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SPECTRUM SHARING

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1 INTRODUCTION

This chapter reviews various trends in spectrum sharing methods used by spectrum managers who are responding to increasing demands for spectrum coming from the unstoppable surge in new services and technologies.

Spectrum sharing encompasses several techniques – some administrative, technical and market-based. Spectrum can be shared in several dimensions; time, space and geography. Limiting transmit power is also a factor which can be utilized to permit sharing. Low power devices in the spectrum commons operate on the basis of that principle characteristic – propagation – and as we shall see later with Dynamic Access Spectrum Sharing, take advantage of power and interference reduction techniques. Sharing can also be accomplished through licensing and/or commercial arrangements involving spectrum leases and spectrum trading.

In considering the need to share spectrum, we begin with a discussion of various sources of spectrum demand and causes of scarcity in relation to spectrum management goals and objectives. It should be helpful to briefly review administrative, market-based and technically enabled solutions for spectrum sharing and then review the important policy decisions being considered by more than a few regulators to change spectrum assignment licensing practises.

Spectrum sharing is not a universal trend for all regulators. There are varying approaches by regulators for managing the unlicensed but regulated spectrum commons ranging from imposing license and permits constraints to few if any constraints at all beyond technical specifications. The allocation of ISM (Industry, Scientific and Medical) bands for unlicensed use by low power devices such as Wi-Fi has been encouraged by the ITU across all regions. Making changes to spectrum allocations is a powerful means for encouraging spectrum sharing by different services such as fixed and mobile but as recent studies have shown many countries continue to reserve significant amounts of spectrum for exclusive (government use)[1]. The WRC-07[2] has made significant strides increasing the amount of spectrum available to broadband services. The next important step by regulators is to begin planning for the use of these bands. We make reference to country examples in both developed and developing country where progress is being made and we will point out the common success factors.

Spectrum sharing can be achieved through technical means and through licensing arrangements. Important techniques and the concepts behind them using advanced technologies such as cognitive radio are reviewed in light of the likelihood that these technologies will not be commercially available in the near future. Spectrum trading is also occurring in several countries and the experiences in several prominent examples are reviewed.

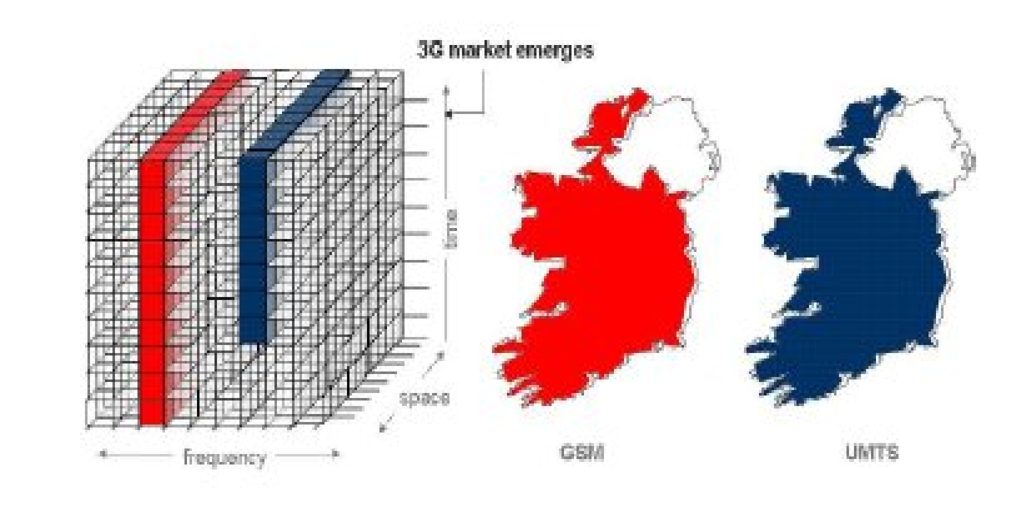
A common issue for both innovative technologies and market-based methods is arriving at the right balance. Resolving interference issues inherent in methods based on the principle of technological neutrality is an issue of great importance. Interference cannot be eliminated and so identifying interference management models which support spectrum sharing under either administrative, market-based and spectrum commons remain as an ongoing requirement and challenge for spectrum managers. These issues are discussed and examples of possible solutions are given.

The chapter finishes by reviewing some best practises for encouraging spectrum sharing by laying down suggestions for a roadmap.

1.1 Traditional Spectrum Management Approach

In the traditional administrative spectrum management model, a spectrum manager specifies detailed rules and constraints affecting how, where and when spectrum can be used and who has access to spectrum. Minimizing harmful interference lies at the heart of the traditional model which places an emphasis on the technical management of radio spectrum. As a consequence, different services are sometimes allocated to different frequency bands, although in most frequency bands, more than one radio service is allocated, and sharing between services takes place under specified technical criteria.

Figure 1: Representation of Frequency Assignments for a Single GSM/UMTS Operator



Note: No notion of Liberalization is assumed in the depiction of license features.

Source: Linda Doyle & Tim Forde: Towards a Fluid Spectrum Market for Exclusive Usage Rights. Trinity College, University of Dublin, 2007

In circumstances where the demand for radio spectrum is below the available supply and innovation is occurring steadily and predictably, as in the past, the traditional model works adequately. In recent years, however, demand for spectrum use has grown significantly, particularly in those frequency bands designated for mobile communications. Furthermore, applications such as mobile telecom services, fixed broadband wireless access services, high definition terrestrial TV services, mobile terrestrial TV services, etc.,[3] are able to work in the same frequency bands.

The economic value associated with contemporary uses of radio spectrum is often considerable and has grown significantly in recent years. The economic significance and intensified competition among the many different applications using spectrum, particularly for bands lying below 3GHz, is undermining the effectiveness of the traditional model. As the traditional approach targets technical factors and focuses primarily on harmful interference, it is relatively inflexible and less amenable for dealing with criteria such as economic efficiency.

The traditional model is viewed as inflexible by a number of commentators. The traditional model usually requires new equipment to be tested regarding interference and this can cause delays to the introduction of new services.[4] The traditional model can also lead to costly regulatory errors, such as those which have occurred in Europe, where regulators reserved certain valuable frequency bands for new services such as the terrestrial flight telephone system (TFTS) and the European radio messaging system (ERMES) that have failed to deliver the benefits proclaimed by proponents.

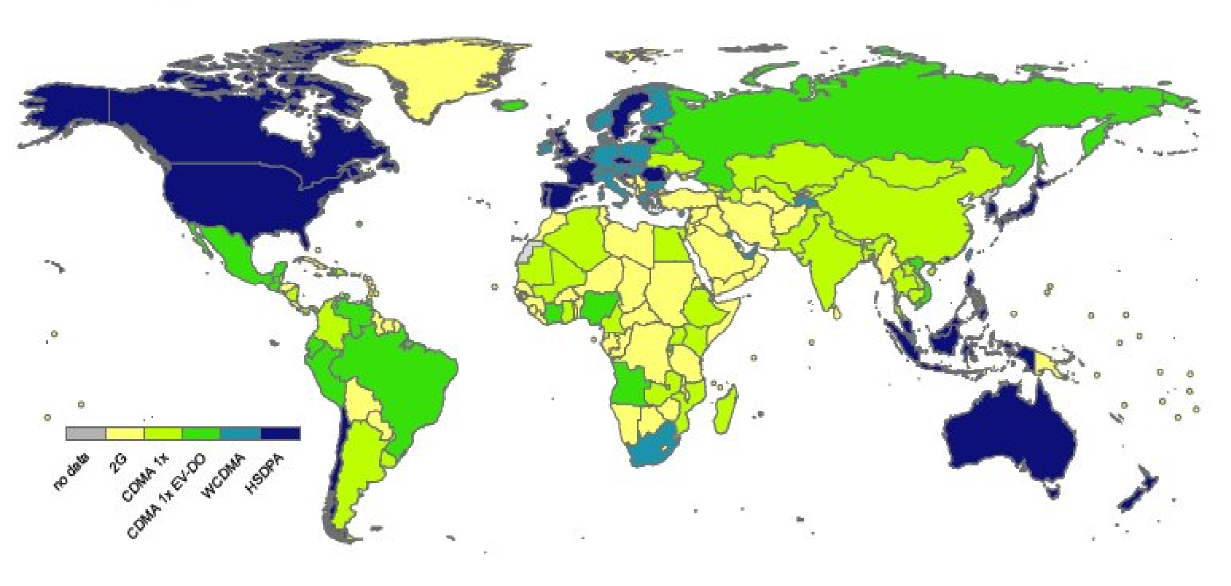
1.2 Mobile Telephony and Broadband Ubiquity

An observer cannot escape noticing the almost commonplace use of mobile cellular phones and wireless laptops whether one lives in Vienna, Vancouver or Vientiane. In 14 out of 31 OECD countries, mobile cellular subscriber penetration rates exceed 100 per cent with Luxembourg having the highest at 157 subscriptions per 100 inhabitants[5]. In developing countries, mobile cellular penetration rates approximate 32 subscribers per 100 inhabitants. And not surprisingly, the average mobile cellular use as a per cent of total telephone subscriptions in least developed countries is more than 92 per cent of total telephone subscriptions[6], a consequence of the lesser cost of wireless infrastructure.

Over the past year, the number of broadband subscribers in the OECD has increased 24 per cent from 177 million in June 2006 to 221 million in June 2007 with DSL representing 62 per cent of all broadband connections. Fixed and Mobile wireless broadband (less than 2 per cent) is expected to become increasingly important in rural and broadband cellular applications. Overall broadband penetration rates in the OECD increased from 15.1 to 18.8 subscriptions per 100 inhabitants a year later in June 2007[7].

Increased penetration and access have occurred along with significant levels of investment in telecommunications services capital equipment reaching 579 billion USD in 2005 growing at a Compound Annual Growth Rate (CAGR) of 12 per cent over the 10 year period from 1996 to 2005. This investment has unleashed widespread innovation and creativity in the development of new technologies and services including IMT and WiMax which are described alongside other innovations later on in Section 2.5 below.

Figure 2: Mobile technologies worldwide, by June 2007



Disclaimer: The designations employed and the presentation of material in this map do not imply any opinion whatsoever on the part of the ITU concerning the legal or other status of any country, territory or area or any endorsement or acceptance of any boundary.

Source: ITU, based on data from 3Gtoday

1.3 The need for Spectrum Sharing

As the demand for spectrum increases and frequency bands become more congested especially in densely populated urban centres, spectrum managers are following diverse approaches to sharing frequencies: using administrative methods including inband sharing, licensing such as leasing and spectrum trading, and the unlicensed spectrum commons combined with the use of low power radios or advanced radio technologies including ultra-wideband and multi-modal radios,

In the next sections of this paper we examine in more detail aspects of the demand for spectrum and spectrum scarcity, innovations in services and technological advances, various spectrum sharing techniques and examples from several countries

2 DEMAND FOR SPECTRUM

2.1 Introduction

The broad theme of effective spectrum management is explored in this section and put into context in terms of spectrum scarcity and innovation. First, generally accepted spectrum management goals and objectives will be put forward. Second, spectrum scarcity is discussed and explained in terms of three aspects: scarcity due to increased demand, administrative processes, and technical issues, such as interference management and technical obsolescence.

Before moving on, it is important to note that the amount scarce spectrum within a country or local is relative and may also vary from one country to another. When examining various spectrum management approaches for spectrum sharing it is important for the spectrum manager to keep in mind that differences do exist between countries and between urban, rural and remote regions,

2.2 Spectrum Management Goals and Objectives

Broadband wireless access is an innovative solution for connecting the world, one of the main objectives of the ITU, extending connectivity to a greater number of people through availability of ICT services to all geographical areas. This can be accomplished through more efficient use of the spectrum resource through promotion of more effective management.

Related core spectrum management objectives include:

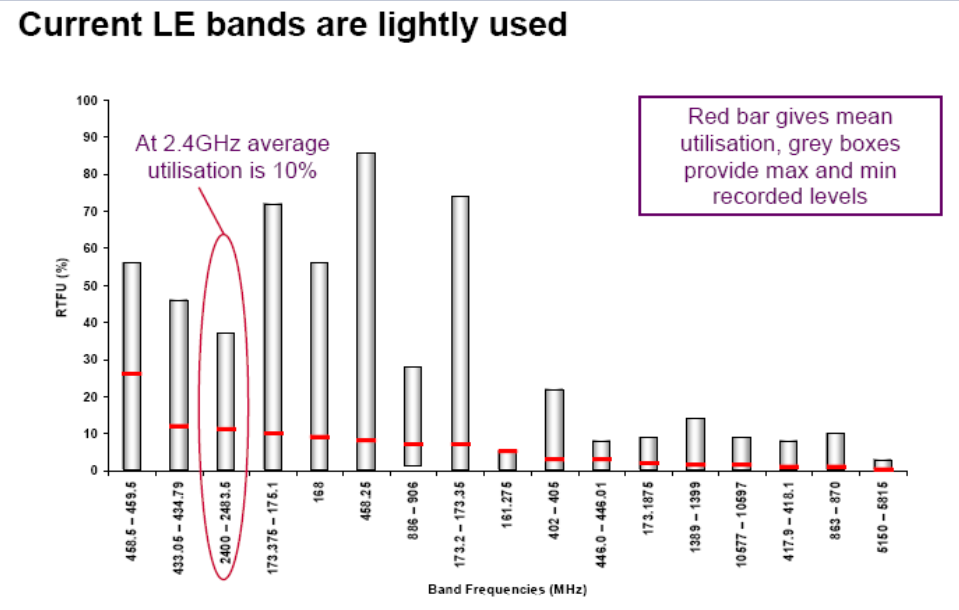
- Planning for future needs and management and monitoring the utilization of the spectrum resource in accordance with legislative and public policy objectives and international agreements;
- Improving the efficient and optimum use of the spectrum resource through adoption of advanced spectrum allocation, management techniques and licensing processes based on operational requirements and technical and economic viability;
- Ensuring flexibility and adaptability and ease of access to the spectrum resource in response to technological advances, and economic, social and market factors.
- Ensuring national interests are protected while striving for global harmonization of spectrum along with coordinated spectrum policies and utilization working with regional and international organizations and in compliance with treaty obligations, including those of the ITU.
- Supporting and promoting innovation, research and development in new radiocommunication techniques and spectrum-based services and applications
- Coordinating and establishing well balanced national spectrum and radiocommunication policies and plans by widely consulting with all interested parties and the general public.

2.3 Spectrum Scarcity

Spectrum scarcity is discussed in the next few paragraphs. It is important to recall that increased spectrum scarcity can be met in part by existing operators. As discussed later on, sufficient incentives are needed to ensure frequencies will be used efficiently by existing users or, as in the case of license-exempt spectrum reduction, in the number of restrictions and barriers on use. As well, as pointed out earlier on, there can be differences between urban and rural areas, where, in the case of the latter, spectrum is less congested. Congestion and scarcity can occur as a result of some types of services allocated for use in certain geographic areas such as maritime services in coastal areas.

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.

Figure 3: UK License Exempt Band Utilization



Note: Ofcom Spectrum Framework Review in 2004

2.3.1 Demand for New Services

As pointed out earlier the growth in demand for wireless mobile telephony worldwide over the past decade is such that the worldwide number of mobile phone subscribers now surpasses the total of fixed-line customers. Increased competition leading to lower prices especially in the mobile and ISP sectors have resulted from a combination of positive effects from liberalization, deregulation and privatization in telecommunication services.

As the demand for services changes, it may be desirable (for example) to switch some services to higher frequencies and reform/refarm the spectrum for better-suited new services, resulting in one of the biggest challenges facing spectrum regulators: the reallocation of spectrum. It is very often difficult to reallocate these frequencies for a different use when frequencies have been used for one purpose, perhaps for decades.

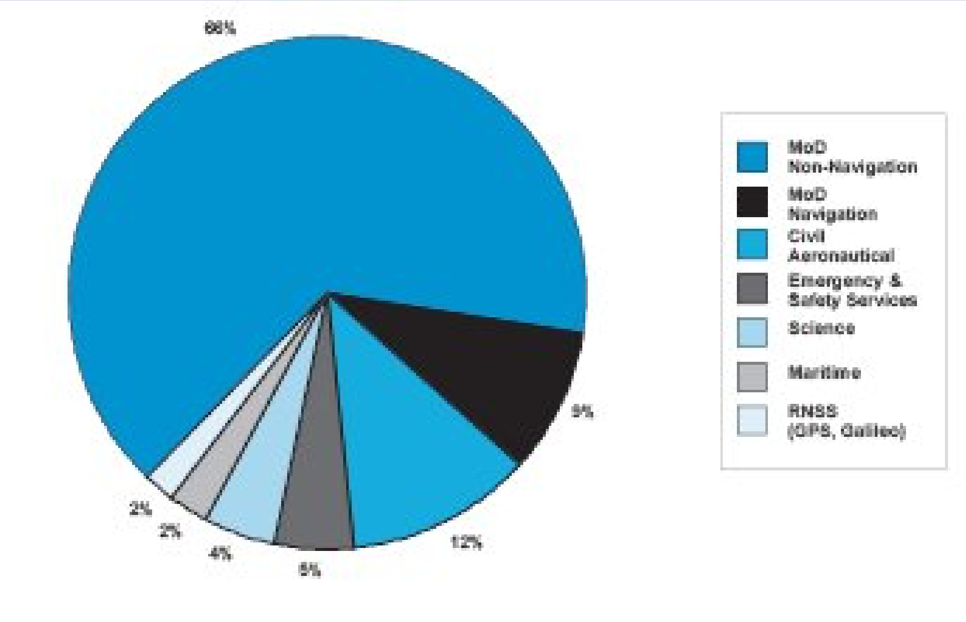
2.3.2 Administrative Scarcity

Administrative processes for determining spectrum use including changes to international and national allocations and the refarming of spectrum from current uses are lengthy and complicated exercises. Resolving disputes between users using fact finding forums, hearings and often leading to the use of dispute mechanisms are costly and very time intensive. These combine to create regulatory-induced scarcity due to excessive rigidity.

European Commission: "The deployment of innovative wireless services and technologies is increasingly hampered by the reservation of certain spectrum bands for narrowly defined services coupled with rigid usage conditions that are unduly constraining spectrum use".[8]

The reallocation (refarming) of spectrum from government exclusive use to civil and commercial uses continues to be a problem in both developed and developing countries. Significant blocks of spectrum are allocated for government use, often for military and other ministry communications systems. As reported in the Independent Audit of Spectrum Holdings (the Cave Audit) to the UK Government in 2005, government holdings of spectrum approximate 50 per cent of the spectrum below 15GHz. Figure 4 below, illustrates the relative share of spectrum between various government services.

Figure 4: Composition of public sector spectrum holdings below 15 GHz, United Kingdom

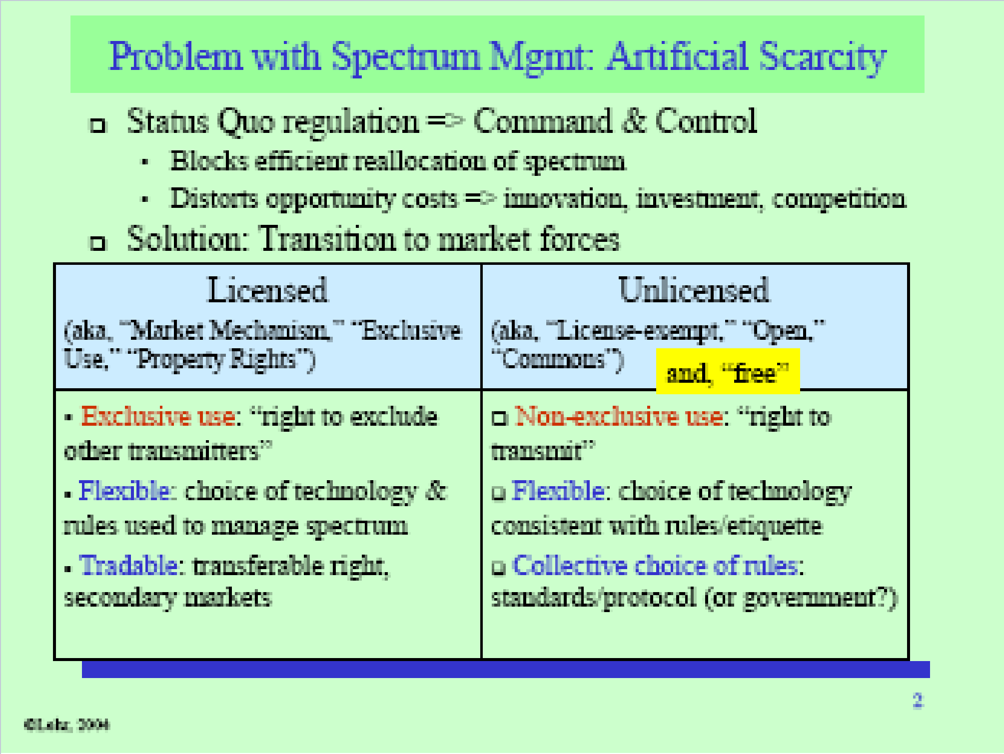


Source: Independent Audit of SPECTRUM HOLDINGS: HM Treasury, 2005, Figure 1, page 13.

Scarcity can also exist due either to delays or even reluctance on the part of stakeholders to engage in efforts to resolve issues related to access to spectrum. This has been a problem for new entrants into mobile markets. There are numerous examples of decisions made by regulators concerning spectrum “set asides” which ultimately favour one party over another creating spectrum scarcity.[9]

Two of the mechanisms gaining favour in efforts to alleviate administrative scarcity are the use of market methods such as spectrum trading or in-band migration and the spectrum commons. Trading of spectrum licenses is taking place in Australia, New Zealand, the UK and United States amongst others with Guatemala utilizing spectrum trades of commercial spectrum assignments since 1996. This topic is explored further in later paragraphs under Section 4.3. Spectrum Authorization Reform: the chart below illustrates how three models of spectrum management, administrative, market-based and spectrum commons, are related.

Figure 5: Artificial scarcity



Source: Managing Shared Access to the Spectrum Commons, William Lehr (MIT) and Jon Crowcroft (Cambridge).

2.3.3 Technical Issues

Technical issues can also contribute to spectrum scarcity. For example, licensees are typically required to comply with an applicable radio system plan and specification which, by implication, may limit the types of efficient technologies used by the licensee. While the intention is to create certain protective technical restrictions improving overall technical efficiency, lack of flexibility in spectrum management may result in scarcity. Another aspect of the same problem is technical obsolescence of equipment often utilized by governments in exclusive allocations of spectrum. The use of innovative technologies in response to these problems is discussed in the paragraphs below.

2.4 Service Innovation

Convergence of wireless telecommunications technology with Internet technology is not a new topic. For spectrum managers, the challenges are to address the evolution of technology and growth in demand, ensuring that sufficient spectrum is available for current and future generations of services while protecting public safety and security. The main issues at WRC-07 were new allocations and identification of spectrum for International Mobile Telecommunications (including IMT-2000, BWA, and IMT Advanced broadband wireless access systems, all known now collectively as IMT). The goal of the conference agenda was to earmark spectrum at a worldwide level to facilitate this development, tapping into the higher frequencies beyond 1GHz, increasing the capacity of new systems. Table I below nicely characterizes the issue:

Table 1: Predicted spectrum requirements by the year 2020 for IMT

Predicted Total ***1280 MHz Low*** *1720 MHz High*	*Identified*	*Low Demand Net Additional MHz needed*	*High Demand Net Additional MHz needed*
Region One (Europe, Africa and Middle East)	*693 MHz*	*587 MHz*	*1027 MHz*
Region Two (Americas)	*723 MHz*	*557 MHz*	*997 MHz*
Region Three (Asia)	*749 MHz*	*531 MHz*	*971 MHz*

Note: Prediction based on one network deployment

Source: ITU 2007

2.5 Technology Innovation

In some countries, a more liberalized approach towards spectrum management has evolved, most notably in the United States, and this has resulted in considerable innovative in the use of Wi-Fi, WiMax and Ultra-wideband (UWB). The use of these innovative technologies has emerged many years before similar large scale deployments, largely as a result of regulatory actions designed to promote flexibility and unlicensed use.

- Wi-Fi is a trademark moniker for a set of product compatibility standards based on the IEEE 802.11 technical standard. It is used primarily for wireless local area networks, typically using the 2.4 GHz ISM or Unlicensed Band;
- WiMax is the next evolution of Wi-Fi based on the IEEE 802.16a amended standard having a range of up to 31 miles. WiMax is primarily aimed at making broadband network access widely available without the expense of stringing wires (as in cable-access broadband) or the distance limitations of Digital Subscriber Line.

Table 2.0 lists bands identified for BWA services:

Table 2: WiMax BWA Bands

Region	*Existing Bands*	*WRC-2007 (Additional Bands)*
Region One (Europe, Africa and Middle East)	*3.5 GHz and 5.8 GHz*	*450-470 MHz, 790-862 MHz[10], 2300-2400 MHz, 3400-3600 MHz*
Region Two (Americas)	*2. 5GHz, 3.5GHz and 5.8GHz*	*450-470 MHz, 698-862MHz[11],2300-2400 MHz,*
Region Three (Asia)	*2.5 GHz and 5 GHz.*	*450-470 MHz, 790-862 MHz[12],2300-2400 MHz, 3400-3500 MHz or 3500-3600 MHz,*

Source: GSR Discussion Paper on WRC-07 Results and Impact on Terrestrial BWA Services

2.5.1 Analogue Broadcast Switch-off and the Digital Dividend

Different approaches have evolved in Europe and United States with respect to the migration from analogue to digital TV.

In Europe, a crowded place, the nature of terrestrial broadcasting signals requires careful planning of frequencies. The ITU Regional Radiocommunication Conference (GE06) establishes detailed allotments to each country based on prospective digital transmission to replace the analogue regime agreed in television in 1960. Within the European Union, the latest date for analogue switch-off is 2015. GE06 leaves significant scope for flexibility in implementing the plan.

- First, there is a high degree of flexibility regarding the location of transmitters within the service area and interference envelope in the plan.
- Secondly, a declaration was signed permitting services other than broadcasting, provided they did not cause interference to allotted broadcast frequencies and would not receive any protection from interference beyond what would be granted for broadcasting use.

In the United States, the regulator has been heavily involved with managing the transition from analogue to digital television. With adoption of the ATSC standard for terrestrial digital television transmission in 1996, the FCC set 2006 as a target date for completing the transition, with provision for reviewing this decision every two years. Recent legislation requires the end of analogue television broadcasting by 17 February 2009 and provides for a digital-to-analogue converter box subsidy. However, legislation permits television stations to retain their analogue authorization beyond that date in markets where household penetration of DTV reception equipment is less than 85 per cent.

3 IMPROVED ACCESS THROUGH SPECTRUM SHARING

3.1 Introduction

Spectrum sharing typically involves more than one user sharing the same band of spectrum for different applications or using different technologies. When a band already licensed to an operator is shared with others it is known as *overlay spectrum sharing*. For example a spectrum band used for TV distribution in one geographical area could be used for an application such as broadband wireless access in another area without any risk of interference, despite being allocated on a national basis[13].

Good questions to ask are: When is spectrum sharing or other methods for improving access to spectrum, such as spectrum trading, truly required; and, when does it make the most sense? For example, does spectrum sharing make better sense in developed or developing countries, in urban or rural areas, and are there different degrees or dimensions to spectrum sharing such as geographic sharing? Another factor to consider in determining whether it makes sense is cost which include the costs of regulation and transaction costs. Will spectrum sharing deliver on the promise of developing innovative broadband applications for developing country users', positively impacting accessibility and affordability of ICT services?

The answer to the question, when is sharing required should be conceptually fairly straightforward. Spectrum sharing is required when sufficient demand for spectrum exists, causing congestion, and the technical means exist to permit different users to coincide; and other means for adjusting spectrum use and assignment have become burdensome and costly undermining the goals of economic and technical efficiency. The implications for spectrum managers are that spectrum management policies are evolving towards more flexibility and market-oriented models to increase opportunities for efficient spectrum use.

The answers to the remaining questions involve some review and discussion and will be explored in the next few paragraphs.

3.2 Forms of Spectrum Sharing

There are generally several ways to share spectrum and to achieve the goal of improving access to spectrum by giving more users greater flexibility in its use by implementing:

- Liberalized methods for assigning spectrum rights such as leasing, trading and the spectrum commons;
- A new paradigm for interference protection taking into account new technologies such as dynamic spectrum access where underlay technologies are used based on power limits, such as UWB, mesh networks, software defined radio (SDR), smart antennae and cognitive radios.

3.3 Which bands can be shared?

There are frequency bands which are being shared by some users by maintaining geographic separation and ensuring strict adherence to operational constraints preventing interference between services. One good example is spectrum shared by satellite and fixed links where the microwave links transmit horizontally and interaction between systems is limited. As well, fixed and mobile services also share bands and do so by maintaining geographic separation and limits on power.

Potentially all bands can be shared and many bands remain underutilized, i.e. it is technically possible to share bands using combinations of administrative means (assignment – time, geographic, and interference management constraints) and technical solutions – filters, smart antenna, smart transmitters (such as SDR and cognitive radio) and transmit power limitations combined with a relaxation of interference constraints. An important exception may result from a spectrum policy decision to maintain exclusive band and assignments for public safety and security services.

The more interesting question is which bands are of interest for sharing? For BWA, bands need not necessarily be contiguous, but must have sufficient bandwidth (i.e., 2.5 MHz) to support broadband applications such as video, and should be located where good propagation characteristics exist (i.e., below 1 GHz), and wide geographic coverage. Bands with low occupancy and utilization could also be of interest (i.e. above 15 GHz).

3.4 Administratively Managed Spectrum Sharing

Administrative management of spectrum sharing generally involves regulator processes, which establish where sharing should take place, define the sharing rules to be applied for radio system performance and applicable technical standards, equipment specifications and equipment type approval. There are several steps which can be taken by the regulator to improve spectrum sharing:

- Establish policies to make spectrum allocation and licensing assignments that are based on marketplace demands and to develop fair, efficient and transparent processes for awarding licenses. This may mean beginning a process to evaluate existing allocations and determine how much spectrum can be allocated on a shared or non-exclusive basis;
- Conduct an independent audit of spectrum holdings to identify bands where immediate changes can take place.
- Conduct consultations with stakeholders to obtain necessary information to support decisions on sharing and technical standards;
- Encourage solutions based on negotiations between affected parties including the payment of compensation;

- Establish specifications which encourage the utilization of spectrum-efficient technologies and implement mechanisms such as the use of spectrum-fee incentives to begin the transition to commercial allocations, assignments and users;
- Consider the use of band managers who manage and resolve issues on the part of licensees within the band. There are several models where the spectrum management activity is delegated by the regulator to a band manager on an exclusive and non-exclusive basis:
  - The Regulator performs the tasks;
  - A Band manager is delegated the tasks;[14]
  - Sharing is non-exclusive: either the regulator or band manager define the rules;
  - Exclusive licenses, such as for a mobile operator, which largely determine the technologies to be used and how to utilize assigned frequencies for various applications and networks.

3.5 Using Markets to Improve Access

As a starting point, economically efficient use of spectrum 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. From an economic efficiency viewpoint, spectrum should be divided in such a way that the benefits to the overall economy are the same from different uses of spectrum for an equivalent incremental amount of spectrum assigned to either use. Market-based approaches such as auctions[15] and spectrum trading are viewed by economists as superior to administered methods with regards to achieving economic efficiency.

3.5.1 Market Solutions to Rebalance Spectrum

Market methods are being employed both at the primary issue of spectrum licences, when auctions are used, and, more significantly, by allowing spectrum rights to be bought and sold in the lifetime of a licence and allowing a change of use of the relevant spectrum.

In cases where spectrum is a scarce resource, and like all scarce resources in a competitive market, efficient allocation decisions are premised on prices. Well designed and properly managed auctions are appealing since they ensure that frequencies go to the firm which bids the most, and that may in certain conditions be the most efficient firm. Efficiency is further enhanced if the successful licensee chooses which services to provide and technologies to use[16].

Spectrum trading contributes to economic efficient use of frequencies since trades should only take place if the spectrum is worth more to the new user than it was to the old user, reflecting the greater economic benefit the new user expects to derive from its use. In the absence of misjudgements or irrational behaviour or external effects, some commentators view that spectrum trading contributes to greater economic efficiency.

3.6 Technically Enabled Spectrum Sharing

Technically efficient use of spectrum, at a basic level, implies the fullest possible use of all available spectrum. Two measures of technical efficiency are occupancy and data rate. Time, for example, can be used as a measure of technical efficiency in the sense of how constant or heavy the usage of spectrum is over time. Data rate means how much data and information can be transmitted for a given amount of spectrum capacity. Spectrum sharing technologies including spread spectrum, dynamic access and Ultra-wideband (UWB) are introduced and described in the next paragraphs.

3.6.1 Underlay Technologies

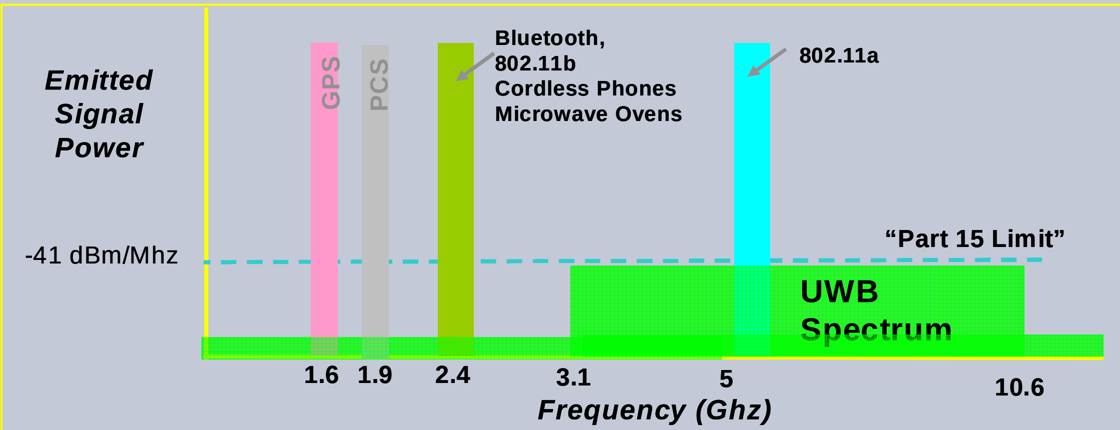
Spectrum underlay technique is a spectrum management principle by which signals with a very low spectral power density can coexist, as a secondary user, with the primary users of the frequency band(s). The primary users deploy systems with a much higher power density level. The underlay leads to a modest increase of the noise floor for these primary users.

Ultra-wideband

Ultra-wideband spectrum is an active overlay technology which transmits information spread over a large bandwidth (>500 MHz) while sharing spectrum with other users. The FCC[17] defines UWB in its Part 15 Rules – see Figure 5 below. The ITU defines UWB in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20 per cent of the center frequency.

Due to the extremely low emission levels currently allowed by regulatory agencies, UWB systems tend to be short-range and indoor applications. However, due to the short duration of the UWB pulses, it is easier to engineer extremely high data rates, and data rate can be readily exchanged for range by simply aggregating pulse energy per data bit using either simple integration or by coding techniques.

Figure 6: FCC Part 15, Subpart F, 15-502-15.525 UWB low-power devices



Source: Microsoft

Spread Spectrum

Spread spectrum is a technique of spreading a signal out over a very wide bandwidth, often over 200 times the bandwidth of the original signal. A spread spectrum transmitter spreads the signals out over a wide frequency range using one of the following techniques:

- Direct sequence spread spectrum - Spread spectrum broadcasts in bands where noise is prominent, but does not rise above the noise. Its radio signals are too weak to interfere with conventional radios and have fewer FCC (Federal Communications Commission) restrictions. Data is altered by a bit stream that represents every bit in the original data with multiple bits in the generated stream, thus spreading the signal across a wider frequency band.
- Frequency hopping spread spectrum - using this technique, the original data signal is not spread out, but is instead transmitted over a wide range of frequencies that

change at split-second intervals. Both the transmitter and the receiver jump frequencies in synchronization during the transmission.

CDMA (Code Division Multiple Access) is a digital cellular standard that uses wideband spread spectrum techniques for signal transmission.

3.6.2 Overlay Technology and Dynamic Spectrum Access

There are two types of overlay, passive or active (dynamic).

- The Amateur radio service has shared spectrum with various government users using passive overlay technologies which require the user to look for a CB radio channel that is free. A passive overlay technology is different from an active overlay technology.
- Active overlay technologies are beginning to emerge and be trialed. A major trial is currently taking place in Ireland involving several major manufacturers of equipment and devices. There are several possible approaches being studied.

In 2007, as part of Pakistan's consultation on infrastructure sharing for mobile companies, the concept of spectrum pooling, which is a form of spectrum sharing achieved by overlay, was considered. It was pointed out in the consultation report that no country has yet to permit this type of sharing.[18] .

Dynamic Spectrum Access[19]

Dynamic spectrum access, which is in its early stages of development, is an advanced approach to spectrum management that is closely related to other management techniques such as flexible spectrum management and spectrum trading. It involves unitizing spectrum in terms of time slots and/or geographically. This allows users to access a particular piece of spectrum for a defined time period or in a defined area which they cannot exceed without re applying for the resource.

It permits communications to work by:

- Monitoring to detect unused frequencies;
- Agreeing with similar devices on which frequencies will be used;
- Monitoring frequency use by others;
- Changing frequency bands and adjusting power as needed.

The benefit of increased access to spectrum and better efficiency need to overcome several hurdles including:

- Potential for increased interference and effect on quality of service and compliance with regulations;
- Technical issues related to unseen devices competing for similar frequencies (the hidden node problem) and development of complex equipment.

Dynamic spectrum access is often associated with, although not exclusively dependent on, technologies and concepts such as Software Defined Radio (SDR) and Cognitive Radio, which are described in the next paragraphs.

3.6.3 Emerging Technology Enablers

In addition to the spectrum sharing techniques described in the previous paragraphs there are emerging technologies which are important to enabling these techniques as well as fostering potential new methods for spectrum sharing. The most prominent enabling technologies are described in the next few paragraphs.

Software-defined Radio (SDR) and Cognitive Radio (CR)[20]

Software defined radio are radio systems implemented on general purpose hardware where specific operational characteristics are implemented in software – different radio systems and standards are essentially loaded as software programmes (e.g. a GSM program or a Wi-Fi program). A radio increases its flexibility as more of its functionality is software-based.

SDR technologies are slowly making their way into commercial radio systems as technology developments make it economical for manufacturers to do so.

SDR enables more flexible spectrum allocation since these radio systems potentially use spectrum more intensively and are more tolerant of interference.

A cognitive radio is a radio that is to some degree aware of the environment by monitoring transmissions across a wide bandwidth, noting areas of unused spectrum and is able to modify its transmission using appropriate modulation and coding methods. From a user standpoint the certainty of finding unused spectrum in congested areas may fall low enough to impair its usefulness of as a mainstay communications device.

Smart Antennas and Other Technologies

Smart Antenna applications and technology have emerged in the past ten years and are interesting for their ability to significantly increase the performance of various wireless systems such as 2.5 generation (GSM-EDGE), third generation (IMT 2000) mobile cellular networks and BWA. Smart Antenna technologies exploit multiple antennas in transmit and receive mode with associated coding, modulation and signal processing to enhance the performance of wireless systems in terms of capacity, coverage and throughput. The Smart Antenna is not a new idea but has been more cost effective with the advent of digital-signal processors and general-purpose processors and application-specific integrated circuits (ASICs).

Multi-modal radios are capable of operating across multiple bands and technologies. The tri-band and world mobile phone are examples of multi-modal radios. Frequencies continue to be divided in discrete elements, reducing the need to harmonize frequency allotments, while harmonizing technical standards on a regional or global basis is not as critical.

4 TRENDS IN SPECTRUM POLICY AND REGULATORY REFORM

4.1 Introduction

In recent years, spectrum management policy and regulation have evolved considerably by reflecting the changes in the demand and supply of services reliant upon radio spectrum. Many significant developments have occurred in both the reform of the institutions and in spectrum authorizations including increased use of market-based mechanisms and greater flexibility by reducing the constraints on applications of new technologies.

4.2 Spectrum Policy Reform

There has been a recent shift away from relying predominantly on the traditional model, most notably in countries where demand for radio spectrum use is rising fast. These trends in spectrum management policy are discussed below.

Two features of more progressive spectrum management policies are liberalization and flexibility.

Liberalization is the extent to which spectrum usage rights can be managed through market-based mechanisms[21]. This covers issues ranging from competitive assignments (such as auctions) to secondary trading. Within this environment, management is delegated as much as possible to participants within the spectrum arena. Spectrum management agencies in this setting perform the role of 'light-handed' regulation.

Flexibility involves the relaxation of constraints on usage and technologies (either as a commons or in the form of managed shared use), as well as the possible expansion of licence-exempt frequencies. Very few countries have opened up large parts of the spectrum as a genuine commons.[22] Most notably the United States has embarked on a path of considerable innovative activity. The use of WiFi, WiMAX and UWB in the US has emerged many years before its deployment in most other countries, due both to the size of the market and as a result of regulatory actions designed to promote flexibility and unlicensed use.

The benefits of liberalization are strengthened in the presence of greater flexibility and the benefits of flexibility are greater within a liberalized environment. Thus liberalization and flexibility are closely intertwined.

4.3 Spectrum Authorization Reform

The European Commission regards technology and service restrictions as increasingly incompatible with convergence. A trading regime is anticipated that will embrace flexibility, i.e., the right of a spectrum holder to use its spectrum for any service subject to technical constraints. Policy in the EU embraces the principle of technological neutrality and service neutrality.

- Technological neutrality means that there should be a minimum of constraints applied while ensuring that interference is appropriately addressed. However, in some cases, the necessary interference management imposes constraints that in practice are more beneficial for one technology than for another.
- Service neutrality means that the choice of service offered via spectrum usage rights is made by the rights holder. It is widely recognized that constraining the services for which the spectrum can be used is generally not justifiable from the standpoint of technical spectrum management. According to the EC, "in the field of terrestrial electronic communications, these categorizations are rapidly becoming obsolete."[23]

Lack of flexibility in spectrum management has, according to the EC, led to a spectrum bottleneck for new radio technologies.[24] Detailed ex ante administrative decisions and a requirement for prior regulatory approval often delays or even prevents the introduction of new products. To render spectrum distribution more flexible, the application of spectrum markets (secondary trading) and licence-exempt use (the "commons" model) have been embraced by the EC.[25]

4.3.1 Spectrum Trading

Spectrum Trading is a mechanism whereby rights and any associated obligations to use spectrum can be transferred from one party to another by way of a market-based exchange. In contrasting spectrum re-assignment with spectrum trading; in a trade, the right to use the spectrum is transferred voluntarily by the present user, and a sum is paid by the new user of the spectrum which is retained, either in full or in part, by the present (transferring) user.

Efficiency Gains

Spectrum trading denotes a mechanism whereby rights to use spectrum are transferred from one party to another for a certain price. This contributes to a more efficient use of frequencies because a trade will only take place if the spectrum is worth more to the new user than it was to the old user, reflecting the greater economic benefit the new user expects to derive from the acquired spectrum.[26] These efficiency gains will not be realized, however, if transaction costs are too high and one of the aims of any spectrum trading regime should be to keep down transaction costs. After all, the goal is to facilitate transfers by establishing a swift and inexpensive mechanism. If neither the buyer nor the seller behave irrationally or misjudge the transaction, and if the trade does not cause external effects (e.g., anti-competitive behaviour or intolerable interference), then it can be assumed that spectrum trading contributes to greater economic efficiency and boosts transparency by revealing the true opportunity cost of the spectrum.

Indirect Benefits

Furthermore, trading has other relevant indirect effects:

- it enables licensees to expand more quickly than would otherwise be the case;
- it makes it easier for prospective new market entrants to acquire spectrum;
- if spectrum trading were combined with an extensive liberalization of spectrum usage rights, there would be a considerable incentive for incumbents to invest in new technology in order to ward off the threat of new entrants in the absence of other barriers to entry (i.e., the unavailability of spectrum); this, in turn, would boost market competition.

Forms of Spectrum Trading

In a consultancy report commissioned by the European Commission, Analysys et al.[27] identify the following methods for transferring rights of use:

- Sale – Ownership of the usage right is transferred to another party.
- Buy-back – A usage right is sold to another party with an agreement that the seller will buy back the usage right at a fixed point in the future.
- Leasing – The right to exploit the usage right is transferred to another party for a defined period of time but ownership, including the obligations this imposes, remains with the original rights holder.
- Mortgage – The usage right is used as collateral for a loan, analogous to taking out a mortgage on an apartment or house.

In terms of the trade itself, there are a variety of mechanisms that can be used. These include:

- Bilateral negotiation: The seller and (prospective) buyer directly negotiate the terms of the sale and are not subject to any particular constraints set by the regulator.
- Auctions: Once a type of auction has been chosen and the rules have been decided primarily by the seller, prospective buyers have the opportunity to acquire the spectrum usage rights by bidding in the auction.
- Brokerage: Buyers and sellers employ a broker to negotiate, with their consent, the contractual terms under which the transfer of usage rights can take place.
- Exchange: This refers to the establishment of a trading platform, similar to a stock market, where transfers take place according to specific rules.

These mechanisms are most likely to be used in combination. In the first instance an auction will be used as the primary means of assignment, tradable spectrum is listed on an exchange and either direct negotiation or brokerage facilitates the transfer of spectrum user rights. As discussed earlier, band managers may be delegated responsibility for managing certain bands on behalf of the regulator.

Property Rights

Minimal enforceable and identifiable property rights are central to trading radio spectrum. Without them considerable additional costs would be incurred by prospective buyers ultimately depressing the amount of trading activity. As well, spectrum could become valueless if others were able to infringe on the spectrum property by way of interference with it. Finally, it is desirable for property rights to be set in ways which minimize the subsequent reshuffling of rights. This is in the interests of greater efficiency since such trading and the bargaining which underlies it may have a transaction cost.[28]

The regulator will have a role in establishing property rights and in maintaining data and registries to facilitate ongoing efficient spectrum market operations.

Tradable Licenses and Spectrum Prices

This is the core to the market-based approach where spectrum licences are fully transferable (primary users may replace each other), and sub-leasing/sub-division should be possible.

The core characteristic of enabling market mechanisms for exclusive licences is to allow such licences to be tradable and amenable to division and aggregation (although with respect to aggregation, there may need to be controls to protect against the creation of undue market power).[29] For tradability, it is best that the primary licensee be able to transfer its licence to a new primary licensee.

The goal of tradable licences has several beneficial implications:

1. First, if licence ownership may be transferred, it is possible for market forces continuously to provide incentives for spectrum to be allocated to its highest value use, and for whatever use for which it is currently employed to reflect its true opportunity cost. This induces powerful incentives to use spectrum efficiently.
2. Second, the more spectrum that is tradable in this way, the more liquid will be secondary markets and the lower the average opportunity cost or scarcity rents associated with spectrum access rights. Encouraging spectrum prices to be as low as possible, consistent with aggregate demand and supply factors, will enable low-cost access for new applications and services which is an important overall goal of spectrum reform.

In short, trading lowers the costs for selling and acquiring new spectrum. Despite these benefits, the transition to tradable licences may need to take place in a two-phase approach as is discussed below.

4.3.2 Interference Management

An exclusive use license defines the rights to occupy the spectrum volume for a user. The primary user has a presumptive right to exclude other users from occupying their electrospace. Secondary users may have the right to occupy the electrospace if they can do so without causing interference to primary users, although they have no interference protection rights of their own.

Spectrum managers are fundamentally concerned with managing interference and in establishing the methods, techniques, information and processes needed to protect users and uses from harmful interference. Harmful interference arises in radio systems when a transmitter's ability to communicate with its intended receiver(s) is limited because of the transmissions of other transmitters. The problem may be thought of as arising from the limitations of the receiver: better receivers are more able to extract the desired signal from a noisy environment of background radiation and other transmitters.[30]

There are three categories of interference that are of principal concern:

1. In-band interference from adjacent areas;
2. In-band interference from adjacent frequencies;
3. Out-of-band interference.

Taken together, by properly defining the electrospace[31] along with the size of the volumes, it is possible theoretically to specify transmitter (Tx) and receiver (Rx) occupancy rights so that a Tx/Rx must operate in different and distinct electrospace volumes to ensure non-interfering operation.

Interference cannot be eliminated and so identifying interference management models which support spectrum sharing under either administrative, market-based and spectrum commons remain as an ongoing requirement and challenge for spectrum managers. The goal is to develop an appropriate regime which protects user rights and finds the right balance for flexibility, innovation, and service neutrality. Finding the balance and structuring the appropriate response continues to be debated.

4.3.3 Government Use of Spectrum – Is it Different?

In a market economy, inputs such as land, labour and capital equipment are distributed throughout the economy via a market process: the provider of capital or employee moves to whichever activity offers the best rewards. Spectrum is one input among others (water, electricity) in a variety of production processes. Market systems, when workably competitive, promote economic efficiency as inputs are put to use where they yield the highest returns[32].

Does this argument apply in the case of public sector trading? At first sight it may seem incongruous to require a public sector body such as a fire service or a defence force to compete in a market place for spectrum with commercial providers of services such as mobile broadcasting.

However this is exactly how public sector organizations acquire other inputs – such as employees, vehicles, land, and office space.

The arguments for special arrangements for spectrum for the public sector seem to be that:

- it is indispensable to the provision of service such as defence radar;
- the service itself (such as an ambulance service) has a very high priority and
- under past spectrum management practice, the only way to acquire spectrum was by administrative methods.

The use of markets to allocate other equally indispensable inputs into vital public services appears to negate the first two and the third could be resolved by the development of a spectrum market place.

Government use of spectrum utilized to provide services similar to those provided by the private sector should be, at a minimum, subject to prices reflecting the market price or opportunity cost and such spectrum should trade in secondary markets.

4.3.4 Spectrum Transfers

Spectrum Transfers are generally understood to mean some form of lease or sublease arrangement including features such as frequency assignment transferability or divisibility.

- Transferability - licences may be transferred (disaggregated);
- Divisibility or divided (partitioned) – licenses may be subject to either approval or notification to the appropriate authority subject to service and technical restrictions. Since spectrum can be assigned nationally or on a regional/local basis, a given assignment can be partitioned and shared by users at different locations[33].

Other examples include:

- Irish model: encouraging smaller market players to provide broadband fixed wireless access in very small service areas (recently updated to cover a 21km radius around a base station)[34].

4.3.5 Spectrum Commons

A spectrum commons is a part of the spectrum that is free from centralized control where anyone can transmit without a license. For this reason it is sometimes referred to as license-exempt or unlicensed spectrum.

In practice what is referred to as a spectrum commons can have varying degrees of management. Licence-exempt bands (e.g. the ISM bands[35]) are an example of a spectrum commons with some management in terms of power restrictions on individual users as applied in the US 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 (e.g. 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. Wi-Fi) which have led some to call for more spectrum to be managed similarly.

Ofcom has published general guiding principles for successful management of the spectrum commons which appear in Box 1.

Box 1: General Principles for Successful Commons Management

1. Clearly defined boundaries – the rights to withdraw resources as well as boundaries need to be carefully and clearly defined.
2. Congruence between appropriation and provision rules and local conditions.
3. Collective-choice agreements – those affected can influence rule changes.
4. Monitoring – active ongoing monitoring of conditions and behavior.
5. Graduated sanctions – sanctions by users and officials for violating operational rules.
6. Conflict resolution mechanisms – rapid access to low-cost arenas for resolving disputes.
7. Minimal recognition of the rights to organize – governments accepts users' rights to devise their own governance institutions.
8. For larger systems including a commons use multiple layers for 1-7 above.

Source: Ofcom 1990

4.3.6 Spectrum White-spaces

Most radio and TV broadcast channels are separated by small amounts of unused channels called white space which are used to limit interference between active channels. Technology companies and consumer advocates believe the use of this underutilized and unassigned spectrum could be used for new services such as BWA. Not surprisingly, TV broadcasters oppose allowing any unlicensed device to use white-space spectrum because, they argue, these devices would interfere with television broadcasts, potentially harming the federally mandated transition from analog to digital TV service.

4.3.7 Regulatory Structure

Regulatory institutional reform leading to the combination of telecommunications, broadcasting and spectrum regulators can help facilitate spectrum sharing. There are several examples of where this has occurred or is being considered.

- In Australia the Spectrum Management Agency, Australian Communications Authority and the Australian Broadcasting Authority were merged in several steps beginning in 1997 to create the Australian Communications and Media Authority;
- The Canadian Telecommunications Policy Review Panel Report recommended to the government that Industry Canada transfer its spectrum regulatory functions to the CRTC.
- The UK has recently set up such a combined regulator (Ofcom) which regulates broadcasting, (wireline and wireless) telecommunications and spectrum.
- In Germany, regulation of spectrum is combined with regulation of telecommunications (and of other infrastructures), but separate from regulation of broadcasting.

It is debatable whether the duties of such an independent spectrum regulator should be combined with those of regulating competition and protecting consumers in downstream service markets.

5 BEST PRACTICES - INTERNATIONAL TRENDS

5.1 Introduction

In most countries, the use of radio spectrum has been, and in many cases remains, very closely managed and supervised, in accordance with an agreed international framework established by the Member States of the International Telecommunication Union (ITU). Such management is predicated on a need to minimize harmful interference and has resulted in the application of what is sometimes referred to as the "command and control" model. In recent years, there has been a shift away from relying predominantly on the traditional model, most notably in countries where demand for radio spectrum use is rising fast.

5.2 Best Practices – Administrative and Market-based Sharing

The aim of this section is to describe best practices in a system of reformed spectrum management that incorporates a greater reliance on spectrum sharing techniques which increase flexibility and are forward-looking. This section will describe (and evaluate) the different routes taken by some countries and regions which have modified and reformed their system of spectrum management to operate more flexible systems that permit a more efficient use of radio spectrum.

5.2.1 Spectrum Planning and Allocation

Spectrum planning processes provide direction and cohesion in support of policy formulation and support future steps to achieve optimal spectrum use. Major trends and developments in technology and the needs of current and future users of the frequency spectrum should be closely monitored and mapped. The types of user requirements for frequency management systems, such as monitoring systems, channel plan techniques, and tools must also be planned and developed.

5.2.2 Spectrum User Rights

When existing licences become tradable and are subject to a change of use, rights should be established consistent with current uses; this will avoid conflicts of rights and permit parties to renegotiate rights when circumstances change. Discussion of spectrum user rights is a very detailed topic dealing with questions such as:

- Easements for new technologies[36] – whether to allow them?
- Vacant spectrum – whether it should be placed in the market place (subject to international agreements)?
- Fall back or insurance policies such as compulsory purchase of spectrum when there are hold-out owners of spectrum - should it be confined to national security needs?
- Spectrum licensees - should users pay a perpetual annual charge, or will these charges discourage efficient trading.

Discussion of these topics and answers to these questions are beyond the scope of this discussion paper.

5.2.3 License Database

The ability of potential sellers and buyers (and regulators) to keep track of current licences is an important component of tradable markets facilitated by a publicly available database. Knowledge of the location of existing Tx's and Rx's (where feasible) will allow potential purchasers of rights to accurately model the existing interference environment they are seeking to enter and to enable them to properly assess the rights they seek to acquire.

The information should enable regulators if called upon to adjudicate spectrum disputes and to enable them to track and assess the usage of spectrum in differing bands.

Finally, the database should include additional tools to analyze data on spectrum historical occupancy/usage and to interpret alternative propagation models.

In the US a spectrum auction and trading system is operated by Cantor-Fitzgerald, the Wall Street brokerage, providing an example of the sorts of capabilities that are needed at a minimum[37]. Cantor Spectrum & Tower Exchange provides an open or closed transparent forum for both primary (auction) and secondary (post-auction) market spectrum transactions in both public and private marketplaces.

- Sellers/Lessees can review FCC licensee information obtained by the exchange and see a snapshot in real-time.
- Qualified licence sellers/lessors or public sector entities offer radio frequency spectrum and digital sub-channel capacity in a multi-dimensional format showing coverage area, population, frequency range, radio service rules, terms and conditions, channel, time slot, etc.
- Buyers/lessees search for specific assets (or receive electronic notification), and can easily evaluate and bid on them.

This type of system helps facilitate the critical matching function that liquid markets depend on.

5.2.4 Dispute Resolution

It is quite likely with the arrival of the spectrum commons and increased sharing of spectrum through transfers and trades, effective means other than regulatory adjudicative intervention will be required to resolve issues between parties.

There are two trends at work:

- rapid changes in telecommunications sector and
- changes in the realm of dispute resolution procedures.

The expansion of the global telecommunications market with its emphasis on innovative and fast-changing technology may need to be accompanied by dispute resolution procedures which are fast and flexible – and suited to the types of disputes which the global telecommunications industry will produce. In turn, the dispute resolution field is increasingly offering new models that may be useful to the telecommunications sector's new needs.

While most regulators decide between the positions of disputing parties, typically after a formal process that involves the presentation of arguments by those parties, there is a trend towards more flexible and consensual methods – alternate dispute resolution (ADR) including: negotiation and arbitration. Most telecommunications licenses include guarantees of access to arbitration. Even so, it is helpful to have developed guidelines for managing ADR processes such as those issued by Ofcom governing ADR between public telecommunications operators and the public:

- Independent and impartial;
- Transparent, providing regular communication to the public throughout the process;
- Effective (with an expectation from Ofcom the disputes will be resolved in less than six weeks);
- Able to properly investigate disputes and make awards of appropriate compensation.

New Zealand provides an interesting example where the devolution of interference management has been taken one step further. Under its framework of tradable "management rights", a "management right" owner would essentially assume the role of the regulatory administration in setting boundary conditions for its "licensees" within the band for which it holds "management rights".

This approach effectively reduces the interference management burden on the administrative regulator. Nevertheless, it has been noted that in one case, the regulator had to intervene significantly:

- Management rights for cellular bands around 900 MHz allowed the operation of AMPS and GSM systems in adjacent bands. Interference problems resulted and the regulator intervened by releasing spare spectrum to act as a guard band.

5.3 Country Examples

The following country examples reflect many best practices described in the preceding section, examining current practices for spectrum trading and spectrum commons. Given the recent focus at the international level on identifying bands for Broadband Wireless Access, this section also looks at the leading practices of several developing and developed countries where BWA is being implemented.

5.3.1 Mauritius – Broadband Wireless Access

In early 2005 with spectrum pollution occurring in the 2.4GHz band, the Information and Communication Technologies Authority (ICTA) conducted public consultations to receive input on proposed BWA frequency band allocations, technical characteristics and regulatory requirements. ICTA issued its decisions within three months. Those decisions opened the 2.5GHz band for Mobile and Nomadic BWA (IMT-2000) applications by 2010, the 3.5GHz band immediately for Fixed BWA and the 5.1 - 5.3GHz band for low power in-building applications. In 2006, ICTA additionally opened the 5.4GHz and 5.8 GHz bands for BWA. Band plans and technical rules were established limiting allowable power levels, separation and channelization.

As of 2007, there are two mobile licensees providing IMT-2000 and WiMax services on a national basis.

5.3.2 Brazil – Broadband Wireless Access

In January 2008, ANATEL in Brazil issued four licenses per licensed area for 3G wireless deployment throughout the whole country. Coverage obligations for all licensed operators will lead to the whole Brazilian territory being covered (probably eight years after the licenses have been issued). Operators are allowed to share network components such as towers as well as spectrum in order to provide services in municipalities with less than 30,000 inhabitants. ANATEL will likely issue new regulations on the conditions for spectrum sharing and sharing of active elements of the network. Spectrum sharing arrangements must be authorized by ANATEL. The rules governing the 3G auction in Brazil refer expressly to spectrum sharing as a means of providing coverage in rural and remote areas (i.e. municipalities with less than 30,000 inhabitants).

ANATEL issued a number of licenses for WiMax in the 2.6MHz band and five licensees in the 3.5MHz band. A new auction for additional 3.5MHz spectrum is planned for 2008. Some of the licenses have already started authorized trials.

5.3.3 New Zealand – Spectrum Trading and Spectrum Commons

The Radiocommunications Act 1989 was pioneering and radically changed the landscape of spectrum management. New Zealand was the first country to redefine spectrum in terms of property rights and to assign it in a tradable form. New Zealand also pioneered the application of competitive assignments based on auctions for radio spectrum, with the first auction held in 1989.

There are three licensing systems that apply to spectrum in New Zealand:

- The Management Rights Regime (MRR) (applicable to spectrum used primarily for commercial purposes);

- The Radio Licence Regime (RLR), earlier known as apparatus licensing, (an administrative assignment process which applies to spectrum used for applications in the public interest); and
- General User Licences for devices such as low-powered devices: garage door openers and Wi-Fi).

5.3.4 Guatemala – Spectrum Trading

Guatemala and El Salvador are two small Central American countries (with populations of 12,728,111 and 6,948,073 respectively) which decided in 1996/97 to adopt a simple but effective form of spectrum market which, in the case of non-public sector spectrum, gave private parties exclusive control over use of bandwidth and confined the regulator to defining, issuing and protecting spectrum rights. This account focuses on Guatemala; the regime in El Salvador is similar but less well documented.[38]

The so-called titulos de usufuncto de frecuencias (TUF) created could be leased, sold, subdivided or aggregated at will and last for 15 years (renewable on request); they are thus virtually private property. Regulation is restricted to setting aside bands for use by the state and adjudicating interference disputes which are not resolved by mediation.

A physical TUF is a paper certificate listing the frequency band, hours of operation, maximum transmitted power, maximum power emitted at the border, geographic territory and duration of right.

5.3.5 United States – Flexible Spectrum Use and Broadband Wireless Access

The United States has been a leader in regard to spectrum liberalization. Liberalized spectrum management primarily relates to non-government spectrum, whereas the framework for government spectrum continues to be traditional. Spectrum Policy Initiative – 2003 addressed several important components:

- Auctions: it was proposed that the FCC should granted permanent authority to assign licences via auction (competitive bidding);
- Spectrum Licence User Fees - to ensure that licence holders pay the opportunity costs of their spectrum use.

The United States has also moved progressively in the direction of flexible use of spectrum, in conjunction with generally liberalized practices. The Communications Act specifically authorizes the FCC to permit flexible use where:

- such use is consistent with international agreements to which the United States is a party;
- the Commission finds, after notice and an opportunity for public comment, that such an allocation would be in the public interest;
- such use would not deter investment in communications services and systems, or technology development; and
- such use would not result in harmful interference among users.[39]

The FCC Spectrum Policy Task Force – 2002 advocated:

- increased reliance on both the exclusive use and the commons models, and reduced use of traditional allocation mechanisms;
- maximum feasible flexibility for licensees, limited only by interference concerns;
- increased use of spectrum trading, including the ability to lease spectrum on a rapid or an overlay or underlay basis.

An example of spectrum sharing in the United States is the deployment of UMTS/HSPDA services. UMTS operators wanting to implement a European style 2100/1900 MHz system needed to share spectrum with existing 2G services in the 1900 MHz band. The 2100 MHz band was unavailable since it is used for satellite communications. Some of the 2100 MHz range was subsequently freed up for 3G services, together with some of the 1700 MHz (for the uplink).

UMTS/HSPDA service in the United States was launched by the end of 2004 strictly using the existing 1900 MHz spectrum allocated for 2G PCS services. As well in some cities a UMTS network using 850 MHz to enhance existing 1900 MHz UMTS network was rolled out using dual band phones.

Spectrum sharing was achieved through the use of dual band network elements, filters, etc. and a channel plan providing for minimal carrier spacing on a site by site basis.

5.3.6 United Kingdom – Flexible User Rights and Spectrum Trading

OFCOM is currently shifting U.K. spectrum policy towards a flexible system of spectrum management through the liberalization of spectrum usage rights and spectrum trading. A gradual approach is being adopted, embracing progressively more bands and greater flexibility in use but relying on competitive assignment methods. This progression is exemplified by OFCOM's intention to apply service and technological neutrality in a forthcoming spectrum assignment involving frequencies currently used to support terrestrial analogue TV broadcasting, the proposed use of spectrum user rights in a forthcoming auction of the L Band, and in other auctions.

The United Kingdom has also adopted the policy of extending market methods of spectrum management to public sector spectrum, giving public sector users the right to trade or lease their spectrum and the obligation to go into the market place to acquire additional spectrum. OFCOM is also extending the application of administrative incentive pricing (AIP). [40]

5.3.7 Europe - Flexible User Rights and Spectrum Trading

The European Union (EU) does not manage radio spectrum; instead the Member States supervise its management at the national level and in international coordination. However, the management of radio spectrum in EU Member States is influenced significantly and increasingly by European legislation which is aimed at facilitating harmonization of regulation and promoting competition through the liberalization of markets. The key legislation is contained in a number of directives and decisions passed in 2002.

The Radio Spectrum Decision[41] laid the foundation for a general EU radio spectrum policy and is binding on all Member States. The objective of the Radio Spectrum Decision is to ensure coordination of radio spectrum policy approaches by facilitating harmonized conditions for the availability and efficient use of radio spectrum.

The Radio Spectrum Decision encourages the European Commission to organize consultations to take account of the views of Member States and all other stakeholders. To facilitate more effective consultations, the Radio Spectrum Policy Group (RSPG) was established by separate decision[42].

The RSPG launched a consultation on secondary trading of spectrum in February 2004 following a request received from the EC in 2003 for an opinion on secondary trading. In November 2004, the RSPG published its Opinion on secondary trading[43].

RSPG has adopted a cautious stance with regard to spectrum trading considering it to "be beneficial in certain parts of the spectrum" and that "European administrations should introduce secondary trading with due care".

The EU now proposes that one-third of the spectrum below 3GHz could have flexible usage rights and be tradable by 2010[44].

RSPG is elaborating on the concept of Wireless Access Policy for Electronic Communications Services (WAPECS) to move away from too narrowly specified allocations and applications, for which specific spectrum is designated.

5.3.8 Canada – Technology Neutrality and Broadband Wireless Access

Access to the spectrum is gained through one of the four forms of authorization: apparatus licenses, spectrum licenses, broadcasting certificates and radio operator certificates. There are two main types of licenses: apparatus and spectrum licenses.

Spectrum licenses represent the more market-oriented form of licensing in the mixed market/administrative system. They authorize the operation of (non-specified) devices within a defined geography. The geography is be defined by bandwidth, geographic area, and time. Licensees are free to use any type of equipment for any purpose, although they are subject to licence conditions and technical frameworks designed to minimize the risk of interference with other spectrum users.

Spectrum licenses are transferable and can be divided and aggregated. They are issued for periods of up to ten years. They are generally renewable.

6 Implementing Spectrum Sharing

Success in implementing spectrum sharing requires both vision and commitment for moving from current regulatory allocation and assignment practices based on a sound understanding of technology and systems operating under predictable circumstances.

Spectrum policies should address incentives for innovation, promote flexibility, establish spectrum users' rights and determine practical methods for compliance monitoring, interference management and dispute resolution. These factors apply whether spectrum is used in the spectrum commons or shared by some other means where implementation relies heavily on advanced radio technologies designed to facilitate spectrum sharing.

An additional step could be to follow the path being used by the FCC and the NTIA in the United States to create a Spectrum Sharing Innovative Test-Bed for studying spectrum sharing emerging radio systems such as software defined radio and methods and techniques such as dynamic spectrum access.

6.1 Action, Market Structure Issues and Practical Steps Implementing Spectrum Sharing

In the next few paragraphs action and practical steps for implementing spectrum sharing are identified.

6.1.1 Planning

Analysis of current and future spectrum uses will be needed to help determine which bands should be included and how and when they should be released, say by auction for example. Planning will involve consultation with various stakeholders and with industry fora. At a minimum careful review and understanding of recent decisions at WRC and certain leading countries will be both helpful and necessary. A chief concern will be ensuring sufficient spectrum is available to satisfy demand and for proper market functioning. As we have seen earlier the extent to which spectrum is allocated for commercial or exclusive government use has an important bearing on improved access. Processes to review and understand government requirements and to shift spectrum away from exclusive use require both time and negotiation.

6.1.2 Assessing Demand and Scarcity

Market-based methods work best when demand is sufficient and rules and rights are clear. We address values and rights below. For developing countries the real absence of scarcity and emerging demand for services might prove sufficient to cause delay in the introduction of spectrum sharing policies and assignment practices. The difficult question to answer is the impact of delay on the economy overall coming from investment and productivity. Favouring the creation of attractive markets for investors who can deploy or utilize advanced services and technologies can not to be ignored by spectrum policy makers.

6.1.3 Valuing Spectrum and Compensation of Public Sector Users

Spectrum should reflect its opportunity cost which is best determined by market methods. Administrative methods for establishing near market prices such as the use of AIP (administrative incentive prices) needed to be considered. Spectrum values should be reflected in investment decisions by all users including government users. By encouraging economic efficiency spectrum sharing is facilitated through trades, transfers and leasing. Decisions will be required to determine whether special markets exist for Public Sector Users and whether they should be compensated to facilitate better access and sharing.

Determining Spectrum User Rights and Interference Rules – the use of service and technology neutral licenses will facilitate spectrum sharing and improve license flexibility while ensuring that user's rights are protected and the utility of spectrum is protected through adequate interference management. Interference management and rules remain as important areas of further study especially as enabling radio technologies such as SDR evolve.

6.1.4 Monopolisation of the Market

If spectrum markets lead to the monopolization of the supply of downstream services (i.e., if a single firm could corner the entire spectrum capable of producing such a service), and there are no other competing or substitute technologies or services, a spectrum market could then easily produce worse results than an administrative system which led to competition among downstream suppliers of services. Is that likely?

This depends upon the degree of flexibility the regulator allows the market to exhibit. If there are no prior allocation restrictions (limiting certain services to certain bands) and if the arena in which the market operated is extensive, building a spectrum monopoly leading to dominance in downstream markets is not likely to succeed. For major services such as mobile voice or data, or mobile broadcasting, the required spectrum holdings would be very large. The danger does increase either if there are allocation restrictions or if the scope of the market is small (and other barriers to entry are high).

Next, if competition law is considered to be inadequate, special procedures can be put into place to limit the acquisition of spectrum licences requiring prior approval of transfers or the application of merger-control procedures which vet a proposed concentration of spectrum for its impact on the relevant anti-trust market.

Finally, spectrum regulators can construct auction rules for the release of new spectrum in ways which promote competition. There are several examples:

- The current debate in the United States over conditions to apply to the forthcoming 700 MHz auction (including a possible requirement that some spectrum should be auctioned subject to an open access obligation);
- Previously mentioned auction rules for 700 MHz in Canada stipulating that there will be spectrum set aside for new entrants.

6.1.5 Market Liquidity

Another key requirement for an effective market is that it have sufficient liquidity (i.e., volume of trades) to provide participants with a reliable method of transacting. Illiquid financial markets notoriously exhibit high spreads or differences between the buy and sell price, to compensate the intermediary for the cost of holding stock.

International experience in spectrum trading was highlighted in the sections above and the following similarities and differences were exhibited:

- there were few , if any, signs of intermediaries being active in the market;

- there were no signs of speculators entering the market;
- several countries exhibited significant levels of trade (Guatemala and El Salvador) or a number of significant (i.e. a value of USD 100,000,000) trades (the United States);
- in Australia and New Zealand, levels of trade were fairly low (roughly equal to the turnover of commercial property) reflecting an orderly turnover in spectrum through trades;
- in the United Kingdom, trades in the limited bands available have been infrequent, but the number of traded bands has been small and the spectrum regulator is in the middle of a large programme of spectrum awards which may provide an alternative source of spectrum to those who want it.

Liquidity of spectrum markets remains a real issue and the design of liberalization measures should be in the foreground.

6.2 Practical Steps

6.2.1 Role of the Regulator

The regulator in exercising its primary responsibilities related to spectrum management goals and objectives referred to earlier in Section 2.2 should decide on what is the appropriate balance and mix of administrative and market-based techniques. It is a matter of reliance on methods which will ensure access and protection from interference. The current balance favours administrative approaches and it is the view of this author that a shift towards market-based methods should be acknowledged and encouraged by regulators. The practical steps involved in this shift in stance include:

- Spectrum legislation and regulation creating expanded authority by the regulator to manage, assign, and license while permitting spectrum use flexibility, technology neutrality, and sharing.
- Creating the necessary mechanisms, tools and processes to capture and include the needs and expertise of current and future spectrum users.

These may seem like obvious steps to take. Making the decision to increase access and improve sharing requires a very strong commitment from the regulator for change and including stakeholders and users as integral partners in the process of determining which approaches, methods and spectrum should be made more accessible. It is the commitment to change and inclusion which is often lacking and so the process sputters to a stalemate.

Advocating the use of innovative technologies is also a key role of regulators. Providing the means to test and trial new technologies by making spectrum available and through test licenses are two very practical steps that can be taken. ComReg in Ireland has indicated that it is keen to encourage innovative developments and more efficient ways to use spectrum through their test and trial licence scheme[45]

6.2.2 Band Allocation Strategies

Regulators have a powerful tool in allocating spectrum for various uses and users. By limiting the restrictions on uses and users access is improved. Knowing how to go about this requires information, some consensus and where this is lacking, the means to smooth an adjustment. What can be done? The regulator can:

- acquire the information needed to assess use, users and utilization. Spectrum audits can be performed to fill in the gaps in information;
- consult with current and prospective users;
- clear zones of spectrum through incentives and adjustments like refarming;

- examine ways to license or unlicense underutilized spectrum to increase use and sharing;
- reinforce the application of technical standards and compliance to ensure interference is managed and manageable;
- utilize band managers to manage use and users in bands where demand has been pooled and where trading can now take place.

6.2.3 Channelling Plans

Creating channelling plans which compact spectrum assignments and increase the number of occupants through techniques such as re-use are critical to easing problems of congestion and potential interference.

7 CONCLUSIONS

Where the demand for radio spectrum is below the available supply and innovation is steady and predictable, as in the past, the traditional model works reasonably well. With penetration rates exceeding 100 per cent in many countries and with penetration growing rapidly in most developing countries, the demand for spectrum is increasing and frequency bands especially below 3 GHz are becoming more congested in densely populated urban centres everywhere.

Administrative spectrum sharing is based primarily on technical decisions – witness the nature of discussion and time taken to reach agreement at WRC – 03 and 07 on IMT-2000 and BWA. Where changes to expand allocations for these types of services are in the forefront of global consensus and agreements, regulators and users are sometimes propelled by market place demand or lag with decision-making processes. Compensation to existing licensees who may need to exit the band in question is often driven by politics or their legitimate demands as interpreted by the courts. Where markets are underdeveloped, demand does not provide sufficient impetus or the financial means to drive and smooth the process.

Spectrum trading occurs primarily in developed markets, although Guatemala and El Salvador are notable exceptions, and depends on clear rules for user rights and interference management. Spectrum trading, like spectrum leasing, is accomplished easiest when the spectrum to be traded will be used for the same service and in the same band which acts as a mechanism for correcting imbalances amongst providers. It is an open question whether trading and flexibility should be confined to a few selected bands. Technical neutrality exists to the extent technical rules governing interference are respected.

The spectrum commons works best for low power devices. In cases where technical rules are obviated such as high power, wide area Wi-Fi as seen in some developing countries early in the application of this technology, problems of interference result. Dynamic Spectrum Access using technologies such as cognitive radio do show promise but are too early for commercial application. Technical rules and interference management will continue to be a primary focus for regulators.

In general, all bands could be potentially be shared, i.e. it is technically possible to share bands using combinations of administrative means (assignment – time, geographic, channelisation) and through technical solutions such as filters, smart antennae, smart transmitters (such SDR and cognitive radio) along with transmit power limitations combined with some relaxation of interference constraints. One important exception will be the desire to maintain exclusive bands and assignments for public safety and security services.

Interference cannot be eliminated and must be managed so identifying interference management models which support spectrum sharing under either administrative, market-based and spectrum commons will remain as an ongoing requirement and challenge for spectrum managers. The goal is to develop an appropriate regime which protects user rights and finds the right balance for flexibility and innovation, and service neutrality. Finding the balance and structuring the appropriate response continue to be debated and technologies such as software defined radio and other techniques hold significant promise.

Spectrum sharing can be successfully implemented by combining vision, commitment and careful planning by spectrum managers and regulators with a view to evolving spectrum allocations and assignments to permit greater flexibility and access to the spectrum resource.

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[1] As reported in the Independent Audit of Spectrum Holdings reported in 2005 by Prof. Martin Cave to the UK Gov't (referred to here as the Cave Audit), government holdings of spectrum approximate 50 per cent of the spectrum below 15GHz.

[2] See also GSR Discussion Paper on WRC-07 Results and Impact on Terrestrial Broadband Wireless Access Systems, at: www.itu.int/ITU-D/treg/Events/Seminars/GSR/GSR08/wednesday.html

[3] These services are able to function within the UHF band of frequencies (300MHz up to 3GHz)

[4] See Hausman, J. and T. Tardiff, "A cost of regulation: delay in the introduction of new telecommunications services" in *The Economics of the Information Society,* edited by Alain Dumont and John Dryden, European Commission/OECD 1998.

[5] OECD Communications Outlook, 2007. The overall rate across the 31 OECD countries is 80 subscribers per 100 inhabitants.

[6] ITU World Telecommunications/ICT Indicators Database.

[7] OECD Broadband Portal – Press Release November, 2007

[8] European Commission: 8 February,2007

[9] 40 MHz out of 105 MHz was set aside for new entrants in the recent decision concerning upcoming auctions of 700 MHz spectrum in Canada: November 27, 2007

[10] Available after 17 June 2015.

[11] Brazil – 698-806 MHz mobile service on a secondary basis.

[12] Additional band 698-790 MHz adopted by China, India, Japan, New Zealand and Singapore.

[13] E.g. US initiatives to permit other users in TV 'white space' spectrum. White space spectrum are un-used frequencies between active channels. See also Ofcom's consultation on the Digital Dividend - www.ofcom.org.uk/consult/condocs/ddr/ddrmain.pdf

[14] For more on Band Managers see ICT Regulation Toolkit Module 5 Radio Spectrum Management, Section 1.6.2 Outsourcing.

[15] Objections to auction rules raised by interested parties are part of the process for ensuring public interests are protected. The 700 MHz band auction in the United States may raise over 15B USD however questions of fairness to bidders raised in arguments concerning preclusion of wholesale rates and minimum bid prices for smaller companies and start-ups such as Frontline do highlight the types of challenges faced by the regulator in getting the rules and design right.

[16] For more on Auctions see ICT Regulation Toolkit Module 5 Radio Spectrum Management, Section 4.5 Auctions and Cave, Doyle and Webb: Essentials of Modern Spectrum Management, Chapter 5, pp. 43-83, Cambridge University Press, 2007.

[17] FCC Title 47 CFR Part 15 Rules

[18] www.pta.gov.pk/media/paper_080807_1.pdf)

[19] This section is taken from 'Dynamic Spectrum Access' ComReg Briefing Paper 07/22 April 2007, pp 8-9

[20] See 'Dynamic Spectrum Access' pp 12-13 and Reports ITU-R M.2063 and ITU-R M.2064. Issues also on the agenda of WRC-11

[21] In some cases market-based methods of spectrum management need to be assisted in the early stages by administrative intervention. This is particularly the case with regard to the pricing of radio spectrum. While secondary trading offers the possibility of spectrum commanding market prices, in practice thin volumes of trade in the initial stages tend to diminish the benefits of relying on the price mechanism. In some countries, notably the U.K., spectrum prices are largely determined administratively, based on economic principles — known as administrative incentive pricing (AIP).

[22] Recently the FCC in the United States has designated 50MHz of frequency in the 3.65GHz to 3.7GHz band as a commons

[23] COM(2005) 400 Final

[24] COM (2005) 411 Final 6 September 2005.

[25] Spectrum Allocation and bottlenecks/competition problems, ERG (06) 45b.

[26] M. Cave and W. Webb (2003), Designing property rights for the operation of spectrum markets, *Papers in spectrum trading*, University of Warwick, Warwick Business School.

[27] Analysys, Dotecon, and Hogan and Hartson (2004), Study on the conditions and options in introducing secondary trading of radio spectrum in the European Community. Final report for the European Community, Cambridge (U.K.), Analysys.

[28] For a discussion of the degree to which transactions costs will deter the emergence of efficient outcomes through private bargaining and trading, see M. Cave, C. Doyle and W. Webb*, Essentials of Modern Spectrum Management*. Cambridge University Press, pp.124-8.

[29] Spectrum caps offer one mechanism for protecting against excess aggregation of market power. If these are adopted, they should be relatively loose and should be linked to other findings of market power.

[30] Focus here will be on intentional transmitters rather than unintentional radiators such as electric motors.

[31] Electrospace has several dimensions: frequency, location, directions of arrival and time.

[32] Several of these paragraphs are drawn from M. Cave, C. Doyle and W. Webb Op.cit. above Ch 15.

[33] In 1998, Industry Canada policy changes set in motion a process whereby a potential new service provider could apply to use un-utilized (otherwise assigned) frequencies in a geographical area. The result being that assigned but un-utilized frequencies would be re-assigned to interested parties who provided a 'comprehensive' plan to deploy mobile services. Where more than one party applied, Industry Canada awarded spectrum authorizations based on a comparative review of accepted applications.

[34] See Trends in Telecommunication reform 2004/2005

[35] ISM bands include ITU Radio Regulation 5.150 unlicensed bands and bands allocated for low power devices. Lower power device frequencies refer to a whole range of frequencies from 160 KHz. to 10.55 GHz.

[36] Overlay" for agile radios or Underlay for Ultra Wideband (UWB).

[37] See www.cantor.com/brokerage_services/spectrum_and_tower for further information about their system.

[38] See G. Ibarguen,"Liberalising the radio spectrum in Guatemala*"*, *Telecommunications Policy* 27, pp. 143-554, 2005. T. W. Hazlett, G. Ibarguen and W.A. Leighton, Property Rights to Radio Spectrum in Guatemala and El Salvador: An Experiment in Liberalization, available on SSRN

[39] 47 U.S.C. 303(y).

[40] Administrative Incentive Prices: intended to encourage licensees of non-auctioned spectrum to use their spectrum rights efficiently; legislation enables annual licence fees to be set above administrative cost to reflect a range of spectrum management objectives (efficient management and use, economic and other benefits, innovation and competition), having regard in particular to availability and present and expected future demand for spectrum. OFCOM has been using AIP since 1998 and revised the approach in 2004. There AIP is used to value spectrum at its marginal value as a proxy for the opportunity cost to the representative spectrum user in those bands where AIP fees were charged.

[41] Decision No 676/2002/EC of 7 March 2002 on a regulatory framework for radio spectrum policy in the European Community (Radio Spectrum Decision).

[42] Commission Decision 2002/622/EC of 26 July 2002 establishing a Radio Spectrum Policy Group.

[43] The RSPG Opinion on Secondary Trading of Rights to use Radio Spectrum, RSPG04-54 Rev. (final), 19 November 2004

[44] Communication from the Commission to the Council, European Parliament and the European Economic and Social Committee and the Committee of the Regions, "A market-based approach to spectrum management in the European Union", COM (2005)400 Final, 14 September 2005.

[45] See ComReg Document 05/35 for details of the ComReg test and trial licensing scheme - www.comreg.ie.