Radio Spectrum Management: Overview and Trends

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Introduction

This paper has been prepared by the authors in conjunction with their work on the Spectrum Management module of the International Telecommunication Union (ITU) and the World Bank's Information for Development Program (*info*DEV) online ICT Regulation Toolkit project. The Spectrum Management module is intended to give readers a foundation of spectrum management concepts and issues, including a review of differences between traditional spectrum management methods and recent innovations and practices. The approach taken is more descriptive than prescriptive, allowing readers to make up their own mind on various perspectives. The authors have found that there are no standard solutions that fit every situation. Spectrum managers need to consider options and the national context when making choices on which approach to take. To aid decision makers, the toolkit includes examples of what is actually being done as illustrated through practice notes and reference documents.

This paper covers the most important concepts as well as issues of policy and standards in a broad range of spectrum management areas. These are further developed in the seven sections of the Spectrum Management module: Overview of Spectrum Management, Spectrum Policy and Planning, Authorization, Spectrum Pricing, Spectrum Monitoring and Compliance, International Affairs, and Developing Spectrum Management Organizational Capacity and Tools.

The Radio Spectrum as a Resource

The radio spectrum is used for a wide range of economic, social, cultural, scientific and developmental purposes with an enormous number of end-user services: communications for firms, households and public bodies, including critical safety and security communications used by defence forces, emergency services and air traffic control; various kinds of radar; broadcasting; scientific

research and so on. From an economic viewpoint, the spectrum is a resource used by a wide range of entities, including public bodies such as defence or emergency services, for a number of applications, including narrow and broadband mobile telecommunications, broadcasting, aeronautical and marine communications, and scientific applications such as radio astronomy and environmental sensing.

From a technical viewpoint, the radio spectrum is the portion of the electromagnetic spectrum that carries radio waves. The boundaries of the radio spectrum are defined by the frequencies of the transmitted signals, and are usually considered to range from 9 kHz(kilohertz; thousand cycles per second) up to 3000 GHz (gigahertz; billion cycles per second). The key characteristics of the spectrum are the propagation features and the amount of information which signals can carry. In general, signals sent using the higher frequencies reach shorter distances but have a higher information-carrying capacity. These physical characteristics of the spectrum limit the currently identified range of applications for which any particular frequency band is suitable.

The spectrum as an economic resource is unusual in that it is both non-exhaustible and non-storable. Unlike oil and water, it will never run out, although it may become increasingly congested. Also, it cannot be accumulated for later use. These factors put a premium on a streamlined process for making spectrum available for purposes which are useful to society. In fact, because spectrum has so many uses, arbitrating among them in cases of shortage can be difficult.

Effective spectrum management can make a big difference to a country's prosperity, especially as wireless technologies have become the main means of connecting businesses and households to voice, data and media services.[1] It is becoming increasingly evident that as developing countries address broader issues of communication and information policy and regulatory reform, wireless services are outpacing wireline connectivity and the spotlight is focusing on the current modes of spectrum management. In a globalizing world with rapid technological innovation and increasing demand[?] for radio frequencies, effective spectrum policy should therefore be promoting the roll-out of services and reduction of barriers to entry and to innovation.

[1] ITU (2002), Geneva. World Telecommunication Development Report: Re-inventing Telecoms, Executive Summary. 2002 marked the year there were more mobile subscribers than fixed-line worldwide in over 97 (mostly developing) countries.

As a resource, the spectrum has both technical and economic dimensions: Section I of the Module provides more detail to the following brief definitions.

- Economically efficient use of spectrum, as a starting point, means the maximisation of the value of outputs produced from available spectrum including the valuation of public outputs provided by the government or other public authorities.
- Technically efficient use of spectrum, at a basic level, implies the fullest possible use of all available spectrum. Two measures of technical efficiency are occupancy and data rate. Time, for example, can be used as a measure of technical efficiency, in the sense of how constant or heavy the usage of spectrum is over time. Data rate, means how much data and information can be transmitted for a given amount of spectrum capacity

What is Spectrum Management?

Spectrum management is an extremely important part of telecommunications policy and regulation. The spectrum is allocated for particular uses, and specific technical and service rules, developed by spectrum managers, govern those allocations and as a result are a crucial determinant of the structure and performance of industry and of institutions devoted to ensuring public safety, security and national defence.

There are four main areas of work in spectrum management: planning, engineering, authorization and monitoring; these are briefly described below.

- Spectrum planning involves the allocation of portions of the frequency spectrum to specified uses in accordance with international agreements, technical characteristics and potential use of different parts of the spectrum, and national priorities and policies.
- Spectrum authorization involves granting access under certain specified conditions to the spectrum resource by various types of radio communication equipment and the certification of radio operators.
- Spectrum engineering involves the development of electromagnetic compatibility standards for equipment that emits or is susceptible to radio frequencies.
- Spectrum monitoring and compliance involves the monitoring of the use of the radio spectrum and the implementation of measures to control unauthorized use.

What are the Economic and Technical Objectives of Managing Spectrum?

Broadly speaking, the goal of economic activity is to provide goods and services to end-users – whether bought in the market place or provided to the public by governments. Spectrum is an input into the services that end-users (households, firms and public agencies) value. In defining high-level objectives for spectrum policy, it is thus sensible to take as a starting point the maximization of value of outputs produced by the spectrum available, including the valuation of public outputs provided by the government or other public authorities.[2]

Allocation of scarce spectrum to different uses should be done in a way that the marginal economic benefit of additional spectrum is the same for every use. Some important conclusions follow from this objective. Suppose a given quantity of spectrum is available for use in only two sectors, mobile communications and commercial broadcasting. How should it be divided between the two uses? Some kind of compromise is required among the value users place on both services, the cost of providing these services and the amount of spectrum used by them. In turn, relating the use of spectrum to its value pressures all users, private and public, to make more efficient use of their allocated spectrum, thereby freeing up more spectrum for use generally. From an economic efficiency viewpoint, the spectrum should be divided in such a way that the benefits to the economy at large from an additional amount of assigned spectrum are the same in each use. Market-based approaches such as auctions and spectrum trading are viewed as superior ways of achieving economic efficiency in assignment than administered methods. The Spectrum Management Module provides a more detailed discussion of economic objectives and their implications.

At first glance, technically efficient spectrum use commends itself as a self-explanatory benefit. Indeed, technical efficiency may rationally count as the leading factor in spectrum allocation decisions. Applying the matter in practice, however can, bring competing policy goals into play.

Occupancy and data rate are two measures used in determining how efficiently certain assigned frequencies are being used by services and users. In practice, however, both of these measures have problems. Some uses are crucial, yet only occasional. In the absence of procedures for sharing spectrum with other users, which may be very costly to implement, capacity which is often left

[2] United Kingdom, Ofcom. Spectrum Framework Review: A Consultation on Ofcom's Views as to how Radio Spectrum should be Managed, November 23, 2004.

unused may be essential for such public safety services. Equally, the data rate measures fail to take account of the value of the information being carried. A meaningless jumble might be sent very efficiently, but it would still be a meaningless jumble. This suggests that such measures make little sense, as they abstract from the key element of economic calculation concerning the value of the service which the spectrum is being used to produce. The Spectrum Management Module provides a more detailed discussion of technical efficiency objectives and their implications.

Even though spectrum management is ultimately in the interests of private and public end-users, there are many more stakeholders involved in the sector. Examples of those using spectrum include equipment manufacturers, technology companies, public sector users and others, all of whom can be affected by spectrum management decisions. It is essential that the processes employed to regulate spectrum use are efficient for all users. Knowledge and expertise of affected users are required. The regulator will have to face the challenge of balancing the needs of all stakeholders with differing sectoral interests.

How is the Spectrum Managed?

At the national level, spectrum management can be undertaken directly by government, as part of a ministry, or by an independent regulator operating under a legislative mandate or policy guidelines. It can also be managed by industry on a self-regulating basis or be assigned to a band manager. Band managers can be in the business of leasing on a for-profit basis valuable spectrum to third parties. Under proposed Federal Communications Commission rules a band manager is granted a license under which the manager will allow others to construct and operate stations at any available site within the licensed area and on any channel for which the band managers is licensed. The preferred option depends upon a nation's historical and institutional circumstances. The key question being what delivers best on objectives.

The governance arrangements for spectrum regulators differ throughout the world, but broadly fall into two categories:

- The regulator is an independent agency, normally established by statute, with specified powers and responsibilities; or
- The regulator is part of a government ministry.

Good governance involves transparent arrangements for accountability and fairness. While decisions on spectrum allocation (among uses) and assignment (to individual users) inevitably reflect public policy objectives, government or political interference in detailed decisions, such as which firm should receive a particular licence, should be avoided. The reward for such forbearance is enhanced investor confidence and, ultimately, more and better services for end-users. Whether an independent agency or a government body is better for spectrum regulation will depend on particular circumstances. In some countries, agencies may be more susceptible to capture by special interests; in others, governments. It is therefore difficult to propose a single rule.

The governance of spectrum use on a global basis is a core responsibility of the International Telecommunication Union (ITU) and in particular, its Radiocommunication Sector (ITU-R). The mission of the ITU-R sector is, *inter alia*, to ensure rational, equitable, efficient and economic use of the radio frequency spectrum by all radio communication services, including those using satellite orbits, and to carry out studies and adopt recommendations on radio communication matters. The ITU is a specialized agency of the United Nations. It is not a global authority in the manner of a national regulator, since the international rules are written by those governed by them, i.e., the member states of the ITU. These rules are administered by the ITU's Radiocommunication Bureau (BR) and conformity with the rules is based on goodwill and supported by regulations at the national level.

In addition to activities carried out within the ITU framework, there are often bilateral and multi-lateral agreements by which the use of spectrum is harmonized across national borders. There are two types of international activities; project activities and transactional activities. International project activities are those which have a defined beginning and ending date such as the World Radiocommunication Conference – 2003 (WRC). Like all types of project activities, tasks and sub-tasks can be defined and milestones established. Transactional international activities such as frequency coordination requests, elaborated on further below, are of an ongoing nature. These activities are described in more detail in Section 6 of the Module: International Affairs.

Some spectrum management functions (for example, enforcement of licences or engineering work) can be outsourced or "contracted out" to private bodies or even to organisations in other countries. This should be determined on the basis of how the functions are most efficiently performed. The

Spectrum Management Module provides a fuller discussion of the potential and options for outsourcing.

Traditional Approaches and Recent Innovations to Spectrum Management

Historically, regulators have assigned frequencies by issuing licences to specific users for specific purposes, limiting access to and use of radio spectrum. This is referred to as the administrative approach to spectrum management which can be prescriptive as to the details of how spectrum is used and, with good planning, how interference amongst uses can be controlled. This reflects the joint concerns of governments to coordinate frequency use internationally and to avoid interference at a time when radio technology was in its infancy. But the last decade has seen significant innovation in the theory and practice of that regulation. This gradual change follows a growing consensus that regulatory practices originally intended to promote the public interest may, in some cases, have in fact delayed the introduction and growth of new beneficial technologies and services, or artificially increased the cost of service. Significant growth in demands made on spectrum and the resulting need for technically efficient use have given rise to policy makers and regulators worldwide focussing anew on spectrum regulation and reform. There is renewed emphasis on striking the best possible balance between the certainty of interference-free spectrum to encourage a stable roll-out of services and flexibility to allow improvements in cost, services and technologies to spread more readily to consumers and public services.[3]

At this stage in the discussion it is important to emphasize a key feature of the administrative method, which is that restrictions on allowable uses are made by the spectrum manager. Potential users of spectrum can make proposals for allocations, for example, for new communication technologies, but without the allocation being made, matters cannot progress further.

As can be expected, such methods are often slow and unresponsive to new technological opportunities. It requires a level of knowledge and foresight on the part of the spectrum regulator which is often more assumed than real. Attention has recently focussed on creating genuine markets for spectrum and spectrum licences under which both the ownership and use of spectrum can change in the course of a licence's operation. This is a major step beyond the typical auctioning of licences

[3] Falch, Morten (2004), Technical University of Denmark. Economical versus Technical Approaches to Frequency Management, *Telecommunications Policy* Vol. 28, pp. 197-211.

which are not subject to trading and change of use. It does, however, require the full specification of what 'property rights' to spectrum can be traded and utilised.

Market methods are employed both at the initial issue of spectrum licences, such as when auctions are used and, more significantly, when users have been authorized to buy or sell spectrum rights in the lifetime of a licence (trading) and permitted to change the use of the relevant spectrum to different services (sometimes called liberalisation).

It is generally believed that with a greater number of spectrum users, a more competitive market exists and there is less need for regulating end-users. The design of the assignment mechanism and of associated conditions of use is crucial to the establishment of infrastructure-based competition. The assignment mechanism can shape the market structure by dividing up the spectrum and limiting the amount that any one user can acquire.

Some spectrum, especially for short-range use (wireless LAN, radio frequency identification devices, microwave ovens, various remote control devices, wireless security systems) need not be licensed at all, either because users seldom interfere with one another or because new technologies can be employed which are capable of dealing with interference as it happens. Unlicensed spectrum was previously of little interest. However, in the last five years it has been debated more widely. This has been made possible by several technological developments:

- Deployments of new technologies in the 2.4 GHz band, particularly W-LANs, have been commercially successful, leading many to ask whether further unlicensed allocations would result in more innovation and deployment.
- The development of ultra wideband (UWB) and the promise of software-defined radio (SDR) have led some to question whether these technologies can overcome historical problems with unlicensed spectrum.

If such coexistence can be achieved, a spectrum commons may be desirable. The Spectrum Management Module provides a comprehensive discussion of the technology and market factors affecting the use of a spectrum commons.

Regulators should look for the right balance among the three methods of administrative assignment, market factors and spectrum commons. The choice will be based on such things as the general scarcity of spectrum in various parts of the country and portions of the spectrum, the human and financial resources available to the regulator, the types of use — commercial or public service, and opportunities for innovation and commerce. The growing recognition that spectrum regulators may not be able to collect and process the information needed to make plans for efficient administrative assignments is one of the factors promoting spectrum reform throughout the world.

While the international framework for the utilization of the radio frequency spectrum is set out in the ITU's Radio Regulations, there is considerable flexibility within this framework for the establishment of spectrum policies at the national level. At the national level, determining who may use the spectrum within a given country requires a certain degree of planning, the extent of which depends on how much the regulator wishes to rely on the market. The greater the reliance on the market, the less planning is required.

What is Meant by Spectrum Planning?

It might be helpful to clarify what 'planning' means as the term can mean different things to different people. Ensuring efficient and effective use of the spectrum resource requires planning. The goal should be to ensure that spectrum is available when it is needed. Plans, at whatever level of detail, should be written, have specific objectives, and the results obtained should be reviewed against these objectives. Plans should be regularly updated.

It may be useful to think in terms of planning undertaken for long-term, medium-term and short-term timeframes[4]:

- Long range (strategic) planning (10+ years) is required to foresee spectrum requirements far into the future. Such long-term planning must take into account the need to accommodate uses that may not have been predictable at the time of inception.

[4] ITU (2005): Geneva. The National Spectrum Management Handbook - Section 2.10 (www.itu.int).

- Medium-term planning (5 to 10 years) is needed to determine what changes should be made to regional, sub-regional, national and local spectrum policies to meet the changing needs of users and evolving technology that have already been identified.
- Finally, short-term planning (anything under 5 years) is important where, depending on the nature of spectrum governance in place, changes to spectrum policies can be made to adjust earlier decisions.

It is critically important to know what the current uses of spectrum are before one can plan for the future uses. Developing a National Table of Frequency Allocations is one of the first steps in long and medium-term planning. There will always be a trade-off between the need for policy stability and the need to be adaptive to rapidly changing demands and technology. Where there is perceived uncertainty or instability, investment will not flow to the sector. In developing policies and plans for the use of the spectrum, consultation with stakeholders and transparency are important.[5]

One of the bigger challenges faced by spectrum regulators and managers is the reallocation of spectrum. When frequencies have been used for one purpose, perhaps for decades, it is often difficult to reallocate these frequencies for a different use. Various approaches have been used by different spectrum regulators to address this issue. Some simply require the user to absorb the cost. In other cases, the beneficiaries of the change are either invited or required to reimburse all or part of the transition costs of the incumbent user. Another approach is for the regulator to establish a refarming fund by setting aside a portion of spectrum revenues. Refarming of spectrum can be a very involved process including various stakeholder groups.

It is generally felt that those who benefit from having access to spectrum should pay for the cost of its regulation. While revenues can be obtained in relation to those parts of the spectrum for which access is payable, no such revenue is forthcoming from unlicensed (free) bands. The funding requirement of regulatory activity or change related to unlicensed bands is probably most efficiently met through general taxation revenue. Such regulatory costs are usually low.

How are Technical Standards Used in Planning?

[5] A Practice Note providing guidelines on consultative processes has been included in the toolkit and appears in Section 2.1.8 Consultation with Stakeholders.

Regulators, users of radio communication services and radio equipment, operators and suppliers rely on technical standards as a basis for preventing interference and in many cases ensuring that radio systems perform as designed. Regardless of the spectrum management approach adopted for different portions of the spectrum, it is important to reduce the possibility of harmful interference. One way of doing this is to ensure that equipment that uses the spectrum meets certain technical standards be they international, regional or national standards. From a planning standpoint, the regulator uses technical standards to determine how certain radio equipment will interfere with other equipment in either shared or adjacent frequency assignments. That determination can then be used to develop spectrum use plans. The mutual interaction of radio and electrical products is known as "electromagnetic compatibility" (EMC). Balanced frameworks for technical standards try to minimise business compliance costs while providing effective protection of the radio spectrum resource.

Technical standards form the basis for certification and testing of radio equipment. Equipment is said to be certified when it complies with applicable standards of the country. The ITU also provides equipment standard regulations and recommendations to its members. Technical standards and certification processes for specific types of equipment should be similar for all manufacturers and importers, ensuring consistent quality for consumers.

Authorizing Spectrum Use

Authorization is the approval process by which users gain access to the spectrum resource and comprises both the users and the radio communication equipment used by them. This may involve assigning specific frequencies to users, or allotting certain frequency bands or sub-bands to specific users who may or may not be able to transfer such spectrum rights to others, or it could also mean simply authorizing the use of specific equipment or categories of equipment. The authorization to use certain frequencies can be on an exclusive or a shared basis. In some cases, the actual assignment process may be carried out by public or private entities. The authorization of spectrum use may be set out in a licence, a certificate, a permit or even simply a letter. Some of the authorization activities associated with spectrum management include: licensing, examination, certification (of radio operators, equipment, etc.), type approval, type acceptance, international notification and registration, etc. In terms of licences, there are various types (e.g., individual

licence, system licence, class licence, general licence, etc.) while some uses of spectrum are not licensed and sometimes thought of as taking place in a spectrum commons. Unlicensed does not necessarily mean unregulated, since equipment may still need to meet certain technical standards in order to be authorized for use.

It is important to distinguish between the methods for determining who will have access to spectrum versus determining the cost of such access. Access to spectrum may be granted on a "first come-first served basis." Spectrum may be reserved for certain uses or users in a form of *a priori* planning. Competitive processes or economic methods such as lotteries or auctions may be held to decide who will be assigned certain frequencies or bands of frequencies. There are clear advantages and disadvantages for each method which are described more fully in the Spectrum Management Module.

Information technologies can play a role in assigning and keeping track of spectrum use as well as administrative functions such as collection of licence fees and preparation of submissions of required information to other countries or to the ITU. The key here is to tailor the application of such technologies to the real requirements and to resources available. Maintenance of any such information systems must also be ensured, underlining the need for competency in these systems.

No matter what method for assigning frequencies is adopted, some level of spectrum engineering support is required to ensure, *inter alia*, that the use of frequencies authorized will not result in interference, as well as to resolve any cases of intra-national or international interference that might arise. Such capability is required to assess, for example, some of the newer technologies such as software-defined radio equipment.

In addition to authorizing spectrum, the spectrum manager must authorize radio communication equipment (often referred to as radio apparatus) for use, even if the use of the specific equipment does not require a licence. Ensuring that equipment meets certain technical standards reduces the possibility of harmful interference. Examination and certification of operators of some radio communication equipment may also be required. Often some of these tasks are delegated to public or private entities.

How Much is the Spectrum Worth?

The role prices have in assigning spectrum will depend on what method of spectrum authorization is used. In a fully liberalized market allowing change in the use and ownership of spectrum, prices are set by the interaction of demand and supply (just as the price of land is set in the land market). When a regulator auctions a limited number of licences for a specific use, the licence goes to the highest bidder. However, if the regulator has deliberately reduced the number of licences available to generate an artificial scarcity, the winning bids will be excessive and consumers will ultimately pay for this through higher end-user prices.

Some regulators have combined administrative assignment of spectrum with so-called "administered incentive prices" or "spectrum efficient incentive prices," designed to encourage licensees to hand back unwanted spectrum. Prices may be charged to recover the spectrum regulator's operational costs or to gain revenue rather than to encourage efficient spectrum use; these should still be set in ways so as to not leave spectrum unused. If the spectrum regulator's costs are properly monitored and controlled, this should be achievable. Finally, price levels should not be set too high (overvaluing spectrum) by the government or by users as that will create barriers to investing in needed expansions to networks or services.

As always, we must go back to high level objectives. If the goal is to generate the maximum benefits for (public and private) end-users, prices should guide spectrum to those activities where it yields a higher benefit than elsewhere, in terms of end-users' valuations. For example, some spectrum can be allocated to either broadcasting or mobile communications — both valuable uses. As a result, its price should be high, because the "opportunity cost" of its use in one application (the alternative service which is sacrificed because spectrum to support it is not available) is high. For less useful frequencies, the opportunity cost might be low and so a low price is appropriate.

For reasons of good governance, when prices are set administratively, they should be set in a transparent and non-discriminatory way. This is vital to maintain the confidence of investors and other stakeholders.

As a general rule, using exemptions from spectrum pricing to achieve particular social or economic goals is a second-best policy instrument because allowing particular users to benefit from zero or

low prices will encourage extravagant use as well as increase the supply of that service. More direct methods of subsidisation of the service, rather than spectrum pricing subsidies, are the preferred route where possible.

Administrative Incentive Prices as a Measure of Value

In pure form, the spectrum regulator will try to set a price which replicates what would emerge in a market, thereby putting pressure on users to economise on spectrum use. Where there is excess supply of spectrum, the price should be zero. The question is how to calculate the administrative price. In principle, it should be the value of the spectrum in its next best use. Looking again at spectrum which can be used both for mobile communications and for broadcasting; if it is used for the former, the administrative incentive price should be its value in the latter use, as calculated by the saving in broadcasting transmission costs which would be achieved if the spectrum in question had been available for broadcasting. Such a calculation is difficult.

In practice, therefore, regulators often resort to what some have called "spectrum efficient incentive pricing." This involves pricing of the spectrum in relative terms according to certain factors such as how much of it is consumed, the scarcity of the particular spectrum in a given area and whether the frequencies are shared or exclusive. Such prices are an incentive for more efficient use of the spectrum resource. In establishing these prices, there is always a trade-off between simplicity and fairness.

Spectrum Royalties

Spectrum royalties involve a payment made to the regulator on the basis of the revenues received for the service provided by the licensee (for example, a percentage of the income of a mobile operator). Essentially, the spectrum regulator is sharing some of the risk of the commercial venture. The terms of the royalty agreement can either be set by the regulator or emerge from an auction-like process, i.e., the spectrum goes to the firm willing to pay the largest percentage of its revenues. A royalty approach can be combined with other approaches such as an annual administered fee plus a percentage of revenues. But regulators need to assess whether it is appropriate for the supplier of spectrum to share the risks along with the benefits of the spectrum-using activity in this way.

Lotteries

Lotteries have been used to assign spectrum on a random basis and usually at a zero price. There is no reason to suppose that the lottery winners will use the spectrum efficiently. For example, winners may, if they are allowed to, sell their rights to others, making a windfall gain which under an auction process would have gone to the government. As a result, lotteries are not recommended.

Auctions – Assigning and Valuing Spectrum

Auctions are a means of using a competitive process to establish a price for spectrum licences made available by the regulator or sold by a private party. There are many variants of auction design, ranging from the submission of sealed bids to an open outcry ascending price process which may encompass several licences simultaneously. The choice of variant is complex but a properly designed auction can ensure that spectrum goes to those who can make the best use of it. The regulator must take care, however, that the higher prices bidders are willing to pay are not purely the result of their ability to exercise market power in the service for which the spectrum is used, to the disadvantage of consumers of that service. High auction prices usually provide a signal that more radio spectrum is needed; however, firms which have paid a lot for spectrum will resist more licences being awarded for the same purpose. Auctions can be also subject to collusive bidding, which reduces government revenues.

Simply introducing ‘primary’ auctions when spectrum is first allocated may make little long-term difference to the way spectrum is used unless it is accompanied by ‘secondary’ trading of spectrum already licensed. It will, however, earn governments revenues and subject them to the temptation to manufacture scarcity.

Market Prices

Market prices emerge from transactions between buyers and sellers in secondary markets or from primary issues of spectrum through auction processes. If the spectrum market is working effectively (i.e., if there is transparency, enough transactions and enough buyers and sellers), the resulting prices will direct spectrum into the optimum uses. For example, if another firm can make more money out

of a block of spectrum than the current licensee, it will make an offer to buy. If the transaction occurs, end-users will benefit by having greater access to the services previously in short supply.

A spectrum market might be controlled by a single firm, or a few firms in combination, which would force prices to monopoly levels by withholding or hoarding spectrum. Measures have to be taken to prevent this happening. They might involve scrutiny of spectrum holdings and transactions in spectrum markets.

Recovering the Cost of Spectrum Regulation

Under a cost-recovery approach, spectrum pricing should result in revenues which are sufficient to pay for the spectrum regulator's costs (to the extent that these are not covered by general tax revenue). Such pricing may or may not relate to some notion of the value of spectrum consumed and hence may or may not foster greater spectrum efficiency. We have already discussed and resisted the notion that spectrum pricing should, in addition, be used to generate government revenue through unnecessarily high prices.

It is natural in the interests of fairness as well as efficiency that such cost-recovery prices are set based on the direct costs of regulating individual frequencies. In practice, however, many regulatory costs will relate to a range of frequencies and the allocation of such 'common costs' may have to be fairly arbitrary. In such cases, rather than cost recovery at the individual frequency level, prices are set so that the cost recovery occurs at a higher level. Prices should not be set at a level which forces any user out of the market so that spectrum lies idle.

Although licensees will normally pay spectrum prices, they will try, and may succeed in, passing them on to their customers if they sell services. The degree of success such licensees have depends on features of the services market, such as the level of competition.

Protecting the Value of Spectrum Assignments

New market entrants and operators of competitive wireless services, along with existing users of frequencies for non-telecommunications applications, have a reasonable expectation of interference-free use of the frequencies assigned to them. Determining interference-free assignments requires the

use of data and EMC verification, as well as monitoring and enforcement activities needed to ensure user compliance with licence conditions.

There are several models operating today in the management of these activities and processes. Government, through spectrum regulators, has traditionally been responsible for the monitoring and enforcement of licence and technical standards. It is common as well to see other departments such as Defence and Transport with responsibility over government-allocated frequencies. In addition to government departments and agencies, there are private sector participants such as industry associations, advisory councils, etc., who plan, manage and monitor frequency use and performance within the associations' collective assignments.

Telecommunications and spectrum regulators in developing countries generally have very little technical monitoring capacity or expertise. Careful decisions are needed in determining an effective monitoring strategy and approach, including what investments to make in equipment, the development of processes and formalized activity, and the appropriate emphasis on which segments of spectrum use to monitor. Recognizing that existing capabilities are typically minimal and that these investments can be very expensive, the correct approach should be to address priorities and make efficient use of existing equipment and capabilities including outsourcing and utilizing existing industry sector resources.

Spectrum Monitoring and Compliance

Properly designed and functioning spectrum management processes like planning, authorization and engineering, require data derived from technical procedures and components with varying degrees of complexity and cost. Spectrum monitoring and compliance activities help users by avoiding incompatible frequency usage and identifying sources of harmful interference.

Spectrum-use planning and resolution of spectrum scarcity issues can be accomplished with the help and analysis of spectrum occupancy data. Maintaining interference-free assignments includes the use of data and electromagnetic compatibility (EMC) verification activities, as well as monitoring and enforcement activities which ensure user compliance with licence conditions and technical standards.

Monitoring and Data Collection

Spectrum monitoring and control activities collect data needed by spectrum managers and users of radio frequencies. Data which measures spectrum occupancy and utilization for purposes of making assignments, including the effects of spectrum reuse and band clearing efforts, is captured. As spectrum becomes scarcer in highly congested areas, monitoring data is used to support spectrum engineering activities including: validation of tolerance levels, determining the probability of interference and development of band-sharing strategies. In addition to supporting assignment and authorization activities, spectrum monitoring reinforces compliance through determination of deviations from authorized parameters, sources of interference and location of legal and illegal transmitters.

Monitoring Technology

Fixed, remote, unmanned and mobile monitoring equipment can be combined to provide tools for verification of licensing compliance, channel occupancy, spectrum planning, and regulatory enforcement, and to provide greater flexibility in the design of national and regional monitoring systems. Monitoring equipment and integrated software tools are complex and expensive and integrated monitoring systems can be very expensive. Fortunately, advances in computerization, monitoring technology and data security techniques permit greater use of remote unmanned monitoring techniques involving integrated spectrum observations.

Alongside advances in technology, tactics and work practices are also changing. There is an increased emphasis on focussing on areas of known problems and congestion rather than on continuous monitoring of all utilized spectrum. For example, the characteristics of radio propagation and a concentration of military applications have resulted in a reduced monitoring effort by the spectrum management organization. Memoranda of Agreement can be used, whereby an agency of government or non-governmental organizations (NGOs) assume responsibility for essential monitoring activities and share information on problems affecting civilian applications. Another example involves industry associations taking responsibility for monitoring and resolving interference problems in fixed-link microwave services. These types of arrangements allow the spectrum regulator to concentrate its monitoring resources on public priority frequency bands

affecting essential services such as air navigational aids, fire, safety, ambulance, police and areas of concentrated commercial activity typically found in VHF/UHF.

Spectrum management policy decisions involve trade-offs among: the desire and need of the regulator and industry for complete and accurate information, the cost of implementation and maintenance, accountability, and technical capacity.

Enforcing Compliance

Spectrum management also requires that users comply with licence requirements and technical rules and regulations. Without effective regulations and enforcement procedures, the integrity of the spectrum management process will be compromised. The spectrum regulator needs an appropriate framework and process for responding to and managing complaints from the public and users, and for settling disputes. Consideration needs to be given to penalties, remedies, enforcement and alternative dispute resolution (ADR) mechanisms for industry disputes with the aim of ensuring rapid resolution.

Developing Spectrum Management Capacity

Strategies for organization, function, process development, staffing, staff retention and training are important considerations for spectrum regulators. The central concerns of spectrum management — namely promoting spectrum access and efficient use, resolving conflicting demands, managing change, enhancing coordination and avoiding interference, fostering communication and consultation, and ensuring that data and information are shared — require a broader view of capacity development. This definition covers both institutional and individual capacity building.

Spectrum regulators need to consider strategies for developing the spectrum management organization, including human resource development, spectrum management functions, process development, staffing and staff retention, and training. These capacity-building strategies flow from legislation, policies and the regulatory framework and includes other agencies are involved in certain aspects of spectrum management.

The traditional spectrum management regulatory functions include:

- Charting the major trends and developments in technology and considering the needs of current and future users of the radio spectrum.
- Evaluating information, capabilities and technology choices to support decisions affecting the allocation, allotment and assignment of radio spectrum.
- Identifying solutions to interference problems and technical compatibility among radio systems are key areas of focus.
- Licensing radio communication equipment and making frequency assignments.
- Monitoring and compliance activities help by avoiding incompatible frequency usage and through identification of sources of harmful interference.

How spectrum managers fulfill these requirements and meet strategic operational and organizational goals represent formidable challenges made more difficult in an environment characterized by change and innovation. These types of capacity-building problems are not new, nor are they unique to spectrum management. Solutions do exist for developing, planning and implementing processes that will improve organizational structure, function and the development of required skills.

Organization

The country's legal and regulatory frameworks, along with policies concerning governance, provide the defining building blocks for the spectrum management organization. The implication for capacity building is the need to develop and maintain human resource skills independently of other organizations, or to find ways of sharing in the development and utilization of human resources through strategies such as matrix management or centres of excellence within the combined regulator.

No two spectrum management organizations will be organized in the same manner, yet some similarities do exist in structures organized around the key functions of planning, engineering and authorization and monitoring. Cost and resource availability put pressure on spectrum managers to create organization and design functions which ensure productivity. This can be achieved through sharing and cross-fertilization of skills.

Human Resources

Spectrum management is a knowledge-based function requiring skilled and committed personnel who are able to keep pace with continuous advancements in radio technologies, and increasingly complex demands from users seeking access to the spectrum resource. Providing a challenging and rewarding experience for staff, trainees and new recruits means giving them the tools and support they need for learning and development throughout their careers.

Designing functions and roles, staffing, and developing necessary skills and capacity do present difficult and important challenges for spectrum regulators, especially those in developing and emerging countries. There are a number of complex tasks which need to be planned, as set out below.

Routine tasks and methods are associated with licensing of radio communications, type approval of radio equipment, and routine monitoring. These tasks are supported by well-defined administrative processes which can be dramatically improved and made more cost-effective through the use of efficient information management systems. Quality of service can be improved by placing service points of presence close to clients and users.

Technical tasks require staff with extensive formal and methods-based training and experience. Frequency assignment, technical standards, spectrum engineering, information systems and radio monitoring are tasks that require these levels of training. Core professionals/specialists work closely with clients.

Conceptual and coordination tasks are associated with planning, coordination, consultation, and strategic initiatives associated with international consultation on spectrum planning matters.

Automated Systems

Planning and engineering functions provide areas for developing expertise needed to ensure the regulator has the appropriate technology, standardized processes and procedures to perform necessary tasks and comply with legislation and regulations. In support of these functions, automated systems can be acquired or developed to support data management and administrative

requirements. Important business processes involving analysis, data checks and processing can be support through automated processes. The time required and costs involved in determining, acquiring or developing automated systems can be great. Spectrum regulators need to carefully analyze needs and develop IT systems and support plans.

Capacity Building through Consultation

The impetus for consultative mechanisms involving stakeholders arises from the need for improved short-term planning and assignment processes which reflect the economic value of spectrum to the public, and for improved transparency in decision-making. The design of consultative processes should take place within a broader assessment of the role, contribution and extent to which industry and stakeholder groups should participate in the implementation and monitoring of the broader agenda of planning and efficient usage of spectrum. Action based on partnerships and involvement of major groups opens up a wider political sphere for the participation of social and economic actors and constitutes a "bottom-up" source of strength.[6]

Consultative processes occur on at least three distinct levels — international, national/domestic, and industry/subject-specific. Processes can be formalized, informal or ad hoc. Planning subjects range from policy and regulatory framework development and formulation through forecasting of demand and technology application to procedures such as channel planning for broadcast frequencies.

Concluding Remarks

There are important initiatives underway to improve upon traditional administrative approaches to spectrum management which will lead to a more liberalised regime. However, there are a number of important issues that need to be understood and resolved beforehand. This paper provides insight into the trends in reform and the important issues. The Spectrum Management Module provides a fuller discussion of the trends, issues, and options for change.

[6] ITU (2005): Geneva. The National Spectrum Management Handbook - Chapter 2, Liaison and Consultation.