

The case for permissive rule-based Dynamic Spectrum Access

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August 2013

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The author would like to acknowledge the contributions of all those who helped shape the arguments and thinking in this paper, especially Microsoft for the intellectual engagement and financial assistance they have provided

However, the views expressed here – as well as any factual errors that remain – are solely those of the author

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Executive summary

‘Dynamic Spectrum Access’ (DSA) can enable wireless devices to make use of the substantial spectrum resources that are assigned to but not used by licensees. There are strong arguments that regulators should adopt permissive, rule-based, non-discriminatory access as the default mode of DSA – doing so will lower barriers to entry in a number of key markets, maximise wireless innovation and promote the efficient use of spectrum. The use of DSA to set-up restrictive, exclusive-use, licence-based access regimes, such as ‘Licensed Shared Access’ (LSA), would represent a costly retrograde step at odds with a world of increasingly heterogeneous and specialised wireless applications. In particular, rules-based access regimes providing multiple parties the freedom to deploy networks and innovations will be far better suited than licence-based access regimes to meeting two great connectivity challenges: meeting the growing demand for wireless data and enabling the Internet of Things.

Wireless devices have become central to human telecommunications and their sophistication and capabilities are increasing at a rapid rate. There is a pressing need to ensure that spectrum is available for these devices to be used to their full potential. Increasingly there is the notion of a ‘spectrum shortage’ or ‘spectrum crunch’. However, a substantial volume of research reveals that the vast majority of frequencies are unused in most places and at most times; this unused spectrum is often referred to as ‘white space’. In fact, the spectrum shortage is largely an artefact of the system of assigning licensees *exclusive* rights to particular frequencies. The standard process of enabling access for new applications has been to clear bands of existing users and grant new licences. However, this process is increasingly costly and time-consuming and provides no guarantee that new white spaces will not be created.

DSA is the notion that wireless devices can use advanced technologies to make use of the unused white spaces without interfering with existing users or requiring costly spectrum clearance. However, there is substantial disagreement over the form of access regime that should govern the use of DSA. Although DSA can allow for a great range of specific spectrum access regimes, each regime will still be one of two fundamental types:

- *Licence-based* access regime – in which a user will need to obtain a licence through a regulatory award or market-based negotiation; or,
- *Rule-based* access regime – in which the satisfaction of certain conditions, such as limited transmit power levels, checking with an online database and/or payment of an access fee permits spectrum access

Licence-based DSA regimes will create exclusive rights to spectrum capacity, in much the same way as existing licensing arrangements. This idea is supported by the influential, but dated, economic characterisation of spectrum as a simple resource, rival in consumption, whose efficient allocation amongst users could be assured through a system of tradable property rights. However, in practice, tradable spectrum licences have not nearly fulfilled the hopes of their proponents. First, activity has been slow and volumes low, with the large majority of ‘trades’ simply representing the transfer of company ownership. Second, and perhaps most disappointingly, tradable spectrum rights have not led to the innovation that was promised by its proponents.

LSA is an extension of the idea of exclusive-use property rights to spectrum and it is unclear how it would avoid the failings of its predecessor.

Rule-based DSA regimes will permit access to spectrum bands in a similar way to the licence-exempt (LE) and light-licensed access regimes currently in operation. Rules-based access is underpinned by newer theories that note productive activities over certain shared partially-rival resources, or infrastructures¹, that can display increasing returns to participation. Therefore, systems of rules-based access, or commons management, by providing a guarantee of access encourage higher participation and thus maximise overall economic benefit.

The successes of the narrow licence-exempt bands demonstrate the power of rules-based access to spectrum. In twenty years of operation licence-exempt technologies now account for:

- *The majority of innovation in wireless communications* – licence-exempt connectivity is near ubiquitous in smartphones, tablets and PCs and is rapidly growing in a vast range of consumer and industrial goods. The licence-exempt bands are also home to a diverse range of open standards which act as a platform for further innovation.
- *The majority of wireless devices* – in 2013 fewer than 2.5 billion devices will be sold that incorporate licensed connectivity and nearly all of these will also feature complementary licence-exempt technologies. However, at least 2.5 billion devices will be sold that use licence-exempt communication technologies *exclusively*. This disparity is set to increase.
- *The majority of Internet data traffic delivered to consumers* – Wi-Fi carries 69% of the total traffic generated by smartphones and tablets and 57% of total traffic generated by PCs and laptops. Overall the volume of Internet data traffic delivered by licence-exempt Wi-Fi exceeds that of cabled connections and licensed mobile networks combined.

Indeed the success of the LE bands has been the most surprising and consequential regulatory action in the previous 15 years of spectrum management. The attendant economic benefits from licence-exempt technologies are substantial, widely dispersed, and likely to exceed \$270 billion per annum globally².

The future of spectrum usage will be marked by a growing diversity of uses – especially due to the emergence of the Internet of Things – with demand growing most strongly on licence-exempt networks. Specifically:

¹ Following Frischmann (2005) I define infrastructure broadly as “a shared end to many means”. Spectrum made available under rules-based access shares many characteristics with a nation’s highway system, another tremendously productive infrastructure. Neither requires users to obtain exclusive licences to make use of the system, thus permitting a vast range of commercial activities to take place. New innovations can be brought to market quickly, requiring neither the permission of a regulator or an exclusive licence. One significant difference between the two is that the capacity of the radio spectrum has increased manifold as technology advances, whereas the capacity of the highways network is laborious to increase. This serves to make the radio spectrum even more amenable to rules-based access than the highways system. Another interesting parallel is the management of congestion and over-use. In road systems, techniques such as congestion charging have been introduced to keep the system productive within a rules-based access framework. This is similar to the use of techniques such as transmit power limits and database checking in licence-exempt spectrum. Furthermore, it is instructive to note that a shared infrastructure does not equate to an unreliable infrastructure: many critical activities, including ambulance services, guaranteed-time courier delivery and emergency services use the shared road network effectively.

² For more details see section 2.1.2 below

- Of the 50 billion wireless devices connected to the Internet of Things in 2020, the overwhelming majority – over 95% – are likely to use licence-exempt technologies. The remainder – less than 5% – will be served by cellular systems. Even using the highly conservative assumption that each licence-exempt node generates only a tenth of the value of each licensed node, over 65% of the value of the Internet of Things would come from licence-exempt devices – a figure equivalent to \$6.5 – 9.8 trillion of global GDP by 2030.
- The traffic over licensed wireless networks is likely to grow by 10.5 EB per month between 2013 and 2017. The volume over licence-exempt networks is likely to grow by over 40 EB per month in the same period.

In such a scenario the opportunity costs of dedicating exclusive spectrum rights for each new use are likely to become progressively more difficult to justify – especially as advances in technology permit greater and more reliable spectrum sharing. Licence-based DSA harks back to an era of few users of spectrum and few networks, and is likely to simply serve to increase the size of exclusive holdings held by individual operators. In addition it risks repeating the mistakes of exclusive allocation that have led to today's artificial spectrum shortage. Instead, regulators should grasp the possibility offered by rules-based DSA to create modes of spectrum access that respond quickly to market conditions, allow for continuous technology upgrades, enable networks with finely tailored speeds, capacities and Qualities of Service (QoS) and effectively multiplex the countless future wireless applications.

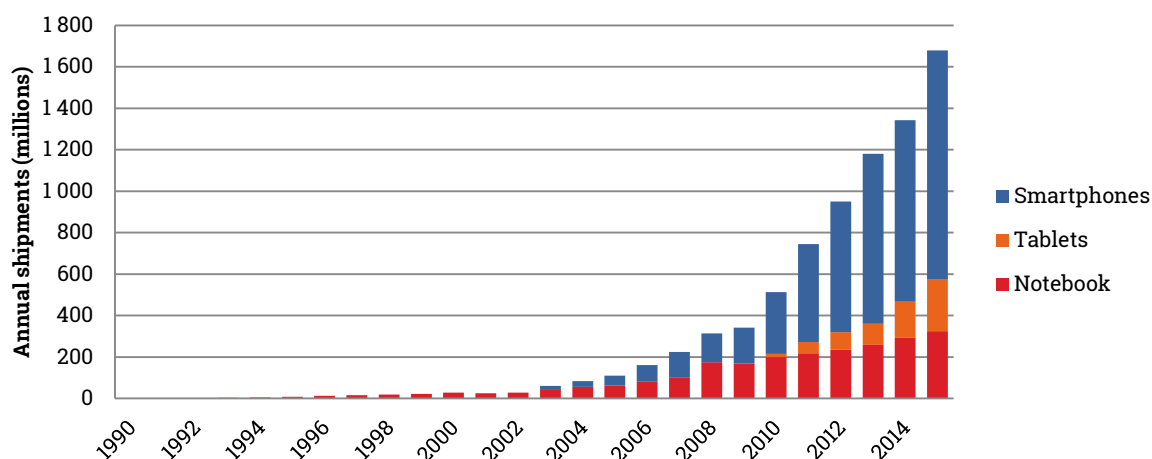
1 Introduction – the promise and challenges of ‘dynamic spectrum access’

As wireless communication assumes increasing importance, the demand for spectrum resources will also increase. However, the traditional approach to spectrum allocation, the use of exclusive frequency licences, has created tremendous amounts of wasted spectrum. Spectrum that is unused and inaccessible to new uses. Dynamic spectrum access (DSA) offers the prospect of enabling rapid and cost-effective access to these unused resources. However, the access regime chosen by regulators to enable DSA will have a crucial effect on the scope and scale of usage, innovation and economic benefits achieved.

1.1 The demand for spectrum and ‘spectrum scarcity’

Wireless devices such as mobile phones, tablets and notebook PCs have become central to human communication connecting people to increasingly valuable online services and resources. The number of people using these devices is set to grow quickly over the coming years, as shown below in Figure 1.

Figure 1 – Sales of wireless Internet capable devices 1990 - 2015³

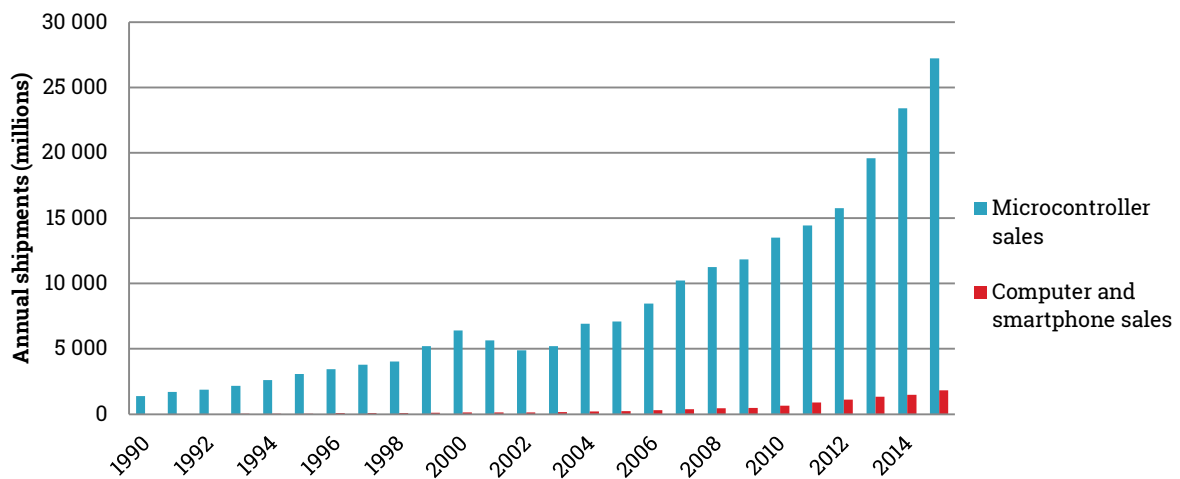


In addition, a rapidly increasing number of machine-to-machine applications are being developed and within a decade we may see many tens of billions of these devices deployed globally. Figure 2 below shows how the growth in the shipments of microcontrollers is outstripping that of even consumer Internet devices. Many of these microcontrollers will be used in machines connected to the Internet. Ericsson expects over 50 billion connected devices to be in operation by 2020⁴.

³ Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*.

⁴ Ericsson White Paper, *More Than 50 Billion Connected Devices*.

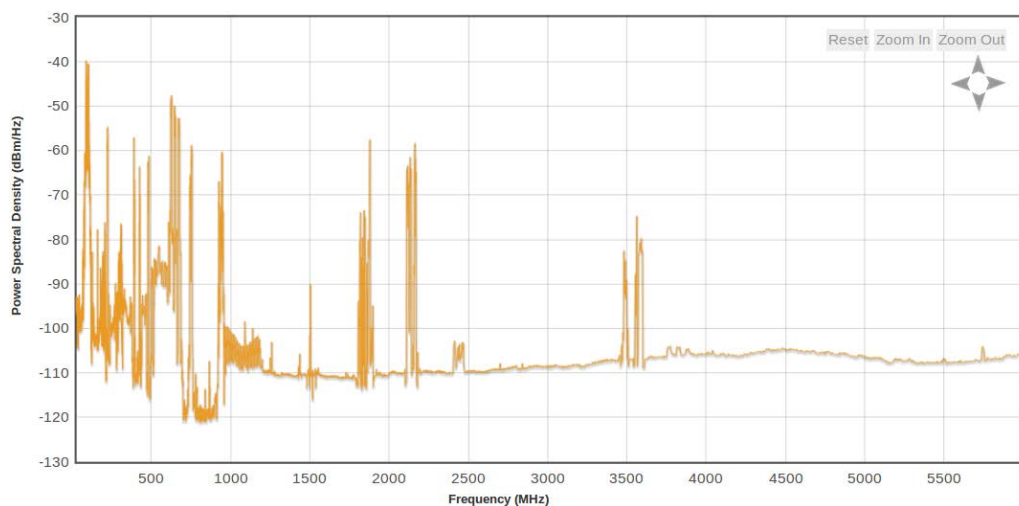
Figure 2 – Sales of microcontrollers and wireless Internet capable devices 1990 - 2015⁵



The rise in the number and intensity of usage of these wireless devices will commensurately increase the spectrum that will be required for these devices to function.

Against the backdrop of this increased usage, there increasingly is the notion of a ‘spectrum shortage’ or ‘spectrum crunch’. However, a large volume of research reveals that the vast majority of frequencies are unused in most places and at most times. Figure 3 below shows the power detected in the spectrum between 30MHz and 6000MHz in the centre of Brussels in January 2013. As can be clearly seen the vast majority of this spectrum – which includes the most intensively used bands – is unused.

Figure 3 – Microsoft Spectrum Observatory readings for spectrum power detection 30MHz and 6000MHz in Brussels in August 2013



In fact, the spectrum shortage is largely an artefact of the system of allocating licences granting *exclusive* rights to particular frequencies. For example, spectrum is not used by its licensees:

⁵ Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*.

- In some places – coast guard services are likely to only use their spectrum allocations on the coasts, mobile network operators do not use their licensed allocations in many rural areas;
- At some times – emergency service users and defence users do not use all of their allotted frequencies at all times;
- Over some frequencies – TV broadcasting uses only a subset of the available channels in any place at any time.

The process of making spectrum available for new uses has often involved rearranging established users in the frequency band to create cleared bands of spectrum. This process is often costly and time-consuming even if the existing users are very light users of the spectrum. For example, clearing the upper part of the TV band in Europe has cost many billions of euros⁶ and has taken longer than a decade. In addition, because many of the bands that could be most easily cleared have already been vacated – future rearrangements are likely to escalate in terms of cost, complexity, and duration.

1.2 Dynamic Spectrum access

The promise of ‘Dynamic Spectrum Access’⁷ (DSA) is to enable access to and use of these vast untapped spectrum resources. Initially most efforts at DSA were focussed on devices that could sense the spectrum around them and automatically choose quiet channels. However, this approach has more recently been superseded by the idea of geolocation databases, in which devices contact a central database which informs them of the permitted frequencies and operating conditions at their location.

There are a number of advantages of DSA. First, it avoids the costs of clearing spectrum. Second, it allows regulators unprecedented ability to maximise the efficient usage of spectrum. For example, if interference is reported then the database could be updated to increase the protection given to primary users, or increase the power levels allowed for certain types of devices in response to technological change, and so on.

DSA is not a theoretical proposition. The world’s first commercial DSA network, operating in the TV white space (TVWS) spectrum, launched in January 2012 in North Carolina in the United States. Since then more TVWS trials have taken place across the world’s continents and a number of nations, including the UK, Canada and Singapore are moving towards authorisation of DSA technology⁸. In addition, major consultations have taken place in the UK, Europe and the United States on the type of access regime that should accompany the use of DSA.

1.3 The choice of access regime

Although new spectrum can be made available through these techniques, regulators will need to decide on what basis these technologies can be used. Today, the large majority of wideband spectrum available for civilian use is managed using licence-based access that grants holders exclusive access to particular sets of frequencies. A

⁶ See Warman, “Digital TV Switchover Begins in London.” As the UK switchover cost approximately €1bn the total for Europe is likely to be many times this number.

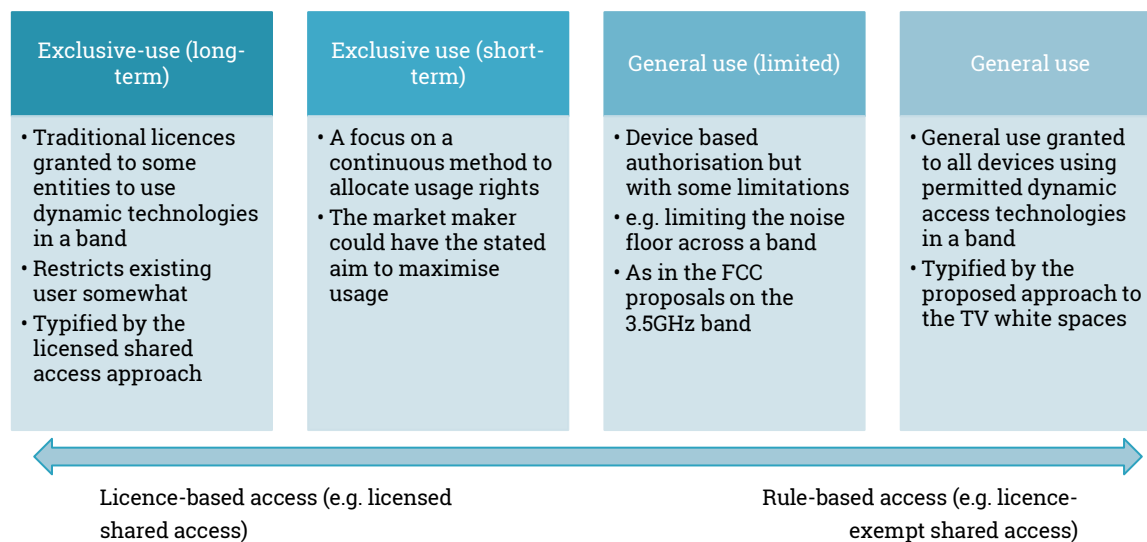
⁷ The first comprehensive description of cognitive radio goals can be found in the 1999 paper by Mitola III and Maguire Jr, “Cognitive Radio.”

⁸ Nekovee, Irnich, and Karlsson, “Worldwide Trends in Regulation of Secondary Access to White Spaces Using Cognitive Radio.”

small number of bands are managed through rule-based access systems such as licence-exemption, which permits access to equipment that follows specified technical rules, and light licensing, which requires users to register their use of a band with the regulator and potentially pay a usage fee.

DSA offers the possibility of many variations on these established spectrum management regimes. Some possibilities are detailed in Figure 4 below:

Figure 4 – An example of the range of access regime possibilities offered by DSA



However, each of the possibilities above still falls into one of two broad regimes, licence-based or rule-based access:

- Rule-based* access regime – in which the satisfaction of certain conditions, such as limited transmit power levels, checking with an online database and/or payment of an access fee permits spectrum access. A rule-based approach is Licence-Exempt Shared Access (referred to as Collective Use Spectrum or CUS by the RSPG⁹). This would use dynamic access technologies to enable widespread access to a particular band, by authorising access for equipment that meets the appropriate technical specifications, as in the existing licence-exempt model. This mode of operation has been adopted by the FCC in its authorisation of the use of the TV white spaces (TVWS), and is also found in the on-going European process within CEPT, and in Canada. The live trials in a number of countries, including Singapore, Japan, and South Africa, are also assuming licence-exempt access¹⁰.
- Licence-based* access regime – in which a user will need to obtain a licence through a regulatory award or market-based negotiation. This is typified by the proposed Licensed Shared Access (often abbreviated as LSA). This regime would limit dynamic access opportunities in a target band to a few entities, creating exclusive usage rights in a way similar to existing licensed spectrum¹¹. Licensed Shared Access has not yet been introduced in practice; however, the

⁹ RSPG, *Report on Collective Use of Spectrum (CUS) and Other Spectrum Sharing Approaches*.

¹⁰ For an excellent overview of global developments in the TV white spaces see Nekovee, Irnich, and Karlsson, “Worldwide Trends in Regulation of Secondary Access to White Spaces Using Cognitive Radio.”

¹¹ At the core of licensed shared access is a proposal made by Qualcomm and Nokia in January 2011 called “Authorised Shared Access” or ASA, with one key difference: in the RSPG’s LSA proposal the regulatory authority (not the licensee) defines the terms under which the secondary licensee will gain access to the unused spectrum.

European Commission's Radio Spectrum Policy Group has recommended further study¹².

Dynamic access to the radio spectrum offers an unprecedented opportunity for generating innovation and growth, addressing the traffic needs of tomorrow and crafting smart public policy. This paper argues that the choice of access regime will have a profound impact on the scale and distribution of these benefits.

There are strong arguments that rule-based non-discriminatory access should be the default mode of dynamic spectrum access. The existing bands permitting rule-based access have been extraordinarily successful, becoming the crucible for wireless innovation, hosting the most wireless devices and carrying most of the wireless data generated by smartphones, tablets and PCs. By adopting rule-based access regimes, regulators can maximise the innovation, competition and spectral efficiency generated by the radio spectrum. Choosing only licence-based approaches such as LSA is likely to yield more exclusive-use spectrum in the hands of a few licensees, much of which once again risks being underutilized. This risks wasting the possibilities for innovation offered by DSA and creating further 'spectrum scarcity' and fragmentation by assigning more exclusive rights in an increasingly heterogeneous and multiplexed world.

The rest of this paper is structured as follows:

- **Section 2** explores the conceptual basis of licence-based and rule-based access regimes and how new understandings of technology and the effects of access regime are challenging accepted ideas in spectrum management
- **Section 3** looks at the differing effects of licence-based and rule-based access regimes on the conditions of competition and innovation in a band of spectrum
- **Section 4** examines the challenges of the rapid growth in data traffic and the advances in the Internet of Things: the two greatest wireless communications challenges facing developed countries in the coming years. Rule-based spectrum access is uniquely placed to meet both.
- **Section 5** briefly lays out the conclusions to this paper.

¹² See RSPG, *Report on Collective Use of Spectrum (CUS) and Other Spectrum Sharing Approaches*.

2 The conceptual basis of spectrum access regimes

Arguments for and against licence-based or rule-based access regimes for DSA are grounded in different characterisations of the radio spectrum as a resource.

The foundations for a property-based licencing approach can be traced back to the work of Ronald Coase in the late 1950s and his proposal that the radio spectrum could be most efficiently utilised through the creation of a system of tradable exclusive rights to frequencies, like any other resource displaying rivalry in use.

The foundations for a rule-based approach are newer, relying on the insight that certain shared resources display increasing positive externalities from increased usage/participation – such as other important infrastructures like global transport networks and the Internet. Rule-based access regimes are likely to encourage usage and may thus maximise the total economic value from such resources.

The experience of tradable exclusive-use licences has been disappointing, failing to generate the innovation and dynamism that proponents of a licence-based approach predicted. By contrast the licence-exempt bands of spectrum have been a runaway success, now accounting for the majority of wireless innovation, the majority of wireless devices sold and the majority of Internet data traffic delivered to end-users.

Continuously advancing technology has rendered obsolete the understanding of spectrum that informed the work of Coase more than half a century ago. Instead, regulators and policy makers must update their conception of the spectrum and its possibilities on the basis of the available evidence which suggests strongly that a rule-based approach to spectrum access and DSA is increasingly appropriate.

2.1 The differing fate of two spectrum experiments – tradable spectrum licences and licence-exempt spectrum

The two most significant experiments that have taken place in spectrum management in the last 30 years have been the introduction in some countries of tradable spectrum licences and the near global introduction of licence-exempt communication technologies. Their differing outcomes can provide regulators with insights as to the possible effects of licence-based and rule-based access regimes with new DSA technologies.

2.1.1 Tradable spectrum licences

Beginning with Ronald Coase in 1959 a number of economists argued that the system of discretionary government licensing was causing gross inefficiencies and lost economic value. Coase characterised spectrum as a simple finite resource and saw “no reason that there should not be private property rights in spectrum”¹³ based around the ownership of frequency ranges. The creation of such rights, according to Coase, would allow spectrum to be traded and put to its highest valued and most valuable uses, maximising the total economic value generated. The view of spectrum as a finite resource best managed through property rights held by individual licensees has come

¹³ Coase 1959

to be regarded as the prevailing wisdom in spectrum management, even perhaps as an inevitability¹⁴.

Auctioning of tradable spectrum licences was pioneered in New Zealand from the late 1980s and then taken up by the US, Australia and the UK in the 1990s. Further legislation in these countries cleared the way for secondary markets trading. In 2005 the UK's Ofcom proposed a sizable extension of market mechanisms, aiming for 71% of frequencies to be assigned under tradable licences by 2010. A European decision of 2002 proposed to introduce tradable licence systems by 2010 across the EU¹⁵.

Underlying this enthusiasm were the supposed benefits that would result from tradable licences. Ofcom claimed that trading would lead to “lower prices for the most profitable and popular wireless services as wider availability of spectrum increases competition and supply; greater choice as alternative suppliers enter the market by acquiring rights to use spectrum; and innovation as entrepreneurs acquire rights to use spectrum and offer new services.”

However, in practice, tradable spectrum licences have not nearly fulfilled the hopes of their proponents.

First, activity has been slow and volumes low:

- In 2006, Europe's first pure spectrum trade happened in the UK, fourteen months after trading was allowed¹⁶.
- In 2007, ACMA, the Australian regulator, noted that “Spectrum trading has occurred in low volumes in Australia and New Zealand”¹⁷.
- In 2011, Peter Stanforth, of Spectrum Bridge – one of the US's biggest spectrum exchanges – identified lack of education, fear of interference, lack of incentives against hoarding, and high transactions costs as the culprits in a presentation entitled “Why Haven't Secondary Markets Been Successful?”¹⁸
- In 2012, the economic consultancy Oxera wrote “while spectrum trading has been possible in a number of countries for some time (such as the UK, New Zealand and Australia), there have been few substantial trades”¹⁹.

Second, and perhaps most disappointingly, tradable spectrum rights have not led to the innovation that was promised by its proponents. Most transfers have been due to companies being bought by others and those that have been pure spectrum trades have often been due to larger firms buying up the licences that had belonged to smaller ones, quite the opposite of Ofcom's hopes for new and innovative entry.

Professor Martin Cave, one of the chief architects of the UK's move to a regime of tradable licences, suggested in 2006 that the success of the regime should be judged over a 3–5 year time frame²⁰. In 2013, we can safely conclude that the experiment in

¹⁴ “Spectrum regulation took a very large step towards property rights when cellular networks eclipsed broadcasting as the dominant wireless sector, and now liberal frequency markets dot the globe. Other markets, and national regimes, will follow. Before long, the transition to standard property institutions will be only a modest leap. In a few decades, the idea of administrative allocation of radio spectrum will be a quaint historical episode.” (Hazlett 2008)

¹⁵ ACMA, *The Economics of Spectrum Management: A Review*.

¹⁶ PolicyTracker, “Spectrum Trading Gets Underway in the EU.”

¹⁷ ACMA, *The Economics of Spectrum Management: A Review*.

¹⁸ Benkler, *Open Wireless Vs. Licensed Spectrum: Evidence from Market Adoption*.

¹⁹ Oxera, *Spectrum Auctions and Trading: Dealing with Competition Problems on Airwaves*.

²⁰ PolicyTracker, “Spectrum Trading Gets Underway in the EU.”

tradable licence-based access has largely failed. LSA is a direct descendent of the of exclusive-use property rights to spectrum and it is unclear how it would avoid the failings of its predecessor.

2.1.2 Licence-exempt spectrum

Perhaps the most significant occurrence in wireless communication in the present century has been the growth in and success of licence-exempt technologies. Wideband licence-exempt usage was first authorised in 1985 by the FCC in the Industrial Scientific and Medical (ISM) spectrum bands at 900 MHz and 2.4 GHz. These bands were chosen for licence-exempt usage because they were inundated by radiation from microwave ovens and medical and industrial equipment, and so were thought to be ‘junk spectrum’ unsuitable for communications usage.

However, the narrow bands authorised for licence-exempt access have proven to be a remarkable success, now accounting for:

- The majority of innovation in wireless communications
- The majority of wireless devices manufactured
- The majority of Internet data traffic delivered to consumers
- The creation of substantial amounts of economic value

Innovation

In wireless communications, innovation can take at least two senses: the introduction of new techniques in wireless communication and the use of wireless technology in new applications. In both cases, innovation in licence-exempt technologies is greatly surpassing that in its licensed counterparts²¹.

Below are set out some of the key recent advances in wireless communication and the date each was first introduced into the two most popular two-way applications: licensed cellular networks and licence-exempt wireless LANs.

Figure 5 – Date of introduction of radio technologies into wireless LAN and cellular²²

| | Wireless LAN | Cellular |
|---|--------------|----------|
| Digital signal encoding ²³ | 1985 | 1991 |
| Spread spectrum ²⁴ | 1991 | 1995 |
| OFDM ²⁵ | 1999 | 2006 |
| MIMO/Adaptive beamforming ²⁶ | 2004 | 2013 |

²¹ Niklas Agevik, “From Skyper to Passpoint.”

²² Thanki, *The Economic Value Generated by Current and Future Allocations of Unlicensed Spectrum*.

²³ Digital signal encoding makes possible the clear static-free transmission of voice information and makes possible high speed data connections, see <http://www.nokia.com/A4303010>

²⁴ Spread spectrum technologies enable much more intensive lower interference use of the radio spectrum, see the First IEEE Workshop on Wireless LANs: Preface and http://www.globalccf.org/history_of_cdma.php

²⁵ OFDM enables transmissions to cope with severe channel conditions caused by frequency-selective interference and fading without complex equalization filters. See <http://standards.ieee.org/getieee802/download/802.11a-1999.pdf> and <http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=189800030>

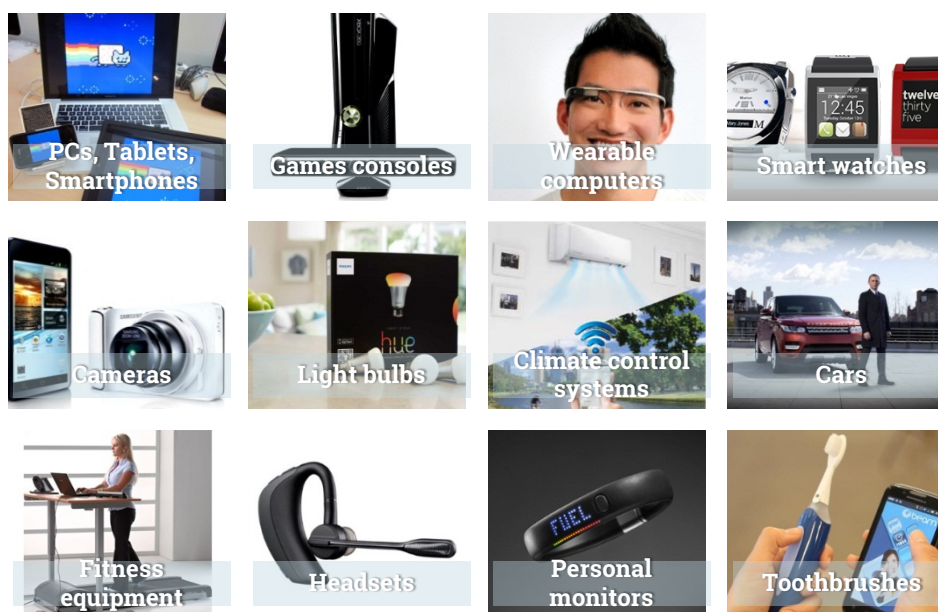
²⁶ MIMO is a form of spatial multiplexing in which the same frequency can be used to encode different streams of data simultaneously. This permits substantial potential increases in spectrum capacity. See http://reviews.cnet.com/routers/belkin-wireless-g-plus/4505-3319_7-31489123.html?tag=lia;rcol

These technologies have led to substantial improvements to the range, capacity, reliability and cost-effectiveness of wireless communications, factors that have benefited consumers and businesses tremendously through higher quality products and services. This is a trend that is likely to continue, due to the open nature of the licence-exempt bands that permits experimentation by large and small firms and the ability of these firms to sell their products directly to a large number of end users, rather than having to negotiate through licence-holding intermediaries.

The innovative application of wireless technology in consumer and corporate products is even more dominated by licence-exempt technologies. Cellular technologies have struggled to expand much beyond traditional mobile phones whereas licence-exempt technologies are accelerating towards ubiquity in a number of product areas.

In the area of consumer products, Figure 6 below illustrates some areas in consumer products where licence-exempt connectivity is enhancing (or even central to) the value proposition.

Figure 6 – Consumer wireless innovations incorporating licence-exempt connectivity



The licence-exempt technologies of Bluetooth and Wi-Fi are now ubiquitous in smartphones, tablets, notebook PCs and games consoles. Wi-Fi is on the verge of ubiquity in cameras, set-top boxes and televisions. Bluetooth has achieved near ubiquity in cars. The technology is also making rapid strides in the connected home, in areas such as lighting, locks and climate control.

Figure 7 below illustrates a range of products targeted at business and organisational users which are incorporating licence-exempt wireless technologies.

Figure 7 – Organisational wireless innovations incorporating licence-exempt connectivity



Many of the products above use the familiar technologies of Wi-Fi, Bluetooth, NFC²⁷ and RFID. However, others such as ZigBee²⁸ and WirelessHART²⁹ are also more common in business and industrial settings. The current and potential economic impact of these technologies has not been wholly quantified. However, the possible impact of the Internet of Things is widely hailed as revolutionary and is discussed further in Section 4.1, below.

The application innovation facilitated by licence-exempt technologies is simply unmatched by licensed technologies.

Sales

The profusion of innovation in and with licence-exempt technologies is matched by similar substantial increases in the shipments of devices that use these technologies. The combined sales of devices that use licence-exempt bands to communicate far outstrips the combined sales of devices that use licensed bands.

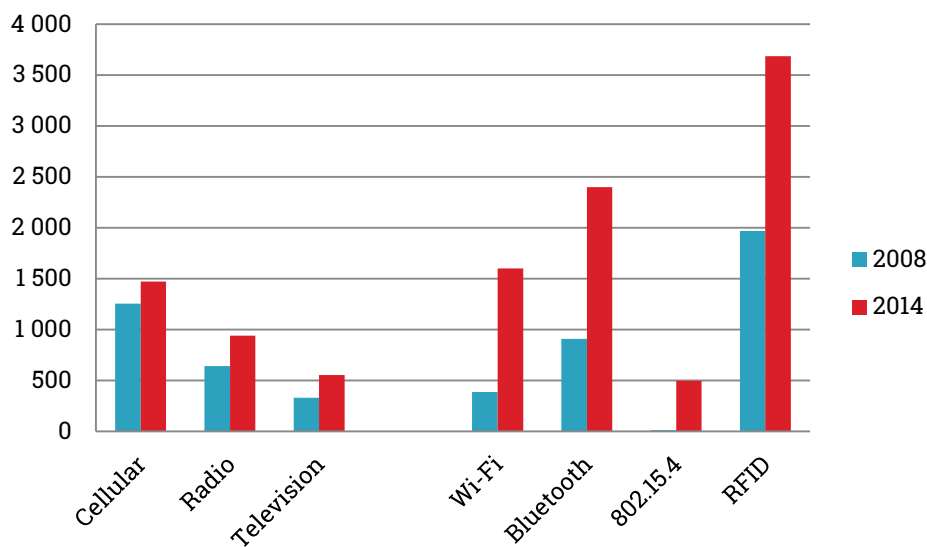
Figure 8 below compares the shipments of some devices that use licensed bands to communicate and the shipments of licence-exempt chipsets.

²⁷ http://en.wikipedia.org/wiki/Near_field_communication

²⁸ ZigBee is a wireless technology developed as an open global standard designed to address the unique needs of low-cost, low-power wireless sensor and control networks. ZigBee uses the 2.4 GHz radio frequency to deliver a variety of reliable and easy-to-use standards to create personal area networks. ZigBee is based on the IEEE 802.15 standard. See <http://en.wikipedia.org/wiki/ZigBee> and <http://www.zigbee.org/Home.aspx>

²⁹ WirelessHART is a wireless mesh network communications protocol for process automation applications based on the Highway Addressable Remote Transducer Protocol (HART). See http://www.hartcomm.org/protocol/wihart/wireless_how_it_works.html

Figure 8 – Sales of devices incorporating popular licensed and licence-exempt technologies



The growth in shipments of unlicensed chipsets has been remarkable since 2008, driven in no small part by the innovation described above.

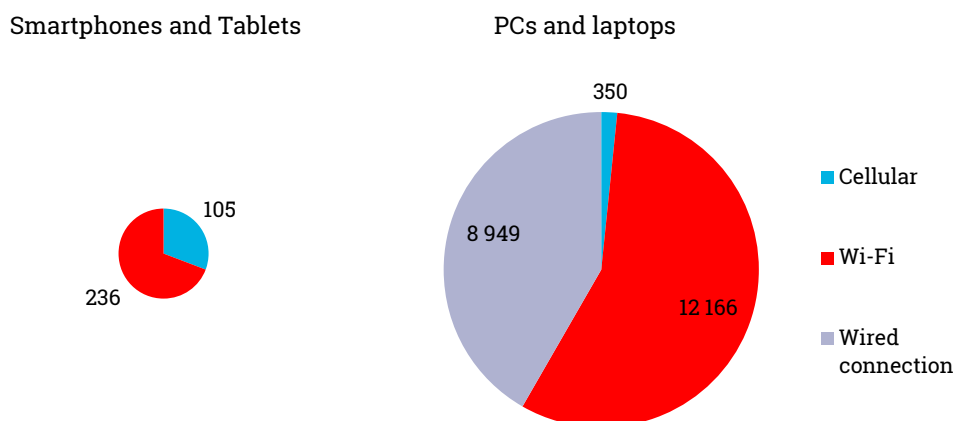
The most recent research suggests that in 2013 fewer than 2.5 billion devices will be sold that incorporate licensed connectivity and the vast majority of these will also feature at least one complementary licence-exempt technology. However, at least 2.5 billion devices will be sold that use licence-exempt communication technologies *exclusively*. This disparity is set to increase over time³⁰.

Delivering data

Wi-Fi delivers the majority of the world’s Internet data traffic, as shown in Figure 9 below.

³⁰ See “Report”; “Gartner.” For licensed devices we use Gartner’s estimate of 1.9 billion mobile phones shipped and that 20% of the 240 million tablets shipped will be mobile enabled. We further assume that the sales of every other device that uses licensed spectrum to communicate, from mobile base station cards and to televisions and radio receiver sets, ship less than 552 million devices – a safe assumption. For licence-exempt devices we directly use ABI Research’s estimate that 5 billion chipsets incorporating at least one licence-exempt technology will ship in 2013.

Figure 9 – The volume of Internet data delivered to end-users by device and delivery type (PB per month)



In the case of smartphones and tablets, Wi-Fi carries 69% of total traffic generated. For traditional PCs and laptops, Wi-Fi is responsible for carrying 57% of total traffic, greater than the share of Ethernet connections and 3G data combined.

The mobile industry might be the single biggest beneficiary from the data carried by Wi-Fi. In the absence of Wi-Fi, approximately 150,000 to 450,000 new radio base stations would be needed to cope with smartphone traffic. Wi-Fi networks are saving mobile operators from needing to make an investment of \$30 – \$93 billion this year alone.

Economic benefit

Two important considerations render the assessment of economic value from bands of spectrum which are accessed under a licensed regime easier than bands permitting licence-exempt access. First, licensees are able to charge end users of the spectrum recurring fees for access to the spectrum. Measures of economic value such as consumer and producer surplus can fairly simply be estimated from charges and quantity sold. In bands offering licence-exempt access such charges are not levied. Second, most licensed bands, such as those used to deliver mobile cellular services, display a remarkable homogeneity of service offerings, which makes the task of economic assessment substantially easier than in the licence-exempt bands – any of which is home to a multiplicity of usage models. Nonetheless, an increasing number of studies are beginning to assess the economic value from licence-exempt uses. Some prominent examples are listed below in Figure 10.

Figure 10 – Selected analyses of the economic value generated through licence-exempt spectrum

| Year | Author | Details | Value |
|------|------------------------------|--|---------------------------|
| 2009 | Thanki ³¹ | US – Value from Wi-Fi enhancing home broadband | \$4.3 – 12.6 billion p.a. |
| | | US – Value from hospital Wi-Fi networks | \$9.6 – 16.1 billion p.a. |
| | | US – Value from clothing RFID | \$3.3 – 13.1 billion p.a. |
| 2011 | Milgrom et al. ³² | US – Consumer value from Wi-Fi capacity | \$25 billion p.a. |

³¹ Thanki, *The Economic Value Generated by Current and Future Allocations of Unlicensed Spectrum*.

³² Milgrom, Levin, and Eilat, *The Case for Unlicensed Spectrum*.

| | | | |
|------|----------------------------------|--|-----------------------|
| | | US – Consumer value from greater speed of Wi-Fi | \$12 billion p.a. |
| 2012 | Cooper ³³ | US – Value from unbilled consumer access to commercial hotspots | \$10 billion p.a. |
| | | US – Cost savings for US mobile operators from Wi-Fi offload | \$26 billion p.a. |
| 2012 | Forge et al. ³⁴ | EU – Economic impact of additional licence-exempt spectrum on the EU economy to 2020 ³⁵ | €506 billion NPV |
| 2012 | Thanki ³⁶ | Global – Cost savings for mobile operators globally from Wi-Fi offload over the next 4 years | \$250 billion NPV |
| | | EU – costs from delayed smart grid implementation due to lack of sub-1GHz spectrum | \$37 – 56 billion NPV |
| 2012 | Britchfield et al. ³⁷ | UK – benefits from releasing sub-1GHz licence-exempt spectrum for smart metering | £6.9 billion p.a. |
| 2013 | Plum Consulting ³⁸ | EU – Additional benefits from a greater allocation of 5GHz spectrum in Europe | €16.3 billion NPV |

As can be seen, the scale of benefits, even from a small subset of the uses to which licence-exempt spectrum is applied, can be measured in the many tens of billions of dollars annually. Considering the sum benefit of a subset of these studies yields an annual global economic benefit of at least \$270 billion per annum³⁹. This excludes any consideration of a range of licence-exempt applications on which no work to date has been done, including:

- Bluetooth in the consumer, automotive, fitness and health sectors;
- Industrial control systems using ZigBee and proprietary systems; and,
- Wi-Fi in the retail, commercial and industrial sectors.

2.2 Understanding the success of rule-based access to spectrum

The great success of licence-exempt technologies is difficult to reconcile with the traditional Coasian view of the radio spectrum. In this view, licence-exempt access simply permits unfettered access to the finite resources of particular bands of spectrum. This creates the conditions for a *tragedy of the commons* in which overexploitation leads to the emergence of a low productivity equilibrium or possibly even a collapse of the usability of the entire spectrum resource⁴⁰. However, the

³³ Cooper, “Efficiency Gains and Consumer Benefits of Unlicensed Access to the Public Airwaves.”

³⁴ Simon Forge, Robert Horvitz, and Colin Blackman, *Perspectives on the Value of Shared Spectrum Access*.

³⁵ It should be noted that this number for the Forge study has been calculated by taking the difference of its scenario 2 and 3 – in which the primary differentiator is additional licence-exempt spectrum (two cleared bands of 50MHz and the use of TV white space devices). The number here should be taken cautiously as the overall estimate of value is €271 – €11,219 billion – the larger number is greater than the GDP of the United States.

³⁶ Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*.

³⁷ Britchfield et al., “Developments with Spectrum for Smart Metering and Smart Grid Applications.”

³⁸ Williamson et al., *Future Proofing Wi-Fi – the Case for More Spectrum*.

³⁹ This simply takes the number from the 2009 Thanki report (which did not include the benefits of offload in its calculations) and the 2012 Cooper report and globalises through GDP extrapolation.

⁴⁰ This view is reflected in the comments of a number of economists. For example: “if there are incentives for parties to cheat on the rules that prevent tragedy of the commons-type results, some cheaters are likely to emerge and thereby undermine the promise of new and innovative technologies that use unlicensed spectrum” (Weiser and Hatfield, *Policing the Spectrum Commons*.) “with allocations for unlicensed spectrum, regulators have dispersed use rights so widely as to make efficient use impossible – tragedy of the commons” (Hazlett, “Spectrum Tragedies.”) and “in a commons regime, the number of “neighbors” is likely to be large and their relationship is unlikely to be long term, so cooperative equilibria are unlikely to exist. Realistically, in commons or markets, court-enforced law or regulation is a necessity whenever cheating could be short-term profitable.” (Faulhaber, “Question of Spectrum.”)

licence-exempt bands appear to have not fallen victim to such a scenario. Indeed, the volume of innovation and investment taking place would appear to rule out a resource system in danger of imminent collapse.

2.2.1 Limited substitutability and capacity as a function of technology

The properties of the radio spectrum and its use for communication are difficult to visualise and intuit. Frequently, the metaphor of spectrum as territory is employed: “It is clear that, if signals are transmitted simultaneously on a given frequency by several people, the signals would interfere with each other and would make reception of messages transmitted by any one person difficult, if not impossible. The use of a piece of land simultaneously for growing wheat and as a parking lot would produce similar results.” (Coase 1959)⁴¹

The use of such a metaphor is misleading, as it ignores two key factors. First, units of land display a high degree of substitutability. Second, the capacity of spectrum is a function of technology.

Rival resources display varying degrees of substitutability. The road network, for example displays a low degree of substitutability – there are not a large number of alternatives to particular segments of the network. This is quite clearly demonstrated by the traffic-jams created by accidents that block key routes or junctions. Conversely, land displays high substitutability. For any particular plot many others will share the required characteristics. The substitutability of radio spectrum is much more akin to that of roads than that of land. For a frequency band to be useful requires a large amounts of infrastructure designed to operate in those frequencies – and vice versa. It is therefore clear why dynamic markets in tradable exclusive-use licences have never emerged but that dynamic markets in Wi-Fi capacity – which is easily substitutable – are already coming into existence⁴².

Crucially, the capacity of the radio spectrum to support communication is a direct function of the technology used to transmit and receive messages. Since the 1950s the technologies available to utilise the spectrum have advanced by orders of magnitude. Some of the most important technologies are grouped by functional type in Figure 11 below.

Figure 11 – Broad techniques that have been employed in improving radio communications

| Technique | Examples and effects |
|--|--|
| Extending the frequency range | A much larger part of the radio spectrum can now be utilised for radio communication – frequencies of many tens of gigahertz are now commonly used for communication. |
| Increasing spectrum reuse | The earliest uses of spectrum broadcast radio signals over many tens of kilometres, cellular networks popularised smaller cell architectures of a few kilometres and Wi-Fi networks range in the tens to hundreds of metres. Each decrease in cell-size increases the possibility of spectrum reuse. |
| Raising spectral efficiency | A number of techniques such as forward error correction, high constellation QAM modulation and encoding techniques such as OFDM have greatly improved the efficiency of spectrum use enabling higher speed communication. |
| Enhancing interference resistance | Encoding techniques such as spread spectrum technology and greater CPU power has provided communication devices the ability to better pick out wanted signals from noise. |
| Directing radio energy | Simple techniques such as TPC, LDC and more complex ones such as adaptive beamforming and MIMO allow a much more precise control of the amount and direction |

⁴¹ See also de Vries, “De-Situating Spectrum” for a fascinating discussion of the metaphors used for speaking around spectrum and their inherent limitations

⁴² For example, see BandwidthX www.bandwidthx.com

of emission of radio energy. This has two effects; it increases the signal strength at the intended target and also decreased unwanted noise received by others.

The combined effect of these technologies has been to increase considerably the capacity of the licence-exempt bands to support widespread, simultaneous, uncoordinated and intensive usage. In many cases the improvements have been on the scale of many orders of magnitude. The improvements are continuing as research and product development progresses⁴³.

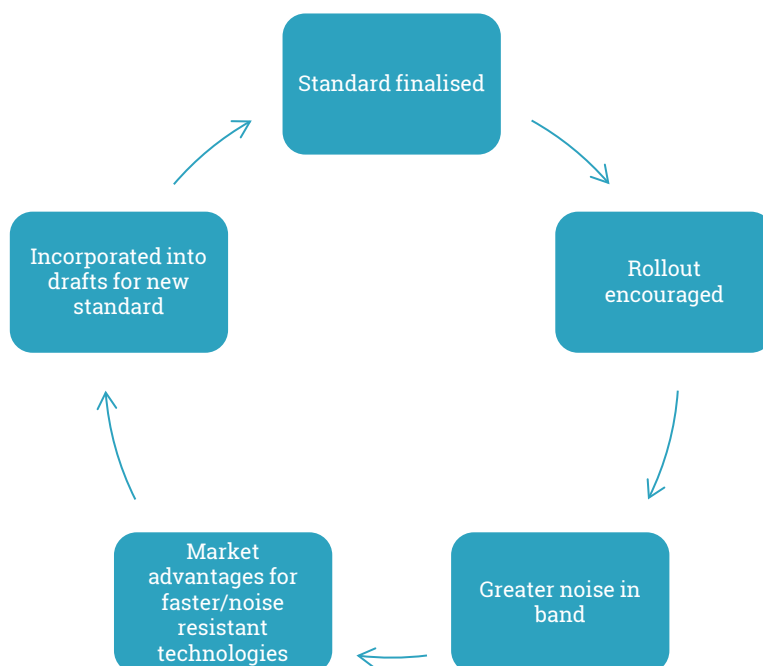
Taken together these two factors explain the success of the licence-exempt bands. The substitutability between different bands of spectrum is low, but the relatively large licence-exempt bands encourage open standards, multiple users, interference-reducing technology and *economies of scale* that can facilitate myriad uses and users.

2.2.2 Standards prevent cheating in rule-based access regimes

Although the capacity of the spectrum for all users is increased through the use of the technologies described above, their use is not mandated by law. In fact, not using some of the techniques above may improve the ability of any particular user to harvest capacity from the spectrum whilst harming the ability of others. What then prevents individuals and companies from deploying equipment that ‘cheats’? The key to this question is the action of standards bodies and their members.

To minimise the risk from developing and deploying new technologies in the free marketplace of licence-exempt spectrum, many large and small firms have banded together to create open standards, which set the requirements for a technology and guarantee interoperability of equipment. These bodies help to create a virtuous cycle as shown below in Figure 12.

Figure 12 – The standards upgrade cycle in licence-exempt spectrum



⁴³ For example much work is focusing on massive MIMO and orbital angular momentum of photons to reduce interference and boost spectral efficiency.

Essentially, the creation of a widely supported standard can help create the economies of scale and market confidence to encourage consumers to roll out with the technology. This will raise the noise floor in the band and create demand for better performing products. Firms in the market can therefore gain by introducing refined technologies that help satisfy consumer demand. These firms also have an advantage to push these technologies into newer revisions of standards to gain royalties on their intellectual property. As new technologies are finalised they encourage the acceleration of the cycle.

A side effect of this cycle is also to discourage cheating technologies. Most smaller, proprietary technologies will choose to maintain compatibility rather than risk being crowded by larger standards. In the case of clashes between standards – such as that which once existed between Bluetooth and Wi-Fi – common membership of standards groups helps to create strong incentives to resolve such issues.

2.3 Recasting the economics of spectrum

The ability of spectrum to thrive under rule-based access links neatly to the theory of infrastructure posited by Brett Frischmann. According to Frischmann a non-discriminatory access regime to an ‘infrastructure’ (defined broadly as “shared means to many ends”) that generates many positive externalities:

maintains openness, does not discriminate among users or uses of the resource, and eliminates the need to obtain approval or a license to use the resource. Managing infrastructure resources as commons eliminates the need to rely on either market actors or the government to “pick winners” among users or uses. This catalyzes innovation through the creation of and experimentation with new uses. More generally, it facilitates the generation of positive externalities by permitting downstream production of public and social goods that might be stifled under a more restrictive access regime. Finally, it sustains the social option value of the infrastructure by precluding premature optimization of the resource for commercial gain.⁴⁴

The licence-exempt bands are rife with positive externalities. These are detailed below in Figure 13.

Figure 13 – Sources of externalities in licence-exempt bands

| Source of externality | Nature of externality |
|---------------------------------|--|
| Open standards | Standards such as IEEE 802.11 are developed by a number of organisations and individuals. However, these then benefit other companies who can build interoperable products – without needing to organise licences for spectrum access. They also provide an important platform reducing the complexity of spectrum access and communication. |
| Technology externalities | Manufacturers develop equipment that is better able to direct radio energy to specific targets because that makes their equipment more performant and raises demand. However, such technologies also reduce emissions of unwanted energy, creating a positive externality for nearby users. |
| Application innovations | Innovations can be patented but underlying ideas cannot. This is a key source of positive externalities arising from the rich seam of innovations encouraged licence-exempt spectrum. A number of markets such as those for wearable computing, implanted medical sensors and home automation are emerging |

⁴⁴ Frischmann, *Defining Infrastructure and Commons Management*.

| | |
|---|---|
| | quickly due to these overflows – with entry not chilled by the need to negotiate spectrum access on an individual basis. |
| Creation of nested infrastructures | Perhaps most powerfully, the LE bands have become an infrastructure that encourages the deployment of further downstream infrastructures, many generating immense value. These include: <ul style="list-style-type: none"> • Generalised wireless LANs in places such as universities, hospitals and factories and households which allow for a multitude of uses including vanilla Internet access, item location tracking, security systems and process automation and control to name a few. • Specialised networks such as smart metering networks, city traffic monitoring and control systems and environmental monitoring systems that seek to improve the performance of existing infrastructures |
| Novel usage externalities | The very prevalence of licence-exempt usage and infrastructure is being used in interesting ways. For example, systems such as Skyhook and Google Maps use the identity of Wi-Fi routers to provide accurate geo-location. |

Under a licence-based approach, any potential user of spectrum would only express the private benefits it might capture in any bid made for spectrum access. This has the potential to systematically exclude smaller users and uses which have higher ratios of uncaptured external benefits to private benefits.

2.4 Regulatory action

A number of insights can be gained from this analysis which relate pertinently to the questions surrounding DSA and the choices between rule-based and licence-based spectrum access regimes.

The metaphor of spectrum as land is fundamentally broken. First, frequencies are not as substitutable as parcels of land. As the experience in many nations demonstrates, markets in exclusive-use frequency rights are likely to neither be dynamic nor generate innovation. Second, although the frequency range is finite, its capacity to support communication is a function of technology. Indeed, were it possible for land to undergo the same improvements in use as spectrum then it would be possible many times over to “use of a piece of land simultaneously for growing wheat and as a parking lot”.

Therefore, systems of rule-based access have exploited both these key characteristics of spectrum to create thriving ecosystems. First, they allow multiple users and uses to use the same technologies in the same frequency range, allowing the achievement of critical economies of scale central to fuelling innovation. Second they maximise the incentives of innovators to bring new radio innovations to market that allow for ever more users and uses to non-destructively share the same band.

Advances in technology are decreasing the need for licence-based spectrum access regimes to manage, such as LSA, whilst increasing the applicability of rules-based spectrum access regimes. The failure of markets in tradable exclusive-use spectrum licences, the success of rule-based licence-exempt access and the development of new theoretical perspectives suggest that rule-based access should be the preferred option for DSA.

In the following section we explore in further detail a number of the areas in which the choice of access regime can have profound impacts on market outcomes and consumer welfare.

3 The market impacts from the choice of spectrum access regime

The previous section looked at the conceptual basis of spectrum access regimes; this section examines the practical impact that the choice of regime can have in two important areas, competition and innovation.

In both cases it is shown that spectrum which is accessible on a non-discriminatory basis based on rules rather than through the possession of licences is more likely to generate more competitive conditions and greater innovation. By making rules-based access the core of DSA, regulators will help to facilitate substantial economic benefits.

3.1 New entry, competition and contestability

The choice of access regime in an instance of DSA will have a serious impact on the competitive conditions that develop in the downstream markets that utilise the bands in question.

3.1.1 Obtaining spectrum access

A new entrant looking to gain access to spectrum resources in a particular band will face very different circumstances depending on whether that band is managed under a system of licence-based access or whether rule-based access is permitted.

Under a system such as LSA the new entrant will need to acquire a licence to operate. Under a system of tradable property rights in spectrum there are a number of potential ways that such a right can be gained, through:

- Purchasing frequency rights or LSA rights from a public spectrum exchange
- Winning an award held by the regulator
- Negotiating a private arrangement with an existing spectrum holder

There was once great hope for the emergence of exchanges in spectrum rights, indeed this was one of the key driving forces behind the move to liberalise licences and make them tradable. However, as described in the previous section, the subsequent experience has not borne out the hopes and expectations. The lack of liquidity has effectively prevented the creation of exchanges that would allow the easy purchases of useful spectrum on the open market.

The remaining avenues, winning auctions and negotiating private arrangements, have the potential to prove difficult and prolonged processes.

The auction process for spectrum rights can take substantial time to go from inception to completion. For example the UK's process to auction the bands at 800MHz and 2.6GHz took more than 5 years to complete and other countries have suffered similar delays. The source of these difficulties is often the intense political jockeying between rival bidders as they seek to influence the packaging and rules of the auction. It is unlikely that these delays will subside when LSA rights are being auctioned by regulators. Other mechanisms for assigning LSA licenses are likely to be time consuming, as well.

The chances of new operators winning access to LSA spectrum may also be limited. The majority of spectrum auctions that currently take place are for spectrum suitable

for mobile networks⁴⁵. These auctions tend to be won by existing operators and even amongst these the concentration of holdings tends to increase⁴⁶. There is no reason to believe that awards of LSA rights will prove particularly different. Such concentration may block opportunities for new entrants to meaningfully enter existing markets.

Most of the secondary market transactions that have taken place have been private sales or leases of spectrum. These have normally been cases of spectrum rights concentrating into the hands of larger holders of spectrum. For example in the US most trades have been by large operators buying up regionally issued licences or sometimes even the whole takeover of firms. Some proposed large trades have had the appearance of attempts to exploit regulatory rules (originally intended to expand the ownership of spectrum) for arbitrage opportunities.

In its 2011 report the RSPG suggested that in addition to the regulator led process of enacting LSA described above, LSA could also “be initiated on a voluntary basis”. However, obtaining spectrum access rights through private negotiations may prove a difficult process, requiring detailed negotiations to disaggregate usage rights between the primary user and the LSA user. Technically such deals have been possible in jurisdictions that have tradable spectrum rights, such as the UK, but so far no instances of shared disaggregated access to a band have been negotiated.

The difficulties described in gaining access to spectrum under a licence-based DSA regime would not be present under a rule-based approach to DSA. In the latter system a new entrant would be able to gain access to spectrum in a routine manner:

- If device authorisation is required (licence-exemption) the device may need to contact a database to determine the frequency and transmission characteristics for its location⁴⁷,
- Other rule-based DSA regimes may require equipment registration to be provided to the regulator and possibly fees to be paid (as in light-licensing). However, such a process could be rapidly automated and combined with database lookups.

In either case spectrum policy should ensure that under rules-based regimes, DSA-enabled technologies can gain access to spectrum resources rapidly and in a predictable fashion.

3.1.2 Competition in network deployment

As described above, the choice of access regime plays a key role in determining the ease of spectrum access in a given frequency band, and also serves to shape conditions in the primary markets that rely on those frequencies.

In sectors in which operators can only use technologies that operate over licensed spectrum, the possession of a suitable licence becomes a pre-requisite for entry and participation. This tends to limit the number of companies that can directly compete in many markets. Furthermore, in markets where capacity is important the amount of spectrum possessed by an operator becomes an important factor in the performance of their network. Spectrum accumulation in the hands of incumbents can, therefore,

⁴⁵ For example of the 14 auctions that have been held by ACMA, the Australian telecommunications regulator, since 2000, 9 have been for licencing mobile broadband related spectrum. See ACMA, “Radiofrequency Spectrum Auctions List.” There is little reason to assume that Australia’s experience is not representative.

⁴⁶ US 700 MHz ref.

⁴⁷ in the future other technologies such as cooperative or individual spectrum

serve as a strong barrier to entry, diminishing the interest of new entrants in entering these markets⁴⁸. The decreasing risks of entry combined with strong technological networks effects are likely to encourage firms that are licence holders to undertake consolidation to reduce costs. The combination of these factors decreases the contestability of established licensed markets.

The situation in spectrum that allows non-discriminatory licence-free access is wholly different. The ease of access means that any entity can deploy a network in these bands, either to offer commercial services to other companies or to self-deploy to meet their own needs. For example, as detailed in the previous section some of the largest operators of Wi-Fi networks have been incumbent mobile operators. Although as in most technology markets there are advantages to scale in the deployment of licence-exempt infrastructure there are no licence barriers. As such the provision of services using licence-exempt spectrum can remain more competitive than in licensed spectrum. For example, although in cities such as London and Paris there are major established operators of Wi-Fi hotspots, there are no legal impediments to the emergence of competitors.

The enhancing of competition is a strong argument for rule-based DSA over licence-based approaches.

The access regime within a band of spectrum affects not only industry at the level of network operators but also affects downstream markets and equipment supply markets. We consider these effects in the next section which focuses on the effect of the access regime on innovation.

3.2 Innovation

The previous section described how licensed access to spectrum guarantees the quality of spectrum available to users but comes at the cost of reducing the forces of market competition, even in the context of static technology. However, wireless technologies are at the forefront of innovation. Furthering the innovative potential of spectrum should be a key concern of regulators looking to implement DSA.

In Section 2 we saw how the licence-exempt bands have become the crucible for wireless innovation, here we will outline the underlying mechanisms promoting this competition and see how they are intimately tied to the access regime in place. These mechanisms are equally as likely to apply to understanding the innovation potential of rule-based and licence-based DSA access regimes.

In essence, the use of licence-exempt technologies provides the majority of innovators looking to launch a new wireless product a substantial range of advantages over the use of licensed technologies.

Only a very few innovations have had the required scale to justify the use of dedicated cleared spectrum. The costs of dedicated spectrum rights are very high, including the expenses and risks of licence acquisition, possible radio development and time to market. In recent years even a number of applications that many considered might possess the necessary scale have failed to succeed, with the notable example being mobile TV. There is no evidence that LSA will materially affect these considerations.

⁴⁸ REFS this also explains why regulatory measure to reserve spectrum for new entrants in awards processes leads to ineffective entry (if at all) due to increasing spectrum cliffs, or MAY simply result in arbitrage opportunities – Comcast.

For the majority of innovations, dedicated spectrum does not make commercial sense. Instead they will incorporate existing wireless technologies. As we have seen in Section 2 above, the vast majority of new applications are favouring the use of licence-exempt technologies. The reasons for this can be ascribed to a number of factors, primarily:

- Cost
- Control
- Complexity
- Certainty
- Coverage

The cost of adding broadband licence-exempt connectivity, such as Wi-Fi or Bluetooth is generally an order of magnitude lower than that of adding licensed connectivity such as WCDMA or LTE. A search of the online wholesale electronics portal alibaba.com shows that the lowest price for an LTE module was \$63 whereas the lowest price for an 802.11n module was \$2.50 and for a Bluetooth 3.0 module was \$3.40⁴⁹. In addition, potential innovators must consider the additional costs of data service over licensed networks.

Licence-exempt technologies provide much more control and flexibility over applications deployed. A technology such as LTE is a highly capable means of backhaul, able to deliver connections to the Internet at tens of megabits per second with latencies as low as 20 milliseconds. However, these are also the limits to the technology. Any innovation that requires higher data speeds, such as medical imaging technology, or lower latencies, such as user input devices, or extremely high reliability, such as critical process control safety systems, will not be able to effectively use general purpose LTE. The wealth of standards available in licence-exempt spectrum from ultra-low power Bluetooth to gigabit 802.11ac offers innovators flexibility not found in licensed technology.

Innovation based on licensed spectrum is also discouraged due to the addition of another layer of complexity: the need for either the manufacturer or the purchaser to enter into a commercial relationship with a licence-holder. When wide area connectivity over a mobile network is required another layer of complexity comes into play: the abundance of different spectrum allocations that mobile networks use and the differences between countries and continents. For example, there are 44 different bands in which LTE is set to operate globally.

For long term operation, licensed bands are also a source of uncertainty. For example, those devices that have been designed to use GPRS data will cease to function if mobile operators decide to repurpose the spectrum used by their 2G networks to roll out LTE. By contrast any network deployed using any flavour of Wi-Fi will continue to operate as long as the spectrum remains licence-exempt and equipment can be replaced at the pace required by the user of that equipment.

Finally, many new products are designed to operate in homes and workplaces, and the near ubiquity of domestic and organisational Wi-Fi means that there are very few areas that will not be covered by these networks. The key advantage for many licensed networks is the ability to use high powers to achieve near ubiquitous coverage outdoors and along major transport routes. This may be attractive for the smaller number of innovations that might require true mobile connectivity. However, even in this segment the greater usage of Wi-Fi for wide area networks and seamless

⁴⁹ “Bluetooth 3.0 Rf Module”; “Airprime Mc7710 Lte/hspa+ Module”; “802.11n 150m Wifi Module.”

authentication technologies like Wi-Fi Passpoint could soon result in greater contestability.

Given these advantages it is unsurprising that spectrum managed under rules-based regimes has become the nexus for innovation in wireless technology and applications. It is likely that spectrum made available through DSA through a rules-based regime will be more likely to generate innovation than that made available under licences.

3.3 Regulatory impact

For regulators around the world, encouraging competition and innovation are important goals. A number of conditions created by allowing rules-based access to spectrum resources help tremendously in intensifying both competition and innovation. As such ensuring that an appropriate focus on rules-based DSA is created alongside licence-based regimes can help ameliorate the risks of regulatory failure from relying only on one approach.

In the following chapter we move to concrete examples where the advantageous properties of rules-based access described above will be seen, looking at the role they will play in enabling the Internet of Things and dealing with the expected deluge of data traffic.

4 Dealing with the wireless challenges of the future

Two of the major challenges facing wireless communications are to accommodate the wide range of applications associated with the Internet of Things and dealing with an expected surge of traffic on data networks. In both cases additional spectrum made available through DSA is likely to be of tremendous importance. However, spectrum made available on the basis of rule-based access is likely to be substantially more effective at addressing both challenges.

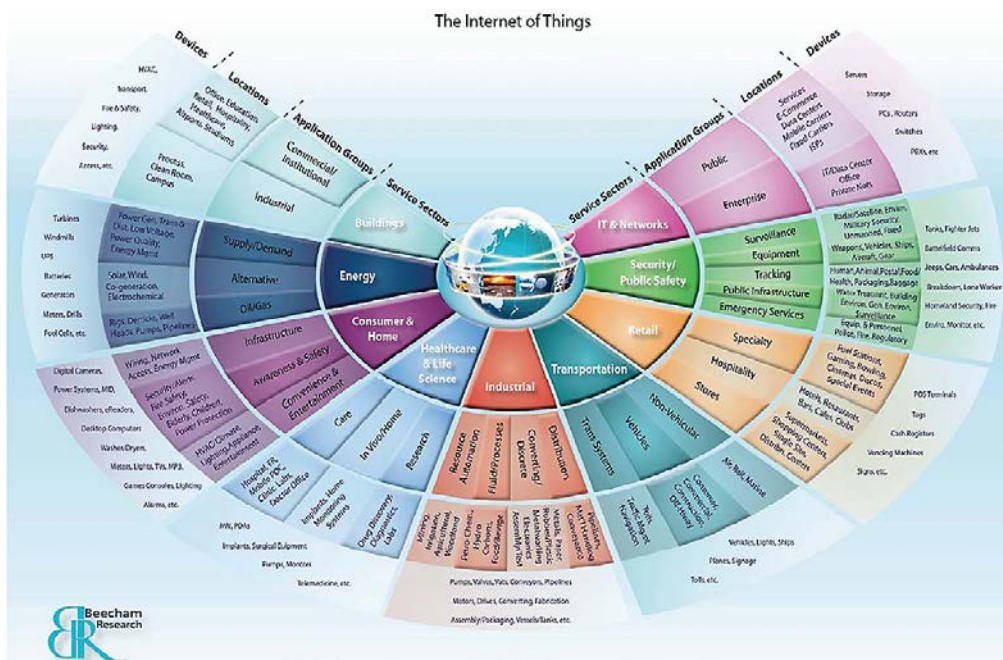
4.1 Implementing the Internet of Things

One of the key challenges for wireless connectivity is to ensure connectivity for the emerging Internet of Things.

At a rapid rate, sensors and actuators, intelligence and connectivity are being incorporated in devices and objects around us including smart electricity meters, precision agriculture systems, and industrial process control networks. This on-going development is called ‘the Internet of Things’. A key challenge for regulation is to ensure that wireless communication does not prove a bottleneck for this process.

The multiplicity of areas which will make up the Internet of Things is shown below in Figure 14.

Figure 14 – application areas in the Internet of Things⁵⁰



The number of end-points making up the Internet of Things is already large and is set to grow exponentially. Cisco estimates that the number of machines connected to the Internet will grow from 2.3 billion today to over 40 billion by 2020⁵¹. Ericsson

⁵⁰ This diagram is taken from Beecham Research’s ‘Sector Map’ from <http://www.beechamresearch.com/article.aspx?id=4>

⁵¹ John Chambers, “Internet of Everything: Fueling an Amazing Future #TomorrowStartsHere.”

estimates that 50 billion devices will be connected by 2020⁵². Although these numbers are large, many times the combined population of the planet, they are by no means unrealistic. A sensor network for home security system may contain hundreds of nodes; a structural integrity monitoring network for a bridge may contain many thousands.

The economic potential of the Internet of Things lies in making existing processes more efficient as well as enabling entirely new applications⁵³. A number of studies have estimated the possible value that these systems might provide in a range of settings. Some notable examples are listed below in Figure 15.

Figure 15 – A selection of studies quantifying the economic impact of the Internet of Things

| Year | Author | Details | Value |
|------|--------------------------------|--|-----------------------------|
| 2008 | GeSI ⁵⁴ | US – energy and fuel savings from solutions based on information and communication technologies | \$140 – 240 billion NPV |
| 2011 | EPRI ⁵⁵ | US – net benefits from the smart grid over 20 years | \$1.3 to \$2.0 trillion NPV |
| 2012 | Machina Research ⁵⁶ | Global – reduce power consumption from connecting heating, ventilation and air conditioning (HVAC) to 2020 | \$40 billion NPV |
| 2012 | GE ⁵⁷ | Global – commercial aviation efficiency improvements and capital cost reduction | \$59 billion NPV |
| | | Global – reduction in rail operating inefficiencies over 15 years | \$27 billion NPV |
| | | Global – oil and gas extraction enhanced by digital oilfield technologies over 15 years | \$90 billion NPV |
| | | Global – reducing health care inefficiencies, better information flow over 15 years | \$63 billion NPV |

The possible scale of the benefits from the Internet of Things is little short of revolutionary. Marco Annunziata, the chief economist at General Electric, writes that it “holds the potential to bring about profound transformation to global industry, and in turn to many aspects of daily life”. More broadly, GE estimates that industrial applications for the IoT could impact up to 46% of the global economy, valued at \$32 trillion dollars.

The Internet of Things presents an interesting challenge for wireless communication. Members of the machine Internet will be much more varied in their requirements for communication than their human counterparts. For example, heart monitors, failsafe industrial systems and houseplant soil humidity sensors will have highly varying requirements for data rates, latency, coverage ubiquity and reliability. In addition,

⁵² Ericsson White Paper, *More Than 50 Billion Connected Devices*.

⁵³ For example a water pollution monitoring network may reduce the need for time-consuming and costly manual checks and also spot potential problems more quickly. However, it will also provide large quantities of data whose analysis may yield even greater insights. Similar principles will apply across a number of application areas, from networks installed in cars which will monitor the health of components to smart agriculture systems that measure soil characteristics, plant health and control irrigation.

⁵⁴ Boston Consulting Group, *GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future*.

⁵⁵ EPRI, *Estimating the Costs and Benefits of the Smart Grid*.

⁵⁶ Machina Research, “The Connected Life: A USD4.5 Trillion Global Impact in 2020.”

⁵⁷ Evans and Annunziata, “Industrial Internet.”

there is likely to be orders of magnitude differences in the economic value delivered by an individual internal cardiac defibrillator and an individual temperature sensor in an agricultural greenhouse.

Figure 16 below assesses the likely characteristics of IoT applications on three dimensions: value, location, and mobility.

Figure 16 – Dominant characteristics of IoT applications

| Value (high/low) | Location (outdoors/indoors) | Mobility (nomadic/static) |
|--|---|--|
| <ul style="list-style-type: none"> The individual value of end points on the IoT is likely to follow a power law distribution: a few high-value uses (eg heart monitors) but most in the long tail of low value (eg building temperature sensors) | <ul style="list-style-type: none"> The majority of IoT application groups will be indoors (home, retail, industrial, administrative, medical) rather than outdoors (environmental, infrastructure, smart city) | <ul style="list-style-type: none"> The vast majority of IoT application groups are likely to remain static or move within buildings, some may require the benefits of true mobility (eg freight and logistics). |

It would appear that the majority of IoT applications will be more suited to licence-exempt rather than licensed operation:

- The lower costs of licence-exempt operation (device, spectrum and battery recharge) will suit the majority of low value IoT uses
- It is likely that the majority of IoT terminals will be in areas where licence-exempt networks already provide coverage
- Static applications will not require the true mobility features that are a the key advantage of mobile systems

In addition, the high number of highly specialised use cases in the Internet of Things will likely necessitate the innovative input of a large number of firms to innovate. Smaller specialist firms designing products for very particular use cases could be expected to use licence-exempt technologies due to the lower barriers to entry and spectrum access certainty. Indeed new standards are being created in order to facilitate this innovation. For example, ‘Weightless’ is a new wireless standard designed for low power/long range operation in the TV white space spectrum, specifically targeting IoT applications⁵⁸

It is therefore unsurprising that of the wireless devices connected to the Internet of Things in 2020, the overwhelming majority – over 95% – are likely to use licence-exempt technologies. The remainder – less than 5% – will be served by cellular systems⁵⁹. Even using the highly conservative assumption that each licence-exempt node generates only a tenth of the value of each licensed node, over 65% of the value of the Internet of Things would come from licence-exempt devices – a figure equivalent to \$6.5 – 9.8 trillion of global GDP by 2030.

Licence-based approaches to DSA, such as Licensed Shared Access (LSA), are likely to yield new spectrum for existing licensees. However, this is unlikely to have a great impact on the possible benefits from the Internet of Things as only a tiny fraction of Internet of Things applications will use licensed technologies. But if the majority of

⁵⁸ See www.weightless.org

⁵⁹ Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*.

spectrum falls under licensed regimes, which are in the hands of a few licensees, given the forecasted growth in the number of devices connected to the IoT, it becomes questionable whether the current amount of spectrum designated for use by unlicensed applications will be sufficient to accommodate the levels of data traffic in the future.

By acting to ensure that the focus of DSA is to establish permissive rule-based access regimes, governments can make available spectrum resources that could then have a much greater ability to address the applications of the Internet of Things. Especially valuable might be enabling licence-exempt access to new regions of the radio spectrum whose properties can enable novel applications. For example, the UHF spectrum in the TV white spaces could be the first broadband capable sub-1GHz licence-exempt spectrum available in many parts of the world. This could enable a host of long range machine uses – from smart city applications to remote infrastructure and environmental monitoring, as is being demonstrated in pilots currently underway in Singapore.

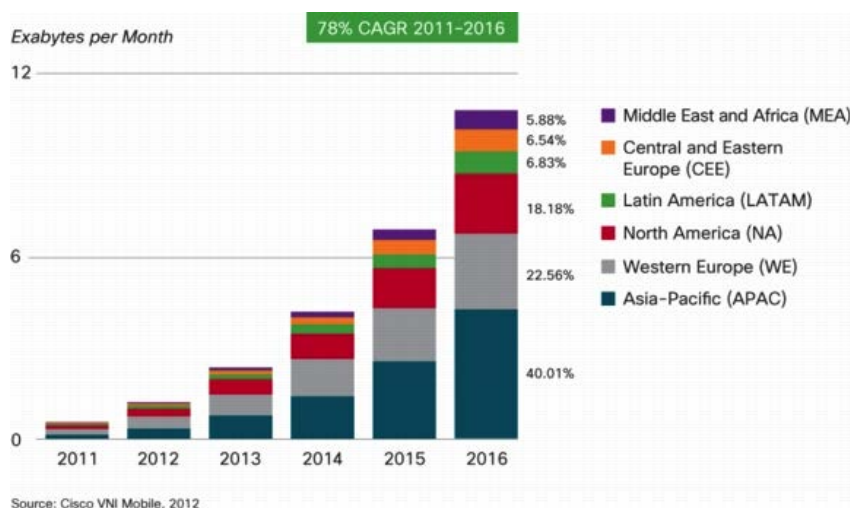
4.2 The demand for data

The previous decade has seen a surge in the traffic that is being carried by networks around the world. Being able to facilitate this growth will be a major challenge of the decades to come.

4.2.1 From mobile networks

Mobile networks have seen a sustained growth in traffic since the introduction of mobile broadband services and this growth is expected to continue in the years ahead⁶⁰. The chart below shows projections from Cisco on the growth of mobile broadband traffic to 2016.

Figure 17 – Cisco's projected growth in mobile data usage by region 2011 - 2016⁶¹



Mobile networks have been a particular area of concern in spectrum policy. Mobile network operators posit a simple argument: exponentially increasing levels of mobile data usage necessitate the correspondingly rapid award of new exclusive spectrum

⁶⁰ Cisco, *The Zettabyte Era*.

⁶¹ Ibid.

rights⁶². However, this argument depends on two fundamental assumptions: that traffic is indeed growing exponentially and that additional exclusive spectrum is the most effective means of addressing this traffic. There is evidence that neither of these conditions holds convincingly.

First, additional exclusive use spectrum is not the most effective way with which to deal with rising traffic. The large-area base station design of existing networks dates from the era of low data rate voice services and uses spectrum very inefficiently. For example a network based on small cells, such as Wi-Fi, is able to achieve an aggregate spectral efficiency at least 30 times greater than large cell mobile networks⁶³. To keep up with exponentially rising demand on wireless networks by simply adding more bands of cleared spectrum would require exponential infusions – an unsustainable proposition. In fact, whereas additional assigned spectrum requires many years to bring into operation additional base stations increase capacity immediately⁶⁴. At present, away from the headlines around LTE and additional spectrum, we are seeing precisely these trends in the mobile industry: a move away from the monolithic macro network towards a network increasingly comprised of small cells⁶⁵.

An even more effective measure than deploying smaller cells is the diversion of traffic away from mobile networks altogether. Wi-Fi access points, the vast majority in homes and in offices, play a central role in today's mobile networks – carrying over 80% of smartphone traffic in many countries⁶⁶. Wi-Fi is also being deployed heavily by operators themselves. For example Figure 18 below shows data from China Mobile's operator-deployed Wi-Fi network, the world's largest⁶⁷, which now carries more traffic than its cellular network. It should be noted that the chart below does not display the contribution of private Wi-Fi networks.

⁶² CTIA, *The Wireless Association® Semi-Annual Survey Shows Significant Demand by Americans for Wireless Broadband*.

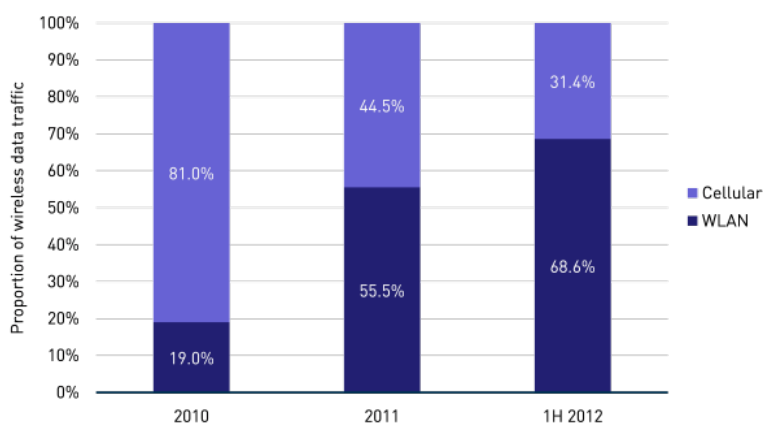
⁶³ Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*.

⁶⁴ For example the eventual auction of the upper 700MHz band in the United States was envisaged in the Digital Transition and Public Safety Act of 2005. However, services using this spectrum were launched only at the end of 2010. In other countries such as the UK this process has taken an even greater length of time.

⁶⁵ In the market for small Wi-Fi based cells competition is fierce with Cisco, Alcatel-Lucent, Ericsson, Aruba Networks, Nokia Siemens Networks and Ruckus as the major competitors (see Mind Commerce, "Global Carrier WiFi & Small Cell Market.") Recently, Cisco announced plans to start developing small cells based on cellular technology, joining a small group of companies such as Ericsson, Nokia Siemens Networks and Alcatel-Lucent (see Lawson, "Cisco to Build Small Cellular Base Stations, Chambers Says."). The market demand for small cells looks set to intensify dramatically over the coming years, 98 percent of operators see them as essential and 9 out of the world's top 10 operators have already begun deployment of small cell solutions. By 2017, small cell shipments could reach 5 million annually greatly exceeding the sales of conventional macrocells which are expected to reach 1.4 million. Operators may need over 40 small cells per kilometre in the denser cities. See Smith, "Big Hopes for Small Cells, But No Clear Path to Success"; Goldstein, "Report"; Gabriel, "Cities Will Soon Need 40 Small Cells Per Square Kilometre - Rethink Wireless." As described above the extremely high price/performance ratio of Wi-Fi will likely prove a decisive factor in its use alongside or even in preference of cellular technology.

⁶⁶ informa, *Understanding Today's Smartphone User: Demystifying Data Usage Trends on Cellular & Wi-Fi Networks*.

⁶⁷ China Telecom aims to have deployed 1 million Wi-Fi hotspots by the end of 2012, see Shen, "China Telecom Aims for 1m WiFi Hotspots."

Figure 18 - China Mobile's wireless data traffic by network type⁶⁸

Operators are turning to Wi-Fi for its universality as every smartphone in the world can connect to Wi-Fi networks and precisely because it is a shared medium, giving mobile operators maximum flexibility to deploy hotspots when and where needed. In contrast, the frequencies and technologies used in cellular systems are increasingly fragmented, for example there are 44 different bands of operation of LTE. In addition, Wi-Fi is cost-effective: a Wi-Fi access point can deliver capacity far in excess of a mobile base station at a fraction of the cost⁶⁹. Judging by the speed and enthusiasm of Wi-Fi take up its advantages would appear to outweigh its use of contended spectrum.

The financial benefit that Wi-Fi is providing for mobile operators is immense. Without the support of Wi-Fi 150,000 to 450,000 new base stations would require immediate deployment, at a cost to the industry of \$30 – \$93 billion⁷⁰.

In the future Wi-Fi is expected to play an even greater role as faster Wi-Fi standards and new automatic authentication techniques, such as Passpoint, are introduced. This will allow the large Wi-Fi networks operated by established mobile operators and other entities such as FON, BT, Sky, Free and Comcast to become much more attractive propositions for the consumer, substantially increasing competition in the markets for the provision of nomadic/mobile broadband. Furthermore, Wi-Fi is as central to the small cell solutions being deployed by mobile operators as are technologies such as LTE.

In addition to dealing with traffic flows, a number of credible sources are now suggesting that the era of exponential growth in mobile data traffic is already ending in developed nations⁷¹. This is due to a number of factors:

- Operators are using price to control traffic;
- The rate of growth in smartphone adoption is declining as penetration rates plateau;

⁶⁸ Source: China Mobile, Analysys Mason see Analysys Mason, *China Mobile's Latest Network Traffic Data Provides an Insight into the Growing Importance of Wi-Fi to MNOs*.

⁶⁹ Wi-Fi is a high volume consumer technology whereas mobile base stations are a specialist low volume technology: "For example a cellular picocell costs from \$7,500 to \$15,000 whereas a much higher capacity carrier-grade Wi-Fi access point costs around \$2,000. The cost of a Wi-Fi chipset for a consumer device is around \$5, whereas 3G cellular chipsets costs around \$30" see Thanki, *The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet*, 32.

⁷⁰ *Ibid.*, 38.

⁷¹ See for example Farrar, "The Myth of the Wireless Spectrum Crisis"; Analysys Mason, *Crisis Ahead for European Mobile Operators: Data Growth Dangerously Slow, and Network Costs Unhealthily Low*. The latter makes fascinating reading, "Growth in Western Europe was 61% in 2011, and every sign indicates it will be far lower in 2012... there is **not enough growth in mobile data** to stop the mobile industry in most developed countries from contracting." This is starkly in contrast with claims from the mobile industry that networks are doomed without additional spectrum.

- The greatest growth in the use of bandwidth intensive applications is in homes and workplaces that are already covered by efficient and cost-effective Wi-Fi.

Indeed in the latest version of its highly cited Visual Networking Index (VNI), Cisco has cut its projection for traffic over mobile networks in 2016 by over 30%.

Especially in Europe, the case for DSA is often focused on using LSA to create additional licensed allocations – primarily for the benefits of existing licensees. However, the evidence does not suggest that exclusive-use LSA is the only route through which existing licensees can benefit from DSA. In fact the use of rule-based access regimes, such as license-exempt dynamic spectrum access, can create greater opportunities for mobile operators to manage their traffic than can further exclusive use licensing or LSA.

4.2.2 From other networks

The strong focus on mobile networks can obscure the fact that other networks will also experience dramatic volumes of traffic growth. Cisco now predicts that traffic on mobile networks will grow from 0.85 Exabytes (EB) a month in 2012 to 11.2 EB in 2017, a 13-fold increase. However, over the same period the volume of traffic offloaded by smartphones onto fixed networks will grow from 0.43 EB a month to 9.6 EB a month, a 22-fold increase. Furthermore, the total growth in the volume of traffic on fixed networks over the same period is likely to be over 40 EB – far greater than the total carried over mobile networks – with the majority likely to travel using Wi-Fi.

The majority of the overall projected traffic growth from all networks will not be transmitted through licensed mobile spectrum but will instead rely on licence-exempt spectrum. According to many analyses a large majority of smartphone traffic is already carried over Wi-Fi. The emergence of super-fast broadband over fibre is already pushing Wi-Fi to its limits⁷². In addition the majority of upcoming tablet and hybrid PCs will be Wi-Fi only devices, further increasing Wi-Fi traffic loads⁷³. As detailed above, the emergence of the Internet of Things is likely to add many billions of new terminals over the next decade, the vast majority of which will communicate over licence-exempt networks⁷⁴. The combined impact of these changes will place tremendous pressure on the existing rule-based spectrum allocations used by technologies such as Wi-Fi.

Faced with such demands for traffic, the use of DSA to enable spectrum to be quickly made available to users could prove of substantial value. Should this spectrum be made available under LSA it will help address only a small part of the overall capacity challenge. It will be unable to provide assistance in dealing with most sources of traffic detailed above. Spectrum released through more permissive rule-based modes of management will better address the data demands across a range of networks, from consumer broadband to machine communication.

⁷² See Farivar, “Google Fiber Is Live in Kansas City, Real-world Speeds at 700Mbps,” for an example of how the speeds possible over the Google Fiber service in Kansas City overwhelm the ability of Wi-Fi to deliver those speeds. Gigabit broadband is being rolled out now in many countries.

⁷³ For example, of the five launch tablets for Microsoft’s new Windows RT operating system only two offered cellular connectivity as an option. The vast majority of tablets using Google’s Android operating system are Wi-Fi only. Apple also likely sells many more Wi-Fi only iPads than those with cellular connectivity.

⁷⁴ Cisco Systems and Ericsson estimate 50 billion using bottom-up methodologies. Using a top down approach Thanki (2012) suggests 100 billion could easily be possible.

5 Conclusion

In this paper we have shown how licence-exempt rule-based access to the radio spectrum has been a phenomenal success. The relatively small ranges of frequencies opened up for non-discriminatory access have quickly become home to the majority of wireless innovation, the majority of wireless devices and the majority of wireless data traffic. This has surprised many in the spectrum management community who expected tradable exclusive licences to be the focus of investment, competition and innovation.

However, should we really be surprised?

The rule-based approach to managing the radio spectrum is very similar to the approach we use to manage a number of other immensely productive and vital infrastructures. For example, the road network of every country is also managed in a rule-based fashion. Whether a heavy truck is part of the vast logistics fleet of the Coca-Cola Company or the single vehicle of an independent road haulier, it has access to the roads on an identical basis. That is not to say the road network is without rules – indeed it has detailed codes, covering every aspect of road use from maximum speeds and vehicle maintenance requirements to laws regulating the transport of hazardous materials and the movement of livestock. Some rules are specifically designed to expedite the rapid movement of certain users such as ambulances and heads of state and others such as congestion charging are designed to ease the general flow of traffic in specific areas. Even toll roads are subject to laws preventing discrimination.

From the viewpoint of strict neo-classical economics the situation on the roads is inefficient. It may well be that some users would value a quicker journey more than others and that advantageous trades may be possible. However, creating a system of property rights that might effectively facilitate trade amongst a multitude of heterogeneous users without creating ghastly complexity is probably beyond reach. Certainly we would immediately question the ability of crude systems of property rights – such as schemes seeking to sell exclusive rights to particular roads, lanes or times of travel – to achieve the ideal of Pareto efficiency. In particular we would be rightly suspicious of any scheme that sought to licence a particular number of operators in any commercial endeavour (from national courier services to local pizza delivery) as a prospect that was almost inviting regulatory failure.

However, that is precisely what is being proposed with tradable exclusive-use spectrum licences. LSA is particularly fraught as the regulator may have to choose just how many LSA users to authorise in a band. These schemes may have worked in the past when the number of entities willing and able to deploy their own wireless networks was very small. However, in the era of ubiquitous Wi-Fi, personal area networks and the legion of uses that will constitute the Internet of Things, the idea of tradable exclusive rights being able to facilitate these myriad uses appears remarkably far-fetched.

One of the last remaining arguments that might support the case for widespread licence-based DSA is that of quality of service (QoS). Indeed, the only real advantage of LSA claimed by the RSPG over CUS is the supposed ability of LSA to provide guaranteed QoS. However, we must question the validity of such a statement. First, the multitude of applications that will inhabit the wireless world will have very different requirements for QoS. For example the QoS demanded by an Internet of Things application that reports a small amount of non-time critical data twice a day will be very different from the QoS required for a live video streaming service. Moreover, rule-

based schemes are inherently more flexible in negotiating QoS. For instance, in the case of the video streaming services that necessitated a very high QoS, a very densely deployed, dedicated, directional wireless system deployed in licence-exempt spectrum can provide greater QoS than a general purpose LTE network that will be shared with ordinary subscribers. Furthermore, technologies operating in rule-based spectrum can be upgraded continuously to accommodate advances in distribution technologies and allocate QoS in the most spectrally efficient manner.

Perhaps the most important characteristic that distinguishes a resource like roads, for which society mandates open access, from a resource like land, which is largely managed using property rights is *substitutability*. As shown by traffic-jams created by accident blocked roads there are very few alternatives to many stretches of road. However, for most uses a plot of land has very many close substitutes. The substitutability of radio spectrum is much more akin to that of roads than that of land. For a frequency band to be useful requires a large amounts of infrastructure that is designed to be able to use those frequencies – and vice versa. It is therefore clear why dynamic markets in tradable licences have never emerged but that dynamic markets in Wi-Fi capacity – which is easily substitutable – are already emerging⁷⁵.

Granting exclusive-usage rights – over frequencies or frequencies at particular times or in particular places – is likely to hinder efficient usage and innovation. Instead, rule-based access has generated a virtuous cycle in which rapidly increasing usage enables and is enabled by advances in technology that allow ever more interleaved, interference-resistant communication. This is creating an unprecedented boom in wireless innovation as innovators are voting with their feet and adopting the licence-exempt bands which offer a multiplicity of low-cost, reliable and globally harmonised standards. Instead of pushing against this trend with schemes such as LSA, whose justification lies in economic theory rather than achievements in practice, better regulation would focus on expanding rules-based access, whose current achievements are only an inkling of its future potential, to further and more varied bands of spectrum.

⁷⁵ For example, see the website of the new startup BandwidthX www.bandwidthx.com

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