CHAPTER 4. GOING MOBILE: MANAGING THE SPECTRUM

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4.1. Introduction

Historically, accessing and using radio spectrum has been highly regulated, in order to prevent interference amongst various users in adjacent frequency bands. Since 2000, there have been significant innovations in the theory and practice of spectrum regulation. There is now a growing consensus that past and current regulatory practices have delayed the introduction and growth of beneficial technologies and services or have artificially increased costs. As a result, there is a renewed emphasis on striking the best possible balance between the certainty of administrative approaches and the flexibility of more light-handed market-based regulation.

This chapter begins by looking at the radio spectrum as a resource and the changing demands for spectrum arising from new technologies and new services. The economic and technical objectives of managing spectrum are described as well as international and national frameworks for planning, and technical standards. The chapter considers mechanisms for assigning spectrum, including spectrum authorization, regulatory strategies and technical aspects of assignment. Spectrum pricing is also described, including objectives and methods for cost recovery. The importance of using the spectrum efficiently and the role of monitoring is emphasized. The chapter concludes with the growing need for flexibility in spectrum management.

4.2. Changing Demands for Spectrum

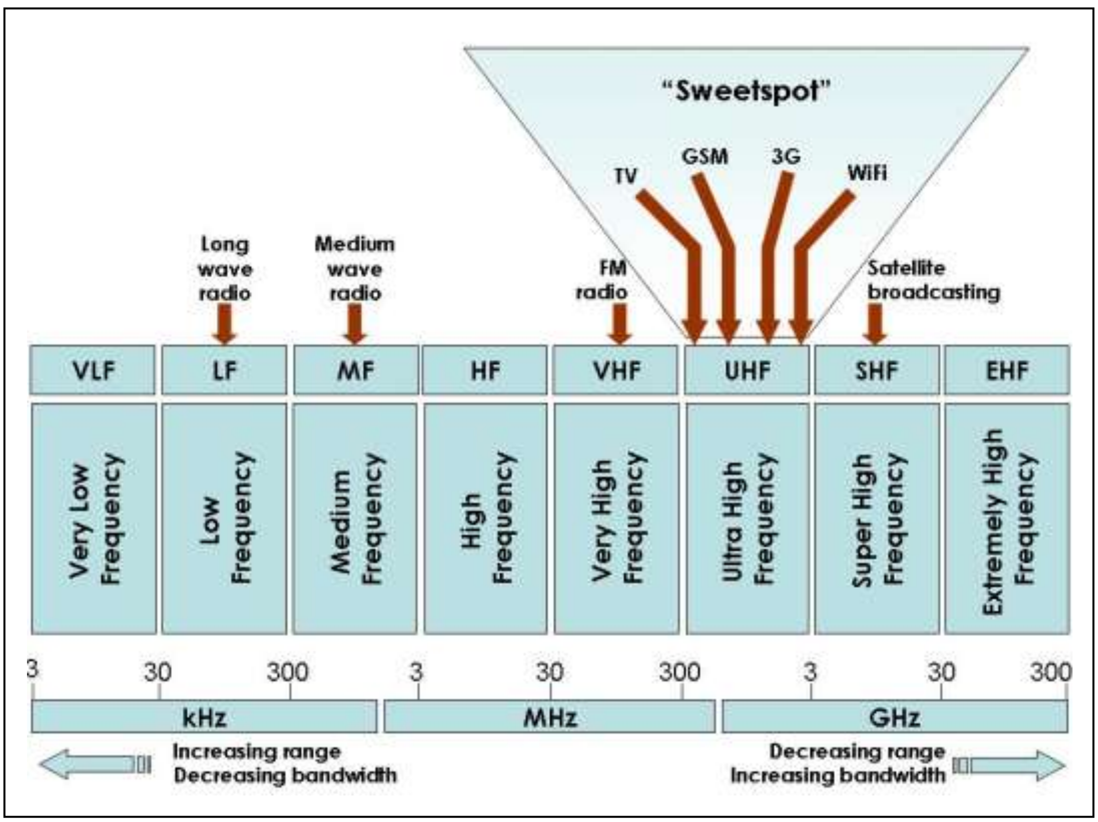
4.2.1. The Radio Spectrum as Valuable Resource

The radio spectrum is used for a plethora 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 defense 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 defense or emergency services, and 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.

The past decade has seen significant changes in this field as the demand for mobile communications has skyrocketed. Globally, the number of mobile cellular subscribers exceeded the number of fixed lines in 2002, and the number of mobile broadband subscribers overtook fixed broadband in 2008 (see Figure 1.1 in Chapter 1). But "going mobile" places even more strain on the radio spectrum and means that pressure to manage it as efficiently as possible will undoubtedly increase.

Technically speaking, the radio spectrum is the portion of the electromagnetic spectrum that carries radio waves (see Figure 4.1). 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) 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 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.

Figure 4.1 The Radio Spectrum and its Use



Source: Adapted from Ofcom.

The spectrum as an economic resource is unusual in that it is both non-exhaustible and non-storable. Unlike oil and water, the spectrum 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. It is becoming increasingly evident that as developing countries address broader issues of information policy and regulatory reform, wireless services are outpacing wireline connectivity and the spotlight is turning to spectrum management. In a globalizing world with rapid technological innovation and increasing demand for radio frequencies, effective spectrum policy should promote the roll-out of services, reduce barriers of entry, and promote innovation.

As a resource, the spectrum has both technical and economic dimensions:

- Economically, the efficient use of spectrum, as a starting point, means the maximization of the value of outputs produced from available spectrum including the valuation of public outputs provided by the government or other public authorities.
- Technically, the 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 how heavy the usage of spectrum is over time. Data rates refer to how much data and information can be transmitted for a given amount of spectrum capacity.

4.2.2. The Need for 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. As a result, technical and service rules are a crucial determinant of the structure and performance of industry and of institutions devoted to ensuring public safety, security and national defense.

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

1. 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.
2. 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.
3. Spectrum engineering involves the development of electromagnetic compatibility standards for equipment that emits or is susceptible to radio frequencies.
4. Spectrum monitoring and compliance involves the monitoring of the use of the radio spectrum and the implementation of measures to control unauthorized use.

4.2.3. Economic and Technical Objectives

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 need to maximize the value of outputs produced by the spectrum available, including the valuation of public outputs provided by the government or other public authorities.

Allocation of scarce spectrum to different uses should be done so 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? Weighing the value users place on both services, the cost of providing these services and the amount of spectrum used by them is necessary. 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. Market-based approaches such as auctions and spectrum trading are viewed as superior ways of achieving economic efficiency in assignment than administered methods.

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 costly to implement, capacity which is often left unused may be essential for 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.

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.

4.2.4. National and international planning

International Planning

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 ITU-R 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.

The international framework for the utilization of the radio frequency spectrum is set out in the ITU's Radio Regulations. Spectrum related information, such as details concerning individual nationally based frequency assignments, are regularly submitted to the ITU's Radiocommunication Bureau for purposes of coordination with other countries and then registered in the Master International Frequency Register. This information is published in the Radiocommunication Bureau's International Frequency Information Circular.

In addition to international activities, there are often bilateral and multilateral 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 – 20012 (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 are of an ongoing nature.

There is, of course, considerable flexibility for the establishment of national policies following recommendations contained within the ITU-R framework.

National Planning

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 license, 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.

There are a number of important policy questions to be reviewed and resolved affecting the regulation of spectrum at the national level. These policy questions include the government's own use of spectrum. One underlying concern for spectrum assigned to government departments is underutilization. Other policy matters include the extent to which market mechanisms should be used to assign spectrum and used set the price for spectrum; and, what are the permanent or temporary property rights of licensed and unlicensed users.

Determining who may use spectrum within a given country involves planning mechanisms. In general where there is greater reliance on the market to assign spectrum, less planning is required.

4.2.5. Traditional Approaches and Recent Innovations

Historically, regulators have assigned frequencies by issuing licenses to specific users for specific purposes, limiting access to and use of the radio spectrum. This traditional, administrative approach to spectrum management can prescribe how spectrum is used and, with good planning, how interference between 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. More recently, there has been significant innovation in the theory and practice of that regulation. This follows a growing consensus that regulatory practices originally intended to promote the public interest may, in some cases, have either delayed the introduction and growth of new technologies and services, or artificially increased their costs. There is, therefore, 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.

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 focused on creating genuine markets for spectrum and spectrum licenses under which both the ownership and use of spectrum can change in the course of a license’s operation. This is a major step beyond the typical auctioning of licenses which are not subject to trading and change of use. It does, however, require the full specification of which “property rights” to spectrum can be traded and utilized.

Market methods may be employed both at the initial issue of spectrum licenses, 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 license (trading) and permitted to change the use of the relevant spectrum to different services (sometimes called liberalization).

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 used which are capable of dealing with interference as it happens. Unlicensed spectrum was initially of little interest, but in recent 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.

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 factors such 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.

4.2.6. Transparent Regulation and Processes

One of the most important features of the work performed by a spectrum regulator is transparency. Transparency must form the basis of all work done by a regulator and should be a feature of every process the spectrum manager puts into force. The public and all stakeholders should understand the functions of the regulator. They should be able to see the work of the regulatory authority as open, accessible, and accountable. In terms of the processes followed, they should find the processes both predictable and fair. These are all easy principles to accept, but sometimes difficult to follow in practice. The benefits of transparent regulation are summarized in Box 4.1.

Box 4.1 Benefits of Transparent Regulation

1. Efficiency and Effectiveness: Open processes enhance consensus and create confidence in the regulator. Increased public participation promotes diverse ideas in decision-making and increases support for rules and policies, making implementation easier. In addition, transparency can lead to greater efficiency by ensuring that duplication of functions is avoided.

2. Certainty and Reliability: Regulatory credibility and legitimacy builds stability and is essential for attracting investment. This is particularly important in newly liberalized markets, where potential entrants need to have trust that their investments will be protected from arbitrary action and that further commercial development will not be thwarted by sudden changes in "rules of the game."

3. Accountability and Independence: Openness promotes accountability and legitimacy, reinforces regulatory independence, and reduces political and industry interference. Stakeholders can thus have confidence that their views will be heard, without bias, by the regulator. When regulatory actions are open to public, regulators are more likely to engage in careful and reflective decision-making.

4. Continuity: A stable set of rules governing transparency will transcend political changes and outlast political appointments, ensuring a continuous regulatory record regardless of who is in charge of the regulatory agency or which political party is in office.

Source: ITU, 2002, Chapter 6.

4.3. Planning and Technical Standards

4.3.1. Spectrum Planning

Spectrum planning ensures that the spectrum resource is used to the fullest extent possible. The radio spectrum supports a wide range of business, personal, industrial, scientific, medical research and cultural activities, both public and private. Communications are foremost among those activities and, together with other radio services, are increasingly important to economic and social development.

It is helpful to grasp the various uses and the characteristics of radio spectrum used to enable these services. Table 4.1 shows different radio services with various frequency ranges and band propagation characteristics.

Table 4.1 Examples of Radio Frequency Propagation and Related Services

BAND	FREQUENCY	RANGE	USE	BANDWIDTH	INTERFERENCE
VLF	3-30 kHz	1000's km	Long range radio-navigation	Very narrow	Wide Spread
LF	30-300 kHz	1000's km	Same as VLF strategic communications	Very Narrow	Wide Spread
MF	.3-3 MHz	2-3000 km	Same as VLF strategic communications	Moderate	Wide Spread
HF	3-30 MHz	up to 1000 km	Global broadcast and Point to Point	Wide	Wide Spread
VHF	30-300 MHz	2-300 km	Broadcast, PCS, Mobile, WAN	Very Wide	Confined
UHF	.3-3 GHz	< 100 km	Broadcast, PCS, Mobile, WAN	Very wide	Confined
SHF	3-30 GHz	Varies 30 km to 2000 km	Broadcast, PCS, Mobile, WAN, Satellite Communication	Very Wide up to 1 GHz.	Confined
EHF	30-300 GHz	Varies 20 km to 2000 km	Microcell, Point to Point, ,PCS and Satellite	Very Wide up to 10 GHz.	Confined

Spectrum resource planning ensures the efficient and effective use of the spectrum resource. Spectrum regulators need to make decisions about the uses of spectrum and on who should be allowed to use it (i.e. uses and users). Planning is usually undertaken for long-term, medium-term and short-term timeframes. Long range (strategic) planning (10 to 20 years) is required to foresee spectrum requirements far into the future. 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.

Forecasting future spectrum use is critically important if future spectrum needs are to be met. The challenge of forecasting spectrum can be overcome by employing various techniques including projections based on historical growth; and through monitoring of new technologies and noting their spectrum requirements. It is critically important to consult with spectrum users for they are usually in the best position to forecast growth in their sector.

It is also important to know the current uses of spectrum as a baseline for future planning. This can be ascertained from existing records of frequency use across the entire radio spectrum. International and often national frequency registers are used to aid planning and facilitated through the use of computer-automated tools.

4.3.2. Technical Standards

Technical standards describe how spectrum is used – spectrum use standards; and standards which state conditions of technical compliance – radio equipment standards:

- Spectrum use standards state the minimal technical requirements for the efficient use of a specified frequency band or bands. Furthermore, spectrum-use standards can be designed to match ITU-R Recommendations.
- Radio equipment standards are used by the regulator in the license approval process, as well as in testing and certification of radio equipment such as transmitters, receivers and antennas to determine compliance with radio or manufacturer specifications. Radio equipment standards state the limits (if at all) on how certain radio equipment may interfere with other equipment in either shared or adjacent frequency assignments and form the basis for certification and testing. Equipment is said to be certified when it complies with applicable standards of the country. The ITU also has equipment standard regulations for reference by its members. Radio equipment standards also:
  - specify the minimal acceptable technical specifications and performance characteristics of radio equipment in general use;
  - exist for both licensed radiocommunication equipment or stations and license-exempt radiocommunication equipment which include low-power devices such as garage-door openers, radio frequency identification devices (RFIDs) or equipment utilizing ISM or unlicensed bands such as WiFi and WiMax.

  As a result, radio equipment standards and certification processes for specific types of equipment are the same for all manufacturers and importers, ensuring consistent quality for consumers. Finally, the regulator can use radio equipment standards to require that manufacturers produce equipment which provides for greater efficiency in spectrum use.

Technical standards are important to users of radiocommunication services and radio equipment since operators and suppliers rely on technical standards as a basis for preventing interference and in many cases ensure that radio systems perform as designed. Standards documentation provides; general information describing the equipment and the application, an indication of licensing and certification requirements, channeling arrangements, modulation techniques used by the equipment, and transmitter power and transmission limits for unwanted emissions.

Other Standards

There are other standards associated with the use of radio such as radiation standards and land use standards. The authority for regulating these standards most likely rests with other ministries and agencies. Once a decision by government on policy or regulation has been reached however, the spectrum management authority may need to take certain measures such as making modifications to radiocommunication equipment standards to ensure public safety.

- Radiation standards refer to electromagnetic emissions at certain frequencies that may be harmful to life or some other concern to public safety. The spectrum manager is not typically responsible for conducting the research and determining the scientific basis for these concerns. Agencies of government such as the ministries of health and public and private research institutes conduct research to substantiate concerns.
- In connection with the deployment of radiocommunication systems, other standards relating to the environment, construction and land use may apply. This is particularly true where location with respect to essential facilities such as power transmission lines and airports is a factor.

Developing Technical Standards

Developing radiocommunication equipment standards and spectrum-use standards occurs at the national, regional and international levels. In some cases, due to the importance and size of the national economy, national standards acquire international importance. Smaller nations routinely adopt, either formally or informally, radiocommunication equipment standards developed by other standards organizations, which is a cost-effective manner of designing a set of standards. Indeed, countries within almost all regions, including Europe, the Caribbean, Africa and Asia have opted to recognize both European (ETSI) and North American standards (FCC and ANSI). There are standards bodies in most regions of the world and particularly in regions where high technology and telecommunication and radiocommunication equipment are manufactured.

Coordinating Technical Standards across Regions

Testing compliance of radiocommunication equipment with national standards is done by either government-operated testing facilities or by private sector laboratories. National governments increasingly favor private sector facilities since technological change and innovation lead to ongoing acquisitions of high-cost test equipment. Policies and regulations have evolved around the coordination of standards testing across regions and markets through the certification of conformity assessment bodies (CABs). CABs are organizations recognized by the spectrum management authority to conduct testing and certification of radiocommunication equipment. A mutual recognition agreement amongst importing and exporting participants to establish mutual acceptance of the results of testing and equipment certification procedures undertaken by those bodies in assessing conformity of equipment to the importing parties' own technical regulations.

Conformity to radiocommunication equipment standards and certification are necessary conditions for interoperability of radiocommunications services and terminals such as handsets. It is not a guarantee, however. Across a region or within a country, a common technology or standard such as GSM or CDMA may be used by service providers with similar networks but operating at different frequencies, making it difficult for users to migrate between networks. The absence of roaming agreements may also prevent interoperability even when frequencies and technologies are the same.

4.4. Mechanisms for Assigning and Pricing Spectrum

4.4.1. Spectrum Authorization

Authorization is the process by which users gain access to the spectrum resource. This may involve assigning specific frequencies to users, allotting certain frequency bands or sub-bands to specific users, who may or may not be able to transfer such spectrum rights to others. In some cases it may mean simply authorizing the use of specific equipment or categories of equipment.

Spectrum authorization activities include analyzing requirements for proposed frequencies in accordance with national plans and policies for frequency allocation. They include actions to protect radiocommunication systems from harmful and obstructing interference. Spectrum authorization strategies are used to ensure proper use, facilitate reuse, and achieve spectrum efficiency.

It is perhaps helpful to define three key terms:

- Allocations are entries in a table of frequency allocations which sets out the use of a given frequency band for use by one or more radiocommunication services. An allocation is a distribution of frequencies to radio services.
- Allotments are entries for designated channels in a plan for use by one or more countries in those countries or within designated areas for a radiocommunication service under specified conditions. An allotment is a distribution of frequencies to geographical areas or countries.
- Assignments are authorizations given to radio stations to use radio frequencies or radio frequency channels under specified conditions. An assignment is a distribution of a frequency or frequencies to a given radio station.

Some basic principles and rules have been established.

- Allocations are made on a primary or on a secondary basis.
- Stations of a secondary service cannot cause harmful interference to stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date.
- Stations of a secondary service cannot claim protection from harmful interference from stations of a primary service to which frequencies are already assigned or to which frequencies may be assigned at a later date.
- Stations of a secondary service can, however, claim protection from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date.

4.4.2. Regulatory Strategies for Allocation and Assignment

At the national level, spectrum is most often allocated in accordance with existing international

ITU frequency allocations and prospective changes resulting from national planning processes. Traditional allocation processes have evolved around service definitions and associated technical rules. Allocations need to support increased usage of cost effective communications achieved through service expansion and interoperability and reduced equipment cost.

Rapid changes in the marketplace caused by demand growth and rapid technology development make traditional service oriented allocations somewhat inflexible. For example, use of spread spectrum techniques and more efficient equipment permits increased sharing of spectrum, even if some minimum levels of interference are experienced.

Spectrum allocation strategies include:

- Flexibility in the use of spectrum achieved by way of less emphasis on services and use of spectrum sharing techniques.
- Consistency with International Allocation Agreements to ensure comparable costs and service integration.
- Emphasis on technology neutrality combined with continued diligence in eliminating harmful interference.
- Protection of frequency use and freedom from harmful interference in sub-bands allocated for public safety and security.

Assignment involves assigning and licensing of frequencies to systems and individual services. An operator is assigned a set of frequencies in order to provide communications services. The assignment of frequencies is done, in a way, to avoid harmful interference with other users in adjacent bands. Spectrum should be used efficiently and so assigned frequencies should follow channeling plans which follow appropriate technical standards and result in the reuse assigned spectrum. Underutilized spectrum and unoccupied assigned spectrum are wasteful uses of the resource. Assignment and pricing techniques should support efficient and optimal use of assigned spectrum.

Spectrum assignment strategies include:

- Users of assigned spectrum must comply with license conditions and applicable technical standards otherwise licenses can be revoked.
- Government should enforce license conditions and ensure interference free use.
- Public safety and security must be safeguarded through active surveillance and enforcement.
- Capacity planning and band planning should be done involving multilateral industry consultative processes and assignment and planning databases should be publicly available.
- The regulator can establish the right to recall and refarm spectrum.
- Certain assignments can be unlicensed due to public interest and administrative efficiency.

Additional spectrum authorization activities include licensing, examination, certification of radio operators, equipment, type approval, type acceptance and international notification and registration. In terms of licenses, there are various types, including individual licenses, system licenses, class licenses and general licenses (see Chapter 3.4). Some uses of spectrum are not licensed. It is important, however, to recognize that unlicensed does not necessarily mean unregulated since equipment may still need to meet certain technical standards.

4.4.3. Technical Aspects of Assignment

A major challenge for assignment procedures arises when technological innovation alters the optimal use to which a particular frequency should be put. In certain circumstances, this does not create a problem. Thus if, under an administrative procedure, a license expires at the moment when a change of use is desirable, a new license can be issued to provide the new service. If a market regime involving secondary trading and involving change of use is in place, then the purchase and sale of the relevant spectrum license should allow the transition to take place without regulatory intervention. Indeed one of the arguments for the use of markets is that it takes the regulator out of the process of responding to technological change which is occurring at an increasing rate.

In reality, however, things are usually a great deal messier. There may be uncertainty over what entitlement to spectrum a licensee has. In a market regime where licenses are of limited duration (e.g., twenty years), there may be a period of uncertainty, when a switch to a new use is desirable but no one is prepared to make the necessary investments to achieve it, because of uncertainty about future access to spectrum.

4.4.4. Methods for Assignment

Several methods can be used to grant access to spectrum. If there is no excess demand for spectrum licenses, the method chosen might be "first-come, first-served": a reserved basis for certain uses or users in a form of *a priori* planning and so-called beauty contests which may be held to decide who will be assigned certain frequencies or bands of frequencies. Applicants might have to be qualified in specified ways but the qualified applicants would be granted licenses until the license term was exhausted.

If excess demand is anticipated, use of a competitive assignment process is normally preferred. For this to be done fairly and transparently, the regulator must set out the various criteria to be employed, relating, for example, to the technical and financial qualifications of applicants, their access to capital, the scope and geographical range of their services, and so on. Each criterion should have a pre-announced weight, and an objective method of measurement should be specified.

If an auction method is used to make an assignment, the procedures to be employed must be set out in fine detail to ensure that all competitors are on an equal footing. For example, if a sealed bid is employed, the date and place at which it must be lodged have to be clear. If an open auction process is utilized, in which bidders make offers for licenses in successive rounds of bidding, a whole range of procedures relating to the frequency of rounds, increments in amounts bid, obligations to make new bids and so on must be specified.

Precisely what the spectrum manager has to do in order to achieve an effective assignment depends on the method chosen, and also upon linkages with other authorizations such as the issuing of broadcasting licenses. New technological developments may change the methods used to issue authorizations and may require "refarming" of spectrum. The process of refarming will require engineering and administrative support and, in some cases, financial support. For example, costs to refarm spectrum can be passed onto new licensees or a refarming fund administered by the regulator can be used to assist new licensees who cannot bear the cost of technology change arising from the relocation of their radiocommunication service to new assigned frequencies (unlicensed or special use).

In all cases, it is vital that the regulatory body abide strictly by the conditions it has specified for the assignment. Any departure or evidence of partiality, prejudice or of conflict of interest will be damaging in several ways. First, legal challenges can delay the start of services of benefit to end users, possibly for many years. Second, doubts about the integrity of the process will deter companies from participating in competitive assignment processes. As a result, inferior candidates may be successful, leading to long-term harm for consumers

4.4.5. License Conditions

Spectrum authorization typically involves the licensing of frequency assignments and radiocommunication equipment by the spectrum manager. Licensing places restrictions on the use of assigned frequencies to prevent harmful interference. Under either administrative or market-based methods, utmost clarity is required about what license conditions are entailed by the license. These must be specified in respect of technology, geography and time.

The most complex is technology. Under administrative assignment of licenses to a particular user providing a particular service (e.g., a specified form of radar, GSM, etc.), the technological restrictions in the license are normally defined in terms of the location, power and geographic coverage of the specified apparatus. The specifications are chosen to avoid interference with other users. Any departure by the licensee from these conditions is a breach of the license. If, however, spectrum licenses are flexible and can be employed for any purpose – following a trade of the license, for example – apparatus licensing of the kind described above does not work, as each possible use will be associated with different equipment. In these circumstances, licensees will have to face restrictions in what emissions their activities are allowed to make at the boundaries of the license area, i.e. what spill over they can make into adjoining geographic areas and frequencies. This is considerably more complex.

The geographical scope of a license is more easily specified once the interference issue noted above has been resolved. The duration of the license must also be specified and can include features such as renewal options and conditions for trading which have been already discussed.

4.4.6. Spectrum Pricing

Administrative methods of setting spectrum prices are increasingly being supplemented by the use of market based methods for determining spectrum prices. Spectrum pricing methods have taken various forms: from setting license fees at a level sufficient to recovering the cost of spectrum management; through to applying administrative incentive prices (AIP); and, to auctions and using them to make initial assignments and as a consequence establish a price for spectrum.

Objectives of Spectrum Pricing

The pre-eminent policy objective for spectrum pricing is that it should be done in a way which promotes spectrum efficiency. Spectrum efficiency comes with a cost and the spectrum manager should attempt to find an optimal cost/benefit trade-off. Second, use of the spectrum provides considerable benefit to national and regional economies and this benefit should be maximized. Next, managing radio frequency spectrum costs money and someone has to pay these costs. As a principle, those who benefit from the use of the spectrum should be the ones to pay these costs. A user-pay principle should apply. Finally, important social and cultural objectives can be advanced by use of the spectrum and spectrum pricing should facilitate the achievement of government social and cultural objectives.

Allowing a spectrum regulator to establish its own charging regime, collecting all spectrum related revenues and retaining them to fund spectrum management activities can be a source of concern to policy-makers. In economic terms, the regulator is effectively a monopoly and has little incentive to contain its costs if it can increase its revenues by raising license fees and other charges. Safeguards can be put in place to avoid such practices, such as putting limits on the growth of the regulator's expenditures.

In countries where spectrum revenues exceed the cost of spectrum management and sometimes by a large margin, governments view this as a spectrum dividend whereby the government and, hence, all members of the public reap the financial benefits of such royalties. However, attention must be paid to the broader legislation within a country, as spectrum revenues in excess of costs may be viewed as taxation. The power of taxation may be reserved to another government entity and the legislation dealing with spectrum management may or may not be constructed so as to allow revenues to exceed costs.

Methods for Cost Recovery

The activities of each licensee impose direct costs on the regulator. These include the costs of issuing, maintaining data, spectrum monitoring and enforcing its individual licenses. Some costs will be common to a band or to a radio service (such as band planning), whereas others will be common to a group of bands. Some, such as management overheads, will straddle all licensees.

Regulators have tackled the issue of setting prices to recover costs in several ways. Some have used detailed costing models to establish which licenses have imposed which costs. Others have used "rules of thumb", such as setting charges on the basis of a percentage of the licensee's turnover, but this may attract criticism from those who think they are overcharged. In these circumstances, a simple model of direct costs can be developed. As well, a method of allocating indirect or common costs will be needed, e.g., based on licensees in proportion to the direct costs which they impose. Or they can be allocated in accordance with the amount of spectrum (e.g., in MHz) with which a license is associated.

Spectrum or license charges can be assessed as a percentage of (royalty on) revenues or profits, which has to be handed to the spectrum regulator under the terms of the license received or profits earned by an operator. This can be a way to cover regulatory costs, or it can be designed to raise revenue for the government.

Another method for recovering costs involves trying to set proxy prices which might otherwise emerge in a market context, and then set charges which license holders have to pay in relation to costs of spectrum management. This is sometimes called "administered incentive pricing" (AIP): "administered" because they are set by the regulator with potential "incentive" properties. These types of license fees are designed to not simply recover the cost to manage spectrum but also promote efficient spectrum use. The idea is that if a user has unused spectrum, they will choose to return it rather than pay the charge. Also, if a user can pay a lower fee by using spectrum more efficiently, that user may adopt more spectrum-efficient operations.

Spectrum should be priced in any use at its opportunity cost by applying the right level of price pressure without forcing excessive economies which result in valuable spectrum being unused. The right level of price can be found by estimating the value of other resources that would be saved if the same spectrum were redeployed to produce some other service, or the extra costs incurred if it were not available to provide the service causing the current service to be produced with less spectrum. Doing this in practice will require the regulator to identify the relevant alternative or alternatives, and perform the necessary cost calculations. This will inevitably produce results which are only approximate, but the regulator may conclude that it is better to apply incentives for cost efficiency via a price which is only approximately right rather than not to charge any price at all.

If AIPs are based on opportunity cost, then it follows that they should be zero (and replaced, probably, by cost recovery prices based on direct cost only) if the spectrum has no alternative use. This might arise because:

- There is no shortage of spectrum in the relevant frequency, so that all users can be accommodated;
- There is a legal impediment to using the spectrum in question for other purposes; this might apply for instance, to spectrum used for the purposes of aeronautical communication under the auspices of the International Civil Aviation Organization (ICAO).

AIP is therefore another tool available to regulators to encourage spectrum efficiency. It is applicable in an administrative regime for spectrum assignments and can be applied to private and public sector users. But the regulator must be sure that the AIP are taking effect. For example, if a ministry paying AIP on spectrum simply has its budgetary allocation increased to allow it to pay, there is no incentive to economize and the regime is ineffectual.

At first sight, cost recovery fees might seem to fall in this category since cost recovery prices may motivate a user to return excess spectrum or to use spectrum more efficiently. However, the primary motivation for this method is to fund the spectrum regulator (and perhaps gain some additional revenue) and prices are more likely to be set too low to impose an appropriate level of discipline on licensees. This arises because the value to a nation of its spectrum greatly often exceeds the cost of operating the spectrum regulation organization.

The choice between these approaches has to be made by the regulator in the light of considerations of fairness, and the likely effect of the charges on spectrum use. If a high allocation of indirect costs makes a license uneconomic, the matter may require reconsideration.

Auctions

Auctions are essentially a method of assigning spectrum at the time of its first issue by the spectrum regulator to those who value the spectrum most highly. It is normal for bids to be made in monetary terms, where the competitor offering the largest sum wins the license. Spectrum prices emerge as a consequence of winning bids in auctions or from secondary trades of existing licenses. Auction and spectrum trading transaction prices not only embody "opportunity costs" – the cost-saving potential of the spectrum license, but also any excess profits which the license holder can derive through exclusivity or market power. As a result, they should be used with caution.

Sometimes bids for licenses may be on terms other than price. For example, competitors can bid against one another over which will offer service over the largest geographical area. Competition can be in terms of which operator will charge the lowest amount for service or requires the least amount of subsidy. Once the rules are established, however, the winner is determined by the operation of the competitive process, not by an administrative decision.

The key differences between auctions and comparative hearings or administrative decisions are that:

1. An auction assigns the license to the firm which bids the most, and that may in certain conditions be the most efficient firm;
2. A competitive auction will, if it operates properly, direct any excess profits from providing the service to go to the government rather than the operator, as would be the case if the operator were chosen via a competitive hearing.

Hundreds of spectrum auctions have now been conducted. Some have attracted great attention by generating billions of Euros or dollars from bidders.

Most have been on a much smaller scale. Even so it still remains the case that most of the spectrum in use in all countries has been allocated by administrative methods. In practice, auctions tend to be confined to cases where:

- The spectrum available is in scarce supply;
- Many firms want to acquire a license;
- The service to be provided with the spectrum can be precisely defined;
- The monetary value of the license is relatively high, justifying what can be a complex assignment procedure.

Some examples are given below:

1. A spectrum regulator proposes to assign a single license for the provision of a national second generation mobile telephone service. The successful applicant must commit itself to providing coverage to 50% of the land area and 80% the population. Sealed bids must be submitted by a specified date, by firms which have pre-qualified (i.e. have shown their competence to be the licensee). The winner in the firm which bids the most.
2. Two or more licenses to provide national 3G mobile services are auctioned. Pre-qualified applicants bid against east other in an open bidding auction, i.e. they have the opportunity to submit new bids for the licenses at pre-specified intervals. The auction ends when the winning bids for each license are the same, in term of bidder and sum bid, as they were in the previous round. To ensure completion of such an auction, firms must be made to bid at a specified frequency.

A successful auction requires a clear understanding by participants of what rights and obligations are available to the winner or will be imposed upon them. If there is uncertainty about this, it will discourage competitive bidding. Auctions differ in two main ways: in the number of lots (or licenses) made available; and the way the auction is conducted. There has been a significant number of mobile licenses grant by auction around the world and they form a good basis for analysis and understanding. In relation to these wireless communication licenses, some the key variables in designing the auctions were:

1. The number of licenses to be offered to the service: this decision is of fundamental importance, since it determines the structure of the services market. The objective of maximizing consumer welfare suggests the harnessing of competitive forces to the maximum – i.e. issuing, subject to spectrum availability, as many licenses as the market will be able to support (plus one or two extras to permit freedom of entry into the market);
2. Any commitments made at the time of the auction relating to restrictions on the award of subsequent licenses;
3. Whether national or local regional licenses are issued; here the regulator may find it helpful to anticipate the kind of business plans (national or regional) firms are likely to have and make licenses available. There is nothing to preclude a mixture of national and regional licenses;
4. How long the licenses will last: too short a period may discourage investment in the services, while too long a period may allow the spectrum in question to stagnate if it cannot be sold on for another purpose;
5. Any obligations a licensee may have to make periodic payments in the course of the license;
6. Any network roll-out obligations or "use it or lose it" clause;
7. Any foreign ownership restrictions.

A range of methods have been employed and some have been judged successful. Regulators can learn from this experience to choose a procedure which meets their circumstances. The greatest experience has been accumulated in the United States, where the Federal Communications Commission (FCC) has run a series of auctions starting in July 1994.

Several lessons emerge from these auctions, which typically have involved the auctioning of multiple local licenses which can be aggregated to provide regional or national services:

- Open bidding is better than a single sealed bid;
- Simultaneous open bidding is better than a sequential auction, in which licenses are auctioned one after another;
- Allowing bidders to bid for packages (e.g., a group of local licenses capable of providing

wider area services) is desirable in principle but difficult in practice;

- Collusion is a major problem, which can be countered by concealing bidders' identities (i.e. publishing the bid, but not who made them), and setting high resume prices, amongst other ways.

The most conspicuous auctions were those for 3G (UMTS) licenses in Europe. In 2000/01 a sequence of auctions took place, beginning with the United Kingdom, where operators bid large amounts ($35 billion for five 3G licenses). Although revenues from the German auction several months later were also high, thereafter they declined on a per capita basis.

Where a small number of national licenses are being auctioned, for example in a developing country, a simpler approach is possible. A good example of this is provided by the auction of three identical GSM licenses in Nigeria in 2002. This was done with a carefully thought-out process which involved invitation and pre-qualification stages, as well as the auction itself. Recognizing the problem of collusion, the designers made alternative plans which depended on the number of qualified bidders for the three licenses. If there were five or more - i.e. if bidders exceeded the number of licenses by more than one, an ascending clock auction would be held. If there were only four, a sealed bid process would be implemented.

Defining Property Rights

Where trading occurs, it is necessary that buyer and seller – as well as the regulator and the courts where appropriate – share the same understanding of the bundle of rights and obligations which are changing hands. This is true of land, for example, and also of a spectrum license. Clearly defined property rights are thus a precondition for efficient spectrum markets. The dimensions of rights and obligations in a spectrum license include:

1. The band which is available for use;
2. The geographical area in which it can be used;
3. The period for which the license is entitled;
4. The uses to which it can be put;
5. The licensee's degree of protection from other users; and,
6. The licensee's obligation not to interfere with other spectrum user's rights.

Freedom from interference and restrictions of rights to interfere with others are two major related dimensions of property rights in spectrum licenses. Under administrative assignment procedures, the license typically specifies the transmitting apparatus, where it may be located, and the power at which it may be operated. By setting conditions for all licenses in this way and using an interference model to simulate the impact of apparatus on neighboring reception equipment, interference can be controlled.

However, when change of use is allowed under a license, this form of control is no longer feasible as the nature and location of the apparatus to be employed are no longer given: they are now up to the licensee. This requires a redesign of the interference model, from one where calculating the impact of specific apparatus is done, to one which sets limits to the emissions the licensee can deliver at the geographical and frequency boundaries of the spectrum it is licensed to use. Various approaches to specifying these limits have been applied in Australia, the United Kingdom, and the United States.

Under a secondary trading regime, licensees can bargain with one another to make adjustments to specified boundary emission levels. If such deals benefit both sides, it is likely, but not inevitable, that they will be made.

Lotteries

Finally, spectrum can be assigned by means of a lottery: a winning ticket chosen at random will carry with it a spectrum award. This is a "non-pricing" method of assignment. Although this procedure may seem attractive and equitable, it has many drawbacks. First, if many apply, the cost of administration may be large, especially if all applicants have to be vetted for suitability. Second, the lucky winners may not have the qualifications to operate the licenses efficiently. If they are not allowed to sell the license, this may be a recipe for disaster. And if, thirdly, they are allowed to sell them on to efficient operators, the winners will be appropriating auction proceeds which would otherwise go to the government.

4.5. Monitoring Spectrum

Effective spectrum monitoring supports activities to ensure interference-free assignments and includes the use of data and electromagnetic compatibility (EMC) verification activities. Monitoring and compliance activities are also needed to ensure user compliance with both license conditions and technical standards, helping users avoid incompatible frequency usage through the identification of sources of harmful interference. Furthermore, spectrum use planning and resolution of spectrum scarcity issues can be accomplished through study and analysis of spectrum occupancy data. Understanding the level of spectrum use or occupancy in comparison to assignments is important for efficient use of the spectrum resource. Spectrum monitoring provides statistical information on the technical and operational nature of spectrum occupancy.

The following central underlying objectives are supported by spectrum monitoring:

- Improving spectrum efficiency by determining actual frequency usage and occupancy, assessing availability of spectrum for future uses;
- Ensuring compliance with national spectrum management regulations to shape and sustain radio environments and user behavior, maximizing the benefit of the spectrum resource to society;
- Resolution of interference problems for existing and potential users.

4.5.1. Spectrum Efficiency

One radiocommunication system is more "spectrum efficient" than another if it conveys the desired information using less of the spectrum resource. Spectrum efficiency also involves the arrangement of communication systems within the spectrum resource. In this broader sense, spectrum is used inefficiently when systems are not packed together as tightly as possible in frequency bands (as when excessive guard bands are used), or when portions of frequency bands are unused while other bands with similar physical characteristics are congested. The allocation of frequency bands, the development of channeling plans, and the assignment of frequencies to specific systems all affect spectrum efficiency.

In order to promote spectrum efficiency, spectrum managers must possess some means of quantifying spectrum use and evaluating various radio technologies and frequency selection techniques. Management decisions can then be based on the relative spectrum efficiency of the various technologies and techniques. Data is collected through spectrum monitoring measures of spectrum occupancy and utilization for purposes of making assignments including the effects of spectrum reuse and band clearing efforts. Also, 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.

4.5.2. License Compliance

Spectrum monitoring also supports compliance with license conditions and regulations through determination of deviations from authorized parameters, identification of sources of interference and location of legal and illegal transmitters.

A radio system can deny the use of part of the spectrum resource to another system that would either cause interference to, or experience interference from, the first system. A radio system is said to "use" spectrum resources when it denies other systems the use of those resources. Spectrum use can be quantified, subject to certain assumptions, both for a single radiocommunication system and for a related group of systems. The spectrum manager needs to choose the measuring system carefully and to ensure capabilities exist with the spectrum management agency to effectively monitor and analyze frequency bands. Circumstances will vary by country and monitoring solutions should be tailored to meet needs, budget and institutional capacity.

The ITU has created a system which classifies radio emissions according to the bandwidth, method of modulation, nature of the modulating signal, and type of information transmitted on the carrier signal. These form the technical basis for establishing equipment specifications for radio systems designed to operate within certain frequencies.

Emissions of a radio transmitter are authorized to an assigned frequency band within the necessary bandwidth and tolerance for the frequency band. Emissions which do not meet technical parameters are unwanted emissions consisting of spurious emissions and out-of band emissions. These types of emissions can be generated accidentally or through distortions caused by various components of the radio system.

Transmission of radio signals emitted by a radio transmitter can therefore be in-band in accordance with technical parameters or unwanted owing to several causes including out-of-band emissions and spurious emissions.

Monitoring is therefore done to obtain detailed information on the technical or operational characteristics of radio systems. The spectrum manager will monitor radio equipment to determine conformity with applicable standards. This can be done as part of an equipment certification process where measurements can be taken and recorded and then used in analyzing the compatibility of radio systems - electromagnetic compatibility (EMC).

4.5.3. Resolving Interference Problems

Spectrum monitoring activities determine measurements of radio waves and radiation causing interference to authorized transmitters and receivers. Interference may be the result of authorized emissions causing unintended results such as spurious emissions. Interference may also be caused by unauthorized transmitters or devices operating beyond technical specifications. In either case, the spectrum manager will use a combination of engineering analysis and data obtained from spectrum measurements to resolve problems associated with interference problems.

The identification of unauthorized transmitters can be difficult to achieve, especially in congested areas and where various services share the same frequencies. In some bands, where spectrum sharing is encouraged through the use of class licenses or radio frequency no protection is provided from acceptable levels of interference.

4.5.4. Management Approaches

At the international level or multilateral and bilateral bases and at the national level, there are several management and process models typically used in spectrum monitoring. ITU member countries often work together to operate monitoring facilities and to coordinate efforts to prevent, detect, and control of (harmful) interference to radio transmitters since it is recognized that development and duplication of monitoring facilities is both uneconomical and operationally inefficient. Article 16 of the Radio Regulations lays down the provisions governing the establishment and operation of the international monitoring system.

Stations comprising the international system check for transmissions that have effects beyond national boundaries, particularly for frequencies below 30 MHz, are in accordance with the internationally agreed conditions of operation. This includes checking frequency, bandwidth, emission type and usage. Where non-compliance with any prescribed condition is determined, the ITU provides for an infringement report to be sent via the Radiocommunication Bureau to the country responsible.

Cooperation involving non-governmental organizations and industry associations who advise regulators on policy and technical matters also occurs between countries. For example, broadcast and microwave propagation issues and solutions are identified and analyzed by associations and confirmed through spectrum monitoring tasks performed by the regulator.

Monitoring and enforcement of license and technical standards at the national level has traditionally been a responsibility of spectrum regulators, whether within independent agencies, or attached to ministries of telecommunications. Departments such as defense and transport also often have responsibility over frequencies allocated to governmental use. In addition to public sector agencies, private sector participants are sometimes involved in the monitoring and problem resolution processes. These include industry associations and advisory councils.

There are several examples where band management organizations govern specified frequency ranges under government authorization. An agency of government or non-governmental organizations (NGOs) assumes responsibility for essential monitoring activities and shares information on problems affecting civilian applications. Another example involves industry associations taking responsibility for monitoring and taking steps to resolve interference problems in fixed-link microwave services. Finally, the spectrum regulator concentrates its monitoring resources on public priority frequency bands affecting essential services, including air navigational aids, fire, safety, ambulance, police and areas of concentrated commercial activity such as is typically found in VHF/UHF.

4.5.5. Spectrum 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. Those can also 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 as well. Fortunately, advances in computerization, monitoring technology, and security techniques have permitted greater use of remote unmanned monitoring techniques involving integrated spectrum observations.

The basic types of monitoring equipment include; antenna, spectrum analyzers, and direction-finding equipment. These basic types can be further categorized by frequency range (HF, VHF, UHF, etc.) and signal type – analog or digital. With the advent of spread spectrum and computer-based radio technologies like cognitive radio, the sophistication, complexity and prices for monitoring equipment have risen. Simple systems for VHF/UHF monitoring can be comprised of several fixed antennas, receivers and limited function spectrum analyzers. More complex systems can consist of multiple sites and mobile and fixed stations. The approaches to monitoring and the architecture of the spectrum manager's monitoring system have a bearing on the types of systems needed and the configuration of operations and resources.

An antenna is simply an electronic component designed to radiate energy and transmit or receive radio waves. Different antenna types are used for different radio frequencies and for different coverage areas. All antennas radiate some energy in all directions but careful construction can result in focused directivity and negligible power radiated in other directions. Antennas are linked to either radio receivers or signal generators of direction-finding equipment and can be applied in mobile and stationary systems, providing complete coverage of the frequency range from 100 Hz to 30 GHz and beyond in the case of some manufacturers.

Spectrum analyzers help determine whether each radio service operates at the assigned frequency and within the allocated channel bandwidth. The common measurements taken by a spectrum analyzer include frequency, power, modulation, distortion, and noise. Understanding the spectral content of a signal is important, especially in systems with limited bandwidth. Since transmitters and other intentional radiators operate at closely spaced adjacent frequencies, power amplifiers and other components are measured to determine the amount of signal energy that spills over into adjacent channels and causes interference. The concern is that these unwanted emissions, either radiated or conducted (through the power lines or other interconnecting wires), might impair the operation of other systems.

Radio Direction-Finding, or RDF, is the technique used for determining the direction and/or location of a radio transmission/transmitter. Radio direction-finding using triangulation techniques can also be used to determine the location of a radio transmission. Radio direction-finding is used by spectrum managers to locate the source of radio frequency interference.

4.5.6. Designing Spectrum Monitoring Systems

Key considerations in the design of spectrum monitoring systems include types of equipment, speed and sophistication of data capture and processing, degree of integration with software tools for analysis and comparison with other license and type approval data. Other considerations include proximity to active airspace, staff skills, and mobile versus fixed locations.

State-of-the-art spectrum monitoring equipment is highly integrated. Integration typically involves the use of graphical user interface (GUI) based spectrum management tools and systems which are specifically designed to operate multiple electronic components simultaneously and remotely over data protocols such as TCP/IP. This allows for an integrated network system for management of the radio spectrum using remote devices. These devices can be located at existing government sites and facilities on the outskirts of population centers. Remote devices permit access to monitoring equipment from anywhere through compatible computer, a modem and a telephone line or network connection (LAN or WAN).

There are organizational and functional aspects to architecting spectrum monitoring systems. Organizational components include centralized, regional and remote locations for siting of monitoring equipment in stations and operational staffing or use of unmanned remote capabilities, where applicable. Functional components of spectrum monitoring systems include: central monitoring control; operational consoles for operation of equipment and analysis of data; and data networking and management systems for data communications and repository.

4.5.7. Enforcing License Requirements

Spectrum users need to comply with license requirements and technical rules and regulations since without effective regulations and enforcement procedures, the integrity of the spectrum management process can be compromised. Spectrum managers are particularly concerned with interference problems affecting public safety and security services such as ambulance, fire fighting, police, and navigational services at airports.

Monitoring is used to obtain detailed information on the technical and operational characteristics of radio systems which are in use or are being tested for future use. Measurements will typically include frequency, power and emission spectrum of a transmitter. License conditions can be verified against actual use of equipment aiding in the determination of electromagnetic compatibility (EMC).

In the case of harmful interference, the spectrum manager may, at the owner's expense, do any one or more of the following:

1. Take suitable measures to eliminate or reduce the interference or disturbance;
2. Remedy a fault in or the improper operation of the equipment;
3. Modify or alter the equipment; or;
4. Disconnect the equipment.

In the course of conducting exercises to resolve interference problems, the spectrum manager may be required to enter user premises and inspect radio equipment to determine compliance with license conditions and technical standards and in some cases seize equipment. An important aspect of completing these tasks noted above is the requirement under law and regulation to establish the appropriate limits on regulatory powers and authorities and clearly establish the duties and obligations of the spectrum manager/inspector and protection of rights for the public under circumstances where inspection of property is necessary. There may be rare occasions when the user of a transmitter causing harmful interference is endangering the public in a persistent and willful manner and the reasonable course of action requires the spectrum manager to seize equipment preventing future endangerment.

Also, it is helpful to have an appropriate framework and process for responding to and managing complaints, for settling disputes, and resolving interference problems. 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.

4.6. Flexibility in Spectrum Management

4.6.1. Spectrum Trading

Secondary trading of spectrum permits the purchaser to change the use to which the spectrum was initially put while maintaining the right to use it. This is viewed by many as the key step to be taken in the reform of spectrum management regulatory practice, capable of unlocking the potential of new technologies and of eliminating artificial scarcities of spectrum which find expression in inflated prices for spectrum-using services.

Once secondary trading is allowed, industry structure can be affected by mergers of companies or the direct transfer of spectrum ownership. There is a risk of a structure emerging which contains a monopoly or, more generally, a dominant firm or firms, which can set excessive prices. This problem can be combated by ordinary competition law where the law exists; for example a dominant position might be broken up or a merger disallowed. But it may also be necessary for the regulator to have the power to scrutinize and, if appropriate, prohibit certain spectrum trades.

A useful aid in dealing with problems of market power is to encourage co-operation between the spectrum regulator, with its technical knowledge, and the competition authority, which is skilled in market analysis. South Africa, for instance, has been successful in achieving this goal.

The issue here, as is so often the case in spectrum regulation, is a trade-off between the costs of *ex ante* scrutiny, which are incurred by firms and the regulator (and hence, ultimately by consumers of spectrum-using services), and potential cost to consumers of abuses of market power, if a trade takes place which triggers that risk. The argument for *ex ante* scrutiny will be stronger if a) spectrum ownership is already concentrated, and b) ordinary competition law is non-existent, underdeveloped, or difficult to enforce.

If spectrum markets are to work properly, participants must have basic information about spectrum holdings adjacent to where they are considering buying licenses. Otherwise buyers will not appreciate the constraints relating to interference to which they will be subject. This raises problems of confidentiality – both commercial confidentiality and the need for secrecy where spectrum is used for security or defense purposes. For a variety of reasons concerned with the policing of interference as well as the policing of competition, the regulator will have to keep a register of spectrum use and license holdings. Much of this can be published, and its existence will be of great help to potential licensees seeking to find out who their spectrum neighbors would be if they offered a particular service in a particular frequency in a particular area.

Several countries have now had experience of secondary trading in spectrum licenses for a decade or more. These include countries in regions as diverse as North America, Australasia and Central America. It is thus possible to evaluate the experience of secondary trading (see Box 4.2).

The evidence suggests that spectrum turns over about as fast as commercial property; between 3 and 10% of licenses changing hands every year. The data suggest that licenses are held as a strategic asset (for use by the licensee) rather than for speculative purposes. A number of transactions are the consequence of mergers and acquisitions, and some are intra-group asset transfers. Changes of use are comparatively rare, but several big transactions have been of this kind, especially on the boundary between broadcasting and mobile communications.

Has trading with flexibility caused interference problems? Given the limited experience so far, it is too soon to say anything definitive on this matter. Clearly, interference problems still persist in many countries, but most of these are due to illegal transmissions, rather than the complicated effects of change of use following secondary trading. Nor is there evidence of firms trying to "corner the market" in particular frequency bands by license acquisition. Indeed, given that many countries where trading is allowed also plan to authorize flexibility, cornering the resulting fairly wide market for interchangeable spectrum will be difficult.

Where there is excess demand for licenses, they can be assigned by lot (i.e. by randomly choosing winners from all qualified license applicants). If the licenses are potentially valuable, thousands or even millions might apply.

Box 4.2 Check-list for Implementing Spectrum Markets

A summary of steps to be taken to introduce spectrum trading.

- The rights and obligations associated with a tradable license are sufficiently clear, in relation to such things as duration, area and interference restrictions that buyers know they are getting.
- Where the licensee can change the use to which the spectrum is put there must be a suitable regime in place to regulate interference (e.g., one which limits emissions at the boundary) to protect other licensees from changes.
- Potential traders must be able to acquire information from a public register about adjacent licensees (those in neighboring areas or bandwidths). This is necessary to allow them to evaluate the consequences of their trades accurately.
- To reduce transactions costs, there must be a simple and clear procedure from registering licensee changes with the spectrum regulator.
- Procedures for scrutiny and reaction by the regulator must be in place to prevent or avert the consequences of trades which confer high levels of market power on firms acquiring licenses.

4.6.2. Unlicensed Spectrum

Spectrum that is free from centralized control where anyone can transmit without a license while complying with rules that are designed to limit or avoid interference is sometimes referred to as license-exempt or unlicensed spectrum. Unlicensed spectrum was, until recently, of little interest. However, more recently it has been debated more widely, as a result of:

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

technologies can overcome historical problems with unlicensed spectrum.

The spectrum commons involves unlicensed spectrum although in practice what is referred to as a spectrum commons can have varying degrees of management. License-exempt bands, e.g., the industrial, scientific and medical (ISM) bands, are an example of a spectrum commons with some management in terms of power restrictions on individual users as applied in the United States under the FCC Part 15 rules. In Europe there is a further degree of control in that devices used for communication in these bands must conform to certain technology standards (i.e. ETSI approval). So far this approach has only been used in limited bands for short range applications. However, significant innovation has emerged in these bands (e.g., WiFi) which have led some to call for more spectrum to be managed similarly.

Broadly, the same history is true in all countries. In the 1920s, essentially all spectrum was unlicensed. The confusion and interference this caused, especially among broadcast stations led to a licensed approach being adopted in the 1930s, although some spectrum was still set aside for unlicensed use.

Over time, the main unlicensed bands were those designated as ISM. These were bands where there was non-communications use of spectrum, for example, for heating purposes. Because this use generated interference, the ISM bands were often made available for unlicensed usage.

In determining the most appropriate regulatory policy regarding unlicensed spectrum, it is necessary to determine:

- Whether there is spectrum that is currently not congested or can be expected to remain uncongested and so could become unlicensed.
- Whether there is spectrum that is congested, but only because of inefficient usage; and where a change in management policy to unlicensed usage will remove the congestion.

There are many factors that influence congestion. Some of these are caused by suboptimal allocation policies and can be expected to be gradually alleviated by the introduction of trading. Some are caused by allowing the use of equipment that is inefficient in its use of spectrum. The other factors influencing congestion are the bandwidth and time of transmissions. These mostly depend on the usage.

Having decided on the most likely use, spectrum should be subject to licensing where any of the following hold true:

1. The band is likely to be congested. Examples of such services are mobile cellular and broadcasting.
2. A guaranteed quality of service (QoS) is needed. This is the case, for example, with most public safety communications.
3. International treaty obligations provide restrictions that would be breached by operation on a license-exempt basis either now or at some known point in the future.

Without regulatory intervention, the problem of dealing with congestion can not be practically resolved. Equipment will only be made efficient to the extent that it is necessary for that piece of equipment to operate reliably and not for the greater good of all the users of the band.

Table 4.2 U.K. Unlicensed Bands

FREQUENCY BAND	APPLICATION
9 kHz to 30 MHz	Short Range Inductive Applications
27 MHz	Telemetry, Telecommand and Model Control
40 MHz	Telemetry, Telecommand and Model Control
49 MHz	General Purpose Low Power Devices
173 MHz	Alarms, Telemetry, Telecommand and Medical Applications
405 MHz	Ultra Low Power Medical Implants Devices
418 MHz	General Purpose Telemetry and Telecommand Applications
458 MHz	Alarms, Telemetry, Telecommand and Medical Applications
864 MHz	Cordless Audio Applications
868 MHz	Alarms, Telemetry and Telecommand Applications
2400 MHz	General Purpose Short Range Applications, including CCTV and RFID. Also used for WLANs including Bluetooth Applications
5.8 GHz	HyperLANs, General Purpose Short Range Applications, including Road Traffic and Transport Telematics
10.5 GHz	Movement Detection
24 GHz	Movement Detection
63 GHz	2^{nd} Phase Road Traffic and Transport Telematics
76 GHz	Vehicle Radar Systems

In summary, many observers conclude that spectrum should be unlicensed if it were unlikely to be congested. Still, there is no definitive way to predict congestion. A judgment needs to be made on the basis of the frequency band, likely use and range. The range in turn depends on the use. Hence, a key stage in predicting the congestion likely in the band is determining the most likely use.

The Ofcom Spectrum Framework Review in 2004 examined the potential for greater sharing and use of License Exempt (LE) bands and determined that utilization of certain LE bands was less than optimal. For example, in the case of the 2.4 GHz License Exempt Band, utilization was in the order of 10%.

Table 4.2 shows the currently unlicensed bands in the United Kingdom.

4.6.3. The Digital Dividend

Switching from analog to digital terrestrial TV releases a significant amount of the radio spectrum that can be used for new uses. This so-called Digital Dividend arises because of the greater compression that is possible with digital signals. Past and current analog signals utilized the entirety of the radio spectrum; however, newer digital signals require less of the spectrum in order to provide the same services.

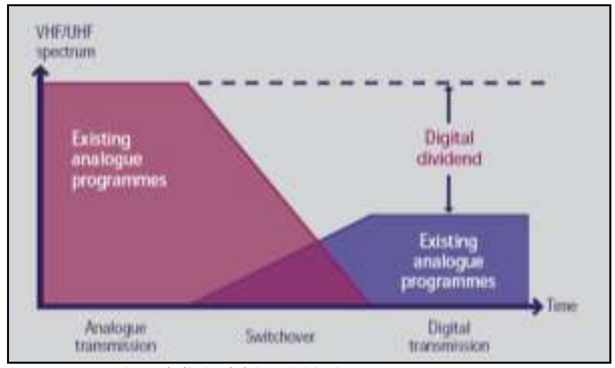
The switchover will therefore free up a significant amount of spectrum (primarily in the UHF band), creating a unique opportunity as a result of:

- superior propagation characteristics of the UHF band and the amount of spectrum that is potentially available;
- the wide range of potential uses of the spectrum; and,
- the potential role in creating economic growth and new employment opportunities.

What is the Digital Dividend?

Digital compression allows the transmission of several (up to eight, depending on the coding and modulation techniques) standard digital television channels in the radiofrequency spectrum previously used by a single analog channel. Typically, four or five terrestrial analog services in a given region will be digitized into a single digital television channel thereby considerably reducing the overall use of spectrum (see Figure 4.2). The gain could be even more substantial if more advanced standards are adopted (e.g., DVB-T2 for infrastructure and MPEG-4 for compression).

Figure 4.2 Digital Dividend Spectrum



Source: ITU, The Digital Dividend 2010.

Using the Digital Dividend

The Digital Dividend denotes a specific part of the spectrum that varies somewhat by country and region but broadly exists between 200MHz to 1GHz (see Figure 4.1). This range denotes a better-quality signal that requires less infrastructure while providing greater mobile coverage, particularly in rural areas, and at a lower cost. However, mobile coverage is just one potential benefit. Other potential uses include:

- New mobile services, with high quality video and interactive media delivered to handheld devices.
- Wireless broadband services, with high-speed data and voice services.
- Advanced business and broadcasting services, e.g., to support major sporting events.
- Additional television channels, including High Definition (HD) TV

Allocating the newly available spectrum has become an international issue and new services and technologies which is challenging policy makers. Achieving a fair and well-balanced reallocation of the spectrum between mobile broadband, broadcasting and ICT industries is necessary to ensure that society reaps the full social and economic benefits of the Digital Dividend.

Harmonization

The switch from analog to digital is happening throughout the world. While countries and regions have their own timetables for the conversion, there is a general consensus concerning the necessity of the switch. (i.e. the United States completed switchover in June 2009; the switch should be complete throughout the European Union by the end of 2012; Japan by July 2011; Ghana: by 2013).

A major success at the ITU World Radiocommunication Conference in 2007 (WRC-07) was agreement on globally harmonized spectrum, including:

- 450−470 MHz band
- 698−862 MHz band in Region 2 and nine countries of Region 3
- 790−862 MHz band in Regions 1 and 3

The 2012 World Radiocommunication Conference (WRC-12) will discuss how mobile and other services can share the band 790-862 MHz in Regions 1 and 3, to ensure the adequate protection of services to which this frequency band is allocated.

The European Commission adopted a Decision in May 2010 establishing harmonized technical rules for EU Member States on the allocation of radio frequencies in the 800 MHz band that contribute to the deployment of high-speed wireless internet services by avoiding harmful interference. In several Member States the 800 MHz frequencies are being freed up as part of the Digital Dividend resulting from the switchover from analogue to digital television broadcasting. If Member States decide to change the existing frequency allocation (for broadcasting) they must immediately apply the harmonized technical rules laid down by the Decision to make these frequencies available to wireless broadband applications. The decision does not itself require Member States to make available the 790-862 MHz band for electronic communication services, although this is under consideration.