Briefing Note

Dynamic Spectrum Access

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1 Foreword

One of ComReg's key roles is to encourage innovation in the Irish telecommunications industry. The Forward Looking Programme (FLP), which consists of a panel of experts from Industry and Academia, is one of the mechanisms used by ComReg to help achieve this aim. It does this by making people aware of various technology developments and trends in the ICT sector, and initiating further debate on emerging issues through the release of Briefing Notes. Such briefing notes typically cover technical topics for those with an interest and basic knowledge of the telecommunications industry.

This briefing note is on the topic of dynamic spectrum access. Dynamic spectrum access is about gaining access to frequencies at a certain time or in a certain geographical location on a relatively temporary basis, even where the frequencies had already been assigned to another user (who isn't using it at that particular time or location). Dynamic spectrum access is both a technology and a management method that could unlock great potential efficiencies in spectrum usage. Increasing pressure, particularly in highly sought after frequency bands is driving demand for faster access to spectrum resources. The potential reward of more flexible spectrum management is greater innovation, but at the risk of devaluing spectrum bands if they become unusable through uncontrolled over exploitation.

Technology developments such as 'smart' and 'polite' radios and ad-hoc networks with decentralised control are all contributing to the advancement dynamic spectrum access. However, regulatory advances may also be needed in order to enable flexibility for different applications to use spectrum in the most efficient way, and this paper explores some possible approaches in this regard.

In summary, this document introduces the concept of dynamic spectrum access and is presented six sections. Dynamic spectrum access is presented alongside other traditional and emerging spectrum management methods in Section Two of the document. Section Three outlines some of the benefits and challenges of dynamic spectrum access techniques. Technology and standards developments are highlighted in Section Four. Commercial and regulatory issues are discussed in Sections Five and Six.

ComReg is keen to encourage innovative new developments and more efficient ways to use spectrum. We would welcome any comments on this document and on any issues it raises[1]. We are keen to encourage development in these systems through our test and trial licence scheme[2], and we would like to invite interested parties to consider using that scheme to investigate the potential of this technology.

Mike Byrne
Chairperson, Commission for Communications Regulation

[1] See Annex 1 for details on how to submit comments.

[2] See Section 6

2 Introduction and Background

In its most advanced form the concept of dynamic spectrum access promises a scenario where a consumer is able to avail of the most suitable service at the lowest cost at any particular time or location, regardless of which operator they are subscribed to. It represents a vision of efficient use of spectrum and advanced intelligent technology, and is as much about spectrum regulation and market conditions, as the technology itself.

In simple terms dynamic spectrum access is a means of gaining access to individual frequencies on a temporary or geographically restricted basis. This makes use of available spectrum that, despite being assigned in some cases, is not being used by existing operators at a particular location or time. This type of operation is available due to advances in technology that can equip dynamic spectrum devices with the ability to be aware of other users of spectrum and to avoid interference with them.

This document outlines the basic concept of dynamic spectrum access, putting it in perspective with existing spectrum management techniques, and highlighting recent technical developments. This note also briefly explores dynamic spectrum access from a market development and regulatory perspective.

2.1 Dynamic Spectrum Access and Traditional Spectrum Management

Radio spectrum is a valuable natural resource relied upon in almost every aspect of our lives from entertainment and communications (personal and commercial) to safety of life. Its efficient management is essential to maximise the benefit that can be obtained for both social and commercial uses.

Since the 1980's and in particular in the last couple of years innovation in wireless systems and services has greatly increased, putting additional pressure on traditional spectrum management regimes. Spectrum managers need to make spectrum available when, where and how it is needed, in order to keep pace with and to further nurture wireless innovation. At the same time spectrum managers have a duty to protect existing users of spectrum.

Technology developments are emerging that could enable a potentially more efficient way of managing spectrum, which could in turn facilitate greater innovation. These developments involve accessing the radio spectrum in a more dynamic way than previously and are known as dynamic spectrum access. A key question is which method of spectrum management has the potential to achieve the most efficient usage of the spectrum, facilitating the greatest levels of innovation? Given the importance of existing technologies and users of spectrum it is likely that the most effective overall policy will be a blend of several different management methods.

A background to traditional spectrum management methods is given below to help illustrate the concept of dynamic spectrum access.

Spectrum Management Techniques:

The following key spectrum management mechanisms are described below:

- Command and control
- Market based
- Flexible spectrum management
- Spectrum sharing (Overlay and Underlay)
- Spectrum commons

2.1.1 Command and Control

Command and Control is the traditional and still predominant method of spectrum management. It involves a central management body with authority to assign usage rights to individuals or organisations. This is an excellent system for managing interference because there is a central source of knowledge for all legitimate operation at any given time.

However, this can be a relatively slow process involving investigation and analysis on a case by case basis for any potential new services. Increased demand and usage of radio spectrum, higher levels of congestion in certain bands and geographical locations, and rapid technological innovation make it increasingly difficult for spectrum managers to keep pace with the needs of the market. The delays experienced and effort needed by potential new users of spectrum to access spectrum represent increased costs (known as 'transaction costs').

2.1.2 Market Based Approaches to Spectrum Management

The next stage on the scale of advancing spectrum management is the application of market mechanisms. Spectrum auctions are now widely used and are a well accepted tool for spectrum managers introducing previously unassigned spectrum into the market. The concept of secondary trading is important to allow market mechanisms to maintain control of access[3] to spectrum. Many countries have now either implemented secondary trading or are considering it[4]. Potential draw backs which must be protected against are:

- Windfall gains: where an incumbent occupier of spectrum is able to gain benefit from trading away its resource as a result of the introduction of spectrum trading.

[3] In spectrum management parlance the term 'allocation' is used to refer to how spectrum can be used (e.g. fixed, mobile, broadcast etc.). The term 'assignment' refers to giving a user access to spectrum.

[4] Spectrum trading is generally not permitted under current Irish legislation. However, a limited form of trading is possible through the 3rd Party Business Radio (TPBR) scheme where existing licences can be traded subject to prior agreement with ComReg. Details of the TPBR scheme including a list of existing licensee can be found at http://comreg.ie/industry/default.asp?STV4=BWO&TV4Exp=y& . Further details can be found in ComReg doc. 05/82R1: http://www.comreg.ie/_fileupload/publications/ComReg0582R1.pdf .

- Spectrum hogging/blocking: where competition is impeded by existing occupiers of spectrum, who retain the rights to certain bands without using them for the provision of services.

- Market fragmentation: where multiple spectrum trades results in small fragmented sections of spectrum, making it difficult for a single operator to compile a contiguous block of frequency to provide more efficient services, ultimately reducing the value of the spectrum.

2.1.3 Flexible Use of Spectrum

Being able to use a particular piece of spectrum for any technology or application is a key factor in nurturing innovation, and is essential to many of the potential applications of dynamic spectrum access. This freedom of spectrum usage is known as flexible use of spectrum.

Managing interference is a different challenge in a flexible spectrum environment than in a centrally managed command and control environment. In an open and flexible environment devices need to adopt 'polite' policies concerning how they use spectrum. This could involve measures such as listen-before-talk, and negotiation with other devices over spectrum access. Relatively recent technology developments such as frequency agile radios and software defined radios are now emerging which can enable such a flexible radio environment. The way in which spectrum is assigned is key to a useable flexible spectrum environment. Spectrum usage rights defining a spectrum mask for example (i.e. a set of perimeter limits for spectrum usage in terms of frequency and power) are appropriate for this type of management. More advanced alternative management methods such as the concept of Interference Temperature could emerge in the future[5].

2.1.4 Spectrum Sharing (Overlay and Underlay)

Spectrum sharing typically involves more than one user sharing the same piece of spectrum for different applications or using different technologies. When a band already licensed to an operator is shared with others it is known as overlay spectrum sharing. For example a spectrum band used for TV distribution in one geographical area could be used for an application such as broadband wireless access in another area without any risk of interference, despite being allocated on a national basis[6]. This is also known as easement use. More radical models where multiple operators could pool their spectrum rights together to be shared out as needed have also been explored from a theoretical perspective.

[5] Spectrum management based on interference temperature can be considered as managing interference at the receiver rather than the transmitter. This is an advanced concept, with many practical problems, which has not been applied to general spectrum management. e.g. FCC initial proposal of interference temperature - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-289A1.pdf

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

Wireless devices used to connect portable audio devices to FM radio receivers (i.e. iTrip[7] type devices) are examples of spectrum sharing in the broadcast FM band. The selection of a frequency is done manually by the users, choosing a frequency where they do not detect any broadcast radio stations. The risk of interference to broadcast services is minimal as theses devices are very short range (i.e. low power) and users are compelled to avoid operating at the same frequency as a broadcast services as it will inhibit their own service. Other examples such as citizens band (CB) radio, and amateur radio make use of a shared common channel that all users can access to set-up further communications on a currently available slot in the shared resource. Dynamic spectrum access is about operating in a shared mode on an automated basis (i.e. without user intervention). The British CT2[8] cordless technology from the 1980's was an early example of this.

Spectrum underlay is a more radical concept where multiple applications are able to share the same spectrum in the same location at the same time. Ultrawideband (UWB)[9] is an example of a type of wireless technology that could operate on an underlay basis. It is able to operate without unduly interfering with other systems sharing the same spectrum. UWB operates at such a low power and over such a broad range of frequencies that it falls within the noise tolerance of existing systems.

2.1.5 Spectrum Commons

In theory a spectrum commons is an area of spectrum that is free from centralised control. In practice what is referred to as a spectrum commons can have varying degrees of management. Licence exempt bands (e.g. the ISM[10] bands) are an example of a commons with some management in terms of power restrictions on individual users as applied in the US under the FCC Part 15 rules. In Europe there is a further degree of control in that devices used for communication in these bands must conform to certain technology standards (e.g. ETSI approval). So far this approach has only been used in limited bands for short range applications. However, significant innovation has emerged in these bands (e.g. Wi-Fi) which have led some to call for more spectrum to be managed similarly. Other proposed schemes would enable users of a particular band to operate in a service neutral way and free from other forms of spectrum planning, once they had been licensed to operate in those specific bands (e.g. FCC rules for the 3650MHz band).

A potential drawback of a commons model is the emergence of a 'tragedy of the commons'[11] where individual users abuse the resource and over use it, creating an

[7] iTrip is the product name for Griffin Technology's FM Transmitter for Apple's iPop line of portable audio players.

[8] CT2 (Cordless Telephony 2) is a standard for short range mobile communications used in the early 90's.

[9] See ComReg Briefing Note on Ultrawideband - http://www.comreg.ie/_fileupload/publications/odtr0159.pdf

[10] ISM – Industrial, Scientific and Medical bands, e.g. 2.4GHz where Wi-Fi developed.

[11] The term 'tragedy of the commons' was originally used by William Forester Lloyd in a book on population. The term was popularised by Garrett Hardin in 1968 in an essay "The Tragedy of the Commons". Source CTVR.

environment with so much interference that it is impossible for anyone to use. Therefore a key characteristic of devices to successfully operate in a commons environment is anti-rivalry (e.g. where a mesh[12] network uses spectrum to allow devices to pass on messages even when they are neither the source nor destination for the message).

2.1.6 Summary

	Opportunities	**Challenges**
Command and Control	Centrally managed and planned Low risk of interference	Slow Requires managers to make technology choices Suboptimal efficiency
Market Mechanisms	Promotes efficient usage. Gets spectrum to the users who value it most	Possibility of hoarding Windfall gains Fragmentation
Flexible Use	Potentially efficient use of spectrum Prevents artificial scarcity and high values of spectrum	Perceived increased risk of interference Relatively untested
Sharing	More efficient use of spectrum that is already allocated	Requires some management Potential for interference Fragmentation
Commons	Promotes innovation Lower cost of regulation	Potential interference 'Tragedy' of commons Untested (except for short range applications)

Table 1 – Summary of spectrum management techniques.

[12] A mesh network is a network of nodes which can communicate without the need for a centralised controlling base station or node. Traffic is passed through the network from one individual node to another, based on the relative layout of the nodes and the load on the network.

3 Dynamic Spectrum Access

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

3.1 How it Works

A dynamic spectrum access procedure would typically follow the following steps:

- Monitor spectrum to see if and which frequencies have no other radio activity (i.e. they are not being used by anyone)
- Agree with other dynamic spectrum access devices in the network which frequencies will be used, via some previously agreed common channel.
- Begin communicating on the agreed frequency band.
- Continue to monitor the spectrum for attempts by other users to access this spectrum.
- Change frequency bands and adjust power as necessary.

The monitoring and managing of the radio resources can be done by a single device in the network (centrally managed network) or by each of the devices individually and cooperatively (autonomous network).

3.2 Potential Benefits of Dynamic Spectrum Access

3.2.1 More efficient use of spectrum.

The main reason for the development of dynamic spectrum access techniques is to provide more efficient use of spectrum – which is essentially a finite, but reusable, resource. Consider that with command and control management a piece of spectrum is being used efficiently during busy hour, but inefficiently at all other times. Dynamic spectrum access would enable spectrum to be used for other services during periods of low utilisation, increasing efficiency. This efficiency could also be extended to creating greater device convergence, allowing multiple services to co-exist in the same devices, as well as in the same spectrum. For example the DRiVE and OverDRiVE projects[13] use dynamic spectrum allocation between mobile cellular and mobile broadcast technologies.

3.2.2 Faster access to spectrum

Lowering barriers to entry by making spectrum available to users who need it as quickly as possible is an important ingredient for wireless innovation. It is increasingly difficult for command and control regimes to be able to keep up with the demand for access to spectrum, particularly where spectrum has already been

[13] www.ist-drive.org , http://www.comnets.rwth-aachen.de/~o_drive/index.html

assigned to users. Dynamic spectrum access attempts to bypass much of the delays here by carrying out its own spectrum management.

3.2.3 Greater Innovation and Competition

The points mentioned above, efficient use of and faster access to spectrum, are both important to help encourage wireless innovation. This in turn results in faster time to market for innovative new wireless services. An environment that supports innovation ultimately contributes to a healthy competitive environment with a greater choice of services for end users.

3.3 Potential Challenges for Dynamic Spectrum Access

3.3.1 Interference and Quality of Service

Generally the biggest concern over the introduction of dynamic spectrum access systems is an increased level of interference. The operation of dynamic spectrum access relies on being able to detect and avoid the transmissions of other wireless systems. The ability to do this in a reliable way in real-time can be a source of concern for existing spectrum users and managers. Interference scenarios such as the hidden node problem are important here. In some cases an increased level of interference will still enable services to function, but at a lower quality of service. Instances of interference in a dynamic spectrum environment are likely to be more difficult for spectrum managers identify, trace and resolve than in a traditional command and control environment.

3.3.2 The Hidden Node Problem

This is important in the case of a dynamic spectrum access system attempting to operate on a shared basis with other services. While the dynamic spectrum access device will 'listen' to determine whether any other device is using the same frequencies at that time, it may not be able to identify all transmissions in its area or nearby areas due to the hidden node problem. Under certain circumstances the presence of a device will not be detected by another system seeking to use the same spectrum. The undetected device is known as a 'hidden node' and it is likely to experience interference with the other system.

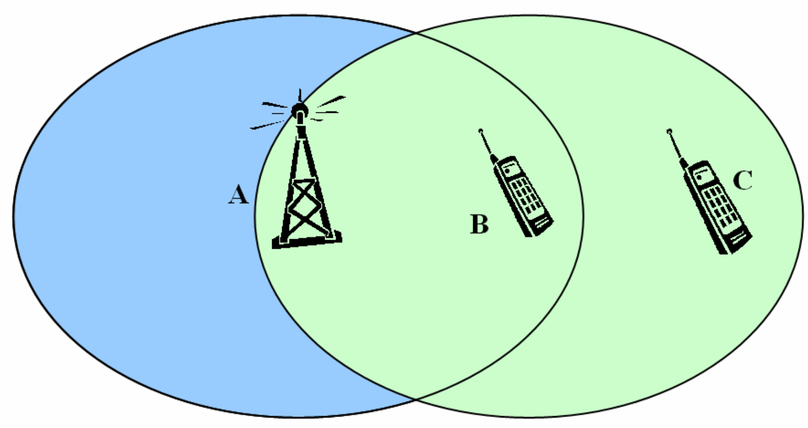

Figure 1 – Device A wants to communicate with B so it monitors for transmissions on a particular frequency (blue area). It cannot detect the presence of Device C, which belongs to another network – Device C is a 'hidden node'. Device B, which does not monitor for transmissions, follows the instructions of Devices A[14] and begins communicating at that frequency (the green area). This results in interference to Device C.

3.3.3 Complex equipment

Equipment which must sense and avoid radio transmissions in addition to carrying out its own basic communications functions has an added level of complexity, and therefore higher costs. Some dynamic spectrum access systems could operate with a form of centralised control, with added complexity of an additional management layer.

3.3.4 Regulatory compliance

While dynamic spectrum access systems will be designed to avoid interference there may still be a possibility that interference may occur. In such instances it would be difficult to determine the source of interference due to the way in which the spectrum is used (i.e. not in a command and control manner).

[14] Note that in a more advanced system with distributed monitoring (e.g. an autonomous system), Device B would detect the presence of Device C and could avert the interference scenario described above.

4 Dynamic Spectrum Technology and Standards

Dynamic spectrum access technologies and standards are still in early stages of development. Although some standardisation work is being carried out (e.g. at the IEEE and the ITU), much of the development is at the academic research stage.

Device and Management Characteristics

Some desirable characteristics that would help define a dynamic spectrum access device or management systems are listed below[15]:

- All transmitters also have receiver capability (to enable monitoring and adaptation).
- Power control and restriction (to limit interference)
- Signalling capability (to enable devices to communicate their resource needs)
- Contention/allocation mechanism (allocate resources in congested environment, or in an emergence situation)
- Enforcement mechanisms (to enforce compliance in cases where the contention/allocation mechanisms are not sufficient to prevent interference)
- Reversibility (to allow resources to be de-allocated and deployed for other users)
- Security and privacy protection (to ensure mechanism respects these needs).

Network Architecture

Due to technology limitations initial dynamic spectrum access systems are likely to operate in a centrally controlled management system rather than in a more complex distributed ad-hoc management system. In a centrally managed system one of the nodes (or devices) acts as a controlling base station that assigns spectrum resources to the individual nodes in the network. The central node might also be responsible for monitoring other wireless activity in the area of its network to identify frequencies to avoid.

A network that carries out spectrum management on a distributed basis is known as an autonomous system. This requires each network node to be able to communicate with other nodes regarding the spectrum usage it detects in its area as well as its own spectrum resource requirements. In some cases this type of system would require individual users to limit their own performance for the benefit of the overall network. While this type of system is potentially good at avoiding the hidden node problem it requires increased complexity in each of the nodes and in the signalling and multiple access protocols used to assign spectrum resources. Different multiple access protocols or rules would be needed for different types of traffic increasing complexity further.

[15] William Lehr, "Managing Shared Access to a Spectrum Commons", *Proc. IEEE Dyspan 2005,* pp420-444, November 2005.

Automatic Detection

In the case of iTrips, amateur radio or CB radio the monitoring of resources to identify unused frequency is carried out manually by the user listening in to each channel. In a dynamic spectrum access system this same function is carried out automatically by a device or multiple devices on the network. Early examples of this type of technology have been deployed in systems such as wireless LAN (e.g. Wi-Fi) where devices are operating in a shared environment. This technology is known as Dynamic Frequency Selection (DFS). This basically involves the receiver in the device sensing which frequencies there is activity on[16].

Software Radio and Cognitive Radio

Dynamic spectrum access is often associated with, although not exclusively dependent on, technologies and concepts such as Software Defined Radio(SDR)[17] and Cognitive Radio. The terms 'smart' and 'polite' are often used to describe these types of systems because they can alter how they operate to best suit given situations without degrading the performance of other neighbouring systems. Software defined radio is an implementation of radio systems on general purpose hardware where specific operational characteristics are implemented in software – different radio systems and standards are essentially loaded as software programmes (e.g. a GSM program or a Wi-Fi program). A radio increases its flexibility as more of its functionality is software based. However this comes at the cost of higher performance hardware. Software defined radio technologies are slowly making their way into commercial radio systems as technology developments make it economical for manufacturers to do so.

Cognitive radio can be considered an extension to the SDR concept (although it could also be implemented using non-SDR radio) that links into the concept of dynamic spectrum access. A cognitive radio is a radio that is to some degree aware of the environment that it is operating in and is able to modify its behaviour accordingly. This could involve altering transmission characteristics such as power levels, frequency of operation and modulation type. A cognitive radio network operates on an opportunistic basis (as could a dynamic spectrum access radio network). Dynamic spectrum access would be an important element of cognitive radio, and in this context it is often known as Policy Based Access (PBA). Applications of cognitive radio have mainly been considered for military and emergency applications (where the radio environment would be unknown).

Research is being carried out in this area at the Centre for Telecommunications Value Chain Research (CTVR)[18].

Resource Allocation

Allocating available spectrum resources among dynamic spectrum devices in the most efficient way is a significant technical challenge. Spectrum Load Smoothing

[16] N. Shankar Sai, et.al, "Spectrum agile radios: utilization and sensing architectures," *Proc. IEEE Dyspan 2005*, pp160-169, November 2005.

[17] See ComReg Briefing Note on Software Define Radio (2001) http://www.comreg.ie/_fileupload/publications/odtr0159.pdf

[18] http://www.ctvr.ie/RF.php

(SLS) is the term given to distributing spectrum demand across a range of frequencies. It applies the information theory concept of 'waterfilling' to spectrum management[19]. This load smoothing can typically be divided into two main categories in dynamic spectrum allocation: temporal and spatial. Temporal dynamic spectrum allocations divide the available resource into time slots (much like a time division multiple access system). Spatial dynamic spectrum allocation systems divide the spectrum resource into geographic areas with frequency separation and reuse as necessary. These allocation methods are implemented in algorithms to manage spectrum resources based on knowledge of the current radio environment. Research into resource allocation has initially found that it can be difficult to maintain temporal allocations as optimal, since traffic loads can be unpredictable[20]. If the time periods are too long then traffic patterns could change within that timeframe.

Spatial DSA is about frequency re-use and uses the fact that certain geographic areas would have particular spectrum demands. For example a recreational area may have a stronger requirement for broadcast type services, whereas a business district may have more of a need for two-way communications. Adjacent spatial DSA areas need to be able to communicate with one another in order to avoid interference. The increase in efficiency of DSA depends on the traffic profiles being experienced. This can be measured as a gain, of DSA over Fixed Spectrum Allocation (FSA).

Standards and Initiatives

A number of standards and initiatives have emerged in the area, or in directly related areas, of dynamic spectrum access. Some of the key initiatives are outlined below:

DARPA XG

The US based Defence Advanced Research Agency (DARPA) neXt Generation (XG) is a policy making framework. The group's goal is to define the system architecture, behaviours and policy language for a generic XG radio. This involves defining policies and meta polices that define how other policies should be enforced. Web ontology language (OWL) is an example.

IEEE 802.22

Dynamic spectrum access is an important part of the IEEE 802.22 standard being developed for wireless regional area networks. This involves a cognitive based air interface to operate on licence exempt basis in the TV broadcast bands (i.e. in TV 'white spaces'. http://www.ieee802.org/22/

IEEE P1900

Initiative to develop supporting standards for next generation radio networks and advanced spectrum management. This group is working on standard terms, definitions and concepts for spectrum management, policy defined radio, adaptive radio and software defined radio. It is also working on a recommended practice for

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[19] Lars Berlemann, et.al, "Policy-based Reasoning for Spectrum Sharing in Cognitive Radio Networks", *Proc. IEEE Dyspan* , Nov. 2005

[20] P. Leaves, et.al. "A Summary of Dynamic Spectrum Allocation Results from DRiVE", *IST Mobile and Wireless Telecommunications Summit*, Thessaloniki, Greece, pp.245-250, 16-19 June 2002

the analysis of in-band and adjacent band interference, and coexistence between radio systems. The group is developing a recommended practice for conformance evaluation of software defined radio – a significant problem for spectrum management authorities. http://www.ieeep1900.org/

ITU Working party 8F

ITU working group 8F is for IMT-2000 and systems beyond which includes consideration of concepts such as software defined radio and dynamic spectrum access. http://www.itu.int/ITU-R/index.asp?category=study-groups&lang=en&link=rwp8f

E^{2}R

End-to-end-reconfigurability (E2R) is an EU 6th Framework project working on wireless and mobile systems beyond 3G. This project is investigating flexible air interfaces. Such interfaces could potentially be used in a dynamic spectrum access system. http://e2r2.motlabs.com/

Some other related Standards Bodies, Industry Forums and Initiatives are listed below:

SDR Forum	http://www.sdrforum.org/
Joint Tactical Radio Systems (JTRS)	http://www.openmobilealliance.org/
Open Mobile Alliance (OMA)	http://www.openmobilealliance.org/
Common Public Radio Interface (CPRI)	http://www.cpri.info/
Open Base Station Architecture Initiative (OBSAI)	http://www.obsai.org/
European Telecommunications Standards Institute (ETSI)	http://www.etsi.org/
Software Communication Architecture (SCA)	http://jtrs.spawar.navy.mil/sca/home.asp
Universal Software Radio Peripheral (USRP)	http://www.ettus.com/

5 Market Implications

The key driver behind dynamic spectrum access is to enable more efficient access to radio spectrum resources. This has implications for any sectors involved in the use of spectrum such as the telecommunications sector and the consumer electronics sector. It is also important to put these developments in perspective at this point given that these are advanced concepts still under development, and without any real commercial implementations. Another important driver of dynamic spectrum access technologies is likely to be convergence between different services and access technologies.

Telecommunications

Dynamic spectrum access potentially allows a greater number of operators and services to exist in a given piece of spectrum, though more efficient access to spectrum resources. This also has implications for how spectrum is valued within the market. If it was found that mobile or broadcast services could be delivered in new bands due to dynamic spectrum access techniques, this could affect the market value of existing mobile spectrum for example.

In more advanced dynamic spectrum allocation networks the increased intelligence that must exist in end-user devices could be viewed as representing a decentralisation of investment for network operators.

Broadcasting

Similarly the utility and value of broadcasting spectrum could be affected by the emergence of dynamic spectrum access technology. TV white spaces in the US are likely to be the first real example of dynamic spectrum access. The FCC is currently working through proposals to allow the implementation of dynamic spectrum access in TV white spaces[21].

Equipment Manufacturers

From an equipment manufacturer's perspective dynamic spectrum access represents a challenge and an opportunity. The opportunity is in being able to potentially develop new products for areas of the spectrum that were previously allocated for specific technologies. The challenge is in being able to develop the advanced technology needed at competitive costs.

End Users

The technologists' vision of a dynamic spectrum access world where users' devices automatically select the most cost effective network to carry a given service at a particular time and location may be somewhat removed from the commercial realities of service provision. It is important to realise that existing service providers who rely on relatively exclusive access to limited spectrum will endeavour to maintain their customer relationships. However it is worth considering the

[21] http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-247169A1.pdf

http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-06-1813A1.pdf scenario where end users have a relationship with a single service provider, but is able to access other networks through a service broker[22].

[22] Ofcom, Technology Research Programme "Research and Development at Ofcom 2005/2006", November 2006.

6 Regulatory Implications

Spectrum managers are faced with striking a balance between facilitating the rapid development of innovative services and protecting existing services and users of spectrum. Spectrum management regimes are generally headed towards more flexible systems with the application of market based mechanisms and change of use. This migration is a lengthy process that affects many existing users of spectrum who have built their businesses, or grown accustomed to using services based, upon existing arrangements. Dynamic spectrum access represents a significant shift in how spectrum is managed and regulated, such that most current regulatory regimes are far from being capable of implementing dynamic spectrum access on a widespread basis.

Flexible Spectrum and Transaction Costs

The availability of flexible spectrum is a key component to the success of dynamic spectrum access. Without flexible spectrum potential dynamic spectrum users would experience an additional level of cost associated with convincing regulators and spectrum neighbours that their technology can operate safely. This cost is known as a transaction cost and would not exist in a flexible spectrum management environment. Clearly defined spectrum rights reduce transaction costs[23].

Regardless of the types of systems that are being developed, some form of control mechanism that is traceable by regulators is needed so that if problems do emerge they can be dealt with (i.e. through licensing). The more complex this system is, the higher the transaction costs.

Developments in other countries

Developments are occurring in countries in terms of spectrum liberalisation (flexible use and trading) e.g. US, Australia, New Zealand, Guatemala, and the UK. However, it is in the US where the most advanced regulatory proposals directly related to dynamic spectrum access are being developed. The FCC has proposed the use of unlicensed devices in the TV broadcast bands that would need to operate on a dynamic spectrum access basis. Depending on the results of studies this programme scheme could be launched by the end of 2007.

Ofcom in the UK carried out some research in the area of dynamic spectrum. Access[24], looking in particular at the advanced roaming type application of the dynamic spectrum access concept (e.g. where a user's device is able to select the lowest cost network to carry out a particular communication).

Network Resilience

Dynamic spectrum access brings increased opportunity to utilise spectrum, particularly during quite or off-peak times, and systems are designed to avoid congestion. However, without the sufficient built in controls, the additional

[23] Roberto Ercole, "Innovation, spectrum regulation, and DySPAN technologies access to markets", Proc. DySPAN 2005, Nov. 2005, pp 494 – 511

[24] Technology Research Programme: Research and Development at Ofcom 2005/2006.

assertiveness and flexibility of dynamic spectrum access devices could potentially cause or suffer from a form of 'grid-lock' during times of heavy network loading (e.g. during an emergency situation, or during a partial network outage). Although congestion management and avoidance is a core element of any dynamic access spectrum system, particular attention needs to be given to ensure resilience. This is something that needs to be incorporated in standards. All flexible devices and systems need to be sufficiently intelligent and controllable to make way for vital communications in a congested situation. Spectrum managers will need to ensure that emergency services are protected from any potential issues associated with this type of spectrum use (i.e. by maintaining some command and control in certain frequency bands).

Spectrum Management in Ireland

While it would be difficult to implement a permanent advanced dynamic spectrum access system in Ireland under current the current regulatory framework (national and EU), it has been possible to allow experimentation. The ComReg Test and Trial licence scheme can be used to carry out tests of dynamic spectrum access within available frequency bands[25].

The ComReg Test and Trial licence scheme is currently being used by the CTVR[26] at Trinity College Dublin to carry out tests on dynamic spectrum technology, and will be used during the IEEE DySpan 07 conference[27] being held in Dublin. These tests will be the first of their kind and involve multiple different radio systems attempting to use the same spectrum on a dynamic basis.

Invitation for Expression of Interest

Interested parties are invited to utilise the test and trial licence scheme to apply and develop dynamic spectrum technology. Some examples of bands where spectrum is potentially available for testing are:

- UHF TV bands
- 900MHz GSM bands
- 1800MHz GSM bands

However, users are encouraged to enquire about any spectrum bands where they are seeking to carry out wireless testing.

Details of the test and trial licence scheme can be found on the ComReg website at:

http://www.comreg.ie/_fileupload/publications/ComReg0535.pdf

E-mail: wirelessopportunities@comreg.ie

[25] http://www.comreg.ie/industry/default.asp?S=4&NavID=241&M=

[26] CTVR – Centre for Telecommunications Value-chain Research - http://www.ctvr.ie

[27] www.ieee-dyspan.org

7 Conclusion

Dynamic spectrum access is a new type of wireless technology that provides an alternative way of accessing and managing radio spectrum. The technology promises more efficient use of, and faster access to, radio spectrum. It also could contribute to the development of end user devices that can select the most cost effective way to access a service on the user's behalf.

Technology developments are at an early stage and many issues will have to be resolved before these systems would be commercially deployable. Several key standards bodies and industry groups are currently working on these challenges.

Dynamic spectrum access can also present some challenges from a regulatory perspective, particularly since in many cases these dynamic spectrum access technologies will be targeted at spectrum bands already occupied by existing services (e.g. broadcasting, mobile etc.).

At ComReg we will continue to encourage the development of more efficient wireless technologies through the wireless test and trial licence scheme. We will continue to follow international developments, from a technological, commercial, and regulatory perspective closely.

The 2nd IEEE DySpan conference is being held in Dublin from April 17 to 20th 2007, to consider these types of issues (www.ieee-dyspan.org). During this event the CTVR will be running some advanced dynamic spectrum tests, highlighting Ireland's lead role in these developments.

8 Annex 1 Comments on this Briefing Note

ComReg welcomes any comments or views on this Briefing Note. Comments should be sent to:

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to arrive on or before Friday 25th May, 2007.

Comments will be reviewed by ComReg when carrying any out further work on issues covered in this Briefing Note. In submitting comments, respondents are requested to reference the relevant section of this document. Responses will be available for inspection by the public on request. Where elements of any response are deemed confidential, these should be clearly identified and placed in a separate annex to the main document.

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