International Telecommunication Union

Technology-focused and Market-based Reforms
in Spectrum Management

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1 Introduction

1.1 Trends in spectrum demand

Over the past few years, the development of new wireless technologies has phenomenally expanded the range of services reliant on spectrum. At the same time, the demand for such services has also seen a corresponding increase in recent years. In the past decade alone, ITU has recorded more frequency assignments than during the entire previous history of radio.

A particularly striking example of this growth in demand for wireless services can be seen in the growth of mobile telephony worldwide over the past decade. In 2002, the worldwide number of mobile phone subscribers surpassed the total of fixed-line customers and this trend is predicted to continue.

To a large extent, the recent trend of liberalization, deregulation and privatisation in telecommunication services, particularly in the mobile and ISP sectors, have increased competition, in turn causing mobile telephony prices to fall and demand to rise.

With its cost advantages and its ability for rapid deployment, wireless access for telephony and data services has also conquered new markets. Wireless networks are fast becoming the preferred infrastructure solution for developing countries and rural areas where fixed-line communications have been found to be too costly to deploy.

Meanwhile, while the recent growth in demand for mobile telecommunication services has driven a large portion of spectrum demand, the growing popularity of new applications such as the Global Positioning System (GPS), which was originally developed for defence purposes, as well as radio tracking applications such as the use of Radio Frequency Identification (RFID) tags have also placed a greater burden on spectrum resources.[1]

1.2 Developments in spectrum technology

Beyond expanding the range of wireless services which have led to increased spectrum demand, advances in wireless technologies have also made it possible for spectrum resources to be used more efficiently.

Traditional radio communications have long assumed receiving equipment to be "dumb", in the sense that it has limited ability to differentiate between the true signal and background noise. The only way to ensure that the radio understands the communication is to have a signal from the transmitter that is received much stronger than the background noise around it on the same frequency. This high signal-to-noise ratio alerts the radio that there is a signal containing information. Recent technological advances, however, have made the computing power of processors in radio equipment sufficiently sophisticated to sift through noise and pick out information intended for a specific receiver. Some of these technologies that are changing the way governments look at spectrum management include spread spectrum technologies, smart antennas, mesh networks, and software defined radios (see Annex 1 for a description of some of these technologies).

Although these technologies have shown great promise in improving spectrum use, radio spectrum management policy often fails to capitalise on them due to a number of reasons such as resistance from strong vested interests in preserving incumbent technologies, as well as from incumbent band operators who fear interference, and the lack of adequate capacity for testing these emerging technologies. As a result, spectrum policy makers and regulators often choose to be conservative in making policy decisions associated with new technologies,

1.3 Need for technology focused, market-based approaches

Added to the increasing demands placed on spectrum resources, the increasing "digitisation" of information and communications and the resulting convergence of technology have also resulted in the "blurring" of the boundaries between the services along which spectrum has been traditionally managed. Where in the past certain radiocommunication services were regarded as distinct, a single platform can now be used to deliver a wide variety of services to customers. Broadcasting, for example, is moving towards more interactive applications with the introduction of IP datacasting, where digital content formats, software applications, programming interfaces and multimedia services are combined through Internet Protocol (IP) with digital broadcasting. Similarly, mobile systems are now capable of delivering access to live broadcasting content.[2] In addition, third-generation (3G) mobile networks are potentially capable of transmitting data rates of up to 2Mbit/s, overlapping with the present performance of broadband fixed wireless access.

In the face of mounting demand and increased complexity, the ability of a country to use its spectrum resources efficiently depends heavily on the way spectrum is managed. Unfortunately, in many countries, this task is made difficult because of the limited resources made available to spectrum managers to manage the increasing volume of spectrum related activity and to effectively monitor and promote the development of new wireless technologies. In such a situation where demand exceeds supply and in a sector where more resources are available to the private sector than to the government, there exists a compelling argument for a greater reliance on spectrum policies that rely more on market-forces.

This paper discusses the merits and practicalities of implementing a number of market-based approaches to spectrum management. These approaches have the potential to promote both efficiency in a number of inter-related spectrum management functions, including spectrum allocation and assignment, as well as spectrum monitoring and enforcement. This paper also presents a discussion of the spectrum policy issues that have been raised by the development and deployment of advanced wireless technologies.

2 Market-based strategies for spectrum allocation and assignment

In general, the objective of the spectrum manager is to maximise the net benefits to society that can be realised from spectrum resources. According to economic theory, this objective can be facilitated through the mechanics of a free market. However, a number of practical constraints, in particular interference management, as well as public policy considerations have led spectrum managers worldwide to exercise a certain degree of centralised command and control over spectrum allocations and assignments. For example, some degree of economic efficiency may have to be sacrificed in order to safeguard the provision of certain public services such as scientific research, defence, safety and public broadcasting. Furthermore, the needs of harmonisation and standardisation, which are often encapsulated in international obligations related to spectrum use, also act as a constraint to the creation of a free market in spectrum rights.

In spite of these constraints, however, a growing number of countries have adopted, or are considering adopting, a wide range of strategies designed to give market-forces a larger role in the determination of how spectrum resources are allocated, assigned and used. This section describes the theory and practice of some of these key strategies: auctions; tradable spectrum rights, market-based spectrum license fees and license-exempt spectrum use.

2.1 Auctions

As part of its Radio communications Act of 1989, New Zealand was the first country to authorize auctions of "spectrum rights". Since then, a growing number of countries have used auctions to assign commercial spectrum licenses where there have been competing licensees. For example, 13 out of the 33 countries that had assigned spectrum for UMTS services by 2002 had used auctions.[3]

2.1.1 Types of auctions

Auctions may take various forms, including:

- the English auction, where the auctioneer increases the price until a single bidder is left;
- the first-price sealed bid auction, where bidders submit sealed bids and the highest wins;
- the second-price sealed bid auction, where bidders submit sealed bids and the highest bidder wins but pays the second highest amount bid;
- the Dutch auction, where the auctioneer announces a high price and reduces it until a bidder shouts "mine"; and
- the simultaneous multiple round auction, as first practiced by the Federal Communications Commission (FCC) in the United States of America. This involves multiple rounds of bidding for a number of lots that are offered simultaneously. The highest bid on each lot is revealed to all bidders before the next round when bids are again accepted on all lots. The identity of the high bidder may or may not be revealed after each round, but is revealed at the auction's close. The process continues until a round

occurs in which no new bids are submitted on any lots. This variant is more complex than single-round auctions but offers bidders greater flexibility to combine lots in different ways, and, because it is more open than a sealed bid process, limits the impact of the *winner's curse*, allowing bidders to bid with more confidence.

2.1.2 Advantages and disadvantages of auctions

Spectrum auctions have been lauded as an efficient mechanism of assigning commercial spectrum licenses for which there is a high demand. Auctions have been seen as a way to decrease the administrative costs and time associated with the spectrum assignment process in comparison with administrative hearings or "beauty contests". At the same time, economic theory dictates that licenses will be put to their most productive use as they are competitively assigned to users who value these licenses the most. License proceeds have also become a lucrative source of income for government treasuries as 3G auctions in the United Kingdom have shown.[4]

Nevertheless, auctions have introduced their own set of inefficiencies.[5] Despite the large body of work dedicated to the study and application of good auction design, the number of variables that need to be considered, such as future demand and technological development, rend the effects of auctions unpredictable. Furthermore, auctions also operate in the rigid framework of administrative spectrum allocations where if too little spectrum is allocated for a particular use or for a particular region, the auction will result in an artificial scarcity premium for the government.

Although auctions have been successful in terms of revenue generation for governments, examples of unintended auction results include the effects of some 3G auctions in Europe that have resulted in the financial difficulties of a several carriers and the return of auctioned licenses. Such consequences can lead to a delay in the rollout of infrastructure and services as well as pressure towards industry consolidation and a reduction in competition in the marketplace.

Auction design typically requires a tailored approach, adapted to the particular circumstances of a country. For example, in Nigeria, experience showed that in order to ensure that nationwide spectrum resources were utilised efficiently, it was necessary to package spectrum according to regions (particularly in terms of distinguishing urban from rural spectrum) as well as to establish certain network roll-out conditions that were attached to spectrum licences. The auction experience in Nigeria has been mixed with several operators unable to meet rollout obligations after winning spectrum licenses at auctions. The country is currently examining how to improve the spectrum management regime in order to allow new operators to come into the market in order to replace or reinvest in operators who are unable to rollout their networks.

2.2 Tradable spectrum rights

While a well-designed auction can assign spectrum resources efficiently at the onset, it cannot continue to ensure that the assigned spectrum will continue to be used in an economically efficient manner in the future. In order to allow spectrum resources to be used by those who value it the most and for the purpose it is valued for the most, a market-based mechanism will have to be introduced to allow spectrum users the flexibility of transferring their spectrum rights and of determining the use to which it is put to.

In their consultation document on the implementation of spectrum trading, the former Radiocommunications Agency (RA) in the United Kingdom identified four major trading modes that reflect different degrees of flexibility that could be allowed to spectrum licensees[6]:

- mode 1: change of ownership;
- mode 2: change of ownership and reconfiguration (covering partition and aggregation);
- mode 3: change of ownership, reconfiguration and change of use, and
- mode 4 : change of ownership and change of use.

Spectrum trading variants also include spectrum leasing and spectrum sharing arrangements.[7]

Changes in ownership

Presently, in most countries, the transfer of ownership of a spectrum licence to another party after the initial assignment is only allowed in very limited and difficult circumstances. For example, in the United States, the Communications Act of 1934 limits the ability of licensees to transfer their spectrum rights without a laborious and costly application and public review process.

By allowing the transfer of spectrum rights, economic efficiency could be more easily achieved as licensees are exposed to the opportunity cost of their spectrum. If the value a licensee places on the spectrum is lower than that placed on it by another party, a transfer of the spectrum rights to the other party would result in a gain in economic efficiency. Allowing transfers would also lower barriers to entry into the market, firstly, by reducing risk by introducing the possibility of resale and secondly, by allowing prospective market entrants easier access to spectrum on the market instead of having to lobby or apply for spectrum to be administratively assigned to them.[8]

Changes in spectrum ownership or licensee through secondary trading have been permitted in some bands by Australia, Canada, Guatemala, New Zealand, the United Kingdom and the United States. The FCC in the United States, for example, has allowed trading in selected licences in secondary markets. Prior approval from the FCC is necessary, however, before a trade can take place and as a result trading has been limited because of the added risks involved. Nevertheless, the FCC is currently reviewing its rules and procedures to lower barriers in the secondary market and to promote more flexibility.[9]

Spectrum reconfiguration

The ability to partition and aggregate spectrum to a user's needs has been identified as an important element in achieving greater flexibility and efficiency in spectrum use. Users would have the incentive to only purchase or retain what they require while also allowing them to respond to changing spectrum needs over time. Allowing spectrum reconfiguration also provides an incentive for licensees to use spectrum more efficiently as they could partition and sell off unused spectrum.

In practice, however, the flexibility to partition spectrum has not been put to great use. In the United States, for example, partitioning rules allow licensees operating certain services the option to divide their licences by geography and frequency. However, the level of activity promoted by this measure has not been significant with only less than 0.1 per cent of licences auctioned by the FCC having been through the partitioning process.[10] This has largely been attributed to a number of factors. Firstly, partitioning the spectrum is seen as devaluing the asset. Secondly, licensees may seek to roll-out networks in their unused portion of spectrum in the future and thirdly, spectrum trading costs in the United States are seen as too high. In general, spectrum leasing is seen to be a better alternative to partitioning and sale.

Changes in use

It has been acknowledged by a number of economists that allowing changes in spectrum use would provide the greatest flexibility in terms of subjecting spectrum management to market forces. Given the unpredictable nature of spectrum demand and technological progress, it would appear that a good approach would be to devolve the decision on how to use spectrum to market players who have the agility to respond faster to changes in technology and consumer wants.

It has been highlighted that restrictions on spectrum use according to predefined service definitions also result in equipment manufacturers and operators concentrating on developing and deploying systems for the specific bands in which their services are allowed to operate, regardless of whether it represents an efficient use of spectrum.[11] In turn, this in-built equipment rigidity also prevents the use of such equipment over other suitable bands that may be under utilized. Allowing changes in spectrum use, however, would allow spectrum and equipment to be redistributed according to market demand. In the United States, mobile operator Nextel acquired (through a series of purchases) a network of local radio trunking licences used for dispatch services. In the absence of a regime allowing changes in spectrum use, these licenses were painstakingly converted into a nationwide licence to provide public mobile telephony through a lengthy and expensive administrative process, illustrating the value of a simplified procedure to allow changes in spectrum use. In New Zealand, where such changes in use are permitted, spectrum sold originally for multipoint distribution service is being used flexibly as multipoint broadband wireless local loop.

In countries where spectrum trading has been introduced, the trend is to provide flexibility in services and use of technologies in commercially tradable bands. For example, in Australia no service or technology constraints are specified in spectrum licences. Australian "standard trading units" (STUs) of spectrum have been designed to accommodate all likely uses. It is important to note, however, that in Australia and New Zealand potential flexibility is nevertheless still constrained by the way spectrum is packaged for initial auction. This is done so as to facilitate the most likely use of the band under consideration. As such it does not result in a completely service neutral outcome. Here, likely use is determined by the availability of equipment and typical international use of the band.

There are a number of important constraints that act on the scope of an administration to introduce flexibility in spectrum use. Depending on the geographic isolation of the country, changes in spectrum use can be constrained by international obligations, such as the ITU Radio Regulations, spectrum harmonization requirements and bilateral agreements. Governments may also seek to restrict changes in use in order to maintain diversity in the provision of radio services. For example, mobile communication services could be offered through a range of alternatives from self-provided trunked mobile systems to cellular telephony. Some of these obstacles to changes in spectrum use are discussed below.

Spectrum leasing and spectrum sharing

Spectrum leasing or sharing typically involves a partial transfer of a licensee's rights to spectrum either for a limited period of time and/or for a portion of the spectrum encompassed in the licence. This includes, for example, the transfer of the right to transmit from one site under a multi-site licence for a temporary period. The flexibility afforded by such an arrangement is particularly ideal for situations where a lessee's requirements are minor or temporary. It also allows licensees to benefit by allowing them to receive returns on portions of their assignment for which they have no present need. This allows unused spectrum to be released into the market and creates a financial incentive for licensees to adopt more efficient ways of utilizing their existing spectrum. In leasing and sharing arrangements, however, it would be important for licensees and lessees to be clear on how rights and obligations are apportioned, especially in cases where enforcement action may have to be taken by the regulator (see Box 1).

Box 1: Spectrum leasing in the United States

In May 2003, the Federal Communications Commission (FCC) adopted a "landmark" order on spectrum leasing that authorised most wireless radio licensees with exclusive rights to their assigned spectrum to enter into spectrum leasing arrangements.

Under the leasing rules adopted, licensees in certain services are allowed to lease some or all of their spectrum usage rights to third parties for any amount of spectrum and in any geographic area encompassed by the licence, and for any time within the term of the licence.

The order also creates two different mechanisms for spectrum leasing depending on the scope and responsibilities to be assumed by the lessee:

The first leasing option – "spectrum manager" leasing – enables parties to enter into spectrum leasing arrangements without obtaining prior FCC approval so long as the licensee retains both *de jure* control of the license and de facto control over the leased spectrum. The licensee must maintain an oversight role to ensure lessee compliance with the Communications Act and all spectrum related FCC rules. In enforcing the rules, the FCC will look primarily at the licensee on compliance issues but lessees are potentially accountable as well.

The second option – *de facto* transfer leasing – permits parties to enter into leasing arrangements, with prior approval of the FCC, whereby the licensee retains *de jure* control of the license while *de facto* control is transferred to the lessee for the term of the lease. Lessees are directly and primarily responsible for ensuring compliance with all FCC rules. For enforcement purposes the FCC will look primarily to the lessee for compliance, and lessees will be subject to enforcement action as appropriate. Licensees will be responsible for lessee compliance in so far as they have constructive knowledge of the lessee's failure to comply or violation.

Source: Report and Order and Further Notice of Proposed Rulemaking (FCC 03-113), Federal Communications Commission.

Box 2: Overlay licenses

Overlay licenses give rights to use spectrum that currently contains an incumbent as soon as the incumbent has moved out (or rights to use a part as soon as the incumbent has vacated that part). The incumbent's security of tenure may be limited by license term so that they may be required to move out by a given date. Incumbents and new entrants may then negotiate over the price to be paid to bring the date forward.

Source: ITU research.

2.2.1 Implementing spectrum trading

The implementation of spectrum trading, in its different modes, involves the consideration of a number of issues. These include how to make the transition from more traditional approaches to spectrum management, how spectrum should be packaged, how long licence or ownership rights should be granted for and what institutional arrangements should be should be established to ensure the smooth operation of the market.

Managing a transition to spectrum trading

Countries that have implemented spectrum trading have tended to adopt a progressive approach to its introduction. A step-by-step approach to trading gives regulators the time to facilitate spectrum reorganization and markets the opportunity to gain familiarity with the new regime.

Limiting spectrum trading to only new assignments of licences and the use of overlay licences (see Box 2), has been found to be a convenient approach in making the transition to spectrum trading while accommodating the interests of incumbents.

As an alternative example, New Zealand's three tiered system of rights have permitted the introduction of transferable and flexible spectrum rights while accommodating incumbent interests (see Box 3).

In most countries where spectrum trading has been introduced, trading is permitted first in certain bands or in classes of licences that have been identified as appropriate. This list is then gradually expanded (see Table 1). Some of the factors that are considered in determining whether a category of licence is suitable for trading and through what mode (change of ownership, repartition, change of use, etc.) include:

- demand for re-allocation of spectrum in the particular band or class of licensees;
- degree of scarcity for frequencies in the particular band and the estimated trading volumes in the future as the introduction of spectrum trading may not be worthwhile if low trading volumes are expected;
- stability of the band, which can be influenced by either imminent changes international spectrum allocation or the introduction of new technology in networks with uncertain market and technical factors;
- spectrum allocation within the Radio Regulations and other international coordination requirements, and
- arrangements for harmonized use.[12]

The introduction of more complex forms of trading that allow for reconfiguration or changes of use or both are more likely to involve an increase in the risk of interference and would require much more detailed licensing conditions.

In general, countries that have introduced or are planning to introduce spectrum trading have earmarked spectrum bands or licence classes covering services such as mobile networks, mobile data networks, paging networks, private business networks and certain categories of terrestrial fixed links as most suitable for trading under one of the various modes. Later phases may subsequently include spectrum bands of licence classes covering services such as sound broadcasting and television broadcasting, as such services commonly involve an element of public broadcasting policy considerations to be taken into account. Nevertheless, it is worth noting that in New Zealand, the spectrum-trading regime was first implemented in the area of commercial radio broadcasting, where the perceived need for reform was the greatest.

Box 3: Spectrum management in New Zealand

New Zealand has shown that it is feasible to create tradable spectrum rights and to auction these rights despite the presence of incumbents in the bands. This was largely accomplished through a three-tier system of rights:

Management rights bestow the exclusive right to become the spectrum manager for a nationwide band of frequencies for a period of up to 20 years. Within this band, the manager can issue licences. They are not constrained as to the uses for which licences are issued.

Licence rights are derived from spectrum licences that are issued by the management rights holder which allow licensees the right to use frequencies within their bands. Licences are use specific and defined in terms of transmitter sites. The management rights holder can issue licences to itself.

In blocks of spectrum where management rights have not been created, the legacy regime of non-tradable **apparatus licences** continues.

The Government favoured a progressive conversion of licences to a spectrum rights regime. As the initial owner of all management rights, the Government has used auctions to make primary assignments of tradable management rights. There were 91 management rights as at February 2004, with the New Zealand Government retaining ownership of 15 of these rights, predominantly over spectrum used to provide public services.

It is left to the ensuing management rights holders whether or not to trade their rights. There are no restrictions on the activities of the operators, the number of entrants into the markets or specialised licensing requirements.

Source: Ministry of Economic Development at http://www.med.govt.nz/rsm/ and http://spectrumonline.med.govt.nz/.

Although secondary trading has been introduced in Australia, New Zealand and Guatemala, the government nevertheless reserves certain bands for specific services and not subject to secondary trading regimes. For example, Australia does not subject satellite services to secondary trading (although it does apply pricing) while the New Zealand government retains the rights over spectrum used for public service broadcasting. Services where governments require universal service provision, in particular, are generally deemed unsuitable for secondary trading.

Table 1: Ofcom's Timetable for Spectrum Trading

2004	2005	2006	2007	Other
Analogue PAMR (Public Access Mobile Radio)	Wide-area PBR (Private Business Radio)	Emergency services	2G and 3G mobile	Mobile satellite
National paging	On-site PBR		PMSE (Programme Making and Special events)	Satellite shared with terrestrial services
Data networks	Digital PAMR		Aviation and maritime communication	Radio broadcasting
National and regional PBR	10 GHz FWA (Fixed Wireless Access)		Radionavigation (Radar)	Television broadcasting
Common Base Stations	32 GHz			
Fixed wireless access	40 GHz			
Scanning telemetry				
Fixed terrestrial links				

Source: *A Statement on Spectrum Trading: Implementation in 2004 and Beyond*, August 2004, Ofcom, London www.ofcom.gov.uk

Dividing and packaging spectrum for trading

The way spectrum is divided and eventually packaged in terms of geography or bandwidth for initial assignment has a considerable influence on the ease of trading implementation and the eventual development of the spectrum trading market.

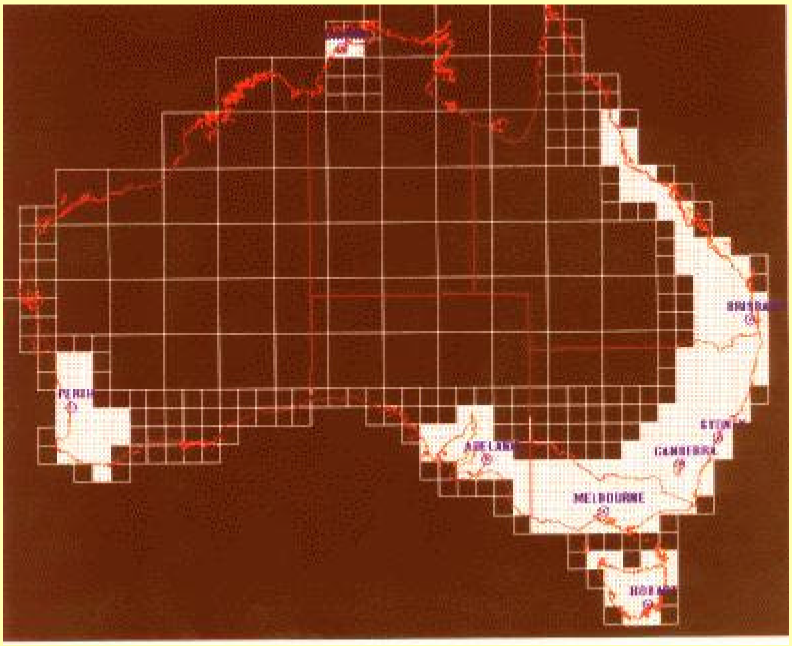
While assigning licences encompassing variable amounts of spectrum on a case-by-case basis is practised by most spectrum trading countries, Australia has adopted a more structured basis as a point of departure by first dividing spectrum into standard units of geographical coverage and bandwidth (see Box 4). Such an approach provides some advantages in terms of flexibility of use and ease of reconfiguration, which in turn facilitates the easier introduction of spectrum trading, but is notoriously difficult to implement given the amount of variables that have to be rationalized in creating uniform spectrum blocks.

Box 4: Spectrum as commodity

Australia and the standard trading unit (STU)

In Australia spectrum blocks owned by licensees are represented in units called standard trading units (STUs). An STU covers a predetermined geographic area and frequency band. STUs can be combined vertically to provide increased bandwidth or horizontally to cover a larger area. An STU is the smallest spectrum unit recognized by the ACA and its bandwidth and geographic dimensions cannot be further divided.

The minimum frequency band for any spectrum licence would have a width of one STU bandwidth. In some bands this bandwidth is as small as 0.0125 MHz. The minimum geographic area for an STU is a single cell of a Spectrum Map Grid. The Spectrum Map Grid covering Australia is shown below, and consists of cells of various sizes depending on their location.



Different cell sizes are used depending on the levels of population. Larger cells are defined in rural areas. Small cells are defined in population density areas, such as cities, towns and their suburban areas

Auction lots of spectrum space are then defined for sale. An auction-lot area is defined by reference to the spectrum map grid. The auction-lot areas are defined to cover the total area available from each band release and with no overlap of areas. Auction-lot areas are created by a process that aggregates map grid cells. The process takes account of the value of populated areas, the incumbent services and the requirements of technical framework itself, for example, the size of the emission buffer zone.

Source: Australian Communications Authority.

Box 5: Fragmenting spectrum in Guatemala

Spectrum rights in Guatemala are granted in fully transferable and fragmentable frequency usage titles (*Titulos de Uso de Frecuencias* or "TUF"s), which have technical limitations to protect against interference but which have no service limitations. Under the system, all spectrum that is not assigned can be requested. Following a request, the regulatory administration determines whether the request would infringe upon any other person's rights and if it does not, it opens up a period where other parties may object to the granting of the right, which must be based on a violation of the protesting party's existing right, and where other parties may seek a portion of that requested spectrum. In the latter case, the administration is obliged to start an auction. In cases where fragmentation would promote competition, the law requests fom the administration that it auctions the requested spectrum in a fragmented fashion.

The first TUF auction in Guatemala was launched on 4 June 1997. It comprised 20.8MHz of nationwide spectrum in the 800MHz range, which was used for trunking or specialized mobile radio (SMR). There were initially 11 bidders, including the incumbent GUATEL. It was decided to fragment the 20.8MHz of spectrum was into 19 pairs of outbound and inbound bands: seven band pairs of 1 MHz each, and 12 bands of 200kHz each. The auction ended after two weeks of intense biding, with total payments of about USD 3 million. Out of the initial seven bidders, 11 bidders won at least one lot.

Source: Pablo T. Spiller and Carlo Cardilli, Towards a Property Rights Approach to Communications Spectrum (1999), Yale Journal of Regulation, Vol. 16, No.1.

Regardless of whether spectrum is divided into trading units or not, regulators will still have to weigh a number of considerations in deciding on the optimum spectrum package sizes for initial assignment. If spectrum packages are too small, users will have to incur increased transaction costs through the process of aggregating the necessary amount of spectrum. Not only would the creator of a national network have to negotiate with multiple spectrum owners, but if any refused to sell, the network could not exist as planned. On the other hand, if spectrum packets are too large, additional costs will be incurred in disaggregating and reselling the spectrum. Furthermore, the assignment of spectrum in large packages can also act as a barrier to entry into the market as higher prices would have to be paid.[13] In thin markets where demand for spectrum is lower, the packaging and assignment of spectrum in smaller lots may increase market interest and the likelihood of additional competition (see Box 5).

Auction theorists have considered this question and some have proposed package bidding as a possible solution. Regulators could let interested parties bid on smaller individual parcels or on a package of individual parcels. If the total bid for the package were greater than the total for the individual parcels, then the spectrum would go to the single bidder for the package. For example, in the United States, the FCC has introduced package bidding into its spectrum auctions.[14]

Competition safeguards

Competition safeguards are central in planning for the introduction of spectrum trading as the possibility of spectrum consolidation may potentially lead to a decrease in the number of competitors. Spectrum hoarding, in particular, has been highlighted as a key concern.

In Australia and New Zealand competition concerns regarding spectrum trading are largely resolved by *ex post* enforcement of competition law.[15] In other countries, regulators have resorted to more *ex ante* competition policy measures, usually in the form of requirements for regulatory clearance of spectrum trades. For example, in the United States, FCC approval is required before a licence transfer can be made.

Other *ex ante* safeguards include spectrum ownership caps that limit the maximum amount of spectrum a single entity is allowed to own. Spectrum ownership caps are applied in a number of countries, for example, in the United States. Such an *ex ante* approach may avoid a lengthy *ex post* resolution of market dominance issues. For example, in New Zealand, a decision of the Commerce Commission - the national competition authority – that deemed that New Zealand Telecom (NZT) would acquire a dominant position if it was permitted to purchase all the AMPS spectrum was deliberated in national courts for a lengthy period of time before being overturned. The New Zealand Government is now reviewing the need for spectrum caps on a case-by-case basis.[16]

Nevertheless, in practice, competition concerns have not materialised to any noticeable extent as a result of spectrum trading. The experience of Guatemala has shown an increase in effective competition following the introduction of spectrum trading despite the absence of *ex post* competition law rules. Examples from

Australia and New Zealand have also shown no significant need for *ex post* regulatory intervention in the secondary market.

Trading mechanisms and market intermediaries

Once a spectrum trading framework is in place, markets can be left to develop of their own accord with the trading process carried out by appropriate private sector intermediaries. These could include brokers, private spectrum exchanges or dealers that purchase spectrum and repackage them for resale. To a certain extent, such services have developed in a few countries where spectrum trading has been introduced. In Australia, for example, specialised consultancies have assumed some of the role of facilitating spectrum trades. However, the emergence of a full range of intermediaries similar to those in other industries has yet to be seen.

In the alternative, administrations have the option of taking steps to shape the development of a spectrum trading mechanism. Specific trading mechanisms could be mandated by administrations, standardizing the means by which spectrum rights can be transferred or a central trading institution could be established in order to establish greater oversight over the trading process.

There is a danger, however, that in such an approach, administrative costs will be high, increasing the costs of trading and decreasing the incentive to trade. There are, however, less interventionist approaches that can be taken to facilitate the development of spectrum trading markets, through means such as the dissemination of various amounts of trading information for example (see Box 6), or through the establishment of a common resource to bring together buyers and sellers, like for example, a public database of spectrum for sale or spectrum sought or the organization of periodic auctions at which spectrum owners could offer spectrum lots.

Windfall gains and high prices

The conversion of licenses to tradable licenses may result in incumbent licensees receiving capital gains, especially when the original license was not obtained through an auction process. Although there are no strict economic reasons to prevent windfall gains, concerns are likely to be raised among the general public if the gains are substantial in relation to the original assignment price. The question of government levies for net gains in spectrum trades has been considered as a possible remedy. Nevertheless, the imposition of taxes or transfer fees on profits may have a negative effect if it reduces the incentive to trade. In Australia, taxation law was one of a number of "unforeseen consequences" by the Australian spectrum regulator that impacted spectrum trading. In particular, State Governments also sought to apply high levels of stamp duty on trading transactions.[17]

Box 6: Information requirements

For a transaction to take place, a potential spectrum buyer requires information as to the spectrum that is available for sale. In other more mature markets information gaps have typically been addressed through private intermediaries, such as through brokers or market analysts that rely on voluntary disclosure. Nevertheless, in the absence of such intermediaries and to facilitate a fledgling spectrum trading market, some administrations that have introduced spectrum trading have required buyers and sellers to provide a certain level of information regarding their trades. At the very least, registries containing basic information such as a list of assigned spectrum and their users have been maintained. For example, Australia provides an online register of spectrum licences that allows buyers of spectrum to search for potential sellers. However, information on confidential users for reasons of national security is withheld and pricing information is not collected or recorded by the ACA. In general, information on transactions can be mandated through regulatory compulsion and disseminated by publication directly or in aggregated form, periodically or in real time, and through a number of means, for example on a publicly accessible website.

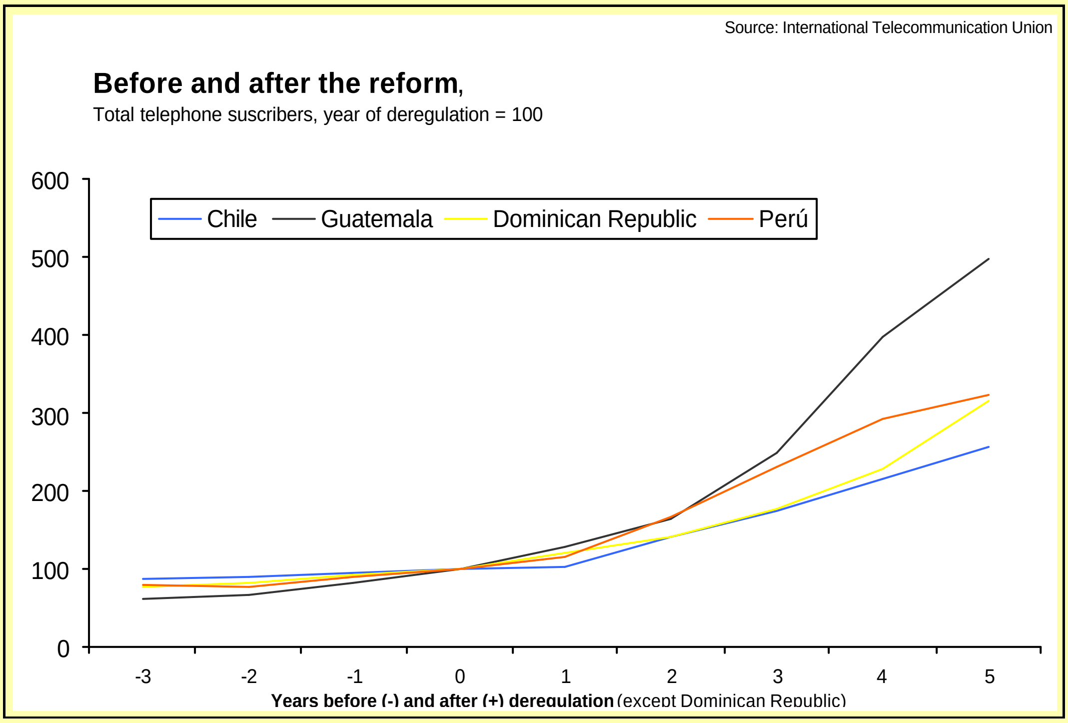
To a large extent, the differing levels of mandatory disclosure reflect a balance between the desire to maintain open and competitive markets against commercial prerogatives to privacy and security. On the one hand availability of information on prices and transactions provide valuable information regarding supply and demand and allows the market to allocate resources efficiently, furthermore, increasing the level of information available to all parties levels the playing field and reduces the scope of informational advantages. On the other hand, market participants may worry that purchase and sale information may reveal sensitive information regarding their business plans.

Source: Implementing Spectrum Trading, A Consultation Document, July 2002, Radiocommunications Agency, UK.

Box 7: Telephone subscriber rates in Guatemala

Before and after the Reform

In Guatemala, the initial effects of the introduction liberalization have been visible in the telephony sector. From 1996 to 2001 the total number telephone of lines (fixed and mobile) increased at an annual compounded rate of 38 per cent. Under State monopoly, the annually compounded rate from 1985 to 1995 was nine per cent. Although the sudden increase in penetration rates can be attributed to privatisation and liberalisation of the entire telecommunication sector, a comparison in performance with other countries implementing the same reforms, except for spectrum trading, have shown more modest growth.



The graph uses as a baseline the year of the reforms: 1988 for Chile, 1993 for Peru, and 1996 for Guatemala. The growth rate in Guatemala far surpasses that for either country. Five years after the reform the annually compounded growth rate for Chile and Peru was 21 per cent and 27 per cent respectively, compared to Guatemala's 38 per cent.

Source: ITU Country Case Study, Radio Spectrum Management for a Converging World in Guatemala.

Some concern over high spectrum licence prices resulting from primary licence auctions have been raised in the context of countries that have introduced spectrum trading. It is generally assumed that spectrum trading would bring about higher bids at auctions for initial rights due to a lowering of barriers to market entry. However, the example of Australia and Guatemala, two countries that have introduced liberalisation of spectrum use and spectrum trading, have shown that spectrum licence prices at auction were generally lower than in comparable countries.

2.2.2 Spectrum trading in review

Spectrum trading has been welcomed to different degrees by different markets. The United States registers an annual trading volume in the thousands while the New Zealand market is characterized by thin trading volumes. Beyond the fundamental issue of market size, some analysts have attributed this low volume of spectrum trading in New Zealand to a number of factors that can be instructional.[18] Firstly, there remains some confusion regarding old and new licences, as well as nervousness in the industry about the expiry date of current licences. There has also been uncertainty about the way spectrum will be treated for international standardization purposes, as the availability of equipment often constrains spectrum utility. As New Zealand uses auctions for initial spectrum assignments, introducing a secondary market will have less of an impact when the primary mode of assignment is already market based. The most important factors, however, are tied to the nature of market demand for spectrum. Spectrum purchases are typically made by operators who intend to build out networks. As such, they have little intention to sell the spectrum in the short term. It also appears that there are few operators vying for spectrum in New Zealand. In the recent 3G-spectrum auction, six blocks of spectrum were offered and only four bids were received.

Admittedly, compared to the long history of centrally regulated spectrum management, practical experience with regard to spectrum trading has been limited to a handful of countries. Nevertheless, it appears that the practice is set to grow. An independent study was conducted for the European Commission and published in May 2004 regarding the conditions and options for introducing spectrum trading in the EU.[19] This study recommended that the EU move toward a framework that requires trading and further liberalization in spectrum use.

Encouragingly, it is also clear that spectrum trading is not purely an issue for developed countries. In Guatemala, the introduction of spectrum trading has been credited with an increase in the telephone subscriber rates (see Box 7). By allowing industry a larger say in spectrum management, spectrum trading also promises to alleviate some of the administrative burdens governments have to shoulder, particularly in the task of ensuring the continued efficient distribution and use of spectrum resources.

2.2.3 Constraints to spectrum trading

Despite these successes, a number of significant misgivings still remain with regard to the introduction of spectrum trading, the most preoccupying being an increased risk of interference. Furthermore, spectrum trading may also introduce its own set of inefficiencies that may include increased difficulties and higher transaction costs in assembling spectrum bands in contiguous areas and in realizing economies of scale or other welfare benefits resulting from international harmonization and standardization.

Interference

National administrations have traditionally regarded interference management as one of their central responsibilities under their overall objective of maximizing the technically efficient use of spectrum. In the absence of exhaustive and precise technical details of all services and systems over different topographical and meteorological conditions, a spectrum management approach that allocates spectrum along the lines of services or systems with homogeneous characteristics (in terms of compatible RF power level, similar bandwidths, similar protection environments, similar potential for interference and similar performance requirements) reflects the most practical way of attaining spectrum efficiency. Within this service-based allocation framework, regulatory administrations then co-ordinate the co-existence of different systems within the same frequency band as well as between systems in adjacent frequency bands through license assignments.

While this approach to interference management brings about a certain measure of technical efficiency by removing some usage variables, it suffers from a certain amount of inflexibility and unresponsiveness. With the introduction of more market-based approaches to spectrum management, a more flexible and transparent framework would be required. Although changes in the way spectrum assignments are managed may not require significant changes in the current regime, changes in spectrum allocation practices that allow for changes in spectrum use will impact the interference environment considerably.

In order to allow greater freedom of use, some critics have argued that usage restrictions on spectrum should be replaced with interference limits designed to achieve the same ends.[20] In some countries where spectrum trading has been introduced, the administration may set the initial limit for interference parameters (e.g. New Zealand, Australia and the United States) or they may be set by industry with oversight from the regulator. For example, in Australia, interference levels are administratively set at the geographic boundaries of each standard trading unit (STU) with while in New Zealand, area and frequency parameters are administratively defined on a case-by-case basis for initial license assignments.

While the approach of setting absolute boundary conditions offers clarity and simplicity in its application, it risks technically inefficiency, as it does not reflect the characteristics of the actual systems that are deployed when spectrum use changes. As such, provided that sufficient technical data and calculation tools are available, the eventual setting of boundary conditions should be delegated in some measure to users. In countries employing such a framework, users are typically given the option of varying initial boundary conditions either through bilateral negotiations or through administrative appeal. For example, in Canada, initial boundary conditions are trigger values for negotiation that are set conservatively to minimize the potential for interference.

In most cases, if an agreement between the affected parties is not possible, then some form of dispute resolution procedure typically applies, for example in Australia, an independent conciliator may be appointed by the ACA if parties are unable to arrive at an agreement. However, the resolution of disputes through the courts was tried but was found to be impractical and lengthy in New Zealand.

To a large extent, the monitoring of interference conditions in these countries is largely left up to the spectrum users, illustrating the practical possibility of devolving such administrative functions to the private sector, thus decreasing the burden on the government.

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 it holds "management rights" for. 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.

International considerations

To a significant extent, spectrum management at the national level is constrained by international obligations resulting from agreements that countries have been entered into for mutual benefit, primarily for purposes of interference management and spectrum harmonization.[21]

- *Harmonisation*

International spectrum harmonization offers both benefits and constraints to countries that adhere to these norms. Internationally harmonized channels are required for the cross-border movement of certain wireless services such as radio communications on ships and aircraft as well as global roaming on mobile phones. In addition, services that transmit signals across borders, such as satellite services, also require some degree of international harmonization. Finally, the harmonization of spectrum usage across countries allows wireless equipment manufacturers in achieving larger economies of scale and operators in achieving a more rapid rollout of new services.

Along with the benefits offered, international harmonization requirements, both global and regional, also impose constraints on changes in spectrum use, which can result in inefficiencies in the form of regulatory delay and which can act as a barrier to the development of new and alternative services for that frequency.[22] Countries can also be restrained from adopting new approaches to national spectrum management, like spectrum trading or open spectrum, which allow spectrum users full freedom to determine spectrum use. Strict harmonization requirements can also inhibit the emergence of competing technologies and services over other frequencies. There are benefits that can be reaped from allowing multiple or competing standards to develop as the type and quality of services offered tend to differ across technologies. For example, CDMA networks introduced more and better data services earlier than those available on GSM networks.[23]

Nevertheless, despite the apparent constraints of in aiming for international spectrum harmonization, there still remains some scope for flexibility. The evolution of harmonization and standardization in mobile communications provides a good illustration of how flexibility and competition between standards and technology may be preserved while allowing the benefits of harmonization, like global roaming for mobile phones and economies of scale, to emerge (see Box 8).

Box 8: Harmonization and standardization in mobile communications

The development of first-generation analogue mobile systems was strongly influenced by the adoption of open and non-proprietary standards. Although AMPS (USA), TACS(UK) and NMT(Scandinavia) systems were based on different technologies, neutral manufacturers were allowed to adopt their standards, leading to the more wide-scale adoption of these technologies in neutral countries. Standards proprietary standards promoted by Japan, France and Germany, however, proved less successful. Although there was little coordinated international effort to harmonize spectrum use for these services, the frequency bands used by the successful standard gained a near-harmonized status (e.g. 450MHz for NMTS and 900MHz for TACS).

The development of the second generation of mobile systems, however, took place during a period when the European Community's desire for a single market came into prominence. The *Conférence des Administrations Européenes des Postes et Télécommunications* (CEPT) undertook the development of a set of common standards for a pan-European mobile network. Representations by the CEPT to the European Commission resulted in a directive requiring Member States to set aside spectrum in the 900MHz band for the eventual deployment of a pan-European mobile network based on the GSM standard. These conditions led to the emergence of an early installed subscriber base which was quickly added to by the rapid adoption of the standard by most countries worldwide. By the end of 1993, there were more than 1 million GSM users in Europe. By contrast, the American policy of not adopting a common standard or frequency led to a fragmented market and to substantial difficulty in exporting American technologies and standards.

Although competition for global adoption between UMTS and CDMA2000 technology characterized the development of an international framework for third-generation mobile systems, the success of GSM demonstrated the importance of global roaming in the eventual service delivery. Internationally, a core band of spectrum was allocated at around the 2GHz band for terrestrial systems in the IMT-2000 family.

Source: JL Funk and DT Methe, "Market and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication", Research Policy 30(2001); Neil Gundal et al., "Standards in wireless telephone networks", Telecommunications Policy 27(2003); and Martin Cave, Review of Radio Spectrum Management, An independent review for Department of Trade and Industry and HM Treasury (2002) available at: http://www.see.asso.fr/ICTSR1Newsletter/No004/RS%20Management%20-%202_title-42.pdf.

The example of the evolution of harmonization and standardization in mobile technology illustrates a few important factors to consider. Firstly, where harmonization is seen as advantageous, it should nevertheless not set more limits than necessary to achieve its goals. For example, it should be aimed at broad categories, such as the entire family of IMT-2000 standards, within defined bands rather than at a specific technology description, such as UMTS. This would allow for competition between technologies and standards to continue. Secondly, after harmonization has delivered its benefits, competing services and technologies should be allowed to access the spectrum. Finally, the creation of standards for harmonized bands should be left open and led by industry in order to facilitate market based competition between manufacturers and operators.

In this respect, at the international level, ITU Radio Regulations and recommendations impose relatively few constraints in terms of mandatory harmonization requirements. Spectrum allocations for the purposes of harmonization are typically confined to that necessary for the efficient provision of cross-border services, such as satellite services, and the facilitation of cross-border movement of radio transmissions, such as in aviation and maritime uses. These are typically phrased in terms of broad service categories and are largely technology neutral.

- *Cross-border interference management*

On a global scale, interference management is largely dealt with through ITU. The most important principle of the Radio Regulations is that spectrum, being a limited resource, must be used efficiently and equitably. In order to achieve this, ITU Radio Regulations and recommendations determine how spectrum bands can be used while the Radiocommunication Bureau (BR) oversees a coordination procedure that requires the registration of systems that have been licensed by its Member States and the dissemination of that information to Member States that may be affected.[24]

Given its broad service categories and emphasis on bilateral coordination, ITU's spectrum management framework can be considered to be more flexible than most national regimes that employ narrower allocations and assignments. Nevertheless, the framework still suffers from the same criticism that is levelled against national approaches that seek spectrum efficiency through administrative spectrum allocation. In addition, its operation also acts as a constraint on the spectrum management approaches that can be taken by national administrations to remedy these inefficiencies. In practice, if national administrations were to implement market based approaches that allow greater flexibility in spectrum use, spectrum usage in border areas would effectively be restricted to the services specified within that ITU frequency band. While this may not constrain geographically isolated countries, it would severely limit the spectrum management options open to small countries that share borders with many others.

Nevertheless, It is important to note that those countries that have developed a flexible, market-based approach to spectrum management have done so largely within the framework of the existing international regulations. Although there is some support for the idea of making allocations on a more generic basis and avoiding allocations to a specific application or technology among ITU member states, there is still considerable reluctance to open a wide-ranging review of definitions as this is likely to be very resource intensive. It may only be necessary to adopt a more flexible interpretation of the existing definitions, or to modernise them.[25]

2.3 License-exempt spectrum

In contrast with spectrum management regimes based on exclusive rights, a licence-exempt model does not assign users exclusive use privileges over spectrum. Instead, access to spectrum is either open to all users (open access spectrum) or to a group of users who hold the rights to that spectrum in common (spectrum commons). In this way, spectrum users are given greater freedom to enter the market and to deploy a more flexible range of services to the consumer.

2.3.1 Open access spectrum

Licence-exempt spectrum use is usually permitted in two forms. The first involves low power transmissions, where interference is limited by strict power limits and regulatory equipment approval. This allows low-power users to co-exist in bands simultaneously used for higher power emissions. The second involves spectrum use in bands allocated for licence-exempt use. Bands like the 2.4 GHz "industrial, scientific and medical" (ISM) band, where 802.11b standard operates, as well as the 5 GHz band, where the 802.11a standard and the emerging 802.16 standard operate, have generated considerable attention in recent times. Most regulators require users of these bands to be subject to certain restrictions, such as output power limits or communication protocols, and other "etiquette rules" aimed at minimizing interference. While users of these bands are permitted higher power outputs due to the protection offered by the dedicated bandwidth given to licence-exempt use, the use of the spectrum itself is typically granted on a non-interference, non-protected basis. Users in these bands are liable for interfering emissions they cause but are not protected from interference from others. Significant incentives are therefore created for users to deploy innovative systems that offer dynamic traffic-channel monitoring and selection and fast frequency hopping spread spectrum waveforms.

In addition to the technological and service innovation brought about by licence-exempt spectrum use, eliminating the requirement for administrative licensing also lowers barriers to market entry and spurs competition. The increasing popularity of services delivered over licence-exempt bands in many parts of the world serves as a strong testimony to benefits that can be reaped from an open spectrum approach (see Box 9).

Despite the rapid success enjoyed by some services provided over licence-exempt spectrum, significant concerns remain regarding the long-term viability of an open access regime. Over time, logic dictates that the increasingly diverse and intense use of such bands would gradually increase the potential for congestion and interference causing an eventual degradation in service quality. The experience of the citizen band (CB) radio in the United States is often highlighted as an example of a tragedy of the spectrum commons, even though it is uncertain as to how large a role service degradation played in its drastic fall in popularity in the mid-1970s.[26] Despite this concern, licence-exempt bands have nevertheless served as a valuable catalyst for the emergence of successful technologies that serve to increase technical spectrum efficiency and minimize interference. Some of these technologies, such as frequency hopping spread spectrum, are described in Annex 1.

Box 9: The growth of "Wi-Fi"

The term "Wi-Fi" commonly refers to the array of technical standards that can be used to create "wireless local area networks", or WLANs (known also as "radio local area networks" or RLANs). Strictly speaking, Wi-Fi is a certification that manufacturers can apply to their products once they satisfy certain interoperability criteria. Meanwhile, WLAN denotes a radio networking technology used to connect personal computers or other appliances to a local network. WLANs can be operated for private use, such as in the home, or to create short-range, public networks. Known as "hotspots," these networks can be found in airport lounges, coffee shops or even neighbourhoods.

There are many technical standards used to create WLANs. Those that have received the most attention are the 802.11 family of wireless technical specifications developed by working groups of the United States' Institute of Electrical and Electronics Engineers (IEEE). The most popular specification is currently 802.11b, which uses the 2.4 GHz "industrial, scientific and medical" (ISM) bands. Many people employ the term "Wi-Fi" to refer strictly to 802.11b equipment, although the term has come to be used by the general public as synonymous with all WLAN networks and devices. That would include the 802.11a standard, which operates in the 5 GHz bands. More recently, the 802.16 standard that has been approved by IEEE which enables wireless metropolitan area networks, or WMANs (these are also referred to as "Wi-Max" networks). For the purposes of this paper, Wi-Fi is used generically to refer to all WLAN products, reflecting its popular usage.

A number of countries have dramatically increased the rate of use of wireless networks. In the United States, for example, it has been reported that the number of Wi-Fi implementations doubled between 2001 and 2002. More than one million Wi-Fi access points are estimated to be in use by more than 700 000 US enterprises.[27] Internet service providers (ISP) have even begun using Wi-Fi technology to cover entire cities.[28]

There are a large number of optimistic estimates about the future growth of the Wi-Fi market. For example, analysts predict that by 2006, there will be 800 000 European Wi-Fi hotspots, 530 000 in the United States and 1 million in Asia. Wi-Fi revenue in Western Europe and in the United States is expected to rise to USD 5.4 billion this year, up from USD 33 million in 2002.[29] In the United States, estimates indicate that more than 5 million American households will migrate to mobile and high-speed wireless broadband networks for their primary connection by 2006.[30] There is another prediction that replacement of wired services by wireless access is expected to accelerate dramatically and will reach an additional 10 million wireless access users by 2005.[31]

Source: SPU Global Market Trends, "Wi-fi takes the sector by storm" available at: http://www.itu.int/osg/spu/spunews/2003/oct-dec/wi-fi.html and "Report on the Development Of Wireless Local Area Networks In OECD Countries" available at: http://www.oecd.org/dataoecd/44/42/2506976.pdf.

Although the decision as to whether to exempt certain bands from licensing is a national matter which may need to take into account license revenue issues and competition issues relating to the use of other (licensed) bands, there is nevertheless, a need for coordination at the international level first before countries take such decisions as they could have adverse cross-border effects. In Guatemala, for example, devices designed for unlicensed use in another country were imported into the country and caused interference with licensed operations in Guatemala. Although the parties involved resolved the situation without government intervention, the global proliferation of such devices will entail greater international coordination.

2.3.2 Spectrum commons

Similar to the approach taken in an open access regime, a spectrum commons does not assign exclusive rights to individual users. However, rather than opening access to all users, access rights to spectrum are limited to a group of users who assume the management of that band. As it is generally assumed that open access resources tend to get overused rapidly, resources for which clear common ownership rights are established are likely to be utilized more efficiently.

This commons approach to spectrum is essentially modelled on common property management regimes that are practiced in other industries, such as fisheries. While the administrative allocation of spectrum for the purposes of establishing spectrum commons have been relatively rare, the management of some licence-exempt frequency bands have nevertheless taken on the characteristics of spectrum commons in some cases (see Box 10).

Box 10: Unlicensed PCS in the United States

Starting in the late 1980s, cellular companies and computer makers began to petition the FCC to allocate new spectrum for experiments with a new generation of personal communication services. The FCC consolidated the proposed new services (isochronous applications, such as wireless PBX, and asynchronous applications, such s nomadic data devices) in a proceeding for unlicensed PCS services (UPCS). The unlicensed status reflected a general agreement among interested parties that a licence-exempt regime with a minimum of regulatory restraints would foster innovation. Two self-governing industry organizations, the Unlicensed PCS Ad Hoc Committee for 2GHz Microwave Transition and Management (UTAM) and the Wireless Information Networks Forum (WINForum) were formed by manufacturers to deal with critical administrative and technical issues. UTAM proposed a plan for band clearing and frequency coordination while WINForum addressed technical issues related to coordination among users. All manufacturers of devices utilizing the UPCS band were required to become UTAM members.

In 1994, the FCC finalized its rules governing the UPCS band. The 1 910-1 920 Mhz band was assigned to asynchronous devices while 1 920-1 230MHz was assigned to isochronous devices. Wireless PBX is the dominant application in the isochronous band, being deployed mainly in large worksites with highly mobile workers. Although there are claims that the band is congested in some areas, spectrum demand is generally accommodated by the rules that promote coordination among users. The asynchronous band, however, lies fallow with no products developed for its use, largely because of problems associated with band clearance and the success of competing technologies using the 2.4 GHz ISM band.

While technological and service innovation has not flourished in the band as envisioned, the market remains healthy and the system of industry governance appears to have worked effectively. The band clearing process has been successful and UTAM has reported a sound financial situation. According to UTAM, no disputes between UPCS users have been reported. UTAM has also been successful in its role as a monitor in preventing the unauthorised use of the band.

Source: Carol Ting, Johannes M. Bauer, Steven S. Wildman, The U.S. experience with non-traditional approaches to spectrum management, Prepared for presentation at the 31st Research Conference on Communication, Information and Internet Policy, Arlington VA, USA, September 19-21, 2003 available at http://quello.msu.edu/wp/wp-05-03.pdf.

2.4 Administrative incentive pricing

The levying of a market-based license fee is another alternative through which an administration can introduce market-forces in spectrum management. Beyond the basic fees that are traditionally based on management costs such as those for processing license applications, the monitoring of spectrum use and other administrative costs, there are other forms of license fees that are designed to reflect the workings of market forces in the absence of other mechanisms such as spectrum trading. These typically take the form of incentive fees (commonly referred to as administrative incentive pricing).

Opportunity costs of the current use of spectrum would reflect the economic value of the spectrum in the best alternative use. In theory, current users would therefore be willing to hand back rights to use spectrum

An incentive fee attempts to use price as a means to provide incentive for spectrum to be used efficiently. In theory, licensees would be encouraged to use as little spectrum as they can to achieve their aims and to return or transfer on unused portions of their spectrum assignment if the opportunity costs of using spectrum, reflected through administrative incentive pricing, are higher than the economic value to that user.

In calculating incentive fees, a number of different elements of spectrum usage have been taken into account by the administrations that have implemented them. These include the coverage area, the extent to which the frequencies can be shared, the population density, power levels allowed, the bandwidth, etc. In a number of countries, simulated auctions and financial studies and extrapolations based on prior secondary market transactions may be used (see Box 11).[32]

Administrative incentive pricing, however, is an imperfect substitution for market-forces. Information deficiencies as well as methodological problems in determining fees equivalent to the opportunity costs of current spectrum use, renders it an imperfect tool. Nevertheless, in the absence of other alternatives, there still remains considerable scope for the use of administrative incentive pricing in the case of public services and other specific services, such as satellite and public broadcasting, which are deemed unsuitable for the application of more significant market based approaches, such as spectrum trading.

Box 11: Spectrum pricing in Australia

The Australian spectrum pricing system is conceived on the assumption that charges to the users of spectrum should serve two objectives:

- act as a rationing device and set in a manner that encourages efficient use of spectrum, and

- deliver a fair return to the community for the private use of a community resource.

The radiocommunication licence taxes (for transmitters and receivers) are based on a formula that takes into account:

- the spectrum location authorised by a licence (some spectrum bands are in higher demand and are therefore more congested than other bands);

- the amount of spectrum (bandwidth) used by a licensee;

- the geographic coverage authorised by the licence; and

- the power of the transmitter (transmitters operating a low power will attract a discount).

ACA acknowledges that, in the interests of simplicity and accessibility to spectrum users, the fee formula incorporates some compromises and a degree of crudeness in the manner in which different factors are measured and charged. Since introducing the fee formula in 1995, the ACA has continued to monitor and adjust the fees. The ACA has a programme to review fee levels, in particular in bands, which are experiencing congestion and in which there is arguably a case for increasing fees. Ideally, in spectrum bands and geographic locations where there is scarcity and congestion, fees should be set at "market" levels. However, the task of establishing those market levels is very difficult. Methods by which values might be established that would match supply with demand include:

- shadow pricing against auction outcomes;

- shadow pricing against alternative (non-wireless) service delivery mechanisms;

- gathering evidence of market values from observing trading in the secondary market, and

- where there is evidence of congestion (excess demand) in a band or location, gradually increasing annual spectrum charges to the level which causes an easing of that congestion.

In addition to commercial services, the ACA levies spectrum pricing on a number of public users of spectrum. For example, the Department of Defence pays around A$ 8.4 million each year for spectrum reserved in the defence bands. It pays a further A$ 979 000 for spectrum it uses outside the defence bands and A$ 245 000 for classified assignments. Although it may be difficult to make judgements about opportunity costs in the defence environment, for example security reasons may prevent full disclosure of the purpose for which spectrum is used, the ACA nevertheless believes that charges for defence spectrum should continue to be made on the same basis as for other users. This provides the best assurance that there will be an incentive for the Department of Defence to make efficient use of spectrum, including surrendering spectrum that it no longer requires. It should be noted that there have been several examples where the Department of Defence has been willing to give up or share spectrum.

Source: ITU Country Case Study, Radiospectrum Management for a Converging World: Australia.

3 Technology-focused strategies for spectrum management

While the introduction of market-based approaches to spectrum management can be expected to yield greater economic efficiency, the introduction of technology-focused policies is a necessary complement in order to promote greater technical efficiency in spectrum use.

However, many new technologies (in particular those described in Annex 1) can only deliver their full potential if current spectrum management policies are reformed. This section examines how these new technologies could be introduced into existing spectrum management frameworks with the least amount of disruption.

3.1 Allowing use of spectrum underlays

All electronic devices produce radiation at various frequencies. As long as there are electronic devices, there will always be at least some level of interference, commonly referred to as the noise floor. As a result, engineers have to build licensed devices that must be able to withstand low levels of interference; that is they must be able to send and receive signals above the noise floor.

Certain technologies, however, have been designed to take advantage of a traditional radio's built-in resistance to noise by keeping all communications at such low power levels that the transmissions blend in with other interference beneath the noise floor (this area beneath the noise floor is referred to as the underlay). Underlay technologies such as ultra-wide band thus offer the potential to drastically increase spectrum efficiency by opening up this previously unused portion of spectrum. The key decision for policy makers, however, is whether these technologies can co-exist without interference with incumbent users of the band.

The FCC is studying ultra-wide band and has approved a low-powered version of the technology in February 2002. Initially the US Department of Defense had concerns that UWB signals would interfere with the GPS navigation system. After extensive testing, the FCC found that UWB would not cause significant disruption at low power levels. The FCC took a cautious approach to UWB, limiting the range of the technology to roughly 30 feet, close enough for home networking indoors. If systems in development work as planned the FCC had mentioned that it would be willing to increase the power limits in the initial ruling.

The FCC decision was an important step for UWB and underlay technology worldwide, in part because there was huge opposition to the technology from licensees. Current license owners are strongly against allowing new services on the same frequencies to which they have legal, exclusive right. The situation is even more complicated when the licensees have bid and paid for exclusive rights in the frequency range, as has been common in recent mobile licenses. Operators who have radio licenses argue that allowing unlicensed devices to operate in licensed bands at low power will hinder the operator's "future network design flexibility as well as their ability to introduce more efficient technologies and systems".[33]

In response, some may argue that current license holders don't own the rights to the frequencies *per se* because interference from other devices will always be present. Instead, spectrum rights are essentially a right to a "lack of significant interference".[34] This idea would imply that allowing unlicensed devices to operate below the noise floor would not be contrary to the original agreements between regulators and operators.

3.2 Developing noise temperature measures

One of the key prerequisites for an underlay system is a regulatory definition of the noise floor, or how much interference is too much for legacy radios. Once the acceptable noise floor is established, underlay technologies can be allowed to broadcast below it. Several regulators are looking into a more dynamic version of a fixed noise floor for all equipment. By developing a "noise temperature" (sometimes called "interference temperature") devices can monitor the amount of interference in an area and adjust their emitting power accordingly. Higher noise temperatures correspond to higher levels of interference. Several regulators, including the FCC's Spectrum Policy Task Force, have been looking into way to improve spectrum efficiency by using interference temperature measures.

Corollary systems have been used in non-telecommunication infrastructure around the world as a way to ease other types of congestion. For example, at times of peak usage, traffic lights on highway entrances allow only one car at a time to enter. During off-peak hours, cars are allowed to enter with no restrictions. Noise temperature systems would apply the same principles to spectrum in a given area and may greatly increase efficiency.

A noise-temperature based system would be very different from the current system where regulators limit the transmitting power of all devices permanently as a preventive measure to prevent high levels of interference in any given place. It would allow for different power levels in different areas depending on the noise temperature.

Currently, there is no standard system for measuring noise temperature. However, the FCC has requested comment on how such a system would work. There are two main ways a potential service could operate. In the first, each RF device would continually take its own measurements of the noise temperature and make its transmission decisions based on the results. Licensed and unlicensed devices would require different parameters to ensure that licensed devices received the highest priority. Such a system would likely be the most efficient because devices would be able to monitor their immediate surroundings before making the transmission decision. However, this precision comes at a cost; the complexity of the transmitting equipment will need to increase, consequently increasing the cost of individual devices.

Another option is to have stand-alone reporting stations measure the noise temperature in their vicinity and then broadcast the corresponding permissions/non-permissions to transmitters in its area. These transmissions would offer different information for licensed and unlicensed radios. The transmitted permissions may be as simple as a "yes or no" signal or more complex signal specifying maximum power levels for each type of radio.

This would allow a much more effective use of spectrum in a given location. Local, unlicensed devices could make use of licensed frequencies as long as there were either no transmissions at a given time or if the noise temperature was low enough for both signals to coexist without significant erosion of the licensed signal.

While both options are currently under consideration, the advancements in smart-radio technology and processing power should allow radios to be able to make the decisions themselves, thus reducing infrastructure cost and making the most efficient use of spectrum.

3.3 Allowing coexistence models

Incumbent users of licensed spectrum bands rarely maximise all the bandwidth to which they are entitled in time and in space. Large portions lie fallow during off-peak hours while certain locations generally experience a lower volume of transmissions. Certain technologies, however, have been developed to take advantage of these gaps.

Frequency hopping technology, such as that utilised by agile radio, has the potential to make more efficient use of the radio spectrum by using vacant frequencies across a wide bandwidth. However, the amount of spectrum such radios will be able to salvage depends on the bandwidth across which they are allowed to operate. If these radios are only allowed to operate in small, open bands then the efficiency gains will be relatively small.

The establishment of "coexistence models" that dictate protocols for frequency-hopping radios to transmit on frequencies licensed to other users, which are vacant at the time of transmission, will enable the use of larger amounts of fallow spectrum. As transmissions cannot effectively exist in the same exact time space as another, the technology of frequency hopping radios must be robust enough to immediately detect a licensed transmission and vacate the frequency before causing interference. For these reasons, a number of regulators are initially limiting the licensing of frequency hopping technologies to certain frequency bands with low existing usage and minimal risk of interference (see Box 12).

Beyond technical complexities, however, establishing a coexistence model in the face of incumbent interests has also been difficult. An example of this complexity can be seen in the United States where a new technology was developed to broadcast on spectrum reserved for satellites without causing noticeable interference. While the technology is a success, the decision of how to allocate co-existence rights has become a contentious issue (see Box 13).

Box 12: Frequency agility

Avoiding interference on a dynamic basis can be undertaken at a macro and micro level. At a macro level, an interference free channel is used for an extended period of time while at the micro level, frequency agility involves the rapid hopping between frequency channel in a sequence. The use of “polite technologies”, such as dynamic frequency selection (DFS) and transmitter power control (TPC), is a good example of the macro approach. In DFS, a transmitter listens for other users before selecting a channel to use while TPC ensures that the transmitter uses the lowest power level commensurate with the quality desired, thus keeping the level of interference down. In the United Kingdom, the use of DFS and TPC was a mandatory condition for the deployment of high-performance radio local area networks (HIPERLANs) in the 5GHz band which was occupied by satellite services. At a micro level, spread spectrum technology using frequency hopping also has interference mitigation characteristics. Rapid variation of the signal reduces the chance for same signal interference in hostile environments such as licence-exempt bands. Radio local area network (RLAN) devices operating in the licence-exempt 2.4 GHz band typically use this technique.

Source: AEGIS Spectrum Engineering, Implications of international regulation and technical considerations on market mechanisms in spectrum management, 2001, available at http://www.aegis-systems.co.uk/download/spreview.pdf.

Box 13: The complexities of spectrum reform – Northpoint

Satellites from the south; Northpoint from the north

In the early 1990's Carmen and Saleem Tawil noticed that all the satellite TV dishes in their area were pointing south to pick up signals. Saleem determined that if all satellites were broadcasting from the South on their frequencies, he could broadcast cable television signals from terrestrial towers, at the same frequency, from the North without causing noticeable inference.

After creating a team of lobbyists and business experts, the Tawil's new company Northpoint approached the FCC in order to use the same spectrum as the satellite TV providers such as DirectTV and EchoStar. The FCC looked at the technology and after extensive testing, ruled that the technology (Multichannel video distribution and data service – MVDDS) could indeed be used without noticeable interference to current licensees. Then the problem of how to allocate the license unfolded.

Satellite TV providers, in general, received use of their frequencies for free from the FCC through an assignment process. However, current views in spectrum management at the FCC have moved towards auctions as a way to ensure the spectrum goes to the most efficient use and also to raise money for the government. Northpoint argues that forcing it to bid on a license for the spectrum would equate to an unfair competitive advantage to satellite providers, which never paid for their licenses.

The stakes are huge with estimates putting the value of the spectrum at auction between US$ 60-100 million. With such large money involved, both sides have built massive lobbying structures to push the government towards their respective positions. Groups opposed to awarding a license to Northpoint for free are outraged by why they see as a windfall payment to Northpoint from the government. .

Source: WSJ, "Fact meets Fiction: Maybe K Street has room for 'K Street', Sept 23, 2003.

3.4 Allowing software defined or multi-purpose radios

One of the most promising elements of software defined radio technologies will be the ability for one generic radio device to function as an all-in-one communication tool. Such a device could conceivable work as a mobile phone, cordless phone, GPS, and Internet data connection. Traditionally, each type of device would fall under different regulatory requirements and equipment must confirm to different regulations. However, if a generic device were to be able to "transform" into new types of devices based on the internal software, regulatory bodies must decide how to categorise such a device and how the approval process would function. In certain cases, the technological flexibility of a device is artificially constrained by restrictive regulations that restrict the use of certain spectrum bands to specific services (see Box 14).

The introduction of such technologies also raises difficult questions linked to equipment approval since rather than focusing on the hardware elements of electronic devices, such as is the case of Part 15 approval by the FCC, the key approval decision would lie with the software that controls the radio.

3.5 Setting aside certain bands as test beds for new technologies

In order to facilitate the adoption of new wireless technologies, regulators could set aside some bands for testing new technologies. The introduction of new technologies, such as agile radios, offers the possibility to recover vast amounts of unused spectrum. Locally conducted tests could demonstrate the potential for these technologies to work effectively without significant interference, giving existing licence holders the confidence to co-exist with such technologies.

3.6 Creating a technology advisory group

A technology advisory group comprised of industry and academic members can help policy makers prepare for technological changes and their repercussions on spectrum management. This has been done in several countries around the world with great success.

Box 14: Confining a RINO

Garmin is best known for its global positioning system (GPS) products but has recently entered the FRS/GMRS market with a product called the RINO (Radio Integrated Navigation Outdoors). The RINO 130 functions as both a GPS and a two-way radio. Earlier versions of the radio (110 and 120) have been popular with outdoor users because the units combine the functionality of two devices in one.

One of the most appealing features of the RINO is the ability for users to "beam" their location to other RINO users. The GPS in the unit determines a user's latitude and longitude, which can then be sent over an FRS radio channel to other RINO users, appearing as a waypoint in their GPS. This allows them to see the location of the people on the GPS screen with whom they are communicating. The feature is an excellent way for people to locate each other in crowds or outdoor settings.

In order to include the beaming functionality into the RINO, Garmin had to overcome a difficult regulatory obstacle, sending data on a voice-only channel. Garmin petitioned the FCC and initially received a waver allowing the transmission of location data on FRS channels. Eventually the FCC made a formal rule change allowing for radios to send location data on FRS channels.

The range of the location beaming service is currently limited to the 2-mile range of FRS, even though the radios are capable of reaching 5 miles on GMRS channels. Garmin has also petitioned for the FCC to allow beaming on GMRS channels but there has been no decision as of yet. This leads to an awkward situation for current radio users.

Users who purchase the radios are likely to choose the GMRS channels because of the increased range of the radios, but by doing so, cannot use the location beaming technology.

This leads to a situation where GMRS users coordinate a quick channel switch to FRS frequencies with everyone participating in the conversation. Once they are all on the same FRS channel, they quickly beam their locations to one another. Then, once everyone has received the beam, they switch back to the longer-range GMRS channels to resume communications.

While current FCC regulations may not allow the "beaming" of locations over GMRS, the software defined radio technology in the RINO allows for it to be quickly upgraded to allow GMRS beaming if the FCC decides to allow it on the channels.

The RINO experience highlights how spectrum policy and regulations can hinder the use of new communication technologies until regulatory bodies are able to make the necessary policy changes. At the same time, the RINO experience highlights how new technologies such as software-defined radios are ensuring that regulatory changes are quickly applied to existing equipment.

Source: *Garmin.*

Two countries offer excellent examples of groups assigned to follow technology and its effect on spectrum. The FCC's Spectrum Task Force has been instrumental in helping the US test and implement new spectrum policy. COMREG, the Irish regulator, has instituted a forward-looking programme that helps identify emerging technological trends to prepare for future regulatory impact. Setting up a technical advisory group, or task force to follow the regulatory impact of new technologies on spectrum is a cost effective, but often productive way for regulators to prepare for future technological changes.

4 Conclusion

There are a large number of policy options for a country to select from when migrating to a more technology-focused, market-based approach to spectrum management. Approaches such as auctions, administrative incentive pricing, spectrum trading, and dedicating more frequencies for licence-exempt use represent different levels of spectrum liberalization countries can choose from. Fortunately, the wealth of experience in new spectrum management approaches has been growing with more countries adopting such approaches. The experience of the pioneering countries thus far appears to suggest that the gradual introduction of a mix of technology focused and market based approaches across different spectrum bands would be the best overall approach.[35]

Annex 1

Selected Wireless Technologies

1 Spread spectrum

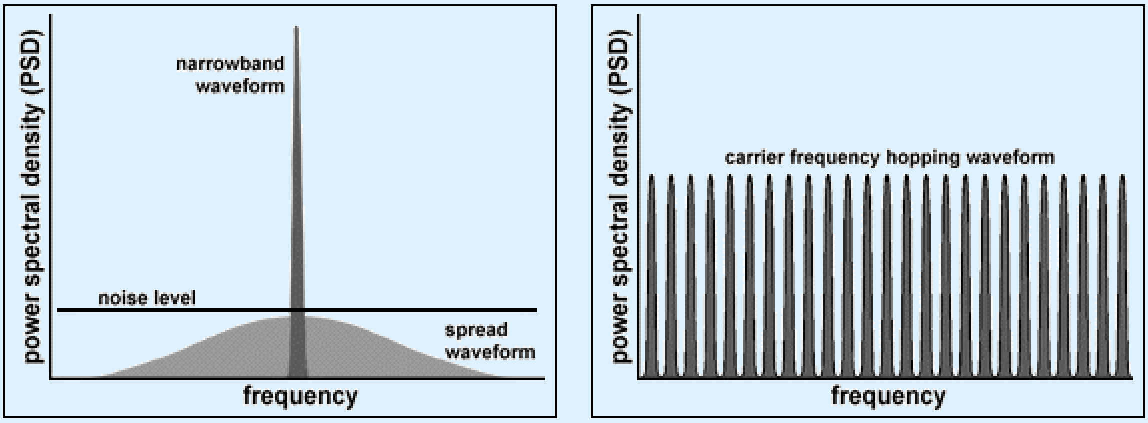
Spread spectrum technologies send information over a much wider band than the actual bandwidth of the information by using a code to either modify the carrier wave or to define a hopping pattern for frequencies. These codes are known as “pseudo-random”, and sometimes as “pseudo-noise". They are "pseudo" because there is an underlying, but secret pattern. Both the transmitting and receiving radios know the pre-defined code sequence in order to code and decode the information at both ends of the transmission. However, to radios without the code, the signals appear to only be radio frequency noise.

Spread spectrum radios may use the same total power levels of similar traditional narrowband radios but that power is spread over a wide range of frequencies. This lower power level is a key benefit of spread spectrum technologies because it allows narrowband and spread spectrum (wideband) radios to coexist with each other as spread spectrum transmission power on any given frequency is so low that the signals are not distinguishable from the “noise floor.”

Spread spectrum codes are used in different ways, depending on the type of system. Each system uses the codes to transform and send a signal over a wide range of frequencies but they are fundamentally different in their approaches. The two different systems are direct sequence (DS) and frequency hopping (FH) (see Figure 1).

Figure 1: Direct sequencing (DSSS) vs. frequency hopping spread spectrum (FHSS)

Both direct sequencing and frequency hopping techniques are used to spread data out across a range of spectrum. DSSS essentially spreads out the carrier signal, allowing for a much lower power transmission (left figure). FSSS can use the same frequency range but uses a narrow signal over a constantly rotating set of frequencies.



Source: Futaba.com at http://www.futaba.com/IRC/irctechlib.htm

Direct sequence

Direct sequence systems combine the information being sent with a high-speed code sequence as a way to modify the carrier signal. The original data is combined with a higher-rate chipping code that divides and separates the original data and uses it to manipulate the carrier wave over a range of frequencies. The chipping code includes a redundant bit pattern for each transmitted bit, increasing the signal’s resistance to interference. That means that even if some bits are lost in the transmission to interference, the original data stream can be rebuilt from other redundant pieces.[36] One of the most successful implementations of DSSS has been the IEEE 802.11b standard, commonly known as Wi-Fi.

Frequency hopping

Frequency hopping spread spectrum (FHSS) is a technology that makes more efficient use of spectrum by constantly hopping between a designated range of frequencies in a predictable pattern. A single “hop" typically has a maximum dwell time of 400 ms, rotating through a minimum of 75 different frequencies.[37]

FHSS technologies help reduce interference by decreasing the chance that two different radios in an area are broadcasting in the same frequency at exactly the same time. This means that a narrowband radio signal at a certain frequency would only bump into interference 1/75 of the time in the presence of an FHSS signal. Multiple FHSS systems effectively coexist together very well because, if timed correctly, they will never interfere and can offer an undisturbed, single channel.

Orthogonal frequency division multiplexing

DSSS and FHSS are the two main components of spread spectrum technology. However, new wireless LAN technology is popularising another modulation technique known as Orthogonal Frequency Division Multiplexing (OFDM). OFDM makes use of multiple frequencies as a way to increase the bandwidth or throughput in a wireless system. Instead of using a single carrier wave to transmit data, OFDM breaks down data information into several streams that are broadcast simultaneously, on different frequencies, to a receiver that collects and reassembles them. This multi-channel approach makes OFDM less susceptible to multipath and other RF interference.

OFDM is used by both IEEE 802.11a and IEEE 802.11g networking protocols, as a way to boost transmission speeds above those possible with 802.11b (Wi-Fi).

2 Ultra-wide band (UWB)

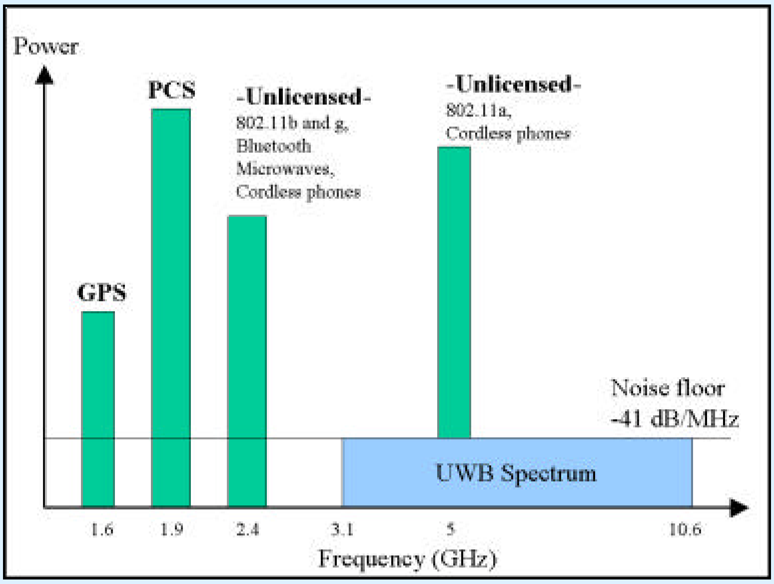
Ultra-wide band technology is designed to transmit data at very high speeds by sending the transmission over a wide range of frequencies but at very low power levels. By employing a wide range of frequencies, UWB also allows for effective transmission through objects, including walls and the ground. UWB can penetrate obstacles that would severely hamper communication using traditional higher-powered, narrow band radio waves. This is especially important for radio applications that suffer from multipath problems because unlike other narrowband radios, UWB signals penetrate dense objects, instead of bouncing off of them.[38].

While traditional radio technologies embed their data onto carrier sine waves, UWB instead uses very fast pulses to represent the zeros and ones of digital communication. In order for receivers and transmitters to effectively communicate, they must be precisely timed to send and receive pulses within an accuracy of a trillionth of second.[39]

One of the most striking elements of UWB communications is the ability to communicate below the noise floor, often referred to as “underlay” (see Figure 2). In theory, this implies that UWB could operate in the same bands as licensed spectrum without causing any harmful interference.

Figure 2: UWB operating below the "noise floor"

UWB operates at a much lower power than traditional radio uses. The power use is so low that it is indistinguishable from ever-present "noise"



Source: ITU adapted from Intel at http://www.intel.com/idf/us/fall2003/presentations/F03USIRDS75_OS.pdf.

One of the most promising uses of UWB is home networking and other short-range, high bandwidth applications. Limiting the power of the pulse could make more effective use of underused spectrum in a home without interfering with the operation of licensed high-powered devices.

3 Smart antennas

UWB and other spread spectrum technologies change the way data is *sent* to increase spectrum efficiency. However, one of the best ways to increase the capacity and reliability of a radio network is to focus on improving the ability of the radio to *listen*, via its antenna and the radio's signal processing power. There are many new "smart antennas" technologies on the market and the term smart antenna doesn't refer to just one technology in general. In fact, the term may be a bit of a misnomer. Antennas are simply ports through which RF energy is sent to and received from other RF devices. Rather, the digital signal processor does analysis of RF signals that give the unit its intelligence.

Smart antennas have three principal advantages. First, they are effective at suppressing interference. Second, the can effectively combat multipath, a situation where signal "echoes" cancel out the direct signal and the transmission is disturbed. Finally, smart antennas are used to effectively increase wireless capacity in a system.

Firstly, the digital signal processor of smart antennas are designed to perform calculations to determine the source of an incoming transmission by listening through two antennas. Knowing where a transmission is coming from is vital in telecommunications because it allows the antenna to focus a signal in one specific location, either to listen better or to avoid broadcasting a response in all directions as is done with an omni-directional antenna. When an omni-directional antenna transmits an RF signal in all directions, there are more chances for the signal to cause interference with other RF devices, especially in a narrow frequency band.

In addition to knowing which direction a sound is coming from, smart antennas can help the radio better understand transmissions coming in, even with high levels of interference. Once a smart antenna determines the approximate location of a particular user, there are several other technologies that can help send and receive "better-targeted" transmissions. These technologies are broken down into two main groups, switched beam and adaptive antennas (see Figure 3).

- *Switched beam antennas*
  A switched beam antenna can adjust sensitivity in any of a fixed number of directions. The 360

degree circle around the antenna is broken up into "fixed" sectors and the radio can then increase sensitivity in the sector where a user is located. The sectors are formed by combining the output of multiple antenna to focus on a narrow area, an area even more narrow than could be achieved with a directional antenna.

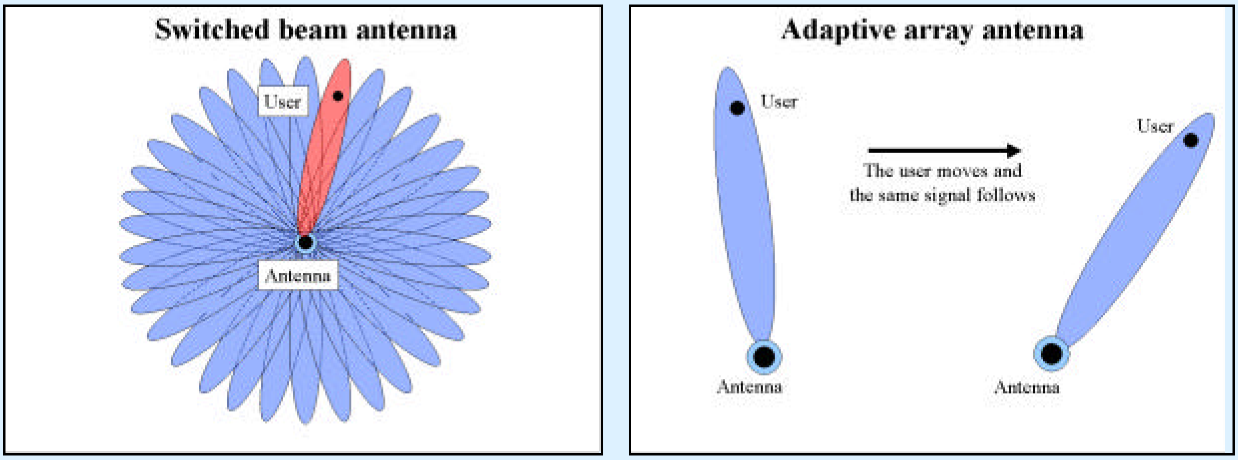
Benefits of switched beam antennas are they are relatively simple and low cost. However, disadvantages include the need for "inter-cell handoffs" between sectors, an inability mitigate multipath interference where the interference is close to the desired signal, and the lack of ability to take advantage of coherent multipaths.[40]

- *Adaptive array antennas*

  Adaptive antennas (sometimes called software antennas) are different than switched beam antenna because they are much more dynamic at tracking a user and continuously adjusting sensitivity based on the actual position of the user, rather than the sector he or she is in. Adaptive antenna systems use complex algorithms to process signals, locate users, and change sensitivity. Benefits include the ability to block signals coming from the direction of an interferer, the absence of inter-cell handoffs since the user is continually tracked, and the ability to combine coherent multipath signals. The disadvantages are the systems are much more complex, and therefore more expensive than switched beam systems. This complexity also requires more processing capability at the tower.

Figure 3: Switched beam and adaptive array antennas

Smart antennas fall into two main categories, switched beam and adaptive array antennas



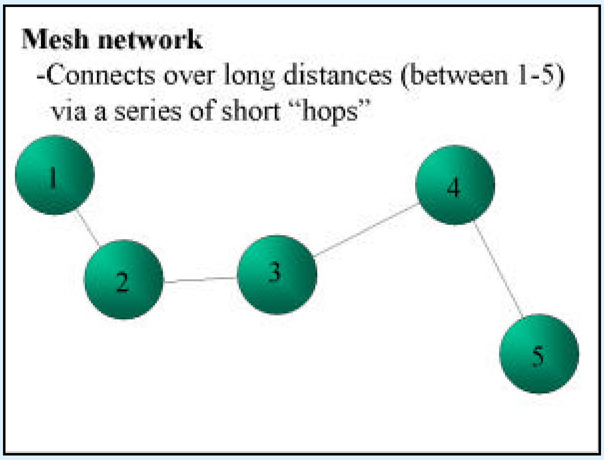
Source: ITU adapted from IEC.

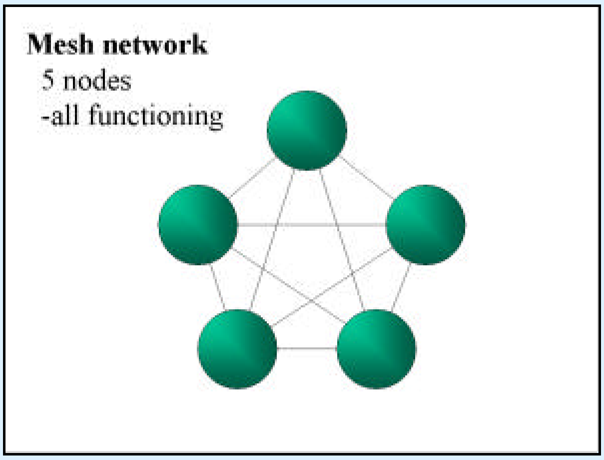
4 Mesh networks (collaborative gain networks)

By definition, a mesh network is a local area network (or LAN) where each device on the network simultaneously connects to and communicates with all devices in range. Devices can then communicate with each over by passing transmissions (e.g. messages) using other devices as intermediaries. The illustrations in Figure 4 show mesh networks with five nodes. Each node is shown as a sphere, and connections are shown as straight lines. The connections can be wired or wireless.

Figure 4: Mesh network topology

Wireless devices on a mesh network don't need to be able to broadcast long distances They only need to be able to transmit as far as the next user on the network (see left figure). By using other devices to pass transmissions along, mesh network transmissions can cover long distances. Devices on a mesh network form connections with every other device within transmission/reception range (see right figure) forming a robust network.





Source: ITU.

The benefits for networking are dramatic. First, mesh networks expand their reach, by their very nature, as the number of users increase. This represents an extremely cost effective way of expanding network access. In addition, increasing the number of users in an area actually increases bandwidth, rather than reducing it like traditional radio communication services such as mobile telephony (see Box 1). Mesh networks are also extremely resilient to one node not being able to pass on the information. The intelligent network can easily reroute transmissions around a problem area by simply finding another user within radio range (see Figure 5).

Box 1: Could a mobile mesh network end the need for mobile spectrum licensing?
How a mobile mesh network needs

Mobile operators have recently paid large sums for radio spectrum in 3G auctions. The high bidding prices reflected perceived value of the spectrum, and to some degree, over optimism about the state of mobile technology and market conditions. If mesh networking becomes a practical reality, 3G auctions may be a thing of the past. There may be no need for operators to buy large blocks of spectrum for mobile users.

Instead, a mesh, mobile network could do away with the majority of cell towers by using other mobile users to carry their mobile traffic. In densely populated areas, mobile phones would only need a small amount of power to broadcast since they would only need to reach the next user, rather than the cell tower. This low-power transmission could even take place in license-exempt areas of the spectrum. Alternatively, mobile phones could use UWB technology at such low power levels that transmissions would fall below the noise floor.

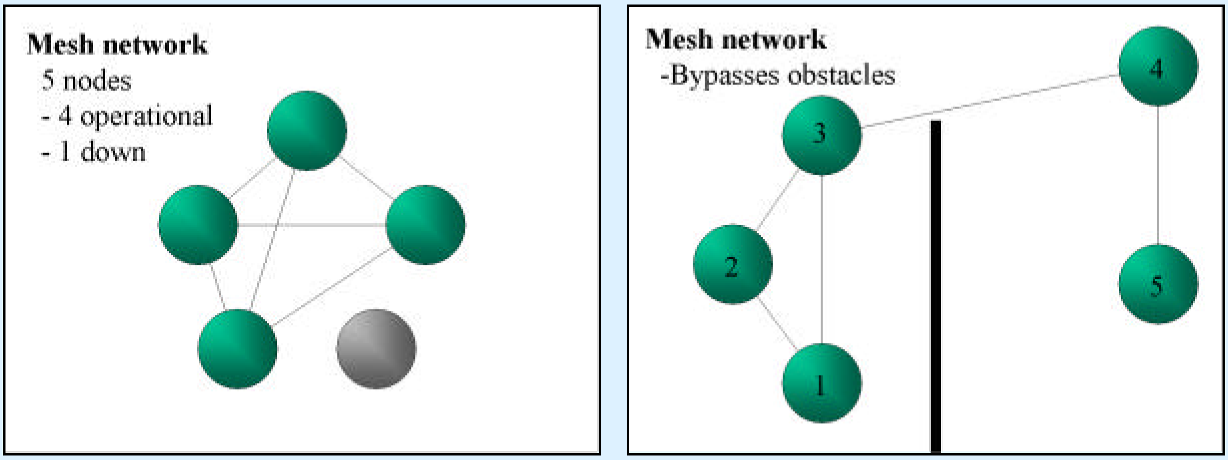
While mesh networking may hold a key for a more effective mobile network, its emergence may still be some time off. Since handsets will function as routing equipment, they'll need to be more complex. In addition, there are definite privacy issues to be addressed as well if data traffic must be passed one by many users along the way to its destination. Finally, advances in battery technology will play a key role as phones will constantly need to remain powered on and transmitting to pass along other traffic. However, the success of a similar network model, the Internet itself, shows there is promise in the technology.

Source: ITU research.

Mesh networks have several key implications for spectrum management. First, mesh networks reduce the need for long distance radio transmission because the signal need only be strong enough to reach another user. This means mesh networks can use higher-speed, shorter-range frequencies than are currently used for many radio communications. The minimal ranges needed for data transmission between users could even open up technologies such as UWB, which require a wide range of spectrum but at very low power levels.

Figure 5: The resiliency of mesh networks

Mesh networking is extremely effective at bypassing dead nodes on the network (left figure) and navigating around impenetrable objects (right figure). Every node (or device) on the network acts both as a client but also as a router, passing on information to other devices in range.



Source: ITU adapted from searchnetworking.com.

5 Software-defined radios

Software-defined radio (SDR) refers to wireless technology where the transmitter modulation is generated or defined by a computer. The most significant asset of SDR is versatility. Wireless systems employ protocols that vary from one service to another. Even in the same type of service, for example wireless fax, the protocol often differs from country to country. SDRs show great promise due to their ability to be re-programmed to accommodate different frequencies, bandwidth, and directionality.

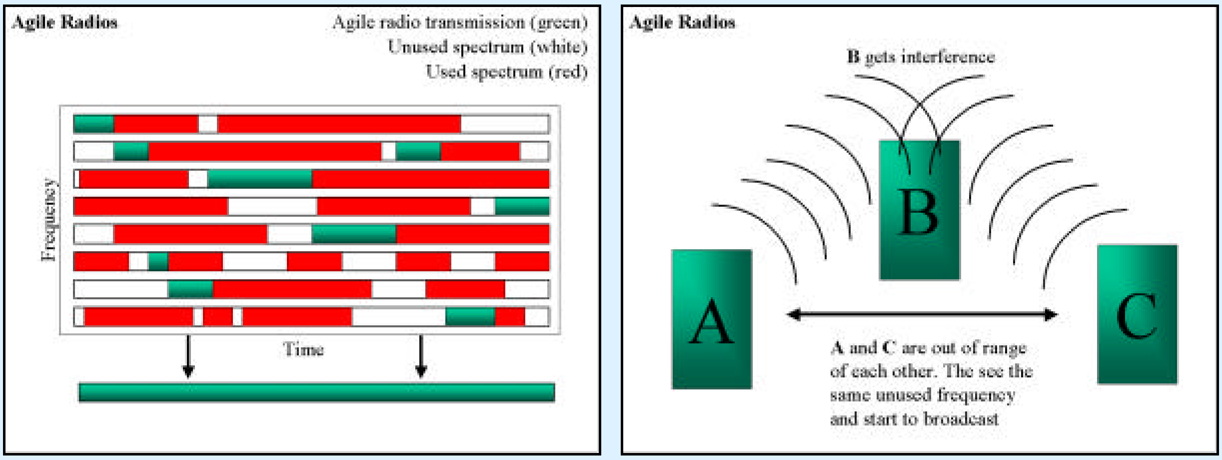
The communication industries have a lot to gain from SDR technologies as one device will be able to handle multiple frequency bands and transmission protocols and be quickly upgraded through new software. Eventually this could mean that a user's mobile phone, cordless phone, pager, and WLAN connectivity could be provided by the same radio, simply by using software[41]. The radio becomes simply a generic terminal that receives its functionality from the software that runs it.

6 Agile radios

Agile radios act as frequency scavengers. They are an innovative technology that aims to make use of periods of inactivity on a wide range of spectrum. An agile radio will broadcast on an unused frequency until it “senses” another radio trying to use the same frequency. At that moment, the radio “hops” frequency to another temporarily unused portion of the radio spectrum. Agile radios are very promising because they can vastly increase the amount of available bandwidth (some estimate 10 times current levels) without requiring any new frequency allocations (see Figure 6, left).

Figure 6: Agile radios

Agile radios can "hop" from one unused frequency to another as way to take advantage of unused spectrum (left figure). However, they also can introduce interference to third parties when radios are out of range of each other but both within range of a third receiver (right figure).



Benefits Drawbacks

Source: ITU.

Agile radios have the potential to be very successful by taking advantage of the inherent properties of radio transmission: time, location, and frequency. Licenses have traditionally been awarded to give spectrum owners exclusive rights in a given location, on a specified frequency, at a given period of time. However studies have shown that large amounts of spectrum lie fallow. A broadcasting radio may be using a given frequency at a certain time, but not in the area where an agile radio would be operating. That creates an unused block spectrum over a small amount of time that could be used by others in the location.

Agile radios also suffer from some technological problems that will need to be addressed. First, agile radios can suffer from the "hidden terminal" problem (see Figure 6, right). This is a situation where there are two radios that are out of range of each other and find the same unused frequency. A third radio, located between the two radios and within range of both, receives two different transmissions at the same time, on the same frequency. This results in interference that could not have been anticipated by either of the two broadcasting radios.

[1]International Herald Tribune, “Toward a Network of Things”, Oct 15, 2003 at http://www.iht.com/articles/113815.html .

[2] Annex 4 to ITU-R WP1B Chairman’s Report, Working Document towards a Preliminary Draft New Report on Technical Convergence with Respect to Terrestrial Fixed, Mobile, and Broadcasting Interactive Multimedia Applications, Document 1B/16-E, 12 Nov 2003.

[3] UMTS Forum at http://www.umtsforum.org/

[4] For more information on spectrum license auctions, particularly in the context of 3G licensing, see ITU New Initiatives Programme “Licensing for 3rd Generation Mobile” at http://www.itu.int/osg/spu/ni/3G/.

[5] For more information on auctions and auction design see Melody WH, Spectrum auctions and efficient resource allocation: learning from the 3G experience in Europe. (2001) Info, 3:5-10.

[6] In addition to the four principal modes, two other modes have also been identified by the RA as appropriate in particular circumstances, for example, during the refarming of a frequency band from one use to another:

- mode 5: custom designed trading as part of a strategic approach; for example, as part of steps taken to assist the replanning of a band, and
- mode 6: trading of “overlay licenses”.

[7] Source: Implementing Spectrum Trading, A Consultation Document, July 2002, Radiocommunications Agency, United Kingdom available at www.ofcom.org.uk/static/archive/ra/topics/spectrum-strat/consult/implementingspectrumtrading.pdf.

[8] See for example Martin Cave, review of Radio Spectrum Management, An independent review for Department of Trade and Industry and HM Treasury (2002) available at http://www.see.asso.fr/ICTSR1Newsletter/No004/RS%20Management%20-%202_title-42.pdf

[9] Principles for Promoting the Efficient Use of Spectrum by Encouraging the Development of Secondary Markets, FCC, Dec 2000.

[10] C Bennet, Rural Telecommunications Group (RTG), Transcript of the Public Forum on Secondary Markets in radio Spectrum, May 23, 2000.

[11] Spiller PT, Cardilli C, Towards a property rights approach to communications spectrum, (1999) Yale Journal on Regulation, 16:53-83

[12] For a more complete discussion on a step-by-step approach to introducing spectrum trading see: Implementing Spectrum Trading, A Consultation Document, July 2002, Radiocommunications Agency, United Kingdom available at www.ofcom.org.uk/static/archive/ra/topics/spectrum-strat/consult/implementingspectrumtrading.pdf.

[13] Stuart Minor Benjamin, Spectrum Abundance and the Choice Between Private and Public Control, New York University Law Review, Dec 2003.

[14] See for example: Procedures Implementing Package Bidding for Auction No. 31, 65 FR 43361-01 (July 13, 2000); Auction of Licenses in the 747-762 & 777-792 MHz Bands, 15 FCCR 8809 (2000).

[15] For a complete review of competition safeguards in the New Zealand market see Final Report: Allocation and Acquisition of Spectrum, Report Prepared for the New Zealand Ministry of Economic Development on Competition Safeguards in Relation to Initial Allocation of and Secondary Markets for Radiofrequency Spectrum in New Zealand at http://www.med.govt.nz/pbt/rad_spec/competition-safeguards/report/.

[16] See Chapter 8, Study into the use of Spectrum Pricing: The Case of New Zealand, NERA and Smith System Engineering, at www.ofcom.org.uk/static/archive/ra/topics/spectrum-price/documents/smith/smith8.doc

[17] See Futurepace Solutions, Comments on Implementing Spectrum trading, 2002 available at http://www.ofcom.org.uk/static/archive/ra/topics/spectrum-strat/responses/ist/futpace.doc

[18] See Analysys, Spectrum trading: increasing the efficiency of spectrum usage 2002 at http://www.analysys.com/default_acl.asp?Mode=article&iLeftArticle=992&m=&n=

[19] “Study on Conditions and Options in Introducing Secondary Trading of Radio Spectrum in the European Community” an independent report by Analysys, DotEcon, and Hogan & Hartson LLC Available at: http://europa.eu.int/information_society/policy/radio_spectrum/docs/ref_info/secontrad_study/secontrad_final.pdf

[20] Michele C. Farquhar and Ari Q. Fitzgerald, Legal and regulatory issues regarding spectrum rights trading, Telecommunications Policy 27 (2003) 527-532

[21] For an exhaustive discussion of international constraints on national spectrum management in the context of the United Kingdom, see AEGIS Spectrum Engineering, Implications of international regulation and technical considerations on market mechanisms in spectrum management, 2001, available at http://www.aegis-systems.co.uk/download/spreview.pdf.

[22] For example, the enhanced radio messaging system (ERMES) was an initiative to create a Europe-wide mobile messaging system. The standard for ERMES was first agreed to in 1992 and two years later the band 169.4125 – 169.8125 MHz was harmonized for its application via CEPT decision. However, in contrast with GSM's success, there has been no notable implementation of ERMES. As a result, CEPT is not in the process of carrying out a review among member states to assess the merits of retaining the harmonisation agreements for ERMES.

[23] See Gandal, Salant and Waverman, Standards in wireless telephone networks, Telecommunications Policy 27 (2003) 325-332.

[24] Given its broad service categories and emphasis on bilateral coordination, ITU's spectrum management framework can be considered to be more flexible than most national regimes that employ narrower allocations and assignments. Nevertheless, the framework still suffers from the same criticism that is levelled against national approaches that seek spectrum efficiency through administrative spectrum allocation. In addition, its operation also acts as a constraint on the spectrum management approaches that can be taken by national administrations to remedy these inefficiencies. In practice, if national administrations were to implement market based approaches that allow greater flexibility in spectrum use, spectrum usage in border areas would effectively be restricted to the services specified within that ITU frequency band. While this may not constrain geographically isolated countries, it would severely limit the spectrum management options open to small countries that share borders with many others.

[25] See the Chairman's Report of the ITU New Intiatives Workshop "Spectrum Management for a Converging World" at http://www.itu.int/spectrum.

[26] For a discussion of the CB Radio phenomenon from a regulatory perspective, see Carol Ting, Johannes M. Bauer, Steven S. Wildman, "The U.S. experience with non-traditional approaches to spectrum management" available at http://quello.msu.edu/wp/wp-05-03.pdf.

[27] According to the Yankee Group. See http://www.yankeegroup.com/public/news_releases/news_release_detail.jsp?ID=PressReleases/news_august012002_wmec.htm.

[28] Paris, the wireless wonder? *International Herald Tribune* (5 May 2003), reporting on a business plan to install Wi-Fi antennas outside of each Paris Metro station to create a single Wi-Fi network, turning Paris into a giant Wi-Fi hotspot. See also article on Spokane, Washington ISP creating a 220 square mile hotspot in that city (www.spokanejournal.com/spokane_id=article&sub=1611).

[29] Analysys report, Public WLAN Access in Western Europe and the USA, March 2002 at http://www.analysys.com. WLAN Hardware sales too were skyrocketing, fuelled mainly by sales in North America. By contrast, Central and Latin American hardware sales represented only 3 per cent of the market, according to an Infonetics Research, Inc. report issued in May 2003 at http://www.infonetics.com/resources/purple.shtml?nr.wlanms.1q03.052103.shtml.

[30] http://www.isp-planet.com/research/2002/newtechs_020130.

[31] This is predicted by International Data Corporation. See http://www.isp-planet.com/research/2002/newtechs_020130.html.

[32] See Report ITU-R 2012 – "Economic aspects of spectrum management" for a wide range of examples of incentive fee pricing submitted by ITU member states available at http://www.itu.int/itudoc/itu-r/publica/rep/sm/2012-1.html

[33] Quote from ATT in "Wireless Industry Still Wary of Use of Spectrum 'Underlays'.

[34] Statement from Mark McHenry of Shared Spectrum Co. (Feb 6, 2004).

[35] For a full discussion on the topic, see Johannes M. Bauer, Spectrum Management and the Mobile Services Industry, 2003, Quello Centre Working Paper 04-03 at http://quello.msu.edu/wp/wp-04-03.pdf

[36] See Webopedia's description of DSSS at: http://www.webopedia.com/TERM/D/DSSS.html.

[37] See Webopedia's site for a the definition of FHSS at: http://www.webopedia.com/TERM/F/FHSS.html.

[38] Multipath is a type of signal distortion that occurs when the original signal, and a reflected signal arrive at different times, "confusing" the receiving radio. One good example of multipath is when a car radio's reception deteriorates at a stoplight but pulling the car a metre forward improves the signal. The signal deteriorates momentarily, in a certain position, because the radio is receiving the original signal, as well as a slightly late echo that essentially cancel each other out. Moving slightly can remove the "echo" and the radio plays normally again.

[39] From the Ultra-Wideband working group's FAQ at: http://www.uwb.org/faqs.html.

[40] See http://www.ececs.uc.edu/~radhakri/Research2.htm#switched_vs_adaptive for a good comparison of switched bean and adaptive array antennas.

[41] Intel offers a detailed review of SDR at: http://www.intel.com/update/contents/wi07031.htm.