with other changes that would not modify the basic functions of the software. A contract was awarded to CGI of Canada in 1997 to modify the software so that English, French or Spanish could be selected, to change to a WINDOWS based structure and to make a number of improvements to the database presentations and the engineering calculations.

The software improvements were completed in 1997. For the seminar in Bishkek, Kyrgyz Republic, the Kyrgyz State Communication Agency has developed WinBASMS with translation of its user interface to Russian. Russian translation of the WinBASMS manual is also available.

The WinBASMS software is presently distributed free of charge in English, French and Spanish (a version in Russian is also available on special request) through regional and area Seminars on the WinBASMS implementation organized by the BDT under the ITU/BDT Valetta Action Plan and within frameworks of ITU/BDT technical assistance missions on frequency management and radiocommunication development.

The WinBASMS is designed for ease of use and maintenance by a single user. Multiple copies of the WinBASMS can be used within an administration to facilitate operating various spectrum management functional requirements. For example, if number of frequency assignments is too large to be treated by one WinBASMS station several of them can be used for different frequency ranges or different services.

The WinBASMS can be used to support most functional requirements defined in the ITU Handbook on National spectrum management, 1995.

Specific technical tools were developed especially for the WinBASMS applications.

1.2 WinBASMS shortcomings

As the first international exercise in this field, WinBASMS is not free from some shortcomings. Major among them are the following:

– significant omissions in implementation of propagation models, particularly given by Recommendation ITU-R P.370;

– extremely simplified interference calculation procedures under frequency assignment features;

– undeveloped frequency coordination and ITU notification features;

– undeveloped spectrum monitoring database section;

– existence of small bugs that make its operation difficult.

It is also necessary to mention that, in the opinion of many experts, the absence within WinBASMS of multi-user support constitutes the most serious obstacle to widespread introduction of the system in many developing countries that have a significant number of frequency assignments. Some experts also indicated, as desired, the introduction of multi-level security features, as well as the Digital Terrain Database and relevant software to provide more accurate calculations during the frequency assignment process.

Therefore, it is obvious that the WinBASMS should be modernized to be more operable in considerably greater number of countries. In this context it is very important to relate WinBASMS modernization with AASMS development to obtain better optimization. Recommendation ITU-R SM.1604 – Guidelines for an upgraded spectrum management system for developing countries, can be referred to in this context.

This Recommendation and an action plan resulting from WTDC-02 is currently being used by the BDT to develop a replacement for WinBASMS to be named SMS4DC that should address all the currently identified deficiencies. It is hoped that this software will be available in time for WTDC-06.

ANNEX 2

TO CHAPTER 7

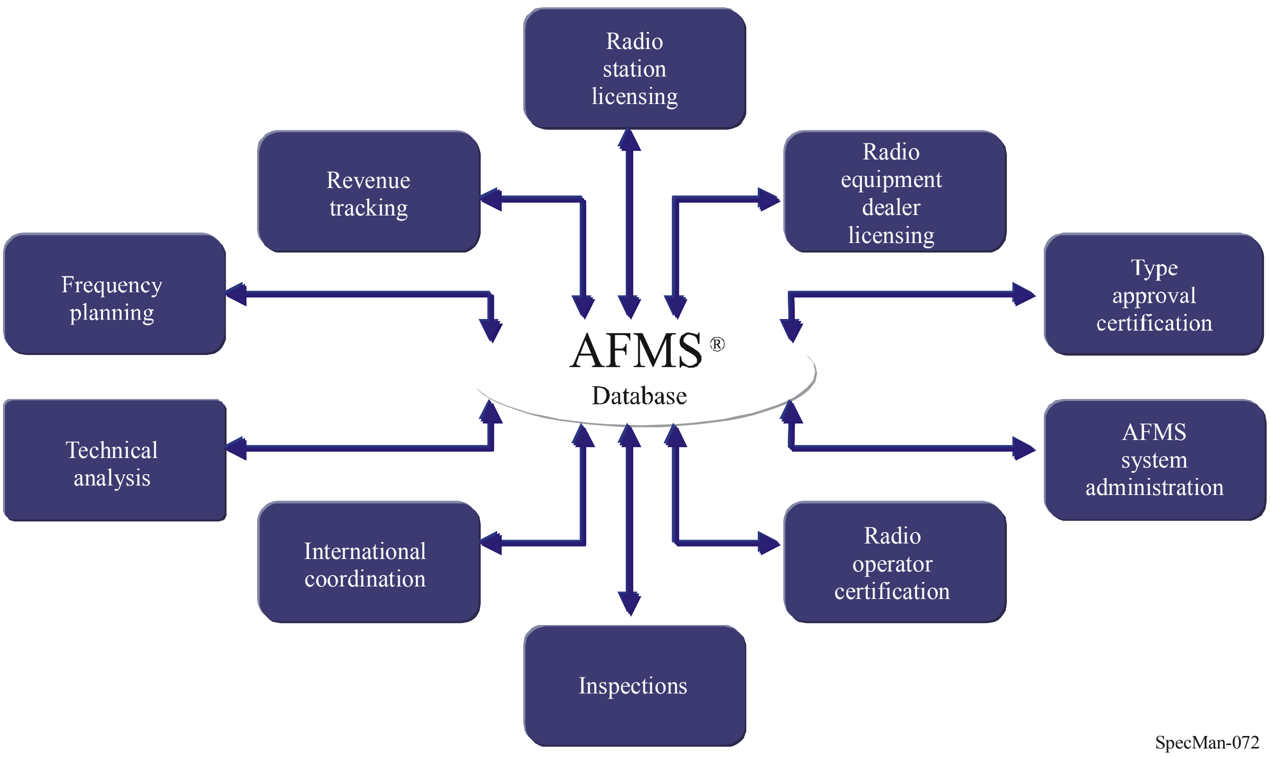
Radio spectrum management in Malaysia
(a case study)

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 Fig. 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 § 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 Fig. 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 Fig. 7.4.

FIGURE 7.3

Functional flow through of the management software

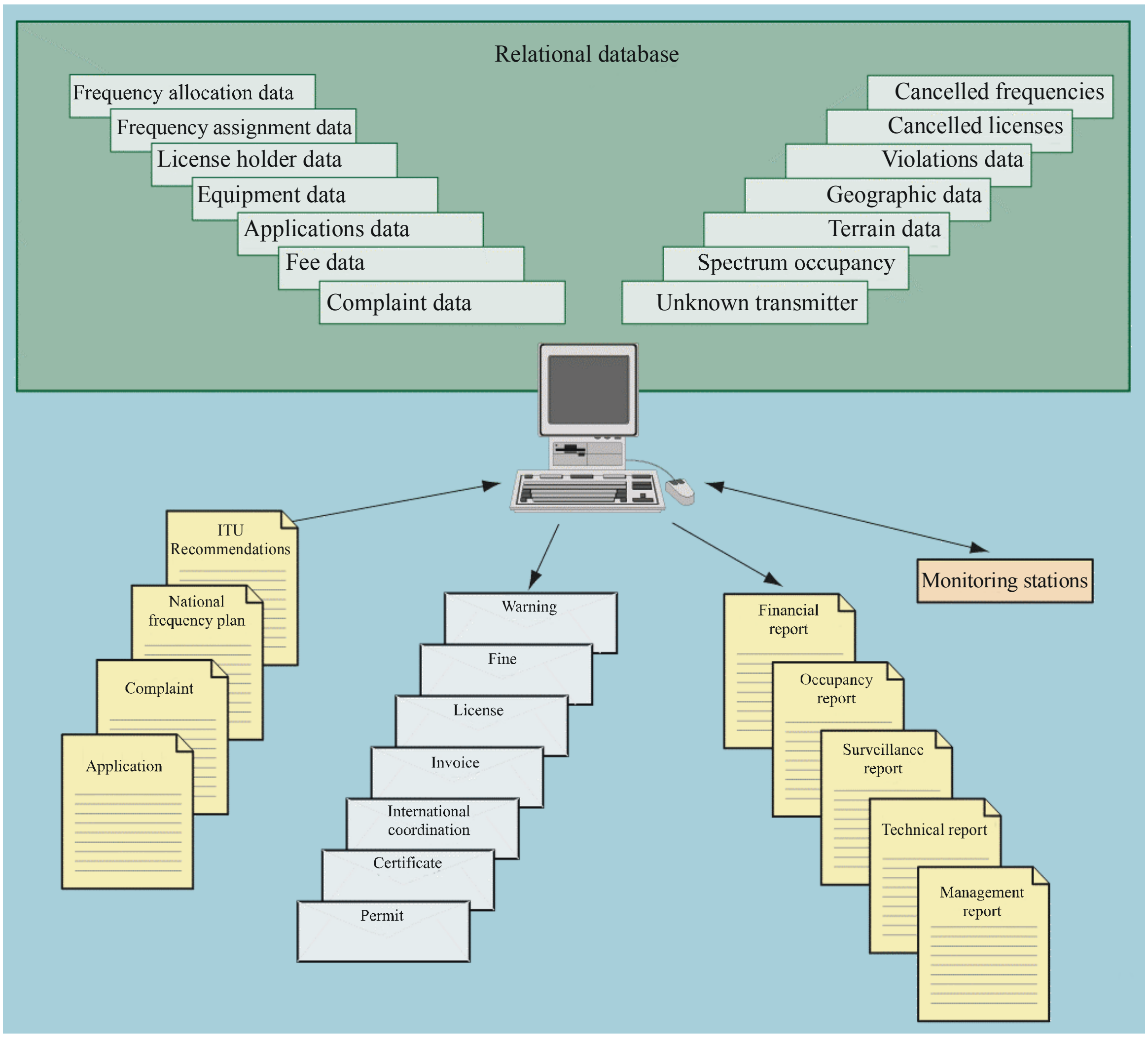


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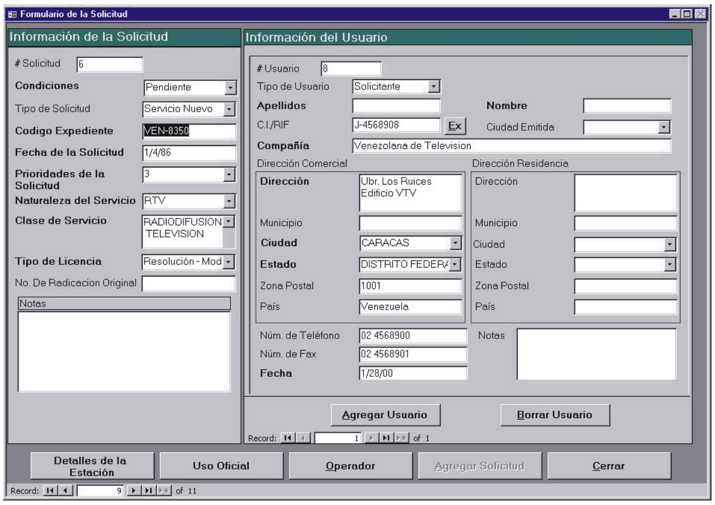
FIGURE 7.4

Application form



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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

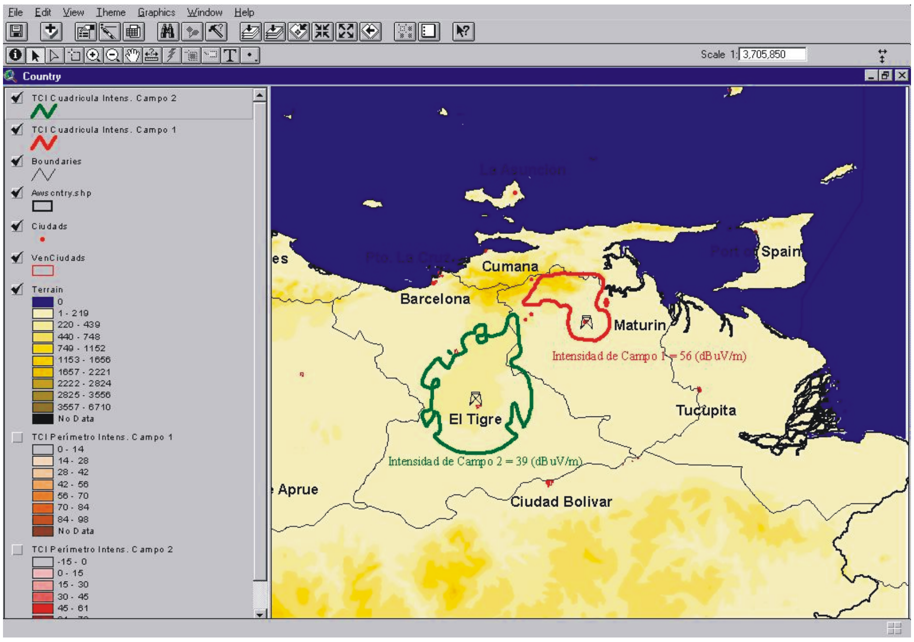
The spectrum engineering analyst accesses the spectrum engineering module to analyze the electromagnetic environment and obtain reports. On selecting a required report, the system presents a screen where the operator enters all the necessary parameters and then may select the format of the report (tabular 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 Spectrum Monitoring Handbook. 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

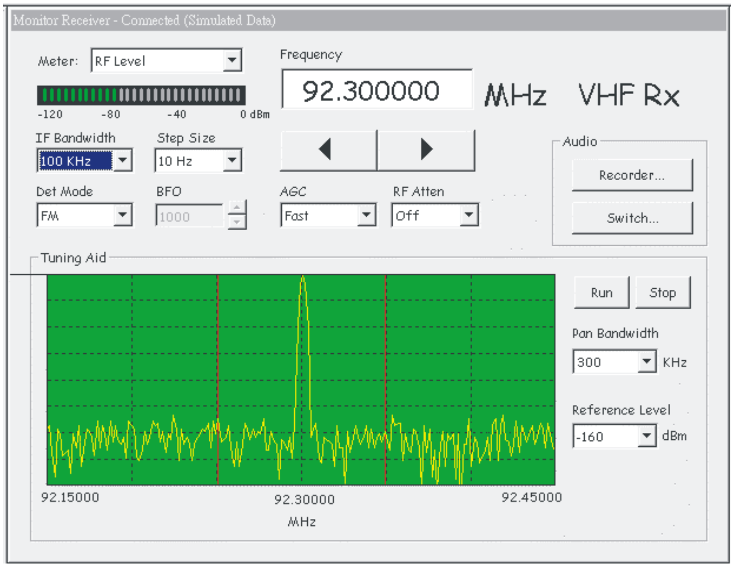
The map window displays the network monitoring stations, results of DF operations, and the locations of emitters (with error ellipses). The system is configured with multiple maps. The operator has the ability to display multiple layers (cities, regions, rivers etc.) of Venezuela by selecting the "Layers" 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), Fig. 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.

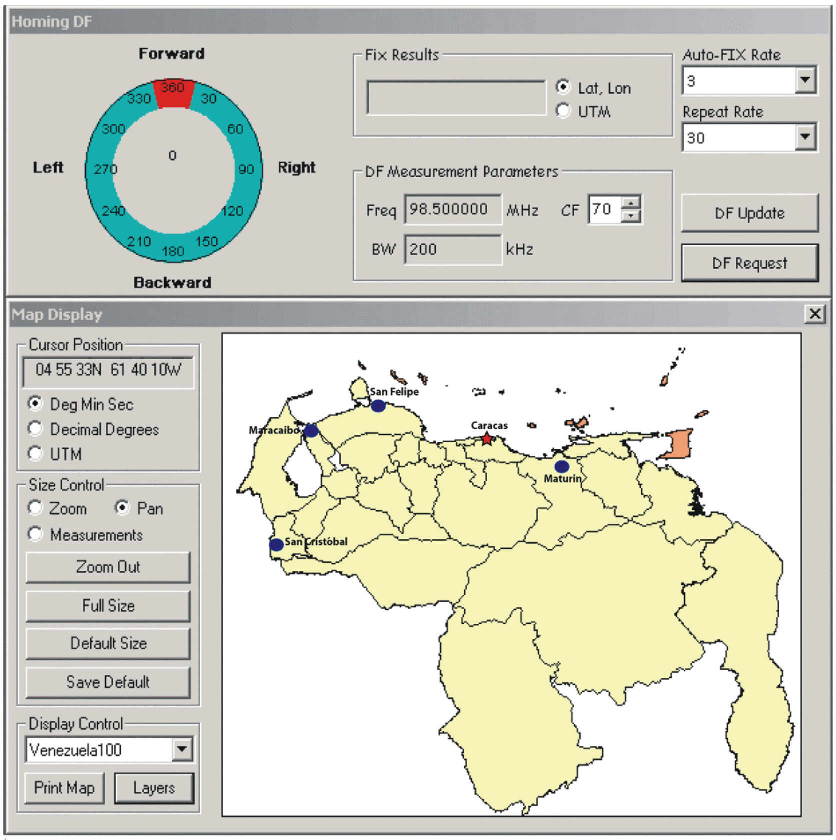
3.5 Direction finding (DF)

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 (Fig. 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.

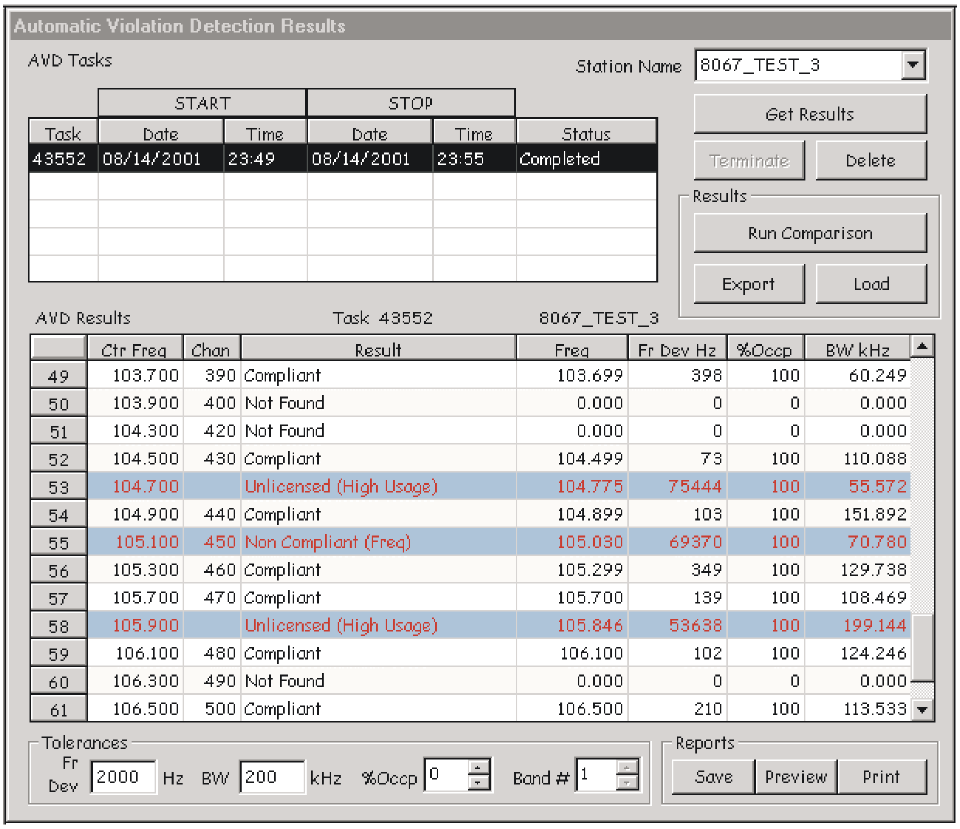
4 CONATEL's use of the system

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.

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.

[*] 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

- 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.

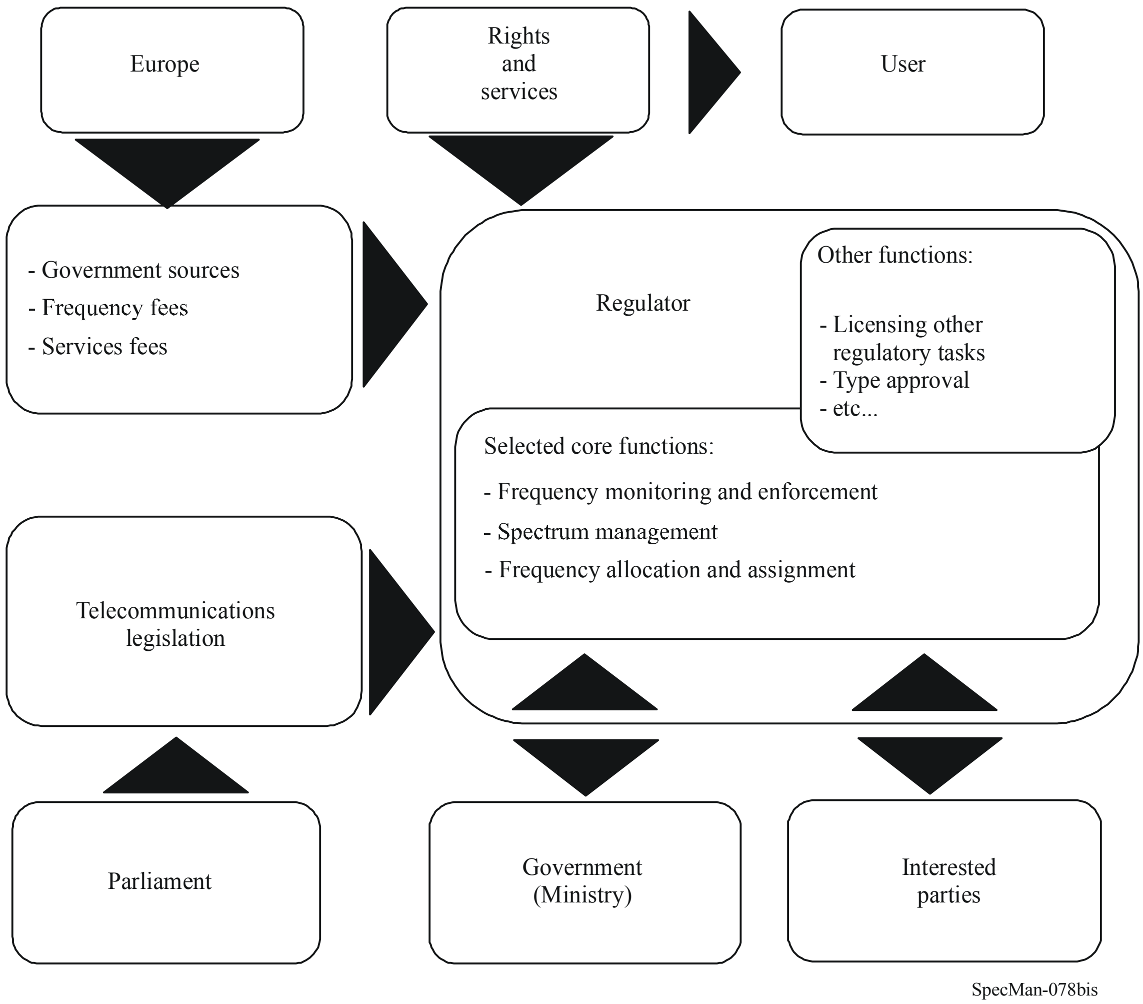
ANNEX 4

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.



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,

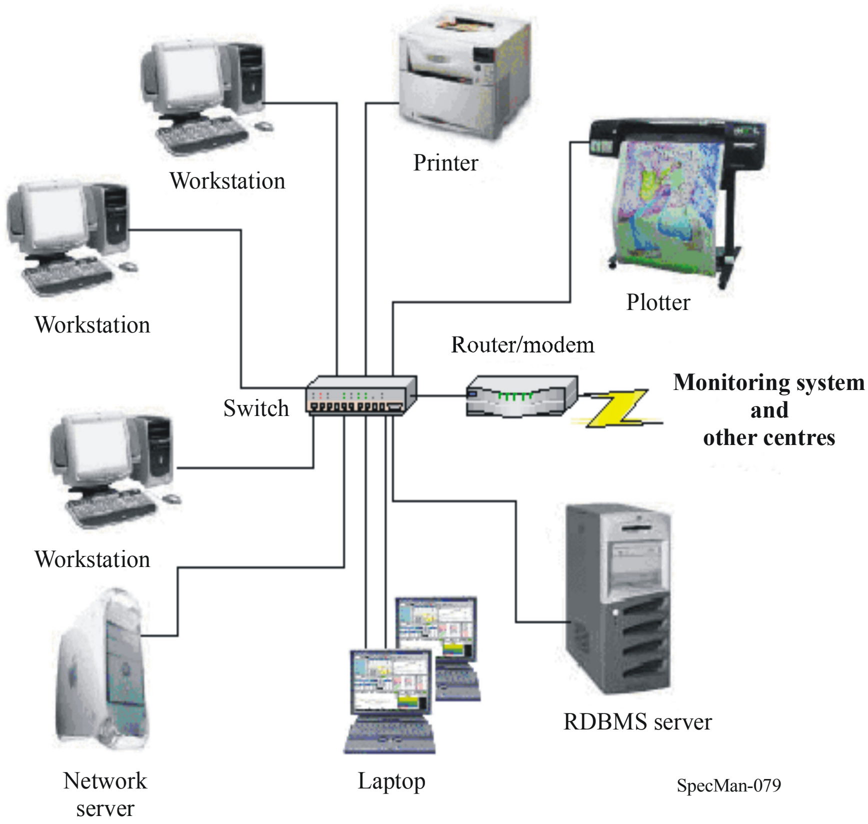
– *a support infrastructure layer*, consisting of operating system, database and database management system, and software tools intended to support application systems,

– *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.

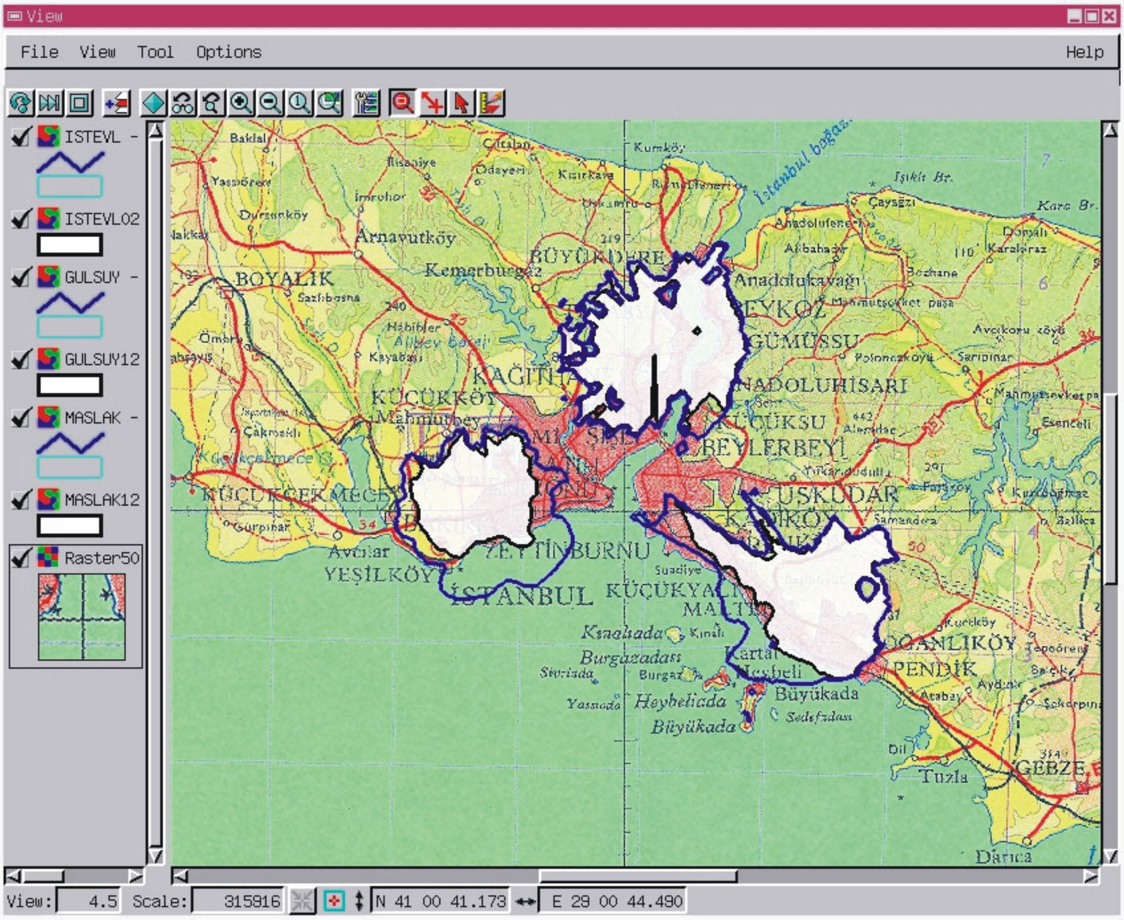
- Automatic calculation of candidate frequency assignments for land mobile circuits operating in HF band (2-30 MHz) by using the ICEPAC program developed by the U.S. National Telecommunications Information Administration (NTIA).
- In the border area, finding and displaying the stations on the map that 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 Fig. 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 & Authorization Licences Management

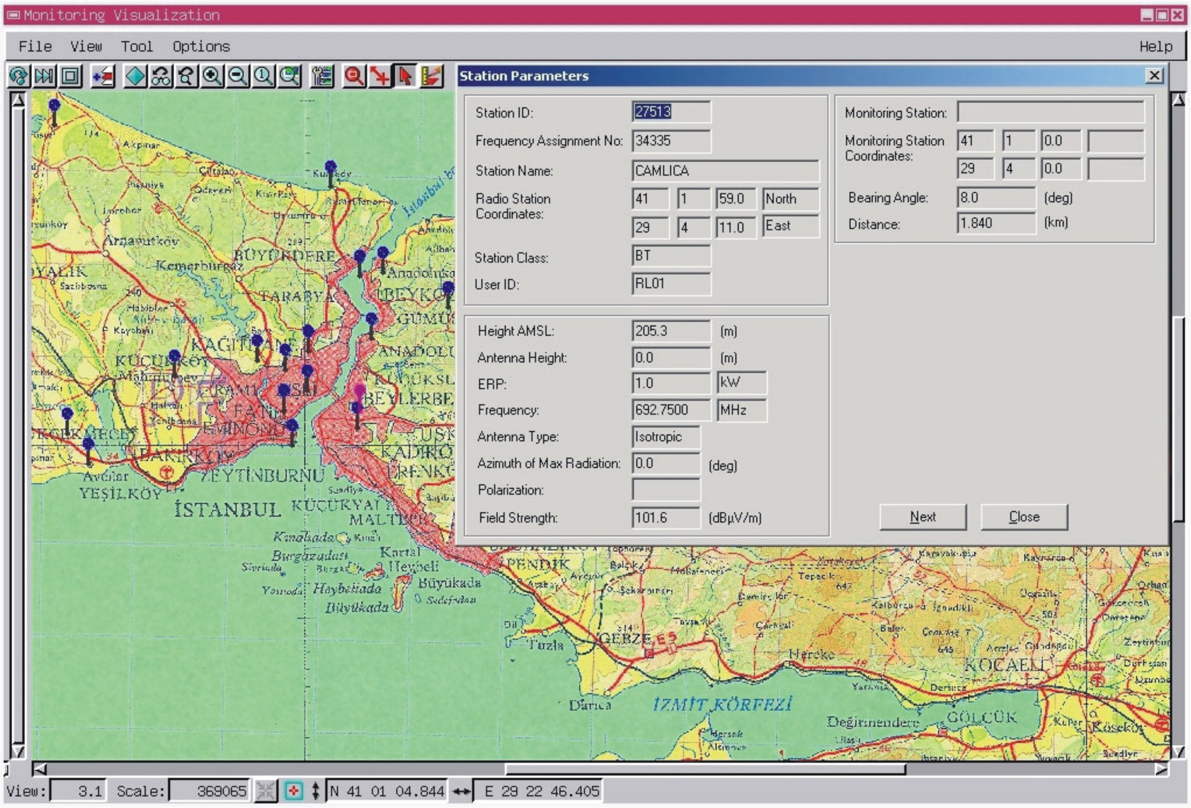
– System Control Management

– 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 Fig. 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[17] (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.

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[17] 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.

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.

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.

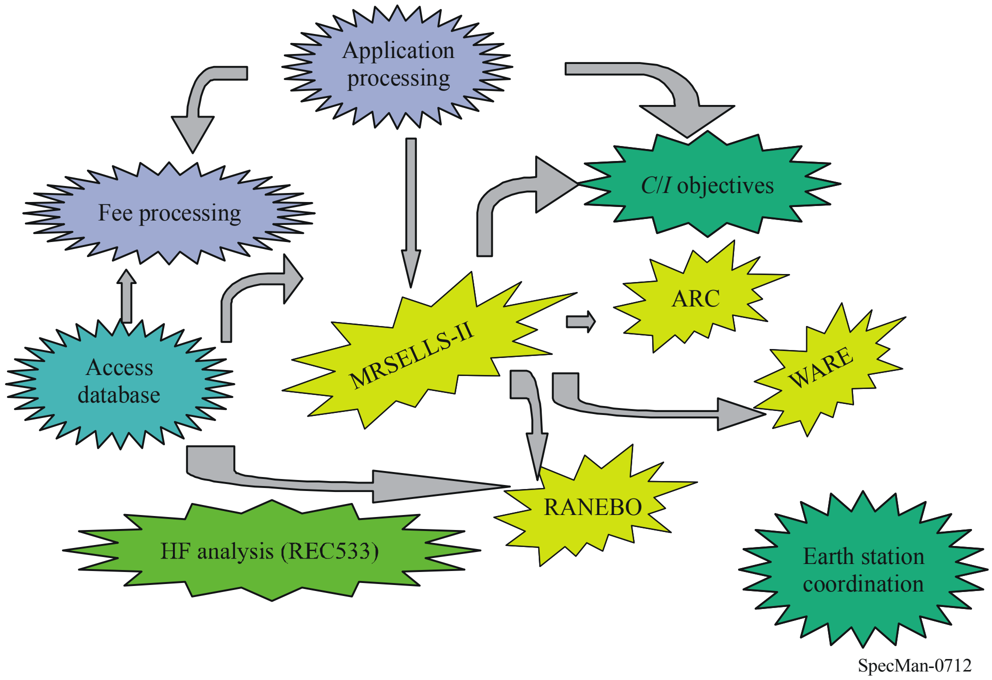
– *ITU-R:* Data pertaining to spectrum allocation, services definitions, etc. was derived from the ITU-R Radio Regulations, the ITU-R International Frequency List (IFL) and other ITU-R sources.

– *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



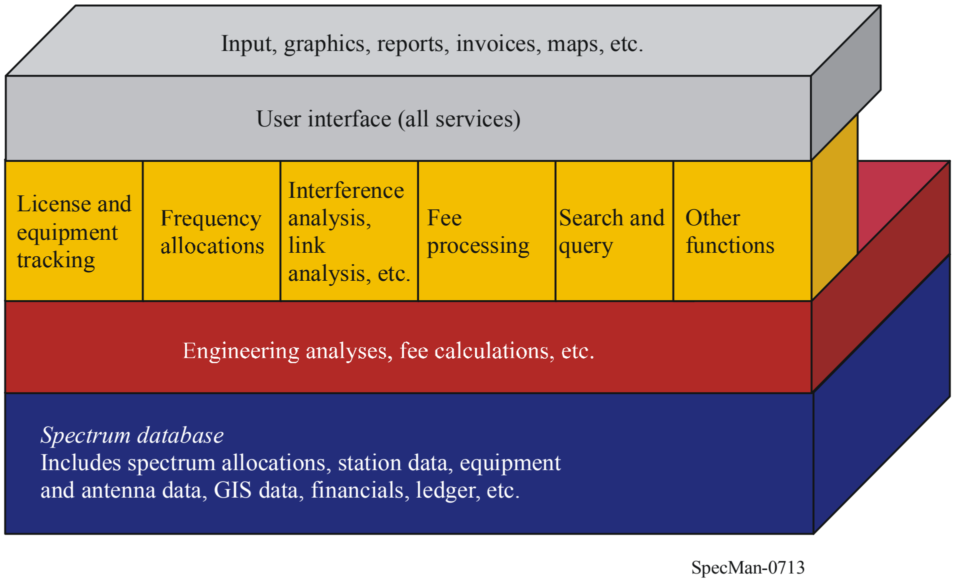
4 Toward a modern unified integrated system

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

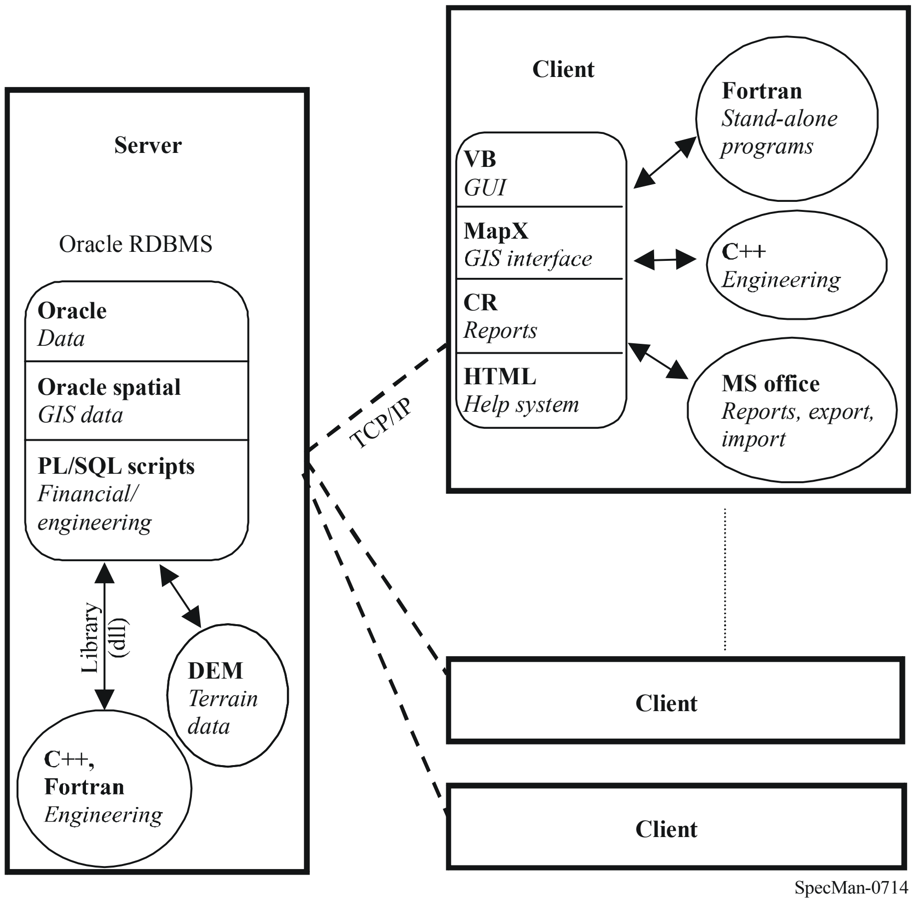


Figure 7.14 shows the architecture of the FMS. This system uses a modular architecture that facilitates customization and upgrading. For example, all numerical procedures are implemented as libraries with a defined application programming interface (API). Thus, Telcordia can update any engineering tool 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 Fig. 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.

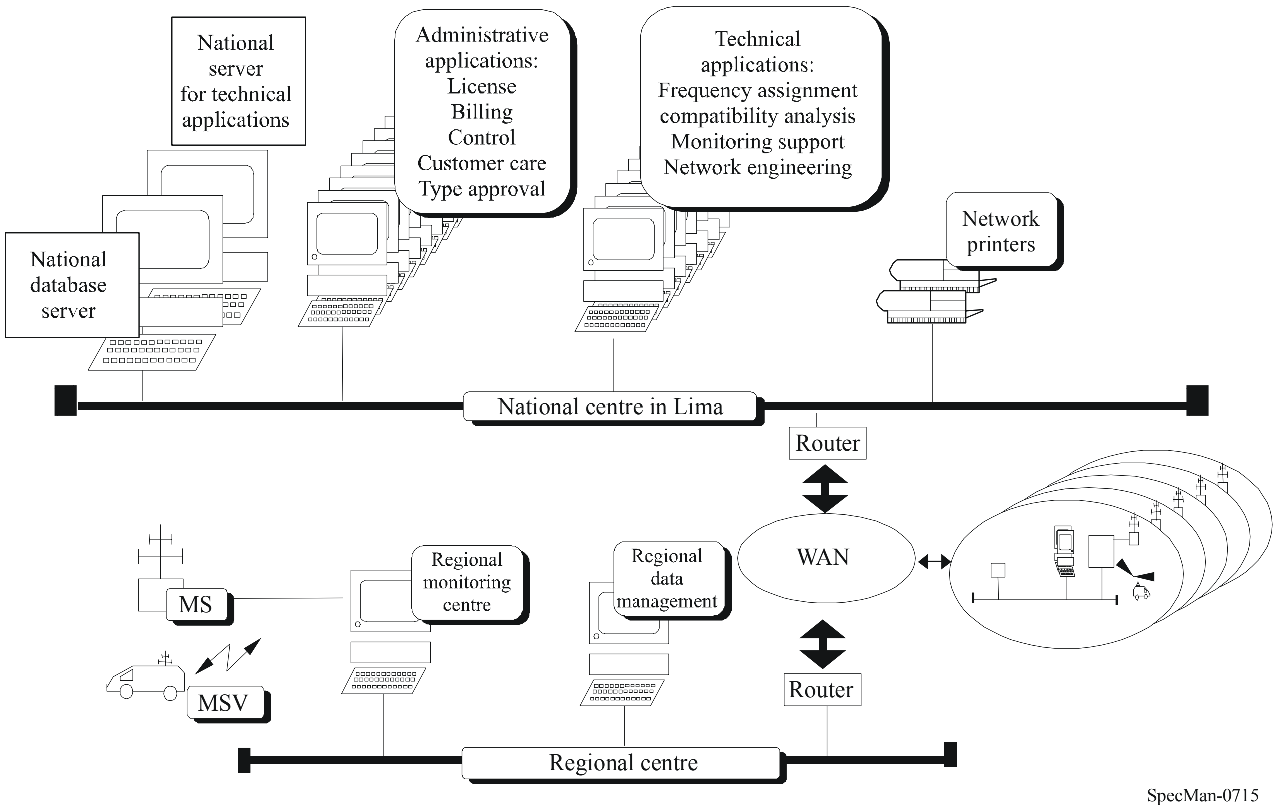
The Regional Centre include:

– 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 Spectrum Monitoring Handbook.

These activities are conducted in the country's capital Lima and some of them in 6 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.

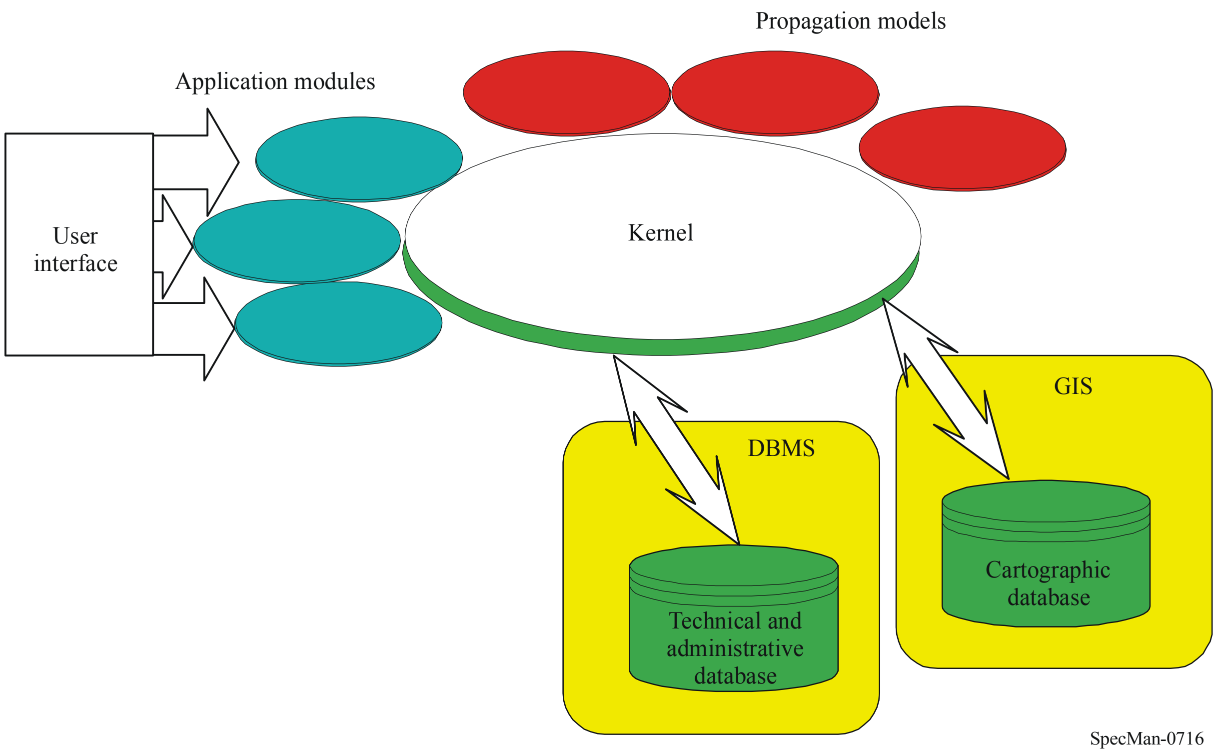
The main technical features of the system are:

- 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:

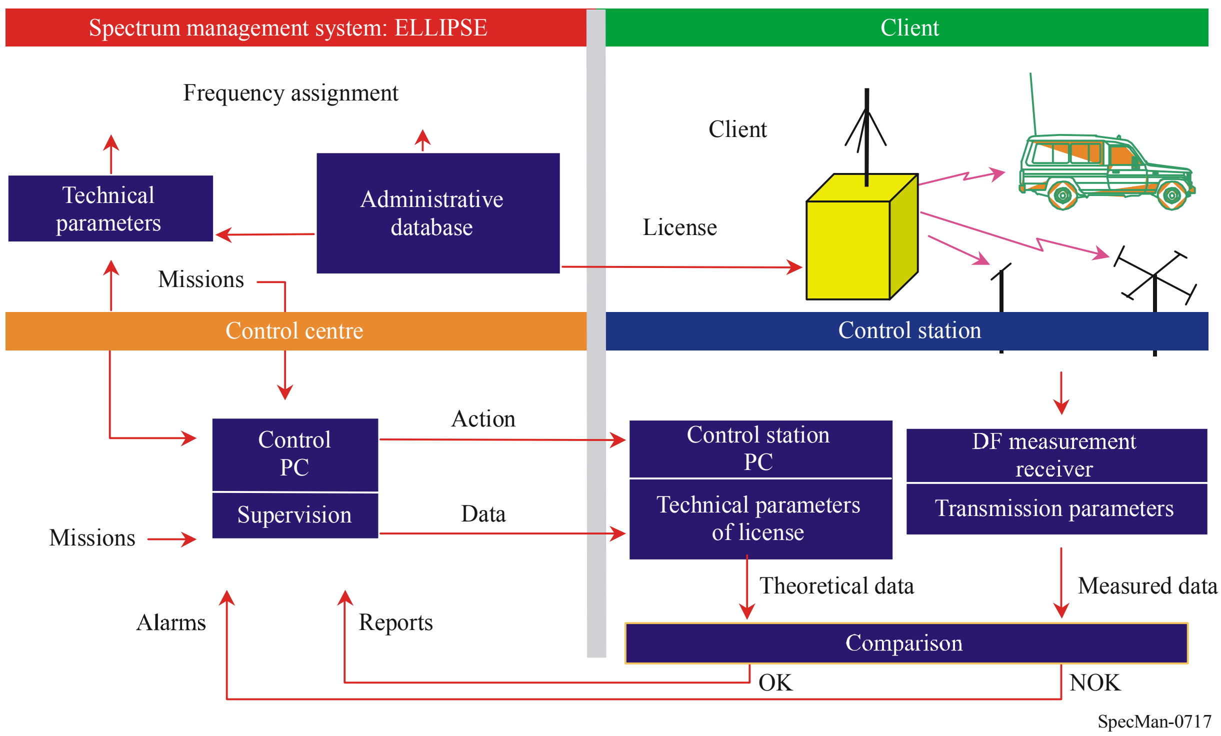
– Technical monitoring session at the initiative of the spectrum management system operator, or

– 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 7.7

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.

Bibliography

ITU-R Texts

Rec. ITU-R SM.1048 Design guidelines for a basic automated spectrum management system (BASMS)

Rec. ITU-R SM.1370 Design guidelines for developing advanced automated spectrum management systems

Rec. ITU-R SM.1537 Automation and integration of spectrum monitoring systems with automated spectrum management

Rec. ITU-R SM.1604 Guidelines for an upgraded spectrum management system for developing countries

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:

$$U = B \times S \times T \tag{8-1}$$

where:

U: amount of spectrum space used ($\text{Hz} \times \text{m}^3 \times \text{s}$)

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. Recommendation ITU-R SM.1536 describes the measuring techniques of such data. 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 (§ 8.2 and Recommendation ITU-R SM.1599), or the second method (§ 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 § 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:

$$SUE = M/U = M/(B \times S \times T) \qquad (8\text{-}2)$$

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:

$$C_0 = F_0 \ln (1 + p_0) \qquad (8\text{-}3a)$$

where F_0 is the bandwidth of the wanted communication, and p_0 is the 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:

$$C_p = F_m \ln (1 + p_s) \qquad (8\text{-}3b)$$

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 SUE's 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.

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:

$$\text{SQI} = \frac{\text{Total weighted occupied spectrum}}{\text{Total weighted (occupied + denied) spectrum}} \qquad \text{or}$$

$$\text{SQI} = \frac{\Sigma\,\Gamma(n)\,\beta_t(n)}{\Sigma\Gamma(n)\left\{\beta_t(n) + D_t(n)\right\}} \tag{8-5}$$

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 vs. FDMA/FM or digital vs. 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 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:

$$RSE = \frac{SUE}{SUE\ std} \tag{8-6}$$

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.

8.8.1 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):

$$P_s = (1 + p_0)^{F_0/F_m} - 1 \qquad (8\text{-}7)$$

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.

8.8.2 RSE example for the land mobile service

Referring to the definition of RSE in equation (8-6), 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:

$$\beta_t(n) = \mathrm{C}\ O_t(n) \tag{8-8}$$

– Spectrum units demanded in the (i)th channel in the (n)th square are approximated by:

$$\beta(n,i) = \mathrm{C}\ O(n,i) \tag{8-9}$$

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:

$$\mathrm{RSE} = \frac{\text{Weighted actual occupancy}}{\text{Weighted NOAS occupancy}}$$

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.

8.9 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.

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Rec. ITU-R SM.1269	Classification of direction finding bearings
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
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Rec. ITU-R SM.1542	The protection of passive services from unwanted emissions
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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

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 § 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 § 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 § 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 discussed in Recommendation ITU-R SM.1370 – Design guidelines for developing advanced automatic spectrum management systems (latest version), and in § 2.8 of the ITU-R Spectrum Monitoring Handbook, Geneva 2002.

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.

Recommended 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 recommended 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, as does the program outlined in Recommendation ITU-R SM.1370.

The staff described in § 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 Recommended 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 advanced automated spectrum management system (ASMS) to assist administrations with their spectrum management responsibilities. The Recommendation lists topics which should be covered in a training course on the ASMS. The duration of recommended course modules is considered appropriate for training on the use of automated spectrum management systems such as described in Recommendation ITU-R SM.1370. Training duration may be substantially longer in most cases when the general subject of spectrum management is being taught, especially to an audience of prospective spectrum managers new to the subject.

The training recommended in Recommendation ITU-R SM.1370 is a useful example of basic training. The incorporation into an organization of new staff is a continuous process. Administrations generally incorporate fresh graduate engineers and train them either through their training centres or by assigning them to different departments for short durations to get the feel of the whole spectrum management process. Training of these new staff can be in accordance with the training guidelines of Recommendation ITU-R SM.1370.

The following list provides a summary of the recommended training in Recommendation ITU-R SM.1370:

Spectrum management applications (1 day). Includes an introduction to spectrum management, and understanding the role of a spectrum management system

Understanding the spectrum management system structure (1 day). Includes discussions of system structure and subsystem integration.

Understanding and using the spectrum management subsystems (10 days). 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 (1.5 days). 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 (3 days). 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 (5 days). Includes introduction to technical analysis and detailed instruction in performing technical analyses.

Understanding/performing international coordination (1 day). Includes notification and registration of frequencies, performing international coordination, queries and reports.

Understanding the user management process (0.5 day). Includes definition of vendors, understanding certification and registration process, and understanding vendor licensing fees.

Understanding the equipment type acceptance process (0.5 day). Includes understanding the type acceptance function and process.

System administration (5 days). Includes understanding and performing system and network configuration, backup and recovery, and database administration, and understanding system access and security.

Database administration tools (5 days). Includes understanding the function and use of RDBMS, using SQL language and using data browsing utilities.

The inspection system (2 days). Comprises understanding and uses of the inspection subsystem.

Maintaining and using licensing system reference tables and codes (2 days). Describes the different types of codes, and the use of each of the code tables.

Understanding the monitoring and direction finding function (10 days). 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 Australia, Canada, France, Germany, United States of America, Italy, Japan, Portugal and the United Kingdom offered in Resolution ITU-R 23-1 (RA-03) 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, USA; Spectrocan, Canada and LStelcom, Germany; and Thales, France, 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 Centres of Excellence and Virtual Training Centre described below. In addition, the Radiocommunication Seminars facilitate training.

4.1.1 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/ITU-R/conferences/seminars/index.html) and can be made available after the seminar upon request, for training purposes within administrations. Such seminars are also occasionally planned in different regions.

4.1.2 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).

4.1.3 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/new/english/index.html) conducts NSM courses to train engineers, lawyers and economists that serve in the Ministry of Communications, or to teach other experts who are connected to NSM. The website provides the content and timetable of the five-days training. The course has been conducted in Israel and in more than 26 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.

4.2.5 The Telecommunications Executive Management Institute of Canada (TEMIC)

TEMIC (http://www.temic.ca), a non-profit organization was created in 1986 by the Government of Canada in response to the Maitland Commission report. The Institute offers a range of Telecommunications training seminars for senior managers from both the public and private sectors. TEMIC is supported by the Canadian government, a number of private sector organizations as well as the ITU. Its tuition-free training is provided in French, English and Spanish.

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-R Spectrum Monitoring Handbook (Geneva, 2002).

Rec. ITU-R SM.1370	Design guidelines for developing advanced automated spectrum management systems.
Resolution ITU-R 23-1	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.

* This attachment provided by TCI (www.tcibr.com).

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.

– 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 – To understand the general principles of Spectrum Management.

Overview of the Spectrum Management System (SMS) Software.

Operation of the System.

Allocation of Frequency Spectrum for Use in Various Commercial and Consumer Requirements.

– Data Entry – To understand the data entry process used in the SMS System.

Combination of lecture and hands-on use of the system and processing of applications.

– Licensing and Administration – To be able to evaluate a license application for approval and manage complaint resolution.

Thorough understanding of the application and licensing process and conformance with required procedures.

– Frequency Assignment, Technical and Engineering Analysis – To understand 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.

– Fee Calculation – To understand the fee calculation process.

Lecture and hands-on processing of required fees.

– System Management and Administration – To enable the System Managers to maintain and troubleshoot Standard Software.

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 as follows:

– Monitoring Operation Training (includes both Fixed and Mobile Units) – To enable operators to effectively perform daily monitoring assignments.

System Hardware Overview, including: Abbreviated Block Diagram of Mobile and Fixed Stations; Difference between Mobile and Fixed Stations.

Spectrum Monitoring Software, including: Terminology and Concepts; The Operating System; The Client/Server-based System; Starting the Software; Exploring the Software; Overview of Interactive Measurements; Overview of Automatic Measurements; Alarms and Scheduling; Evaluating Monitoring Results; Diagnosing and Reporting Problems; Direction Finding.

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 as follows:

Maintenance – To enable technicians to troubleshoot and repair system components.

Block Diagram.

Overview of Calibration, Diagnostics and Error Messages.

Diagnostics and Error Messages.

Calibration.

Field Replaceable Unit Repair and Replace.

Preventive Maintenance.

ATTACHMENT 2

TO ANNEX 1

Spectrocan and LStelcom training programs*

1 Training program

Spectrocan, Canada has merged with LStelcom AG, Germany and the combined company offers a wide variety of training courses, professional workshops and seminars that address all aspects of Spectrum Management and Spectrum Engineering.

As part of its training activities, the Company participates in the Telecommunications Executive Management Institute of Canada (TEMIC) to sponsor representatives from developing nations to come to Canada on extended training leave. In addition, to enhance and formalize the training services to developing nations, the Company also 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 Canada, or 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

* This attachment provided by Spectrocan, Canada (www.spectrocan.com) and LStelcom, Germany (Lstelcom.com).

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

– 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.

* This attachment provided by Thales (www.thalesgroup.com) and Cril Telecom Software (CTS) (www.criltelecom.com).

– 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).

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

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[18] 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,

   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

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[18] Whenever the term "services" is used in this Handbook, it means applications and recognized radiocommunication services.

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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Printed in Switzerland
Geneva, 2005
ISBN 92-61-11301-X