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The economic value generated by current and future allocations of unlicensed spectrum

Final report

PERSPECTIVE
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About this study and its author

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Perspective Associates was established in January 2008 to focus specifically on issues related to public policy and regulation as they apply to the media and communications sectors.

Using high level experience in gained in government, regulation and creative production, we offer wide-ranging and authoritative advice to clients across the media and communications industry as well as to governments and public bodies.

Contents

Preface

The use of the radio spectrum has opened up enormous opportunities for citizens and consumers alike. Through careful husbandry and enlightened management, advances in communication and connectivity have allowed audiences to share, individuals to communicate, citizens to participate and commercial enterprises to innovate. At the same time, governments have been able to share in the wealth generated by this activity, as well as themselves benefiting from the ability to communicate more directly with the people they govern.

The desire to use the spectrum in increasingly efficient ways to reach large numbers of people has itself been a motor for innovation. But, as we aim to show in this paper, innovation has been at least, if not more, marked in applications that, while aiming at mass consumer markets, were nevertheless able to use the freedom of unlicensed spectrum to develop, test and refine uses that have enriched the communications experience of individuals and the commercial performance of businesses.

Our contention is that regulators and legislators have the option now to reinforce the level of innovation and advancement in communications by recognising and supporting the use of unlicensed applications in areas of spectrum that are being liberated by technological advance – most notably, the 'white spaces' that exist in the valuable frequency bands currently used to transmit television.

By actively encouraging the use of this spectrum for unlicensed development and use, we argue that there are powerful opportunities for citizens, for consumers, for business, for government and for the widest international community. In this paper we attempt to quantify what we think some of those benefits could be – not as an exhaustive list, but as an indication of the powerful arguments that can and must be developed. We root our analysis in the demonstrable benefits that have already accrued from the use of unlicensed applications, combined with the powerful potential of the white space spectrum itself.

For our argument to succeed, we believe that there are a number of important preconditions. First, the economic analysis needs to establish the potential benefit that can stand alongside the benefits that could accrue from a more conventional licensing approach. Second, regulators and governments need to be convinced of the power of these arguments, such that refraining from licensing becomes an important tool in the maximisation of value in spectrum rather than an approach for spectrum for which no other use can be found. Third, international cooperation will be needed if we are to secure the highest value from this approach.

This paper embarks on the first of these pre-conditions. It is not exhaustive – by definition, seeking to expose the innovative potential of a particular approach to a particular band of spectrum can only hint at the uses that might develop were the spectrum to be available. But we hope that it is more than suggestive: we hope that it is convincing in making the case that unlicensed use of white spaces represents possibly the most exciting step so far in our attempts to use the spectrum for the widest social and commercial gain.

1. Introduction

The use of the electromagnetic spectrum has facilitated a sequence of revolutions in human communication.

The first mass-market applications enabled were broadcast radio and television, and their effects cannot be overstated. A large part of the cultural change experienced in the 20th Century was communicated through, and even shaped by, these media. Indeed, many of the significant moments in the history of the last century were shared simultaneously by millions of people through television and radio, and are retold using the pictures and sound that were broadcast. Alongside this cultural significance arose substantial economic benefits. Creative, commercial and manufacturing industries were established around these platforms.

The introduction of mass market cellular telephony in the 1980s marked a second phase in the expansion of devices using spectrum; the first widespread deployments of two-way communications devices. In a relatively short period of time, mobile phones have gained near-universal popularity and the number of global mobile phone connections has eclipsed the number of fixed lines. By allowing people to communicate with others, wherever they are, mobile phones have had a dramatic effect on the manner in which people conduct their lives. The consequent economic and social impact has been significant.

Broadcasting and cellular telephony are both applications that use licensed spectrum, in which network operators have exclusive use of a particular range of frequencies in a particular geographic area. Indeed, the majority of spectrum is held under such exclusive use arrangements, either by the government or by private entities.

Today we are beginning to witness a third phase of significant growth in wireless devices, marked by a proliferation of devices using not licensed spectrum, but unlicensed spectrum.

Some uses of unlicensed spectrum are familiar, such as Wi-Fi to connect to the internet or a Bluetooth headset to speak on a cellular phone, hands-free. With others there may not even be a common awareness that radio frequencies are being employed, such as with a SmarTrip card used on the Washington DC subway or a wireless controller for a games console. An increasing number of applications are removed from the consumer sphere. These include Wi-Fi to provide rapid communication between doctors and nurses in a hospital, and wireless sensor networks within industry to measure and control processes, and by governmental agencies to monitor pollution in the air and water.

The essence of unlicensed spectrum is that any certified device can operate within it, with only minimal restrictions placed upon the uses to which it may be put. By providing guaranteed and non-excludable access to spectrum, unlicensed spectrum encourages manufacturers to collaborate in the development of open standards, and to compete in the delivery of low cost components and user equipment. The availability of mass-produced hardware and guaranteed access to spectrum has encouraged experimentation and innovation, leading to new products and models for service delivery. Some of these are mass-market successes, such as Bluetooth and Wi-Fi, whilst others are bespoke applications, targeting particular specialised markets.

The remarkable innovation seen in unlicensed spectrum shows no sign of abating. Radio-frequency identification (RFID) tags are becoming commonplace in passports and in credit cards; they are also being used to make substantial improvements in the supply chain across a number of sectors. ZigBee and Bluetooth Low Energy are vying to become the standard for low power short-range connectivity within homes and offices and will be increasingly encountered embedded in commonplace electronics and appliances. Combined with smart meters monitoring energy usage, these devices may soon enable significant savings in power and improvements in the quality of life. Wireless connectivity is being added in radical ways to existing critical health devices such as pacemakers and insulin pumps.

This innovation in unlicensed spectrum is built on the competition between thousands of manufacturers, service providers and systems integrators of varying scale and scope competing to sell a wide range of products and services directly to the end-user. In contrast, voice and data services in licensed spectrum are provided by a small number of network operators, selling largely similar bundles of services. The lower barriers to entry and transaction costs that characterise unlicensed over licensed spectrum have enabled the development of a more vigorous free market.

As we determine in this paper, devices using solely unlicensed spectrum are poised to outsell those that solely rely upon licensed spectrum. This trend is rooted in a new paradigm in communications. Whereas devices using licensed and unlicensed spectrum have traditionally enable the transmission of data to or between people, a large and growing number of unlicensed devices are designed to transmit data between electronic devices.

Many benefits are likely to flow from this increase in unlicensed usage. New ideas for applications will lead to new companies forming to exploit the opportunities available. In turn this is likely to generate jobs, economic growth and knowledge which can be exported to other markets. New products and services built on the use of unlicensed spectrum have already led to substantial improvements in productivity in a number of areas. We quantify some of these benefits in this paper. Further improvements will allow greater cost-savings in commerce, healthcare, education and in government, allowing the delivery of more effective products and services.

A more subtle but potentially as appreciable benefit could arise from the substantial increase in the number of networked devices that is forecast over the coming years. Just as the value to any one user of the telephone network increases as more subscribers are added, the value of the networked world will increase as an increasing number of devices are interconnected. As the number of devices increases in a linear fashion, the number of potential connections between them increases exponentially, and this is likely to lead to any number of new applications and innovations which cannot yet be predicted with any certainty.

This increased focus on unlicensed applications naturally leads to questions about of the adequacy of existing unlicensed allocations, and the potential for new innovations and application that could arise from future allocations. The television 'white spaces' is one such allocation. These channels occupy a frequency band whose characteristics differ substantially from existing unlicensed allocations. Transmissions using these frequencies can attain a greater range for the same power – or lower power consumption for the same range – than existing allocations. Allowing unlicensed usage in the white spaces has the potential to improve existing applications and generate innovative applications. In this paper, we attempt to quantify some of the economic value that might be realised.

Chapter 2 provides a brief overview of the development of both licensed and unlicensed spectrum.

Chapter 3 details both the spectrum bands available for unlicensed usage and the technologies that have been developed to make use of this spectrum. It also outlines the large ecosystem of uses that has already been established. Our analysis in this chapter suggests that over the coming 5 years the sales of devices using only licensed spectrum are likely to be overtaken by sales of devices using both licensed and unlicensed spectrum. The sales of devices operating solely using unlicensed spectrum are likely to eclipse both.

Chapter 4 assesses the economic value of three existing unlicensed applications, Wi-Fi in homes, Wi-Fi in hospitals and RFID in clothing retail outlets in the US. Our conservative estimates put the existing economic value being delivered by Wi-Fi in homes at **$4.3 – 12.6 billion** a year. In combination these three uses could generate an economic value of **$16 – 37 billion** a year over the coming 15 years. Although substantial, our modelled uses only account for 15 percent of the total projected market for unlicensed chipsets in 2014 and therefore are likely to significantly underestimate the total value being generated by unlicensed usage over this time period.

Chapter 5 examines the potential for innovation in both licensed and unlicensed spectrum

Chapter 6 introduces the white spaces and assesses their suitability for licensed or unlicensed use

Chapter 7 outlines the economic value that might be generated from existing Wi-Fi applications improved through using the white spaces. This could be in the range of **$3.9 –7.3 billion** a year over the next 15 years.

Chapter 8 looks at some new unlicensed uses that could be enabled by the white spaces, specifically the enhanced ability to deliver rural broadband and the potential for water saving in agriculture. Our modelling here estimates the magnitude of the benefits from a European perspective, and puts the annual economic value that might be generated at **$0.8 – 4.3 billion** a year. The order of magnitude of these benefits from a US perspective may be similar.

2. The forms of spectrum management

From free-for-all to restricted licences

In the early days of radio, attempts by the US government to restrict the number of radio licensees failed, when in 1923 a federal court ruled that the Secretary of Commerce had no legal basis on which to do so. Subsequently there was an explosion of new radio stations. This resulted in a free-for-all in which broadcasters engaged in 'power races' and 'frequency races' to drown out each others' signals and listeners were often only able to tune in to garbled static.

In response to this situation, civil actions were filed and the courts began to adjudicate the usage rights to spectrum. Hazlett (1990) presents fascinating details of this era and the common law that began to be built to address this situation[1]. However, these developments were cut short by the Radio Act of 1927 which established radio spectrum as an inalienable public resource and gave over its management to the Federal Radio Commission, a forerunner of the FCC. This action marked the beginning of strict governmental control of the airwaves.

The methods by which spectrum came to be managed has been termed one of 'command and control'. This referred not only to the means of licence allocation (often by beauty contest or lottery), but the conditions that were attached to the licences, such as a strict specification of technologies to be used and service or application to be provided, and restrictions on transfer. Indeed terrestrial broadcasting in most countries operates within 'command and control' licences.

However, in the latter part of the 20th Century, governments and regulators began to introduce greater market forces into the usage of spectrum, to improve the efficiency with which it was allocated between uses. Two methods have been employed, liberalised exclusive-use spectrum licences and unlicensed spectrum.

Liberalised exclusive-use spectrum licences

Ronald Coase's seminal paper in 1959[2] laid out deficiencies in the command and control method of spectrum management. Coase argued that this method led to serious inefficiencies in the use of spectrum. Furthermore, he presented an approach based on property rights and market mechanisms which he believed could improve the allocation and utilisation of spectrum. Although these ideas were initially dismissed, over time they have gained recognition, especially in the US and in Europe.

The extent to which Coase's ideas have been adopted varies across nations. However, a number of common components can be identified:

- Spectrum auctions – to allocate spectrum initially. Auctions are supposed to ensure that those entities that value particular spectrum most will be able to gain access to it
- Secondary markets – to allow the trading of spectrum licences so entities can aggregate and disaggregate spectrum holdings according to their commercial needs[3].

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[1] (Hazlett, 1990)
[2] (Coase, 1959)
[3] Spectrum markets have remained undeveloped. A number of reasons have been postulated for the inactivity. Some have suggested that these markets will need time to develop, and that not enough tradable spectrum has been released into the market. More sceptical voices suggest that there is very limited substitutability

- Liberalised use – to provide holders of spectrum licences freedom to change the use to which they put their spectrum, subject to technical rules to prevent interference to other services and applications.

Much of the spectrum used by cellular networks is held under liberalised spectrum licences.

Unlicensed spectrum

A second method by which market forces have been introduced into the usage of spectrum has been through unlicensed spectrum. A pivotal moment in the history of unlicensed usage of spectrum came in 1985, when the FCC ruled to allow the use of direct sequence spread spectrum (DSSS) technology for communications in the ISM bands in the US[4]. These bands were primarily used for non-communications industrial applications, and as such, were regarded as 'junk spectrum'. However, DSSS was designed to be resistant to noisy environments and thus enabled the deployment of robust and valuable services.

Thereafter, a number of important uses of this band were launched: initially specialist proprietary wireless local area networking (WLAN) systems, subsequently consumer-orientated Wi-Fi and Bluetooth, and more recently devices based on the IEEE 802.15.4 standard, such as ZigBee and WirelessHART[5]. It is now common to see a large number of Wi-Fi access points in densely populated areas of cities. These points are able to work well collaboratively due both to the use of DSSS and politeness protocols devised by the industry standards bodies, which can be most easily thought of as machine versions of the human rules which amateur and CB radio operators were expected to use. A rich ecosystem of uses has subsequently developed in unlicensed spectrum.

A more detailed description of the development of spectrum management can be found at Annex 1.

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between various spectrum bands, and that in very valuable spectrum bands, as long as utilisation remains high relative to capacity, spectrum will remain a core strategic asset, and is only likely to change hands when whole companies are bought and sold.

[4] (Negus & Petrick, 2008)

[5] The relationship between IEEE 802.15.4 and ZigBee and WirelessHART is similar to that between IEEE 802.11 and the Wi-Fi Alliance.

3. The ecosystem of applications using unlicensed spectrum

A number of different bands of spectrum permit unlicensed use, and a variety of proprietary and open standards for communication have been developed to make use of the spectrum available. Applications built using these standards have been deployed in many sectors, including for use by consumers, businesses, public bodies and in industry.

The different bands available

The bands available for unlicensed usage in the US can be split into two categories, narrowband and wideband spectrum. A number of very narrow bands are available, especially at lower frequencies. These do not provide the necessary bandwidth to permit fast data communication.

Figure 1 – Low bandwidth unlicensed spectrum in the US

Band location (MHz)	Size of band (MHz)	Uses
0.130 MHz	0.009	RFID
0.144 MHz	0.008	RFID
6.780 MHz	0.030	RFID
13.560 MHz	0.014	RFID
27.120 MHz	0.326	Telemetry, Telecommand and Model Control
40.680 MHz	0.040	Telemetry, Telecommand and Model Control

Source: Perspective analysis

In addition to these narrow bands, there are wider bands of spectrum available, largely above 1GHz. Devices using these bands can provide faster data transfer; however, the propagation characteristics of this spectrum limit non-line-of-sight communications to a relatively short distance.

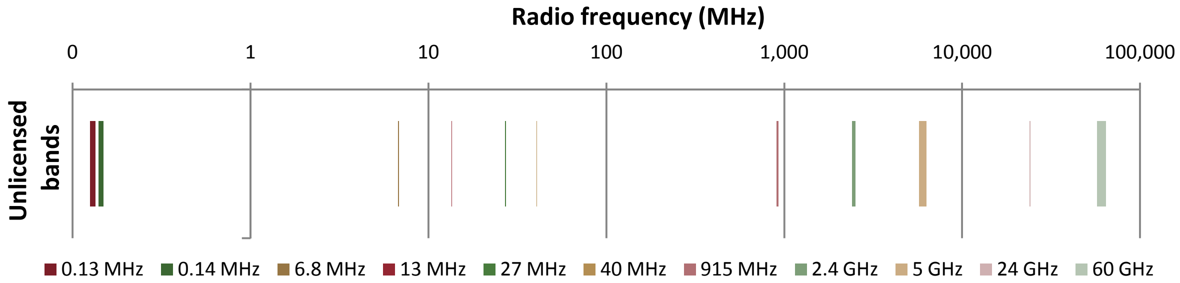
Figure 2 – High bandwidth unlicensed spectrum in the US

Band location (MHz)	Size of band (MHz)	Uses
900MHz	26	802.15.4/ZigBee, RFID, cordless phones
2.4 GHz	84	802.11/Wi-Fi, 802.15.1/Bluetooth, 802.15.4/ZigBee, RFID, cordless phones, CCTV
'5 GHz' (5.8 GHz)	555	802.11/Wi-Fi, 802.16/WiMAX, microwave point-to-point links, cordless phones, road traffic and transport telematics
24.125 GHz	250	Movement detection
60 GHz	7000	WirelessHD/WiGig, 2nd phase road traffic and transport telematics

Source: Perspective analysis

Figure 3 below shows that only a very small part of the radio spectrum is available for unlicensed usage.

Figure 3 – Unlicensed spectrum in the US



Source: Perspective analysis

The different technologies using unlicensed spectrum

In this chapter we describe in more detail some of the major unlicensed uses of spectrum mentioned above. We begin with the shortest range uses, and then move on to longer range ones.

RFID

Radio-frequency identification (RFID) is the use of an object (typically referred to as an RFID tag) applied to or incorporated into a product, animal, or person for the purpose of identification and tracking using radio waves. Some tags can be read from several metres away and beyond the line of sight of the reader.

RFID is becoming increasingly prevalent, and is finding applications in many different sectors. Some of these are outlined in Figure 4 below.

Figure 4 – Uses of RFID

Use	Description
Supply chain management	the key early driver for developments and implementation of the technology
Asset tracking	tracking of assets in offices, labs, warehouses, pallets and containers in the supply chain, books in libraries
Medical applications	linking a patient with key drugs, personnel giving the drugs, biometric measurements
People tracking	security tracking for entrance management or security, contact management at events, baby tags in hospitals to manage access to post natal wards
Manufacturing	tracking of parts during manufacture, tracking of assembled items
Retail	tracking store trolleys in supermarkets, active shelves
Transport payments	paying for public transit systems, such as Washington DC's SmarTrip system and for highway toll systems
Warehouses	real-time inventory by automated registration of items in a warehouse or storeroom
Livestock	implanted RFID tags in animals for tracking and linking the animal to food, location. Applicable to farming as well as exotic breeds in zoos
Timing	sports event timing to track athletes as they start a race and pass the finish line

Source: rfidXchange

Later in this paper we attempt to quantify the economic value generated by the use of RFID in the retail clothing sector.

Wireless HD/WiGig

WirelessHD and WiGig are standards in development to use the 60 GHz unlicensed band to achieve multi-gigabit data transfer over the range of a few metres. These systems will take advantage of the high absorption caused by oxygen in the 60 GHz band, which limits signal propagation to a few metres, to reduce interference with neighbouring systems.

Wireless HD is focussed on the transfer of uncompressed high-definition audio-visual signals for consumer electronics products. It also has provisions for content encryption and protection.

WiGig is a standard being promoted by a group that includes Intel, Microsoft, Nokia and Panasonic. The technology is being designed for more general data transfer than WirelessHD, including applications such as file transfer and the attachment of high bandwidth computer peripherals such as HD displays and storage devices. The technology is likely eventually to become part of the Wi-Fi standard, providing connectivity over the 2.4GHz, 5GHz and 60GHz bands, at different speeds, depending on the strength of the signal in different locations.

Since both the WirelessHD and WiGig standards are in active development the list of uses in Figure 5 below represents a preliminary view of the applications this unlicensed band might enable.

Figure 5 – Uses of 60GHz unlicensed standards

Use	Description
Home entertainment	streaming uncompressed HD video within rooms
Data networking	transferring very large files and other data between computers and storage systems
Wireless docking	linking a device to external displays, storage and printers, also replacing the last metre of Ethernet cable found in offices
Industrial, scientific and medical	communication with sensors such as digital imaging chips, producing hundreds of megabytes of data a second

Source: Perspective analysis

Wireless PANs 802.15.1/Bluetooth

A wireless personal area network (WPAN) is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one's person. The reach of a PAN is typically a few meters. PANs can be used for communication among the personal devices themselves, or for connecting to a higher level network and the Internet. The most widely used such technology is Bluetooth, which was used as the basis of the IEEE 802.15 standard. However, the 802.15 working group within the Institute of Electrical and Electronics Engineers (IEEE) has now severed its links with Bluetooth.

Bluetooth has proven enormously popular and is now found in most cellular phones[6] and portable computers. This expansion of Bluetooth enabled devices is expected to continue as described at the end of this chapter.

[6] (In-Stat, 2009)

The uses for Bluetooth are shown in Figure 6 below.

Figure 6 – Uses of Bluetooth

Use	Description
Mobile phone connectivity	headsets linked to a mobile phone via Bluetooth were one of the earliest applications to become popular. Bluetooth is now increasingly used for this purpose in automobiles, to allow handsfree calling
PC networking	PC networking in a confined space and where little bandwidth is required
PC input and output devices	communication between a PC and a mouse, keyboard and printer.
Replacing wires	communications in test equipment, GPS receivers, medical equipment, bar code scanners, and traffic control devices
Gaming	two seventh-generation game consoles, Nintendo's Wii and Sony's PlayStation 3, use Bluetooth for their respective wireless controllers.
Wireless payment	credit card payments in restaurants, bars and other commercial premises
Marketing and promotion	sending small advertisements from Bluetooth-enabled advertising hoardings to other, discoverable, Bluetooth devices
Industrial	wireless bridge between two networks
Medical	wireless blood pressure monitors, stethoscopes, weight scales and other devices

Source: Perspective analysis

Low data rate wireless PANs 802.15.4/ZigBee/Bluetooth Low Energy/Wireless HART

The IEEE standard 802.15.4 intends to specify a type of wireless personal area network (WPAN) which focuses on low-cost, low-speed ubiquitous communication between devices (in contrast with other, more end user-oriented approaches, such as Wi-Fi).). Devices can transmit from 10 to 75 metres at a maximum transfer rate of 250 kbps. The key distinguishing feature of 802.15.4 among WPANs is the importance of achieving extremely low manufacturing and operation costs and technological simplicity, without sacrificing flexibility or generality.

ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard. It is aimed at the home and commercial market. Bluetooth Low Energy was launched in 2009 and is expected to be a direct competitor to ZigBee.

WirelessHART is also a technology founded on the IEEE 802.15.4 standard. Whereas ZigBee and Bluetooth Low Energy are focussed on consumer and commercial products, WirelessHART’s focus is more on the industrial sector providing sensory and control devices. It transmits on the 2.4GHz band globally.

Figure 7 below lists a small number of the existing uses of 802.15.4 products.

Figure 7 – Uses of 802.15.4

Use	Description
Home automation	consumers can control their energy consumption, environment, lighting, safety, and security in their homes or small offices.
Smart energy	wireless home area networks (HAN) for managing energy, advanced metering and demand response programs by utilities and energy service providers.
Building automation	allows Integration and centralised management of lighting, heating, cooling and security. This can improve conservation, flexibility and security
Health care	interoperable wireless devices enabling monitoring and management of

	healthcare services targeted at chronic disease.
Remote controls	RF remotes for consumer electronics devices can allow operation of devices from greater distances and removing the existing line-of-sight barriers. They also enable two-way communication between the device and the remote.
Wireless sensors	wireless sensor networks cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.
Process control and automation	industrial processes such as controlling the rate of flow, switching on and off systems can be controlled remotely or in collaboration with sensor networks.

Source: Perspective analysis

Wireless LANs 802.11/Wi-Fi

A wireless LAN (WLAN) is a wireless local area network that links two or more computers or devices using radio spectrum to enable communication between devices in a limited area. This gives users the mobility to move around within a broad coverage area and still be connected to the network. IEEE 802.11 is a set of standards specifying WLAN communication in the 2.4 and 5 GHz unlicensed bands. “Wi-Fi” is a trademark of the Wi-Fi Alliance for certified products based on the IEEE 802.11 standards. This certification warrants interoperability between different wireless devices.

Devices using Wi-Fi have become increasingly popular, with WLANs deployed in over 50 percent of broadband using homes, according to research by the UK regulator Ofcom. A similar level of deployment is to be expected in the US. Large numbers of organisations use Wi-Fi for networking and providing internet access to staff and guests. Wi-Fi is also being integrated into many other electronic devices, including consumer electronics and health applications. The uses of Wi-Fi are summarised in Figure 8 below.

Figure 8 – Uses of Wi-Fi

Use	Description
Broadband access	Wi-Fi is one of the most widely deployed methods used to connect to the internet, especially in laptop computers, smartphones and other devices such as portable media players.
Home WLANs	Used for connecting multiple PCs to the internet, streaming media, transferring files between computers and home automation and security
Commercial WLANs	Used for transferring payment data and allowing access to databases and other centralised storage. Also used to provide enhanced services to consumers[7]
Educational WLANs	Colleges and universities have uses wireless networks to provide internet access to staff and students across an entire campus for a number of years
Healthcare WLANs	Hospitals are increasingly using WLAN to enhance technologies such as electronic health records (HER), computerised physician order entry (CPOE) and rapid voice communication for staff.
Industrial WLANs	WLANs are used in industrial settings to provide access to central databases, communication between staff and monitoring activities.
Governmental WLANs	A number of municipalities have rolled out Wi-Fi networks to cover entire cities. In addition to providing broadband services for residents, these networks are used for providing services to municipal employees (such as building inspectors, and those involved in traffic control) as well as more recently for smart metering and lighting control .

Source: Perspective analysis

[7] One very interesting example is the use of 802.11n to power Disney’s new Toy Story Mania rides in Anaheim and Orlando. Here, Wi-Fi is essential in providing a rich interactive experience for the public. (Marsan, 2009)

Microwave

Point-to-point microwave communications relate to wireless data communications via radio frequencies in the multi-gigahertz range. In most cases the links are line of sight and capable of being fairly tightly beamed from transmitter to receiver. Although point-to-point links largely use licensed spectrum a large number of systems also use unlicensed spectrum, especially in the 5GHz band.

IEEE 802.16 is a series of Wireless Broadband standards authored by the IEEE. It has been commercialized under the name “WiMAX” (from "Worldwide Interoperability for Microwave Access") by the industry alliance called the WiMAX Forum. The Forum aims to promote and certify compatibility and interoperability of broadband wireless products based on the IEEE 802.16 standards. WiMAX is standardised to operate in both licensed spectrum bands, such as 2.5GHz on which Clearwire has begun its network roll-out in the US, and in the unlicensed 5GHz band.

Figure 9 below summarises some of the uses of unlicensed microwave applications

Figure 9 – Uses of microwave

Use	Description
Mobile and fixed broadband	fixed and mobile broadband services can be provided using unlicensed spectrum
Point to point connectivity	for businesses looking to transfer two way data between two locations, including backhaul for broadband access networks

Source: Perspective analysis

Figure 10 below summarises the uses of these unlicensed technologies in 6 sectors; consumer, commercial, educational, healthcare, industrial and government.

Figure 10 – Unlicensed applications by sector and technology

<table>
<tr><th></th><th>Consumer</th><th>Commercial</th><th>Educational</th><th>Healthcare</th><th>Industrial</th><th>Government</th></tr>
<tr><td rowspan="5">Wireless LANs 802.11/Wi-Fi</td><td colspan="6">Broadband extension</td></tr>
<tr><td colspan="6">Local area networks</td></tr>
<tr><td>Consumer electronics</td><td>Commercial hotspots</td><td>Campus networks</td><td>Records management</td><td>Process monitoring</td><td>Municipal networks</td></tr>
<tr><td>Home monitoring</td><td>Card payments</td><td></td><td></td><td>Process control</td><td>Wide-area systems control</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Process automation</td><td></td></tr>
<tr><td rowspan="3">Wireless PANs 802.15.1/Bluetooth</td><td colspan="6">Personal area networks</td></tr>
<tr><td colspan="2">Mobile phone headsets</td><td></td><td>Medical devices</td><td></td><td></td></tr>
<tr><td>Remote controls</td><td>Bluetooth marketing</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RFID</td><td>Contactless payment</td><td colspan="5">Asset tracking</td></tr>
<tr><td>Transport payment</td><td>Supply chain</td><td></td><td>Human implants</td><td></td><td></td></tr>
<tr><td>Identification</td><td>In-store</td><td></td><td>Drug authenticity</td><td></td><td></td></tr>
<tr><td rowspan="5">Low data rate wireless PANs 802.15.4/Zigbee</td><td colspan="6">Smart metering</td></tr>
<tr><td colspan="6">Sensor networks</td></tr>
<tr><td>Home control</td><td>Premises control</td><td></td><td></td><td>Exact process monitoring</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Exact process control</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Exact process automation</td><td></td></tr>
<tr><td rowspan="2">Microwave/WiMAX</td><td colspan="6">Mobile and fixed broadband</td></tr>
<tr><td></td><td colspan="5">Point-to-point connections</td></tr>
<tr><td rowspan="2">WirelessHD, WiGig</td><td colspan="6">Wireless HD displays</td></tr>
<tr><td colspan="6">Very high rate date transfer</td></tr>
</table>

Existing uses

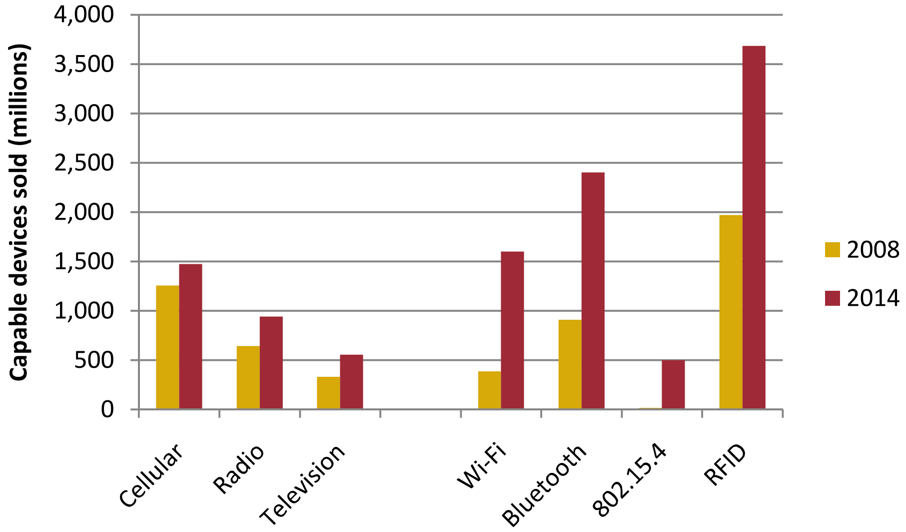
Uses in development

Source: Perspective analysis

The prevalence of unlicensed usage

Although licensed usages have traditionally been the most widespread, significant increases in the sales of unlicensed devices have been taking place. Figure 11 below shows the annual sales of selected wireless enabled devices[8], both for 2008 and market projections for 2014.

Figure 11 – Global sales of wireless enabled devices in 2008 and 2014



Source: Perspective analysis

The first three categories in the chart show applications in licensed spectrum. Cellular enabled devices, including phones, modems and laptops, sold more than 1 billion units in 2007, and our analysis of the available market projections show this figure is set to rise to almost 1.5 billion annual shipments by 2014[9]

Devices enabled to receive broadcast radio, including portable and fixed sets, mobile phones and vehicles, sold more than 600 million units in 2008, our analysis of the available market projections show this figure is set to rise to over 900 million per year by 2014[10].

Broadcast television decoding devices, including TV sets and set-top boxes, sold almost 350 million units in 2008. This figure is set to rise to over 600 million by 2014[11].

---

[8] We have used chipset sales as a proxy for device sales.

[9] Gartner reports that 1.22 billion mobile phones were sold in 2008, an increase of 6 percent on the previous year, see (Gartner, 2009). Juniper research predict sales to increase to 1.34 billion in 2014, see (Juniper Research, 2009)

[10] We have based this estimate on 32 percent integration of FM radio in 2008 from GPS World (Acharya & Faintuch, 2008). According to the same analysis this will rise to 45 percent in 2012, which is the figure we have used for 2014. According to Scotia Capital, 52.2 million vehicles were sold worldwide in 2008 (Scotia Economics, 2009). We have assumed that the global vehicle market grows at 5 percent a year to 2014. The UK communications regulator, Ofcom, estimated that 8.8 million conventional radios were sold in 2008 in the UK (Ofcom, 2009, p. 150). We have grossed this up by global GDP to arrive at global radio sales of 200 million in 2008. To arrive at the 2014 total we have assumed a yearly growth of 5 percent in the sales of stand-alone radios.

[11] DisplaySearch estimated the total global market for televisions to be 205.3 million units (So-eui, 2009). iSuppli estimated the total 2008 sales of set-top boxes to be 131.2 million (iSuppli, 2009). For 2013 iSuppli forecast the market at 200 million units, and we have assumed the same figure for 2014.

The final four categories in the chart above show applications in unlicensed spectrum. Wi-Fi has seen rapid growth since its launch in 2001, with over 387 million enabled devices sold in 2008. This growth is likely to continue, albeit at a lower rate, and sales are likely to reach around 1.5 billion devices a year by 2014[12]. The key reason for the growth is the increasing number of devices with embedded Wi-Fi, including mobile phones, netbooks and other consumer electronics devices, such as portable media players, TVs and cameras.

Almost 1 billion Bluetooth chipsets were sold in 2008. Market growth estimates project that sales are likely to increase significantly by 2014 to almost 2.4 billion units per year. The growth will largely be due to the increase of Bluetooth in mobile phones, wireless headsets, games consoles, consumer electronics and cars.[13]

The market for IEEE 802.15.4 devices, including ZigBee, in both consumer electronics and commercial markets, is set for significant growth over the next five years as new applications and systems are built upon the standard. For example, this includes a new family of consumer electronics remote controls, developed by the RF4CE Consortium. In addition, smart metering trials have used ZigBee, and these deployments have grown worldwide. 802.15.4 chipset shipments are projected to grow from 15 million in 2008 to around 500 million in 2014.[14]

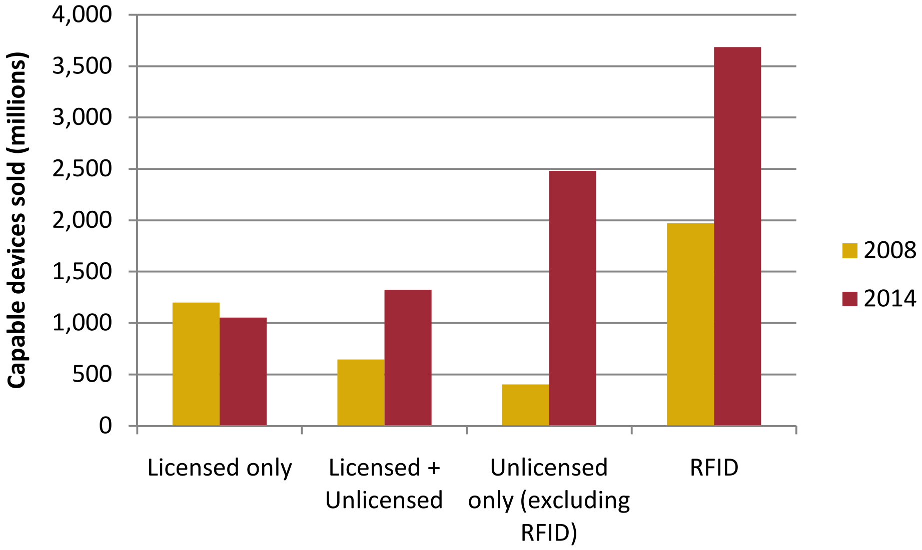
The research agency, IDTechEx, predicts that the value of the entire RFID market will be $5.56 billion in 2009, up from $5.25 billion in 2008. The volume of RFID is growing strongly, with 2.35 billion tags likely to be sold in 2009, up from 1.97 billion in 2008[15]. ABI Research predicts that annual growth will remain steady over the next five years, expecting the market to reach more than $9.2 billion in 2014[16]. With falling prices it is almost certain that the volume of tags sold will increase by at least this proportion, and if so will reach over 3.6 billion in 2014.

Figure 11, above, shows the number of devices sold enabled for each technologies. However, there is an element of double counting, as a number of devices will be enabled for use with more than one of these technologies. In Figure 12, below, we show estimates for the number of devices sold that

[12] From ABI Research (ABI Research, 2008).
[13]GPS World states that the current Bluetooth attach rate in mobile phones is 52 percent (Acharya & Faintuch, 2008). The Nintendo Wii and Sony PS3 sold a combined total of 37.3 million units in 2008 (VGB, 2009) and (Sherman, 2009). We have assumed that two times this many controllers were shipped. The Bluetooth attach rate in laptops is approximately 50 percent and global laptop sales were 139 million in 2008 (ABI Research). IMS research estimate that 24 million Bluetooth chips were used by automotive companies in 2007, see (Miller, 2009). We have assumed the same number were used in 2008. ABI Research project that 2.4 billion Bluetooth chipsets will be sold in 2013 (Choney, 2008). We assume the same number will be sold in 2014.
[14] (ABI Research, 2009)
[15] (Das, 2009)
[16] (Trebilcock, 2009)

just include licensed spectrum technology[17], those with both licensed and unlicensed[18], and those using unlicensed spectrum only[19].

Figure 12 – Global sale of devices by type of spectrum used in 2008 and 2014



Source: Perspective analysis

Although arriving at the results displayed in Figure 12 above has involved a number of approximations, we believe the results are broadly correct and comprehensive – and remarkable. They show that shipments of devices using only licensed spectrum, including phones and 3G and 4G dongles, televisions and radios, will remain stable, perhaps even decline. The shipments of hybrid devices, including Wi-Fi and Bluetooth-enabled mobile phones, 3G and 4G enabled laptops, Wi-Fi enabled televisions and set-top boxes, and cars possessing Bluetooth will likely double, perhaps edging out the sales of licensed-only devices. The sales of devices using only unlicensed spectrum are likely to soar, led by Wi-Fi and Bluetooth enabled consumer electronics and laptops, 802.15.4 devices in the consumer, commercial and industrial sectors, and RFID devices.

[17] To arrive at the number of licensed-only devices, we have taken the number of cell phones less those with Bluetooth, plus the number of embedded 3G and 4G devices (Disruptive Analysis, 2008), plus the number of televisions and set top boxes less hybrid IPTV models which we assume will all use Wi-Fi, plus vehicles less those with integrated Bluetooth (ABI expect this to be 30 percent in 2014 (Choney, 2008) plus stand-alone radios.

[18] To arrive at the number of dual licensed and unlicensed devices, we have taken Bluetooth enabled mobile phones, Wi-Fi enabled televisions and set-top boxes (IMS Research expect 82 million hybrid IPTV containing STBs to ship in 2014, we assume all contain Wi-Fi (iSuppli, 2009), and Bluetooth enabled vehicles.

[19] To arrive at the number of purely unlicensed devices we have taken the total projected sales of Wi-Fi and Bluetooth devices and removed double-counting between phones and laptops possessing both technologies. We have assumed that 802.15.4 and RFID devices are not integrated alongside other technologies, this may slightly overestimate the total number but we do not believe that this would have a substantial effect on the trends observed.

4. The economic value generated by unlicensed usage of spectrum

Perhaps the prevailing view amongst policymakers is that the vast majority of economic value derived from the usage of the spectrum is derived from licensed rather than unlicensed usage. This view is expressed in the foreword to a recent report by Rysavy Research:

> Research in the UK has shown that licensed applications such as cellular and broadcasting generate far more value to the economy than commons usage – in the case of the UK only 1% of the total value from the use of spectrum was generated by commons usage such as Wi-Fi. Other developed countries are likely to see similar numbers. Since most commons usage is short range it therefore makes sense to place it above the frequencies that are readily usable for cellular and broadcasting. However, bands such as at 2.4 GHz are an exception to this because they would be of limited use to cellular due to the interference already occurring in the band. [20]

This line of argument can be characterised in the following way:

Figure 13 – The Rysavy argument

However, both the premise and conclusion of the argument are open to challenge. In this chapter we attempt to quantify the current and future economic value delivered by some of the unlicensed uses. In the chapter following, we briefly examine the innovation potential of both licensed and unlicensed spectrum. Finally, in the latter half of this document we turn to the television 'white spaces' and examine the implications of our analysis for this important spectrum allocation decision.

Europe Economics' valuation of licensed and unlicensed use

The claim above, that in most developed nations only around 1 percent of the total value from the radio spectrum comes from unlicensed usage, can be traced to a study undertaken by Europe Economics for Ofcom in 2006[21].

This exercise attempted to estimate the yearly benefits derived by consumers and producers, in the form of consumer and producer surplus, for use of spectrum in a number of industry sectors. These were chosen to reflect a range of public and private uses of spectrum:

1. Public mobile – including cellular mobile, paging, public mobile data networks, and public access mobile radio;
2. Broadcasting – including analogue and digital TV, and analogue and digital radio;

[20] Foreword by William Webb (Rysavy Research, 2008)
[21] (Europe Economics, 2006)

3. Satellite links – meaning the operation of satellite links, such as VSATs and permanent earth stations;
4. Fixed links – meaning the operation of radio fixed links, for example to substitute for or supplement cable links in telecommunications infrastructure;
5. Wireless broadband – meaning the provision of Wi-Fi and other wireless access services; and
6. Private mobile radio – meaning mobile radio communications services provided for non-public use, such as by emergency services, taxi companies and transport companies

The results of Europe Economics' work are presented below in Figure 14.

Figure 14 – Economic value generated by spectrum applications in the UK

Sector	Total economic value[22] (£ billion)	Percent (%)	Consumer surplus[23] (£ billion)	Producer surplus[24] (£ billion)
Total	**42.4**	**100**	**37.8**	**4.6**
of which:				
Public mobile	21.8	51	19.0	2.8
Broadcasting	12.3	29	10.6	1.7
Satellite links	2.8	7	2.8	-
Fixed links	3.9	9	3.9	-
Wireless broadband	0.3	1	0.3	-
Private mobile radio	1.2	3	1.2	-

Source: Europe Economics

For both public mobile (cellular) and broadcasting, Europe Economics used willingness-to-pay surveys to estimate the consumer benefits. Extensive work has been done in both these areas to assess the maximum prices that consumers would be willing to pay for these services. By then deducting the actual prices consumers do pay from what they are willing to pay, the total benefit to consumers, or surplus, can be calculated.

It is possible to cross-check the UK numbers for the consumer value of mobile services by comparing them to the value derived by Hazlett[25] for the corresponding value in the US. Europe Economics' value of $537 per subscriber per annum is broadly comparable to Hazlett's figure of $589[26]. Taking Hazlett's valuation of $81 billion dollars per year in 2003 to be broadly correct for the US in 2003 and adjusting for the subsequently increased subscriber base, we can estimate the 2009 surplus at $147 billion per year.

Figure 15 below uses the Europe Economics numbers to estimate the total value of licensed spectrum in the US.

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[22] Total economic value is the sum of consumer surplus and producer surplus in each sector
[23] Consumer surplus is the total maximum price consumers would be willing to pay for the services is question, less the total price they do pay
[24] Producer surplus is the total revenue earned by an Industry less all its costs including a return on all the capital employed
[25] (Hazlett, Spectrum Tragedies, 2004)
[26] This figure has been adjusted for consumer price inflation between 2003 and 2006

Figure 15 – Estimated value generated by spectrum applications in the US

Sector	Value ($ billion)	Percent (%)	Consumer surplus ($ billion)	Producer surplus ($ billion)
Total	**277.0**	**100**	**249.1**	**27.9**
of which:				
Public mobile	168.7	61	147.0	21.7
Broadcasting	44.9[27]	16	38.7	6.2
Satellite links	21.7	8	21.7	
Fixed links	30.2	11	30.2	
Wireless broadband	2.3	1	2.3	
Private mobile radio	9.3	3	9.3	

Source: Perspective analysis

Even though the simple scaling of Hazlett's consumer surplus number may have overestimated the value of cellular[28], the total economic value generated by licensed uses of the spectrum is substantial, and can be thought of as being around $250 billion per year.

Although the major licensed uses of spectrum are represented in Europe Economics' study, it only looks at a single type of unlicensed usage, that of consumer use of Wi-Fi networks. The first element of the calculation is a valuation of home usage of Wi-Fi networks. In the absence of willingness-to-pay surveys, Europe Economics uses the number of UK households in 2006 which used Wi-Fi[29] multiplied by the average consumer surplus of broadband. The second element is the use of Wi-Fi in UK airports[30], although the method used to calculate this value in unclear. The sum of these two calculations, a consumer value of £300m per year, does indeed come to only 1 percent of the value generated by licensed applications.

Two observations on Europe Economics' method can be made. Firstly, they have looked only at a very limited number of unlicensed uses, and secondly their methodology to determine value appears to be limited.

To come to a more reliable understanding of the value of unlicensed spectrum, we attempt to measure the economic value that is generated by three existing applications using unlicensed spectrum:

- The value of generated by wireless broadband within homes (using an alternative methodology to that employed by Europe Economics),
- The value generated by voice applications and wireless electronic health record applications using Wi-Fi in hospitals, and
- The value generated by RFID tags for in-store item-level tagging in the clothing retail sector

[27] The value of broadcasting as a spectrum use in the US has been scaled down relative to the UK since far more Americans subscribe to cable television, which does not use the radio spectrum to broadcast to the consumer

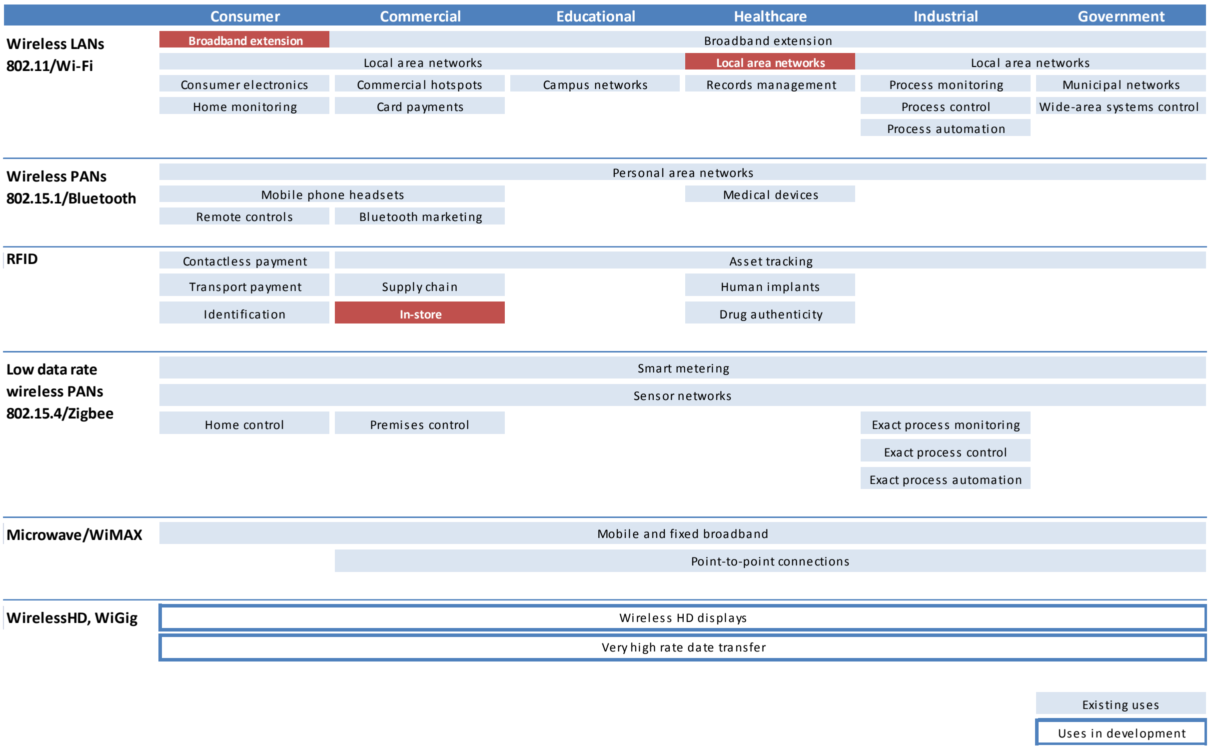
[28] Since the later adopters of cellular phones are likely to be those value the service at a lower level than the earlier adopters. However, this overestimation is likely to have been counteracted by the increase in functionality provided by the Smartphone in the last couple of years

[29] (Strategy Analytics, 2006)

[30] (BWCS)

These three areas represent only a small part of the ecosystem of uses inhabiting unlicensed spectrum bands, as shown below in Figure 16.

Figure 16 – Areas of the unlicensed ecosystem valued



Source: Perspective analysis

Therefore, the estimates below are likely to represent only a proportion of the economic value generated by unlicensed usage of spectrum.

The value of generated by Wi-Fi in homes

No comprehensive work has been done on users' willingness to pay for Wi-Fi connectivity in the home. However, there is compelling evidence to suggest that Wi-Fi is now integral to the home broadband proposition. A survey of a UK broadband comparison site in August 2009 showed that a Wi-Fi router is a standard part of the broadband package offered by almost every provider[31]. This suggests that a very strong complementarity between home broadband and Wi-Fi, with many consumers now viewing both as part of a single package.

Our key assumption is that some of the value consumers attribute to broadband is derived from the wireless connectivity provided by Wi-Fi. As the basis of this alternative methodology to that of Europe Economics, we employ the findings from a recent study by Jonathan Orszag, Mark Dutz and Robert Willig, "The Substantial Consumer Benefits of Broadband Connectivity for US Households"[32]. This is a landmark paper. It uses robust economic analysis to calculate the consumer surplus generated by broadband in the United States. They provide a number of estimates. The estimate based on a Forrester willingness-to-pay survey of over 4,000 US households calculates the consumer

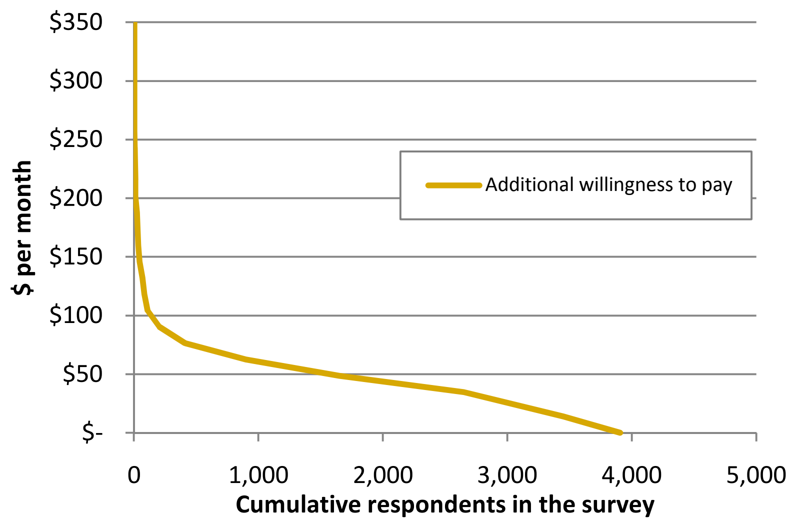
[31] On the Top 10 Broadband site in August 2009, 45 of the 46 packages listed included a free wireless router. See http://www.top10-broadband.co.uk/packages/
[32] (Orszag, Dutz, & Willig, 2009). This paper is currently awaiting peer review.

surplus to be $22.8 billion per year. The result from their preferred method, based on econometric analysis of transactional data for 30,000 households, is $32.0 billion per year.

Methodology

Below, in Figure 17, we reproduce the key finding from their consumer survey work, that of US consumers' additional willingness to pay for broadband, above and beyond the amount they already pay.

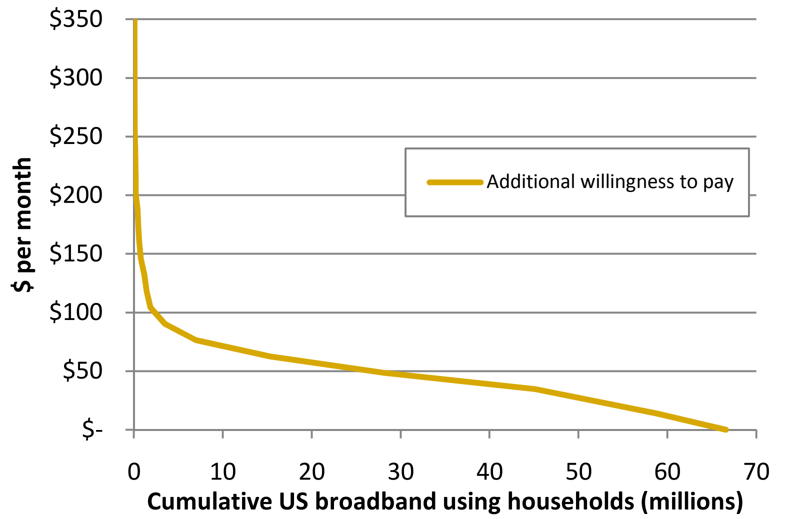
Figure 17 – Additional willingness to pay for broadband, Orszag et al sample



Source: Orszag et al (2009)

These findings show that approximately half of the respondents in the survey would be willing to pay an additional $50 per month or more for their broadband service. Since the sample survey was chosen to be representative of households in the United States, we can extrapolate these numbers accordingly. This is shown in Figure 18 below.

Figure 18 – Additional willingness to pay for broadband, all US households

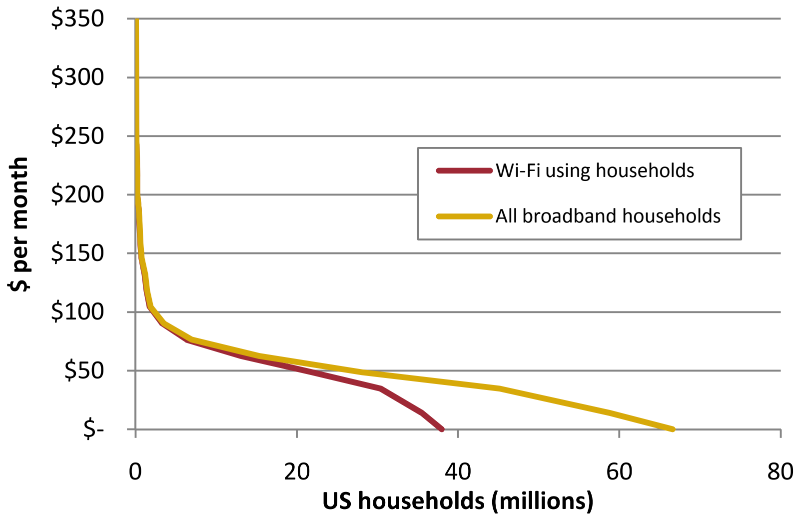


Source: Perspective analysis

The area under this curve is the economic value to consumers delivered by broadband, as found by Orszag et al. However, for the purpose of our modelling we are interested only in users of Wi-Fi. The latest research from Ofcom in the UK suggests that 57 percent of broadband households in the UK use Wi-Fi. For the purposes of our valuation we assume that the US has the same percentage of Wi-Fi users as the UK[33]. This implies that there are 38 million households using Wi-Fi in the US.

As to the distribution of the Wi-Fi using households amongst total broadband using households, it would be a reasonable assumption to make that those users who would be willing to pay the most for broadband are the Wi-Fi users, as one could assume that these users would be more likely to want to use broadband throughout the home. However, as a more conservative assumption we assume that the 10 percent of households that value broadband the most are 50 percent more likely to be users of Wi-Fi than the average (86 percent rather than 57 percent), the next 10 percent of households that value broadband the most are 40 percent more likely to be Wi-Fi users, and so on, until we reach the 10 percent of household who value broadband the least, who we assume to be 50 percent less likely to be Wi-Fi users than the average (29 percent rather than 57 percent). The derived additional willingness to pay for broadband amongst Wi-Fi using households is shown in Figure 19 below.

Figure 19 – Additional willingness to pay for broadband in the subset of Wi-Fi households



Source: Perspective analysis

Treating these Wi-Fi households as a separate market, we can use this additional willingness willingness-to-pay information to construct a traditional economic supply curve and demand curve. We assume that the supply curve is horizontal at the average price of broadband in the US, judged to be $44 per month by the OECD. We then translate the Wi-Fi curve in Figure 19 upwards by $44 to derive the demand curve for broadband by Wi-Fi using US households. The resulting supply and demand curves are shown below.

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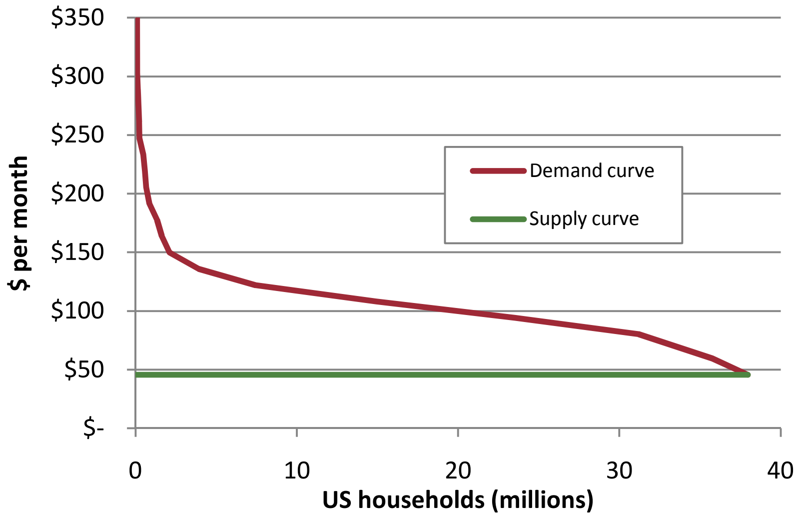
[33] (Ofcom, 2009)

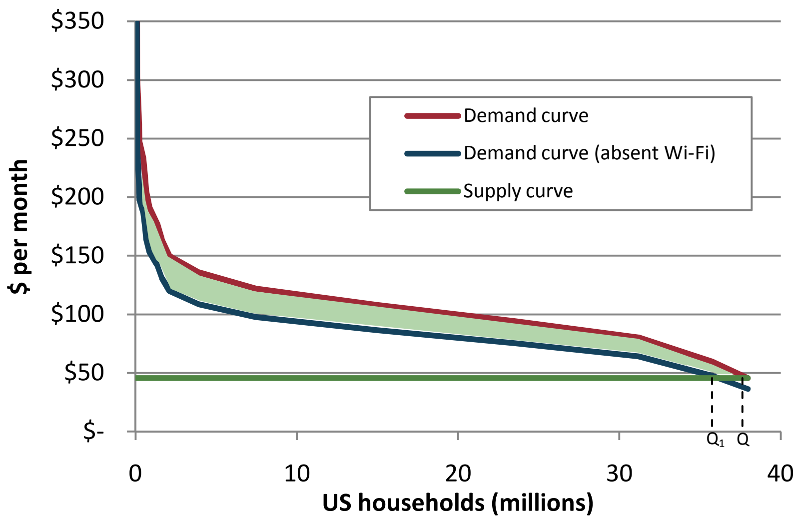
Figure 20 – Supply and demand curves for broadband for Wi-Fi using US households



Source: Perspective analysis

It is at this point we introduce our central modelling assumption, that in the absence of Wi-Fi these households would be willing to pay less overall for their broadband packages, reducing the overall level of demand. We assume that in the absence of Wi-Fi each household's total willingness to pay would be reduced by a fixed percentage. Figure 21 below shows the effects for a 20 percent reduction in demand at each output level.

Figure 21 – Incremental demand for broadband generated by Wi-Fi



Source: Perspective analysis

The reduction in demand has two effects. Firstly the area between the supply curve and demand curve is reduced by the shaded area. This represents the loss in consumer surplus, as each consumer would gain less value from broadband. Secondly, the point of intersection between the demand curve and the supply curve shifts from Q to Q_1. This is due to some households now valuing the broadband proposition less than the price and so choosing to discontinue their subscriptions. This chimes with the notion that Wi-Fi has driven broadband growth by making broadband a more valuable proposition.

We have modelled three scenarios,, a low case, where Wi-Fi represents 10 percent of the overall value of broadband, a base case in which Wi-Fi represents 20 percent of the overall value, and a high case in which Wi-Fi accounts for 30 percent of the value. Given the speed at which Wi-Fi has become part of the standard broadband package and at which it has been adopted[34], these figures do not seem unreasonable, but could, of course, be refined through consumer survey data or transactional analysis.

Results

The results of our modelling exercise are summarised in Figure 22 below.

.

Figure 22 – Annual economic value generated by home Wi-Fi usage in the US

Proportion of broadband value derived from Wi-Fi	10%	20%	30%
Annual consumer surplus generated by Wi-Fi ($ billions)	4.3	8.4	12.6
Incremental broadband adoption due to Wi-Fi (millions of households)	4.3	6.6	9.8
Average consumer surplus per Wi-Fi household per month ($)	*9.5*	*18.5*	*27.6*

Source: Perspective analysis

These data suggests that Wi-Fi usage in the home for this particular purpose may be generating anywhere between $4.3 and $12.6 billion in annual economic value derived by consumers in the United States. This is using conservative assumptions for the proportion of the benefit from a home broadband connection that can be attributed to the flexibility provided by Wi-Fi.

A second benefit is also illuminated by the results. By enhancing demand for broadband, Wi-Fi may have increased adoption by anywhere between 4.3 to 9.8 million households.

Value not captured

This analysis only accounts for the value that consumers might place on the ability to use broadband wirelessly. However, there are a number of other uses for a home Wi-Fi network. These include online gaming using consoles, the ability to stream rich media content and large files around the home and increasingly that of home automation and smart metering applications. Furthermore, many of the applications increasingly being downloaded and used on smartphones are restricted for use only over Wi-Fi networks, so as not to overburden cellular carriers' 3G data networks. Therefore these results are likely to represent a strict lower bound for the value of Wi-Fi in homes. This analysis also does not capture a more structural effect, that the shift of the PC market towards laptops and the convenience they bring has also been facilitated by the availability of Wi-Fi

[34] The current penetration of Wi-Fi is at around 36 percent of all US households (57 percent of broadband using households) only 9 years after its introduction compares favourably with the rates of take-up of both broadband, when 36 percent penetration was achieved some time in 2006 – 8 years after its introduction (Pew Research Center, 2008), and cellular phones, when 36 percent penetration was achieved in 2001 – 18 years after the first commercial services became available in the US (Palenchar, 2006). This rapid rate of take-up suggests that consumers are deriving significant value from Wi-Fi.

Further work in this area could seek to improve upon the analysis above by seeking directly to measure the value consumers place on Wi-Fi, and also attempting to quantify the broader benefits of home networks.

The value generated by wireless local area networks in hospitals

Medical facilities have a necessarily mobile workforce, and as such the health care industry has been one of the early adopters of wireless technologies. Hospitals have predominately turned to Wi-Fi networks to provide in-building data coverage. ABI Research estimates that 82 percent of the hospitals in the United States have Wi-Fi networks, or around 6,100 of the 7,526 hospitals[35]. For an organisation such as a hospital the deployment of such a network is likely to have three types of value. The first is that of generating cost savings, the second is the ability to deliver a better product or service, in this case healthcare, and the third is increasing levels of staff satisfaction. The total economic value for a hospital of the Wi-Fi network will be the sum of these benefits.

While a number of case studies of the use of Wi-Fi in hospitals are documented, unfortunately, the large majority do not provide the data with which to make an assessment of the economic benefit that has been generated through deployment. However, following a year long trial of Wi-Fi equipment at the Children's Hospital at Westmead (CHW) in Sydney, Australia, consulting firms Aegis Group and Applied Economics collated the results and presented a report to the state government[36].

The infrastructure consisted of 40 wireless networking access points, 40 hands-free communication badges, 10 notebook computers, operating on battery-powered trolleys known as 'computers on wheels,' or COWs, and six PDAs. 80 registrars, surgeons, visiting medical practitioners and nurses were involved in the trial. The aims of the trial were to test the effectiveness of two applications over a wireless LAN:

- access to patient records
- a rapid voice over Wi-Fi communication system.

The main findings for the evaluation period were:

1. Staff reported a very high level of satisfaction with the technology's ability to support their delivery of care.
2. 7,439 hours of staff time were saved over the year. If this technology were rolled-out across all hospital departments, Applied Economic estimates the potential time savings at around 122,000 hours per year.
3. The probability of a fast or very fast triage response increased from 38 percent to 46 percent. The probability of a slow or very slow triage response decreased from 42 percent to 34 percent

Although the economic value of the improved staff satisfaction or improved triage response was not measured, Applied Economics did calculate the value of the time savings. The cost savings that result from applying these two wireless applications to all departments in CHW is estimated to be about AUD $7.4 million (6.6 million US dollars) per year for an overall capital outlay of AUD $4.8 million. The net present value of such a project, based on a 9 year lifespan and a discount rate of 7 percent, was calculated to be AUD $35 million.

[35] (Smith, 2008)
[36] (Miller M. , 2007)

These findings form the basis of our modelling of the potential benefits in a US context.

Methodology

In our modelling we attempt to measure a part of the economic value that would result from the deployment over time of voice over Wi-Fi and wireless electronic health records in US hospitals. We only measure the cost savings in employee time that might be achieved using such systems and do not account for the value generated through improved patient care and greater staff satisfaction. We have chosen these applications as they are relatively simple to install over a Wi-Fi network and the data exists to estimate the incremental benefits of the wireless elements, over and above other systems.

Firstly we model the coverage these applications achieve over time. With $19 billion of spending to incentivise the adoption of health IT specifically earmarked in the American Recovery and Reinvestment Act of 2009, the Congressional Budget Office has estimated the take-up over time of electronic health records in US hospitals. Even without stimulus funding, the CBO anticipated that the take-up of electronic health records would become near-universal over the next quarter century.[37] The effect of the additional funds will be to accelerate take-up: "CBO estimates the incentive mechanism would boost… adoption rates to about 70 percent for hospitals and about 90 percent for physicians by 2019." We assume that the potential market for the applications we model will be these 70 percent of hospitals in 2019, which we assume to be the biggest hospitals by beds in the US. In total these have 880,000[38] fully staffed beds of the US total 940,000[39]. By 2029 we assume that EHR has been adopted by 99 percent of US hospitals.

In 2009, we estimate that 90,000 beds in US hospitals are in departments already using these technologies[40]. The three adoption scenarios we model are:

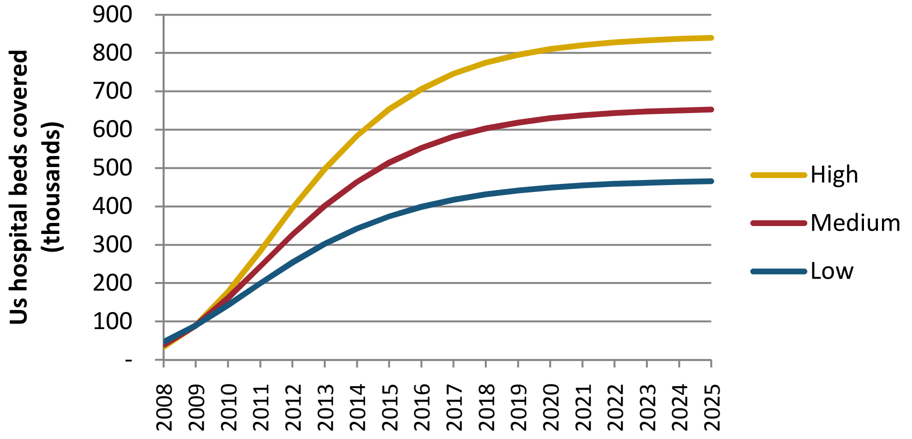
- Low - 50 percent of beds are in departments using voice over Wi-Fi and wireless EHR by 2019, and that this is the maximum penetration achieved in hospitals using EHR
- Medium - 70 percent of beds are in departments using voice over Wi-Fi and wireless EHR by 2019, and that this is the maximum penetration achieved in hospitals using EHR
- High - 90 percent of beds are in departments using voice over Wi-Fi and wireless EHR by 2019, and that this is the maximum penetration achieved in hospitals using EHR

We predict a high level of base take-up due to the effects of the economic stimulus funds, as well as the statement by CHW that the technology trialled was equally applicable to all its departments, and its subsequent decision to extend the services to accordingly. This view is supported by a study from ABI Research, predicting that worldwide sales of Wi-Fi-enabled health care products will hit $4.9 billion in 2014, an increase of nearly 70 percent over 2009 levels. ABI believes that this will be driven in large part by the health sector in the US making use of stimulus funds.

[37] (Congressional Budget Office, 2009)
[38] (Agency for Healthcare Research and Quality, 2008)
[39] (American Hospital Association, 2009)
[40] This is a rough estimate, based on the information that Vocera, the company whose voice over Wi-Fi solution was used at CHW, supplies 400 hospitals in the US (Fallon, 2008). We assume that Vocera is the market leader with a 50 percent share of hospitals, giving 800 hospitals using this technology. Furthermore we assume that it is the largest 800 hospitals using this technology and each has 25 percent coverage of Wi-Fi by beds.

We use a Gompertz function[41] to project the growth of these technologies over time. The growth scenarios are shown in Figure 23 below.

Figure 23 – Assumed take-up of voice over Wi-Fi and wireless HER in US hospitals 2009 – 2025



Source: Perspective analysis

In estimating the benefits and costs of deploying these applications, we have converted the findings from the CHW study from Australian dollars at 2007 prices into US dollars at 2009 prices. Furthermore, we have uplifted the benefits figures by the blended ratio of doctor and nurse average salaries between the US and Australia. Furthermore, we have also assumed that no deployment of these WLAN based services is as successful initially as the case study at CHW. We have assumed that only 50 percent of the CHW benefits are derived in the first year, 75 percent in second year, and 100 percent is only reached in the third and subsequent years. In accounting for the costs of deployment, we have assumed that all of the initial and ongoing costs of the deployment are incurred in the first year. However, we have assumed that there is year-on-year 5 percent reduction in the capital costs as this nascent technology matures and becomes cheaper.

We assessed the net benefits derived in each of these scenarios over the period to 2025 and we have used a social discount rate of 7 percent to calculate both a net present value and an annualised benefit over the period.

Results

These results of our analysis are presented in Figure 24 below.

Figure 24 – Economic value generated by voice over Wi-Fi and wireless EHR in US hospitals 2009 – 2025

Scenarios (2009 – 2025)	Low	Medium	High
Net present value of increased producer surplus ($ billions)	91	122	152
Annualised value of increased producer surplus ($ billions per year)	9.6	12.9	16.1
Annual increased producer surplus in 2019($ billions per year)	*12.6*	*17.7*	*22.7*

Source: Perspective analysis

[41] A Gompertz function is related to the standard logistic growth function but in many cases is a better predictor of the adoption of technologies (Singh, 2007)

According to our modelling, the projected cost savings, and so increase in producer surplus, generated by the use of voice over Wi-Fi and wireless EHR systems come to a net present value of $91 – 152 billion, or an annualised $9.6 – 16.1 billion a year between 2009 and 2025. These cost savings represent savings in the time of healthcare professionals which could translate into lower prices for the purchasers of healthcare, the ability to provide similar care for more patients, or be 'reinvested' into higher quality care. In any case, this increase in producer surplus is likely to impact upon the economic benefits derived by consumers from healthcare.

Value not captured

There are a number of factors which suggest that the modelled value might be conservative. Firstly, we have assumed that value generated per installation of each of these services does not rise above that found in Applied Economics study at CHW. However, the authors of this study believed that given time to scale the learning curve, the time savings generated are likely to increase. Secondly, we have assumed that a fresh WLAN installation would be needed for each adopting institution, when ABI's research above suggests that 82 percent of hospitals already have Wi-Fi installed, which may substantially decrease the costs of adoption.

The benefits calculated as possible by the use of voice over Wi-Fi and wireless HER are large, but they are only a part of the benefits that could accrue from the use of Wi-Fi in the healthcare sector. The key insight is that once the wireless infrastructure is in place a number of different services can co-exist upon it.

One such service is computerised physician order entry, or CPOE. This is a process of electronic entry of instructions for treatment of a patient which are then transferred over a network to the relevant departments. Since a CPOE system is based around complex software to manage records and workflows, it is a much more difficult undertaking than either of the two uses we have modelled above.

Nonetheless, CPOE systems are becoming more commonplace in US hospitals. According to a report published in 2008 by KLAS, nearly 10 percent of hospitals possess some level of CPOE, compared with just 3.5 percent five years earlier. Among larger hospitals, the numbers are even higher, with 17.5 percent being users. Furthermore, the inclusion of CPOE as a demonstration of 'meaningful use' of health IT in the relevant provisions in the stimulus bill is likely to drive usage. The benefits from CPOE have been widely reported, a recent study by the New England Healthcare Institute found that such systems could prevent 55,000 medication errors and so save $170 million in Massachusetts each year. Extrapolating to the US as a whole[42] the benefits would come to around $8.5 billion a year.

Although CPOE does not necessitate wireless usage, research from KLAS[43] found that 94 percent of hospitals reported using either a combination of fixed and wireless CPOE (67 percent) or wireless-only CPOE (27 percent). Whereas desktops used to be the most popular device, now computers on wheels, laptops, tablets and PDAs comprise 67 percent of the devices in use[44]. If the ability to use wireless CPOE were to drive 20 percent of the national take up then around an additional $1.7 billion dollars of value would be generated from Wi-Fi.

[42] We simply use Massachusetts hospital beds to US hospital beds in this ratio
[43] (Gamble, 2009)
[44] Ibid

A number of other services can also utilise the wireless network including wireless asset tracking and broadband internet access for staff and patients.

The value of RFID tags in the retail sector supply chain

As outlined above in the previous chapter, RFID has been successful in a very large range of applications, from contactless transport payments to animal tracking. However, there are few sectors in which the value generated by RFID has been as closely studied as in the retail sector.

The initial excitement around RFID in the retail sector was inspired by an ambitious vision, that of being able to track components and raw materials to the factory, and then final products through the warehouse to the consumer. However, initial attempts to use RFID for pallet and case tagging have met with mixed results. This kind of set up necessitates multiple organisations agreeing on common technologies and techniques. The benefits of RFID in this scenario are not equitably split between organisations, which results in different levels of enthusiasm for the technology. Moreover, in this particular application, RFID does not yet offer compelling benefits over a simpler, cheaper and more established technology; bar coding[45].

Although the grander plans for RFID in the supply-chain have not yet come to fruition, an area in retail that has shown recent encouraging results is that of store-level item tracking, especially in the clothing sector. Two in-depth case studies have been released in 2009, one focussing on American Apparel and the other on Bloomingdales.

The American Apparel pilot involved tagging new merchandise either at the factory or upon arrival at the store. Replenishment for the shelves in each trial store was triggered by the reading of the RFID tag upon sale of an item. Previously, this information was generated with a bar code scan. The reading upon sale alerted the storeroom that an item must be replaced. As items were moved to the retail area, a reader scanned the items in transit confirming the move. The previous process required the manual scanning of each barcode, which took more time and led to inaccuracies. The RFID tags were also used to perform bi-weekly inventory counts.

The pilot produced two major benefits in-store. Firstly, the stores had fewer out-of-stock items, and sales in each store were projected to increase by $260,000 a year due to the new system. Secondly, over 2,200 hours of labour time were saved in each store, resulting in a saving of $27,000 per year. As a result of these savings, American Apparel is introducing this technology across its 260 worldwide stores by the end of 2010[46].

These findings are largely mirrored by the study at Bloomingdales, conducted by the RFID Research Center at the University of Arkansas. This found that inventory accuracy improved by more than 27 percent, with a corresponding decrease in out of stock events of 21 percent. Beyond this, the Bloomingdale's study also found much faster inventory counts with a reduction in the time taken to perform an inventory check of 96 percent[47].

[45] This view is well expressed by Ronan Clinton, managing director of the RFIF specialists Heavey RF: "When you analyze a lot of problems, you can see that bar coding does work and is relatively economically viable. When you consider all of the implementation costs and the technical difficulties that remain with RFID, it just doesn't add up. It doesn't make sense to spend a lot more money on a lot more complicated technology that's not necessarily going to give any verifiable benefit" (All, 2009)
[46] (Robert W. Baird & Co, 2009)
[47] (Hardgrave, Miles, & Yana, 2009)

The key finding in both of these trails is that more limited implementation of RFID, when a single entity can control the way in which the technology is deployed and used, can generate significant commercial benefits.

Methodology

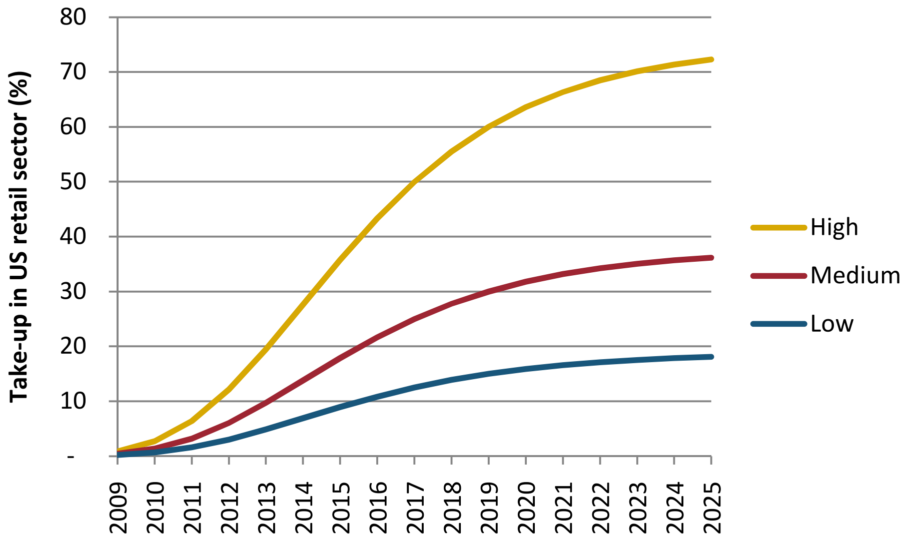
We have used the results as derived by Baird from the American Apparel study to estimate the wider economic benefits that might result from this particular application of RFID technology.

Of the two sets of benefits, the labour time saving can be regarded as an efficiency gain – the same output being achieved at a lower cost. As such it can be directly added to producer surplus and is an economic gain. However, the greater benefit to the retailer comes from an increase in its gross profit as a result of increased sales. This cannot be directly attributed to either consumer or producer surplus and cannot be regarded as an economic gain. However, the increased ability to ensure that items are in stock is likely to lead to additional benefits for consumers, both in terms of time saved and greater consumer surplus from being able to purchase their desired item. For the purposes of our analysis we assume that each instance of stock-out results in 15 minutes of time lost per consumer, and value this at the average hourly US salary to take account of the opportunity cost.

As for the costs of this technology, we assume that the costs of installation and equipment fall 5 percent year-on-year.

We project three scenarios for the take-up of this technology. This particular usage of unlicensed technology is at its infancy, and is far less developed than the other two uses that we have examined above. Therefore, we have modelled a wide range of take-up through the retail clothing sector. We have assumed that take-up reaches 60 percent by 2019 for our high take-up scenario, 30 percent for our medium scenario and 15 percent for our low. These are shown in Figure 25 below.

Figure 25 – Assumed take-up of item-level RFID tagging in US clothing retail stores 2009 - 2025



Source Perspective analysis

Results

These results of our analysis are presented in Figure 26 below.

Figure 26 – Economic value generated by item-level RFID tagging in US clothing retail stores 2009 – 2025

Scenarios (2009 – 2025)	Low	Medium	High
Net present value of economic value ($ billions)	19	38	77
Annualised economic value ($ billions per year)	2.0	4.1	8.1
Annual increased economic value in 2019 ($ billions per year)	*3.3*	*6.6*	*13.1*

Source: Perspective analysis

The results of our analysis suggest that even forecasting a relatively low take-up of the type of technology that is being rolled out by American Apparel would generate annual economic value in the billions of dollars. Our estimate of the benefit to the US economy between 2009 and 2025 is between $2.0 and 8.1 billion per year.

Value not captured

Our analysis has focused solely on the time savings to businesses and consumers due to item-level RFID tagging in clothing stores. It has not considered the value that might be generated by this use of RFID tags in preventing shrinkage (largely due to theft), reducing inventory holdings or data gathered, and its possible use for marketing purposes.

Furthermore we have not analysed the usage of RFID tagging in any other areas of the retail sector. Nor have we considered any other sectors of the economy, which, as described in the previous chapter, could make use of RFID technology in a number of ways.

Summary

Figure 27 below summarises the annualised economic benefits we have found from our analysis of selected unlicensed applications.

Figure 27 – Summary of modelled economic benefits of selected unlicensed applications in the US

Scenarios (2009 – 2025)	Low	Medium	High
Economic value generated by home Wi-Fi ($ billions per year)	4.3	8.4	12.6
Economic value generated by hospital Wi-Fi ($ billions per year)	9.6	12.9	16.1
Economic value generated by clothing RFID ($ billions per year)	2.0	4.1	8.1
SUM OF ANNUAL ECONOMIC VALUE ($ billions per year)	**16.0**	**25.4**	**36.8**

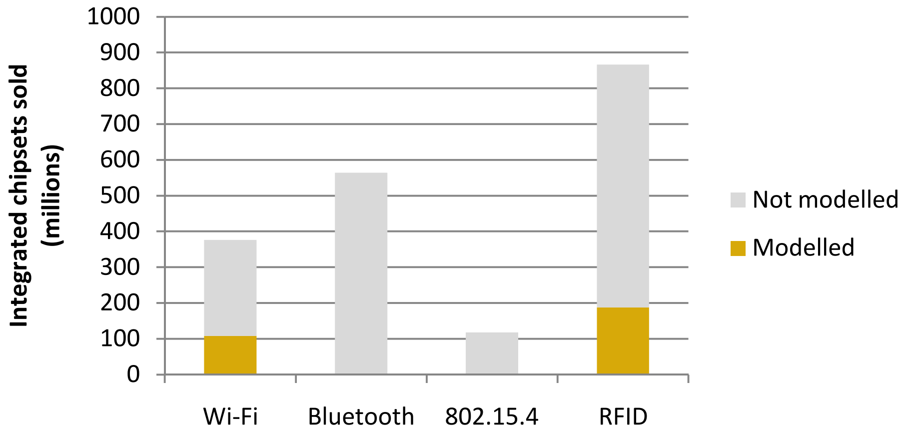
Source: Perspective analysis

The three applications we have chosen to analyse – Wi-Fi enhancing broadband access in homes, Wi-Fi delivering voice services and wireless access to patient records in hospitals and RFID tracking inventory in clothing retail stores – together may generate $16 - $37 billion per year in economic value for the US economy over the next 15 years.

Although the value generated by these applications is substantial, our earlier approximation for the value of licensed spectrum in the US suggested an economic value generated of around $200 billion per year. This is an order of magnitude greater than the combined value created by the three unlicensed uses we have assessed.

However, the two numbers cannot be directly compared. Whereas the $200 billion figure encompasses the vast majority of licensed usage of spectrum, our estimate of $16 - $37 billion only looks at a small part of the increasingly large unlicensed ecosystem represented above in Figure 10. The numerical scale of this underestimate is shown graphically in Figure 28 below.

Figure 28 – Shipments of unlicensed chipsets in modelled scenarios as a proportion of the entire unlicensed market 2014



Source: Perspective analysis

This figure takes our earlier market forecasts for 2014 and results from our modelling and shows the proportion of total forecast shipments of unlicensed devices in the US that are accounted for by our three analyses[48]. Our modelling accounts for less than 30 percent of total Wi-Fi shipments, and less than 25 percent of total RFID shipments. No account is taken of Bluetooth or 802.15.4 – both of which are forecast to grow rapidly in volume sales over the coming years. In fact our estimate covers only 15 percent of the unlicensed chipsets that our projections estimate will be shipped in the US in 2014. Therefore, it is likely that the economic value generated by unlicensed devices over the coming decade will be significantly greater than $16 - $37 billion per year. Using only a fraction of the spectrum, the value derived from unlicensed usage may even become comparable to that generated by licensed usage as the number of unlicensed applications continues to proliferate. The unique innovation potential of the unlicensed model, which underlies this proliferation, is examined in the following chapter.

[48] We have assumed that the US remains the destination for 20-25 percent of all shipments of unlicensed devices. For home Wi-Fi, we have estimated the shipments of laptop and desktop PCs, mobile internet devices and access points for the consumer sector forecast to be sold in 2013 as being the relevant base of Wi-Fi devices. For hospital Wi-Fi our model allows us to ascertain the number of Wi-Fi enabled devices that will be sold for this purpose in 2014. For RFID, we do not have the number of chipsets but our analysis can provides an expenditure figure for 2014, we have used this to apportion the total projected RFID tag sales in the US that year.

5. The innovation potential of unlicensed spectrum

In the previous chapters we have examined the ecosystem of uses that has developed in unlicensed spectrum, and attempted to quantify the economic benefits derived from some of these uses. Even in the relatively few instances we examined, we were able to estimate substantial amounts of economic value being delivered by these uses. However, in addition to debates about the tangible economic benefits there are also disputes over the levels of innovation found in both licensed and unlicensed spectrum.

Differing views have been expressed over whether unlicensed spectrum facilitates innovation. Two contrasting views are laid out below. The first is from the foreword to a recent Rysavy Research report on mobile broadband spectrum. The second is from Dr Greg Raleigh, founder of Airgo Networks, the company which developed the first commercial MIMO chipset[49] and was acquired subsequently by Qualcomm.

> …while innovation occurs in commons it also happens in licensed bands, and indeed many of the most important innovations of the last decade such as GPS, wireless email, mobile TV, texting and more have all occurred in licensed spectrum.[50]

> When we started Airgo Networks, we asked the question, 'We have a great technology here that's going to get a 10x performance advantage in any market we bring it to, what market should we bring it to?' So we looked at two: we looked at cellular and we looked at Wi-Fi, and we decided on Wi-Fi, because in Wi-Fi things move very quickly. It's a retail distribution channel and consumers make decisions about their choice of technology. In the cellular market things take longer: you've got the service providers who pay for the spectrum, the spectrum is licensed so in order to operate a piece of hardware you have to have a license from the carrier, and the carriers work with very large equipment providers who develop equipment over a longer period of time than the short cycles we have in Wi-Fi[51]

Rysavy's assertion seeks to downplay the innovation potential in unlicensed spectrum[52]. Raleigh's views appear much more positive about the potential for innovation in these bands. Specifically, his statement suggests four differences between networks operating in licensed spectrum and those operating in unlicensed spectrum:

- More buyers of equipment
- More and smaller manufacturers of equipment
- Quicker upgrade cycles
- Purchasing decisions taken by end users, not service providers

---

[49] MIMO is a technique that uses multiple antennae at either or both radios to achieve two goals: greater spectral efficiency and markedly better signal strength in very cluttered environments, such indoors or in city streets.

[50] (Rysavy Research, 2008)

[51] (Raleigh, 2005)

[52] Rysavy's statement is, moreover, incorrect in stating that "GPS, wireless email, mobile TV, texting" are "innovations of the last decade", when all apart from mobile TV are older than this: GPS, 1995 – wireless email, early 1980s – texting, 1992

But before undertaking any further analysis, it is useful to develop a clearer notion of 'innovation'.

Defining innovation

Numerous attempts have been made to define innovation and the conditions which promote it. For a clear and simple definition we can turn to Max McKeown, a writer, consultant, and researcher specialising in innovation strategy, leadership and culture:

> Usefulness is in the eye of the user. If you have an idea for improving something but do nothing with it – then you have not invented or innovated. If you don't share it you haven't even helped anyone else to invent or innovate – the idea will die with you. If you share your idea then it becomes an insight. If you put your insight into practice, it becomes an invention. If your invention is useful to someone then the invention has become an innovation. If the innovation increases human happiness then perhaps we have made progress.[53]

According to this definition we can simply define innovation as the useful application of an invention. With regards to wireless we can distinguish at least two forms of innovation:

- Innovations in wireless technology: the useful application of a new invention to wireless communications
- Innovations using wireless: the application of wireless communications to enhance products and develop new models for delivering services

Innovations in wireless technology

There have been a number of developments in wireless technology over the previous 25 years that have been applied widely. Below are set out some of the key recent advances in wireless technology and the date each was first introduced into two of the most popular two-way communications applications: cellular networks and WLAN.

Figure 29 – Dates of commercial introduction of wireless technologies in Wi-Fi and cellular

	Wi-Fi	Cellular[54]
Digital signal encoding	1988[55]	1991[56]
Spread spectrum	1988[57]	1995[58]
OFDM	2001[59]	2006[60]
MIMO/Adaptive beamforming	2004[61]	2008[62]

Source: Perspective analysis

[53] (McKeown, 2008)
[54] We have included mobile WiMAX here as a cellular technology; neither OFDM nor MIMO and adaptive beamforming have yet been commercialised by the established cellular technologies
[55] (Negus & Petrick, 2008)
[56] (Nokia, 2009)
[57] (Negus & Petrick, 2008)
[58] (CCF, 2009)
[59] (Negus & Petrick, 2008)
[60] (Shim, 2006)
[61] (Brodsky, 2004)
[62] (Electronic Design, 2008)

The table shows that the innovations listed above appeared commercially in WLANs before being introduced in cellular networks. This is reflected in the rapid rate at which the headline speed for Wi-Fi has increased in comparison to cellular systems.

The evidence would appear to support Greg Raleigh's assessment that the speed of technology development and deployment in unlicensed Wi-Fi is greater than in licensed cellular spectrum. The key to this difference is that manufacturers of Wi-Fi equipment can market their products directly to consumers, who can, by upgrading their access points and clients, immediately take advantage of the new technology. In cellular networks, the consumer has little control over their handsets, which are normally carrier selected and subsidised, and no control over the network infrastructure. As such, upgrade decisions are in the hands of a small number of cellular network carriers.

The vitality of technological innovation in Wi-Fi has been vividly displayed by the rapid growth in products shipping based on the draft specification for the latest iteration of Wi-Fi, 802.11n, even before the IEEE has even finalised the standard. This has led to a vigorous debate over the merits of the certification process employed by the Wi-Fi alliance and whether it is safeguarding[63] or hindering[64] the standard.

Perhaps the most telling indication of the value of Wi-Fi as an arena for innovation in radio technology can be seen in Carl Ford's summary of the main speakers' sentiments at the 4G Wireless Evolution conference in September 2009:

> In the battle between LTE and WiMAX, both sides confessed their gratitude to Wi-Fi in pioneering the technologies of OFDM and MIMO which are at the core of all these alternative technologies.[65]

Innovations using wireless

The second category of innovations includes innovative products and services enabled by wireless technology. Those listed by Rysavy, "GPS, wireless email, mobile TV, texting and more", fall within this category. Some of these advances appear to be the simple addition of wireless connectivity to pre-existing wired services. However, GPS, or satellite navigation more generally, appears to be a truly novel use of wireless in that there is no wired equivalent. To distinguish between these – and innovations in general – we can again turn to McKeown:

> **Incremental innovation** involves small steps, something that is a minor improvement to an existing solution. Small steps have taken Gillette from one razor blade, to two, three, and now five blades.
>
> **Radical innovations** take big steps, creating major improvements that are often very different to existing solutions. Cloning 'Dolly' the sheep qualifies as a radical innovation – it was a first and it was certainly a breakthrough.
>
> **Revolutions** happen when groups of these innovations can together cause a huge, far-reaching impact. The computing revolution was achieved because of thousands of new technologies including the microprocessor, the telephone and the

63 (Judge, 2004)
64 (Brodsky, 2004)
65 (Ford, 2009)

television. Globalisation, the Human Genome Project, and the Lunar Landing would not have been possible without it.

In Figure 30 below we have attempted to apply this categorisation to a number of the innovations that have taken place using licensed and unlicensed spectrum in the previous 25 years. We explore some of these innovations further below.

Figure 30 – Categorised innovations using licensed and unlicensed spectrum

	Licensed spectrum	Unlicensed spectrum

Incremental innovations	• Mobile TV
	• Incremental services over wide-area networks
	  ○ Text and picture messaging
	  ○ Video calling
	  ○ Secure email
	• Data over broadcast networks
	  ○ Subtitling and video text
	• Fixed point-to-point connections
		• Personal area networks/Cable replacement
		  ○ Computer mice, keyboards and printers
		  ○ Headsets and headphones
		• Contactless payment
		• Supply chain improvements
		• Consumer electronics
		  ○ Wi-Fi radios
		  ○ Wi-Fi STBs
		• Identification
		  ○ Humans – RFID passports/entry cards
		  ○ Animals – RFID tagging
		  ○ Goods – RFID authenticity markers
		• Remote controls

Radical innovations	• Precise global outdoor positioning (GPS)
	• Satellite based communications
	• Wide-area cellular networks
		• Local area networks/wireless broadband
		• Precise urban positioning (Skyhook)
		• Automatic building control
		• Wireless sensor networks
		• Real-time location services
		• Novel wireless connectivity
		  ○ Critical device monitoring (Pacemaker)
		  ○ Monitoring and control in adverse environments

Source: Perspective analysis

Incremental innovations

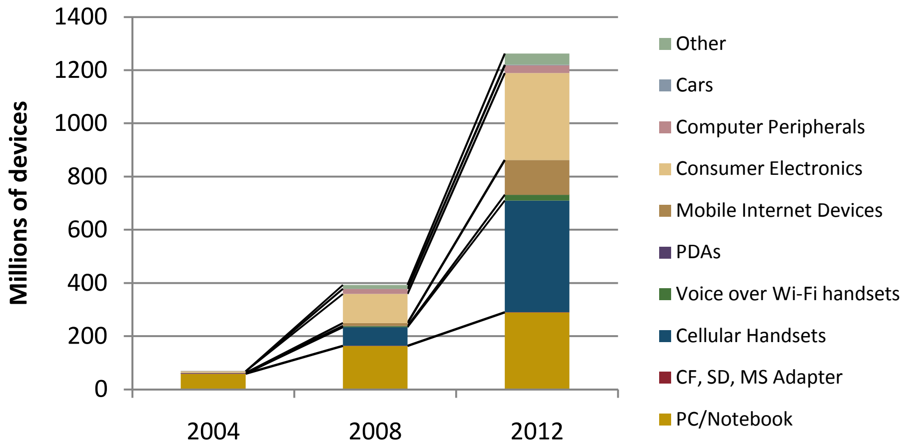
Incremental innovations in licensed spectrum have tended to leverage existing large-scale networks to provide additional services. Classic examples of these are the value added services provided by cellular operators, such as text and picture messaging, and broadcasters, such as subtitles and audio description.

Unlicensed spectrum has fostered hundreds of small scale incremental innovations due to the low costs involved. The spectrum is free to use and there are a number of existing standards, such as Wi-Fi, Bluetooth and 802.15.4, for which low-priced components are available. Unlicensed spectrum has become an important part of the engineer's toolkit when faced with a problem. A good analogy is the internet. The availability of low cost spectrum based solutions has led to a large number of niche applications taking hold, much in the same way that the availability of low-cost online retail venues (say on Amazon or eBay) has allowed small retailers to demand and offer a long-tail of niche products.

Some of the innovations that have used unlicensed spectrum in an incremental fashion have been very simple. A good example is the wireless computer keyboard and mouse, where the same information is transmitted using the radio spectrum as is done over a wired connection. However, others have been quite complex. For example, the introduction of smart card payment for subway systems in many major cities around the world could be argued to be only an incremental improvement over paper-based systems, but the complexity and logistical challenges of implementing such schemes have been significant.

As an illustration of the ability of unlicensed technologies to foster incremental innovation, Figure 31 below shows the types of devices into which Wi-Fi chipsets are integrated in 2004, 2008 and projections for 2012.

Figure 31 – Sales of Wi-Fi chipsets by device, 2004, 2008, 2012



Source: (ABI Research, 2008)

In 2004, the majority of Wi-Fi chipsets were destined for PCs and notebook computers. By 2008, around half were used for this purpose, and significant proportions were incorporated into cellular handsets and consumer electronics devices. Projections for 2012 show that shipments of Wi-Fi for use in both these latter categories are set to overtake those destined for PCs and notebooks, which will account for only 20 percent of chipsets. This demonstrates clearly the growth in the range of devices into which Wi-Fi is being integrated to provide wireless connectivity. A similar story cannot yet be told for cellular connectivity.

Radical innovations

There have been a number of radical innovations using spectrum and we describe some of these in more detail in this chapter.

Although in the last 25 years there have only been a handful of truly radical innovations using licensed spectrum, their impact has been tremendous. Most have involved large upfront costs incurred by a small number of entities but have spawned a number of mass market applications.

GPS (and other comparable systems like the Russian GLONASS, and the proposed European Galileo) has the ability to provide precise positioning for users anywhere in the world. This has been achieved through tremendous levels of investment; 24 to 32 satellites are required per system and these have to be kept in highly accurate orbits. Other advancements in satellite communications also now provide voice and data services over vast geographical areas.

The advent of wide area cellular networks has also led to a radical transformation, as described elsewhere in this paper. The mass market output, initially voice and now data services, was able to provide a return on the cost of the investments made by operators.

Unlicensed spectrum, on the other hand, has arguably delivered a greater number of radical innovations than licensed spectrum. These innovations, whilst not requiring the same scale of investment as those described above for licensed spectrum, have often leveraged the freedom and flexibility of unlicensed spectrum to deliver applications that are striking in their ingenuity and scope. Some of these have led to mass market products, whilst others are just beginning on the path to widespread adoption in specialised sectors.

Possibly the most widely recognised unlicensed innovation has been Wi-Fi. Since its introduction in 1999 it has become hugely popular as the de facto method for wireless broadband connectivity. Although 3G networks now provide broadband connectivity in many areas, these cannot yet match the capacity and speed that is possible with Wi-Fi. Indeed, many cellular carriers have been actively investing in Wi-Fi networks to be able to handle the increasing data demands of consumers. Perhaps the most radical aspect of Wi-Fi has been its creation of the notion of the ‘internet without wires’. By moving broadband access away from the desktop PC, it has arguably both spurred the take-up of broadband[66] and accelerated the development of functional wide-area data networks based on 3G.

The profusion of Wi-Fi and of wireless devices more generally has made possible a number of other radical innovations. One of these is the Skyhook service. This provides quicker, and potentially more reliable, positioning within cities using the unique identifiers attached to the myriad consumer and business Wi-Fi access points typically deployed in a city[67]. This is a radically different approach to the investment-heavy one used by GPS. While necessarily more limited in its scope, the advantages of the service have led to Skyhook’s rapid adoption in consumer electronics devices, such as in Apple’s iPhone[68].

Other radical innovations using unlicensed spectrum have provided important benefits in more specialised areas. Automatic building control holds great potential for energy savings and quality of life improvements. Wireless sensor networks are being deployed in a number of areas, often in ways that would have proven impossible using wired sensors. These are used to measure environmental factors such as light, heat and pollution. Increasingly these networks could be employed to measure the stresses and strains on buildings and the structural integrity of important infrastructure such as bridges and tunnels. Real-time location services (RTLS), often based on Wi-Fi[69], allow organisations to quickly locate key pieces of equipment, whether specialised health equipment in a hospital or safety equipment in industry. Finally, unlicensed spectrum has been used to provide wireless connectivity to devices which previously could not have been connected. In August 2009 the first Wi-

[66] As our modelling also indicates in chapter 3, above.
[67] From an economic stand-point it is interesting to note that Skyhook takes advantage of an information externality generated by homes’ and businesses’ deployment of Wi-Fi. Other applications may also become possible as unlicensed wireless technology becomes more commonplace in more devices.
[68] (Wortham, 2009)
[69] (Molta, 2006)

Fi pacemaker was fitted in the US, allowing doctors to remotely monitor the operation of the device and the health of the patient's heart[70].

Revolutions – 'ubiquitous computing'

All of the applications and innovations described above have been enabled by two significant revolutions that both took hold during the 20th Century: the computing revolution which brought us the microprocessor and the communications revolution which allowed us to exploit voice and data communication and the radio spectrum. Although predicting the shape of the future is largely the domain of science-fiction, many of the trends we are seeing suggest that the computing revolution is broadening its impact. As processing power and wireless communications are added to more and more devices, some commentators have suggested that another revolution is well underway; that of 'ubiquitous computing'.

The idea of ubiquitous computing was first proposed by Mark Weiser in 1988, who until his death was Chief Technology Officer at Xerox Palo Alto Research Center (PARC):

> Inspired by the social scientists, philosophers, and anthropologists at PARC, we have been trying to take a radical look at what computing and networking ought to be like. We believe that people live through their practices and tacit knowledge so that the most powerful things are those that are effectively invisible in use. This is a challenge that affects all of computer science. Our preliminary approach: Activate the world. Provide hundreds of wireless computing devices per person per office, of all scales (from 1" displays to wall sized). This has required new work in operating systems, user interfaces, networks, wireless, displays, and many other areas. We call our work "ubiquitous computing". This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere.[71]

Weiser saw ubiquitous computing as a third stage in the progression of the computing revolution:

> Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives.[72]

At the heart of the concept of ubiquitous computing is the notion of many different embedded wirelessly-networked devices, each fulfilling a set of functions not necessarily requiring a person's active attention or input. Indeed, some of the innovations we have described in this chapter can be seen as devices that fit this description, such as wireless sensor networks or a Wi-Fi pacemaker. The benefits of ubiquitous computing are likely to reflect and amplify the benefits already being delivered by unlicensed applications, including savings in time and cost, the greater availability of information and the ability to create better products and services.

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[70] (Gruber, 2009)
[71] (Weiser, 1991)
[72] (Weiser & Brown, 1996)

Licensed spectrum, especially for wide-area cellular networks, is important to this vision. Alongside fixed networks, cellular networks will share the task of transmitting across data long distances and will provide wide-area connectivity.

Unlicensed spectrum, on the other hand, is critical to this vision. Whereas for longer distance communication wired networks prove a partial substitute for cellular networks, wireless communication is essential for the final link with an embedded networked device. Indeed, our work in chapter 3 suggests that over the coming decade there is likely to be substantial growth in the sales of devices which connect using unlicensed spectrum. As machine to machine communication increases further – within the home, the workplace or the community – the availability of suitable and sufficient spectrum for these purposes is likely to become even more important.

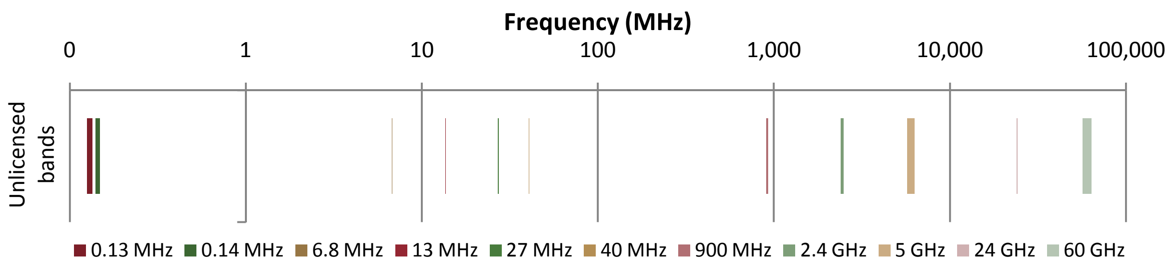
Summary

Unlicensed spectrum possesses a significant potential for innovation, both in terms of applying the insights of physics and radio engineering to improve the performance of wireless devices and in the application of these devices to solve problems and create new products and services. Our analysis also suggests that unlicensed spectrum may have a greater potential for innovation than licensed spectrum.

In Figure 10, above, we saw the wide uses to which unlicensed applications are being put to in the consumer, commercial, industrial, educational, healthcare and governmental sectors. In each of these sectors there are thousands of equipment manufacturers and systems integrators creating new products and services, and thousands of buyers exploring new ways in which they can use wireless devices. This market interplay is the origin of the innovation in unlicensed spectrum we have described in this chapter.

This level of innovation has been achieved in a short-time scale. It has been less than 25 years since the FCC permitted the use of communications devices in unlicensed ISM spectrum. Furthermore, this innovation has all taken place in a limited amount of spectrum, as Figure 32 shows.

Figure 32 – Unlicensed spectrum in the US



Source: Perspective analysis

The previous two chapters have demonstrated the substantial levels of economic benefit and innovation that are delivered by unlicensed usage of spectrum. As Figure 32 shows, this has been largely achieved using narrow slivers of low frequency spectrum, or larger allocations of higher frequency spectrum. However, there is no larger allocation of spectrum for unlicensed usage between 100MHz and 1GHz, spectrum which has excellent characteristics both in its ability to carry broadband data and in its ability to penetrate walls and other obstacles using low transmit power.

This may have adversely affected the development of longer-range, more reliable and ultra low-power unlicensed applications requiring high data rates[73].

The future of one band of spectrum that lies in this frequency range is currently under active regulatory discussion. These are the television 'white spaces', which have the potential to be opened up for unlicensed usage. The remainder of this paper addresses the opportunities that could arise from the unlicensed use of these frequencies.

[73] For example, a number of municipal Wi-Fi networks failed due to the inability of the Wi-Fi signal at 2.4GHz to be received indoors.

6. The regulatory decision on the white spaces

In this chapter we describe the television white spaces, and the associated decision faced by regulators and policy-makers: whether to make this spectrum available for licensed or unlicensed usage. We explore the potential from maintain the status quo and licensed usage in this chapter. In the following two chapters we describe the potential benefits and costs from unlicensed access to the white spaces.

The white spaces

Terrestrial television operates using very high powered transmitters, which broadcast signals over a very large area. A typical DTV transmitter will broadcast using a power of hundreds of kilowatts, and can cover millions of households. In contrast, a cellular base station transmits at a power of tens of watts and can cover typically an area of a few square miles. To avoid interference, neighbouring DTV transmission areas do not use the same frequencies for transmission. This results in a large number of vacant channels in the television bands in any particular location, and these are termed the white spaces. In the US, the white spaces lie in the VHF channels 2 to 13 (54 to 88MHz and 174 to 216 MHz) and in the UHF channels 14 to 51 (512 to 698 MHz), the spectrum in which DTV now broadcasts. Some wireless microphones used by entities responsible for television programs and motion pictures are authorised to use the white spaces.

The key attractions of the white spaces are twofold. First, they contain a significant amount of unused spectrum. Mishra & Sahai[74] project that between 8 and 15 UHF TV channels, 48 – 120 MHz, could be usable in an average location. This compares favourably with the size of the 2.4 GHz unlicensed band. Secondly, the propagation characteristics of this spectrum are very good, and will allow better range and better in-building penetration than higher frequency bands.

Technology companies such as Microsoft, Dell, Google, and Hewlett-Packard, public interest organisations, and other groups have advocated in filings to the FCC that the white spaces should be opened up for the use of unlicensed applications. Some groups, including cellular carriers, have argued for the auction and licensing of the white spaces. The wireless microphone and broadcasting communities, as existing users of the white spaces, have expressed concerns with any departure from the status quo.

The regulatory decision and the limits of market mechanisms

The regulatory decision-making process is one that has become increasingly informed by economic thinking. For licensed spectrum regulators have increasingly used market mechanisms, such as auctions, to attempt to ensure that licences are awarded to users that will generate the greatest economic value. In unlicensed spectrum, class licences are issued which leave the decision on the uses of this spectrum to market actors. However, the prior question, whether particular spectrum should be licensed or made available for unlicensed usage, is one that is impossible for a market mechanism to resolve. The UK regulator Ofcom's statement in its LEFR consultation document illuminates this point well:

> If it were possible, we would ideally like to allocate spectrum for licence-exempt use through a market mechanism…To date, the view has been that market

[74] (Mishra & Sahai, 2009)

mechanisms are unlikely to be able to allocate spectrum for licence-exempt uses because it is difficult for multiple licence-exempt users to join together to purchase spectrum at auction.[75]

The difficulty can be easily seen looking at the 2.4GHz band, the first to be widely used for unlicensed high bandwidth services. The first WLAN equipment appeared 3 years after the FCC rules were changed to allow communications use of the ISM bands[76]. Mass-market equipment, Wi-Fi and Bluetooth, followed 11 years later. In the interim the standards underlying both Wi-Fi and Bluetooth had been developed in an open, collaborative fashion through the work of a large number of companies and individuals. Wi-Fi and Bluetooth chipsets are increasingly commoditised and, as such, the market for equipment is highly competitive. The result is that the large majority of the economic surplus is retained by the end-users, especially as the sellers of equipment do not charge an ongoing monthly fee as do cellular carriers. No proposed market mechanism could have aggregated demand from producers who had not yet finalised a standard, and in many cases did not exist, or from consumers who had no experience of these products, in order to participate in a spectrum auction.

Therefore, the decision between licensing spectrum and allowing unlicensed usage remains with the regulators. The relevant question facing regulators is simple, 'which course of action with regards to the white spaces will generate the greatest economic value?' However, the answer to this question is not readily apparent. The regulator has at least three choices:

1. Maintaining the status quo
2. Award the spectrum under exclusive-use licences
3. Permit unlicensed usage

In order to choose, the regulator must ascertain the net benefits from each potential course of action. In this chapter we explore the costs and benefits of the first two options. In the following we discuss the potential for unlicensed usage.

Maintaining the status quo

This would involve neither licensing the white spaces nor making them available for unlicensed use. Instead they would remain largely unused, apart from in the very few areas in which wireless microphones are being used.

This option would result in no new economic benefits, no new costs and perhaps most importantly, a very limited potential for innovation. However, this might still be the best approach if all the other options would lead to net economic costs.

Awarding the spectrum under exclusive-use licences

The potential for usage

We look at three potential licensed uses of the white spaces: cellular networks, mobile TV and a recent proposal that they be used for backhaul services for cellular networks.

[75] (Ofcom, 2007)
[76] (Negus & Petrick, 2008)

Cellular

There are technical and economic hurdles that might prevent the effective deployment of cellular services.

The primary advantage of low frequency spectrum over higher frequencies for cellular services is that for the same levels of transmitted power at base stations and handsets a greater range can be achieved. However, to avoid interference with television reception, restrictions on the transmit power for devices operating in the white spaces are necessary, especially power leaking into the channels used for broadcasting. Therefore handsets using the white spaces may have to be designed to transmit at less than their typical 0.1 – 1 watt of power[77] and restrictions will also be necessary on the power output of base stations. This will have a corresponding effect on the range of transmission and thus serve to negate one of the primary benefits of white spaces as a lower frequency band.

In addition to this technical limitation, there is an economic barrier. As there are substantial allocations for cellular services in the spectrum below 1GHz, it is questionable whether there is appetite in the market to invest to overcome the technical challenges described above.

Mobile TV

Another potential use of the white spaces is for mobile television broadcasting, potentially using the MediaFLO system that has already been deployed by Qualcomm on former TV channel 55. Since this is a high-powered unidirectional service it faces far fewer technical difficulties than high-powered two-way cellular use. However, although the technical case for mobile TV's use of the white spaces is sound the same cannot be said for the economic case. Take-up of mobile TV services in the US and most of Western Europe has been slow, and shows no sign of imminent growth[78]. Combined with the fact that using MediaFLO, a single 6MHz channel provides enough capacity for over 10 full motion channels, it seems unlikely that there will be a significant demand for greater capacity for mobile TV.

Backhaul

Some parties have suggested that the white spaces be exclusively licensed for backhaul purposes, to transmit data between the transmission towers of a cellular network[79]. This proposal has gained some support from both Sprint Nextel and T-Mobile USA. The vast majority of cell sites are in fixed locations in urban or suburban areas. With the introduction of higher speed 3G services their bandwidth requirements will continue to grow rapidly.

However, it is not clear that the use of the white spaces would alleviate the problems faced by cellular carriers. Firstly, even if the full complement of white spaces were available it is unlikely to be able to cope with the demands of rising cellular traffic; at best it could offer a very short-term solution. Longer term solutions are likely to demand very high bandwidth microwave connections, or ideally fibre optic cables. Secondly, the sub-1GHz spectrum appears to be an odd choice for backhaul as it is more difficult to focus into the small beams used for point-to-point connections than higher frequency spectrum, which is also more plentiful. Furthermore, the white spaces have less of a propagation advantage over higher frequencies when the connections are line-of-sight, including backhaul connections.

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[77] (Varrall & Belcher, 2003)
[78] (Hansell, 2009)
[79] (ex parte by Fiber Tower, Sprint, RTG , 2009)

Benefits and costs

Due to the difficulties outlined above, there appears to be little potential for economic benefit to be derived from licensed uses of the white spaces. This is likely to be reflected in low auction proceeds. Furthermore, the white spaces are highly geographically variable and so their packaging for an auction is likely to be complex, this may deter bidders and so further depress any return to the taxpayer.

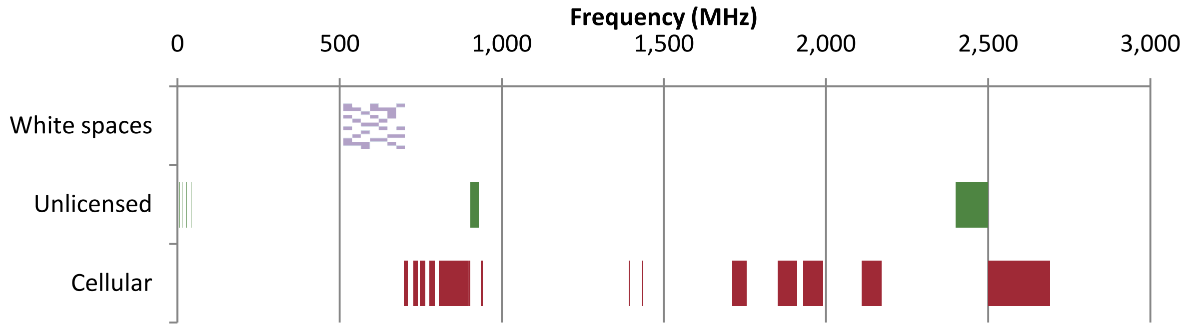
In the next chapter we look at the potential for unlicensed usage of the white spaces.

7. Economic benefits from the unlicensed use of the white spaces

The benefit of a particular band of spectrum to an application is determined by two interrelated factors. Firstly, what are the barriers to the effective usage of the band? These could be technical, such as the difficulties involved in using the white spaces as described above, or economic, such as a lack of international harmonisation leading to expensive and lower-quality equipment. Secondly, what are the alternative bands available? If there are alternative bands available then the benefits from using the band in question may not justify overcoming any costly difficulties involved.

Figure 33 below shows the spectrum up to 3GHz and the existing unlicensed allocation and the allocations available for cellular use. It also shows the UHF white spaces, which are most likely to host unlicensed applications

Figure 33 – UHF white spaces, cellular and unlicensed allocations in the US in sub-3GHz spectrum



Source: Perspective analysis

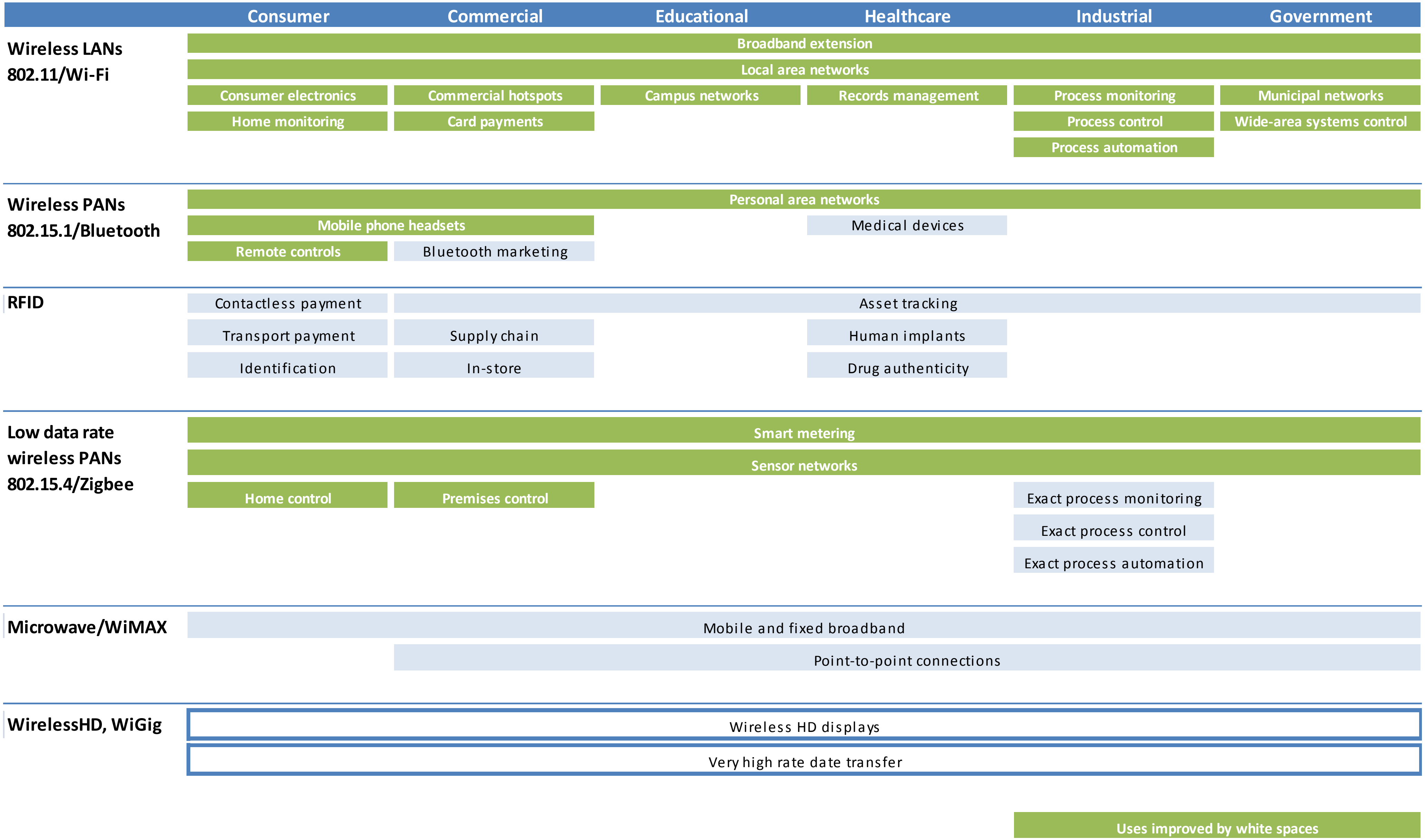
A large proportion of the spectrum between 500MHz and 1GHz has already been allocated for cellular use, including the recently awarded 700MHz band. However, although there is a narrow unlicensed band at 900MHz, there is no high bandwidth unlicensed spectrum available between 500MHz and 1GHz.

The unique propagation characteristics offered by the white spaces in this band have the potential to enhance existing unlicensed applications. We explore some of these uses in this chapter. Furthermore, the white spaces may also make possible new and innovative applications, and in chapter 8 we outline two such applications, which have the potential to generate substantial social as well as economic benefits.

Applications which benefit from unlicensed white spaces

A substantial number of the unlicensed applications introduced in chapter 3**Error! Reference source ot found.** could benefit from the availability of high bandwidth lower-frequency spectrum, such as that contained in the white spaces. In many cases there are likely to be substantial gains, either in terms of lower costs of deployment or from an enhanced quality of operation. We highlight the applications that are most likely to benefit in Figure 34 below.

Figure 34 – Unlicensed applications improved by the use of white space spectrum



Source: Perspective analysis

A technology that would benefit across a number of applications and sectors is Wi-Fi

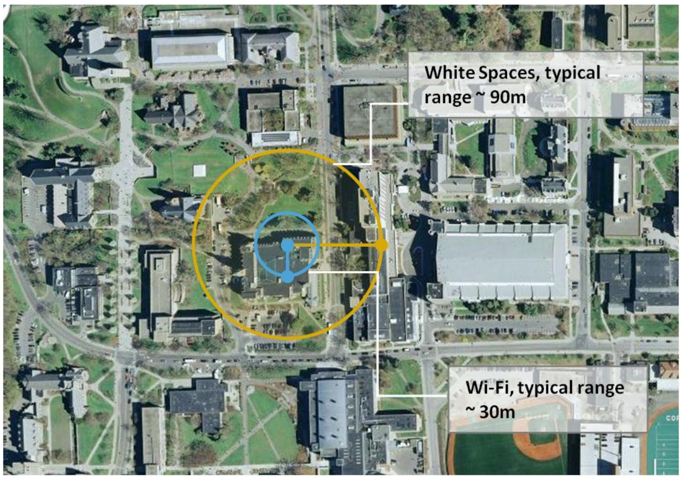
The advantages of white space enabled Wi-Fi

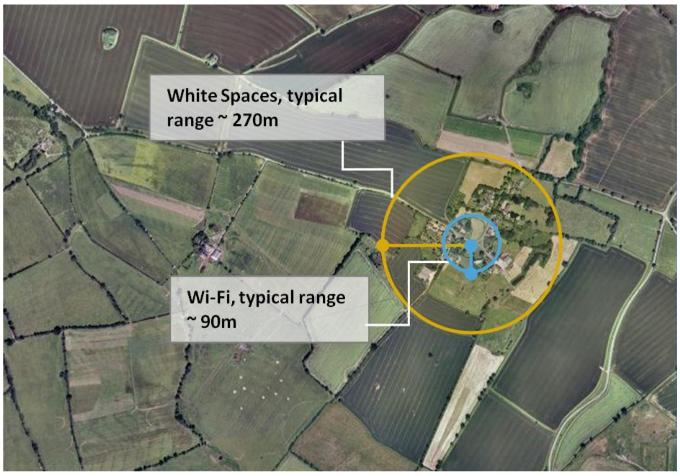
Bahl et al were awarded the SIGCOMM 2009 prize for their paper, "White Space Networking with Wi-Fi Like Connectivity"[80], demonstrating the strong interest in applying Wi-Fi to the white spaces.

The propagation advantages of sub-1GHz spectrum

Signals using sub-1GHz spectrum can travel significantly further than signals using 2.4GHz for the same power level, and may increase the possible range of communication by a factor of 3, and correspondingly increase the area of coverage by a factor of 9[81]. Figure 35 below shows the difference in range that might be achieved in both indoor and outdoor scenarios.

Figure 35 – Indicative comparisons of Wi-Fi range using 2.4GHz and white space spectrum





Source: Perspective analysis and Google Maps

These images indicate the scale of the enhanced range and coverage that Wi-Fi devices able to use the white space will be able to provide. The first picture, for a university campus, shows that a single

[80] (Bahl, Chandra, Moscibroda, Murty, & Welsh, 2009)
[81] De Vries (2009)

access point could fully cover a large building and the neighbouring grounds and areas. In the second, a single access point could provide coverage throughout a small village and the surrounding area. Furthermore, at ranges below these maxima, these enhanced devices will be able to employ power levels lower than those necessary today with Wi-Fi.

The additional capacity provided by the white spaces

The second principal benefit from using the white spaces will be the additional spectrum it will allow for high speed data connectivity. Figure 36 compares the size of the unlicensed allocations at 2.4GHz and 5GHz to that available in the white spaces.

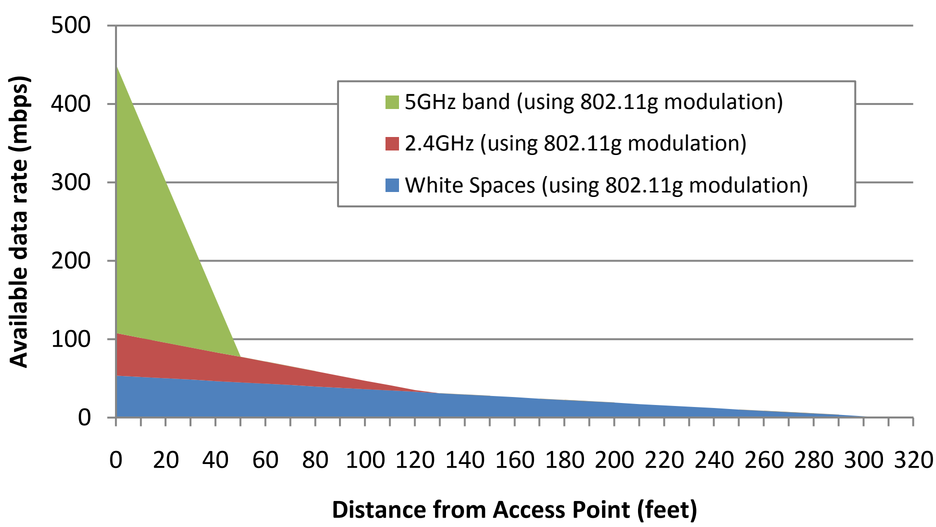
Figure 36 – A comparison of the incremental bandwidth of the white spaces

Band	Spectrum available in the US
2.4GHz	83.5MHz
5GHz	480MHz
white spaces	~48 – 120 MHz

Source: Perspective analysis

The addition of the white spaces spectrum would increase the amount of unlicensed spectrum available for high data rate Wi-Fi communication by around 9 – 22 percent in a typical location in the US, and a similar amount in other parts of the world. However, this simple comparison does not demonstrate the full importance of the white space spectrum. Figure 37 below shows the total bandwidth available for Wi-Fi communication using different bands at increasing distances[82].

Figure 37 – The availability of non-line of sight Wi-Fi suitable capacity moving away from an access point



Source: Perspective analysis

The diagram illustrates that very close to an access point; the largest capacity available is in the 5GHz band. At these ranges, the addition of the white spaces provides only a modest increase in the

[82] This analysis is based on an approximately linear decrease in the speed of an 802.11g connection with an increase in range. Three such streams could be run over the three non-overlapping channels in the 2.4GHz band. The maximum range was scaled down by 2.5 to reflect the poorer indoor propagation of 5GHz spectrum but the bandwidth was scaled up by a factor of 24. For the white spaces, the range was scaled up by 2.5 to conservatively reflect better propagation. The bandwidth available was deemed to be the same as 2.4GHz. This analysis does not reflect some features found in 802.11n, such as higher order modulation and MIMO.

capacity available, around 15 percent. However, moving away from an access point results quickly in the 5GHz spectrum losing its effectiveness as more robust but less efficient data modulation is required to maintain the connection. At a distance of around 50 feet, the addition of white space spectrum more than doubles the available unlicensed capacity. Further than 120 feet, white spaces would be the only unlicensed band that is usable.

Benefits for the users of Wi-Fi

The improvements in the performance of Wi-Fi from the addition of white space capability are likely to provide tangible benefits in each of the six sectors identified in Figure 34 above.

Consumer

White space enabled Wi-Fi is likely to provide more reliable coverage throughout the home. It also offers the potential for communities to share a high speed internet connection in a rural area or create their own networks.

The creation of community networks could allow for a host of applications. Live video and media could be streamed from schools and community events, without incurring the costs of distribution over wide-area networks. Membership of such community networks could allow for better localisation of news and information on the internet, thus allowing for a more geographic and social angle from which to aggregate and share data.

Commercial

Whereas homes largely rely on a single access point, businesses tend to use multiple access points to provide connectivity throughout the workplace. White space enabled Wi-Fi could substantially reduce the number of access points required to provide this level of coverage, whilst also providing more reliable coverage in areas where signals at 2.4GHz do not propagate well. These benefits are also likely to extend to outdoor commercial hotspots, such as those used by specialist operators or cellular networks.

Educational

Colleges and universities often employ substantial Wi-Fi networks to provide coverage across the area of a campus. White space enabled Wi-Fi is likely to provide both better coverage and reduce the number of access points needed.

Healthcare

Hospitals provide a challenging environment in which to deploy WLANs. The challenges are well described by Geier (2007):

> An issue with deploying WLANs in hospitals, though, is the difficulty in providing adequate wireless LAN coverage. Hospitals include x-ray rooms surrounded by lead, irregular metal objects, and unpredictable traffic flows of people. These factors lead to significant signal impairments. In addition, RF interference from other wireless systems operating in the 2.4GHz band, such as frequency-hopping spread spectrum devices, can cause degradation in performance. As a result, installers must conduct

> thorough RF site surveys when identifying optimum placement of wireless access points.[83]

Again, white space enabled Wi-Fi could greatly simplify the installation of WLANs in hospitals, enabling the types of application whose value we modelled above to be deployed more quickly and at a lower cost.

Industrial

Industrial environments are likely to provide an equally challenging environment to that found in hospitals. The additional reliability provided by white space enabled Wi-Fi may enable the use of WLAN for critical monitoring and control systems.

Government

Many of the early attempts at setting up citywide Wi-Fi networks were not as successful as hoped. A large number of access points were required and the propagation characteristics of 2.4GHz spectrum did not provide reliable coverage indoors. White-space enabled networks might allow these public access networks to be realised.

However, these city-wide networks have other uses apart from providing public broadband, many of which are only being recently understood. These include providing a closed network for city employees, control of street lighting and traffic management, and smart metering. White space enabled Wi-Fi, with its nine-fold area coverage advantage over conventional Wi-Fi, may prove the ideal tool with which to set up these networks.

The economic value from white space enabled Wi-Fi

In this chapter we quantify the magnitude of the potential benefits that could be realised from white space enabled Wi-Fi under a number of scenarios. Although this involves making a series of assumptions, we believe that reasonable approximations can be employed. Wherever possible these are informed by our more detailed analysis above.

Methodology

Our analysis is based on the premise that white space capability will become integrated into the broader Wi-Fi technology. The Wi-Fi standard has been upgraded a number of times and the rate at which the new revisions have become mainstream has been very rapid. We assume that white space capability is commercialised for the Wi-Fi standard in 2012, and that sales of non white space capable chipsets drop-off at the same rate as sales of 802.11b chipsets did upon the introduction of newer standards[84]. This would result in all Wi-Fi chipsets attaining white space functionality by 2021.

We have also projected the annual sales of Wi-Fi chipsets in the US market. To do this we have used data from ABI Research, and adjusted their figures to arrive at three broad scenarios.

- **Low growth** – in this scenario, growth in the Wi-Fi chipset market begins to tail off from the ABI projections in 2011, with a 50 percent reduction in the growth rate each year

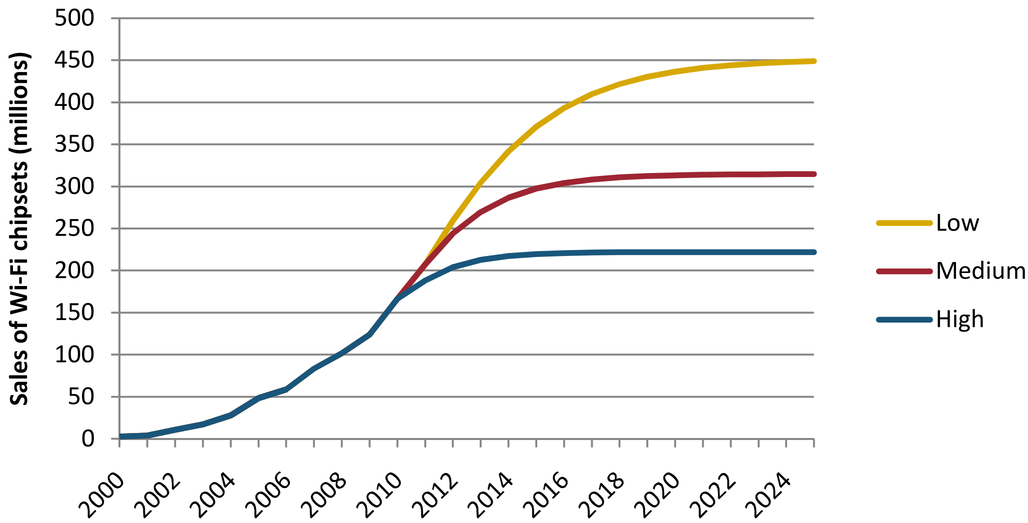
[83] (Geier, 2007)
[84] Data from ABI research

- **Medium growth** – in this scenario, growth in the Wi-Fi chipset market begins to tail off from the ABI projections in 2012, with a 40 percent reduction in the growth rate each year

- **High growth** – in this scenario, growth in the Wi-Fi chipset market begins to tail off from the ABI projections in 2013, with a 30 percent reduction in the growth rate each year

The resulting scenarios are shown in Figure 38 below

Figure 38 – Projections of Wi-Fi chipset sales in the US to 2025



Source: (ABI Research, 2008) and Perspective analysis

White space capable chipsets will cost more than existing devices in the short run. We have assumed that the cost of a white space capable chipset is $10 higher than existing chipsets in 2012 but that this differential decays towards $1 at a rate of 30 percent a year[85].

An estimation of the potential benefits can be informed by results from two of the analyses we have conducted above, our assessments of the value of Wi-Fi in the home and in hospitals. From the models we can derive the average monthly economic value generated by each Wi-Fi device, by dividing the annual economic benefit in 2014 by the population of Wi-Fi devices in use. This is presented in Figure 39 below.[86]

Figure 39 – Annualised economic value per Wi-Fi chipset in modelled applications

	Consumer Wi-Fi	Hospital Wi-Fi
Economic value generated per month per Wi-Fi chipset ($)	$6.20	$540

Source: Perspective analysis

[85] Data from ABI Research suggests that a similar price differential and decay operated on the introduction of 802.11g and the latest Wi-Fi standard, 802.11n

[86] The Applied Economics case study provides the number of devices that were used in the original trial. For home broadband use we have assumed that each Wi-Fi household in the US possesses a Wi-Fi access point and two client devices.

The average economic value generated by each Wi-Fi device in a hospital is significantly greater than that generated by one in the home, and there are likely to be further variations across the wide number of applications and sectors in which Wi-Fi is used. In our discussion above we noted the particular benefits that white space enabled Wi-Fi would bring for entities such as universities, hospitals, industrial plants and municipalities which would be deploying larger networks. For the purposes of our modelling we assume three scenarios for the additional average monthly value that a white space enabled chipset would provide. In our low value case we have assumed 50 cents of additional value per month, for our base case we have assumed $1 of additional value per month, and for our high value case we have assumed an additional value of $2 per month.

We have assumed that 25 percent of Wi-Fi devices are retired each year and from our growth projection we are able to determine the population of each standard of Wi-Fi device and therefore of each device that has white space capability. We are then able to determine the net benefits of the adoption of unlicensed white spaces.

Results

The NPV of economic benefits for all combinations of our scenarios are shown in Figure 40 below.

Figure 40 - NPV of economic value generated in the US by white space enabled Wi-Fi 2012 - 2025

		Projected increase in Wi-Fi sales		
	($ billions)	Low	Medium	High
Additional value generated by white spaces	Low	17	37	75
	Base	24	51	104
	High	33	68	140

Source: Perspective analysis

The corresponding annualised economic benefits over the period 2012 – 2025 are given in Figure 41 below.

Figure 41 – Annualised value of economic value generated in the US by white-space enabled Wi-Fi 2012 - 2025

		Projected increase in Wi-Fi sales		
	($ billions per year)	Low	Medium	High
Additional value generated by white spaces	Low	1.8	3.9	7.9
	Base	2.6	5.4	11.1
	High	3.4	7.3	14.9

Source: Perspective analysis

Although the exact validity of the assumptions of this modelling exercise can be questioned, even under modest assumptions – that Wi-Fi growth is substantially short of ABI Research's projections and that each enhanced device generates only an incremental 50 cents of economic value per month – the economic value generated from white space enabled Wi-Fi would be billions of dollars a year.

The benefits to other technologies from unlicensed white spaces

Although the preceding discussion has focused on the benefits that white spaces might provide to users of Wi-Fi, other unlicensed technologies are also likely to gain from its use.

A number of Bluetooth devices are designed for low power usage, and using the white spaces could provide substantial power savings compared to the existing 2.4GHz spectrum used by Bluetooth.

802.15.4 devices can benefit from both the greater range and lower power transmission offered by the white spaces.

Wireless sensor networks deployed using 802.15.4 would be able to enhance their range of application by using the white spaces. This could result in a greater area potentially being covered by the same number of nodes. Furthermore, as a number of industrial control processes require very reliable communications, 802.15.4 devices equipped with white space capability might be able to find use in areas where signals at 2.4 GHz cannot effectively penetrate.

Some uses of sensor networks are in areas which are off the power grid and therefore have to be powered by batteries or use energy harvesting methods such as renewable power. The use of the white spaces could help increase the battery life of some devices and the reliability of operation of others.

Costs from unlicensed usage of the white spaces

As discussed for licensed usage in the previous chapter there are obstacles for unlicensed deployment in the white spaces.

Firstly, the variability of the white spaces leads to an uncertainty of capacity in any particular location. This may serve to discourage potential buyers of white space enabled equipment. However, it may be possible for vendors of equipment to inform buyers in any particular area of the likely availability of capacity. In urban areas this might be exacerbated as initial surveys of the white space show that less spectrum is likely to be available[87].

Secondly, there is the issue of interference with incumbent users. The lower power employed by unlicensed applications, as opposed to licensed ones such as cellular, could help to ameliorate this problem. Nonetheless, unlicensed usage will have to be able to successfully avoid transmitting at frequencies and at powers that result in interference. A number of methods have been suggested to achieve certainty. Much work has been done on spectrum sensing and also on the use of geo-location databases to determine the available channels. Work is also being done on the ways in which reliable networking would be constructed in variable spectrum[88]

Summary

A number of applications could benefit from the availability of the white spaces on an unlicensed basis, including those using Wi-Fi, Bluetooth and 802.15.4. These benefits are likely to be experienced across all sectors of the economy, from better consumer goods to cheaper college networks. An analysis of the potential benefits only to those applications using Wi-Fi suggests the potential for substantial economic benefits. The ability to deploy cheaper, more reliable and higher quality local area networks is likely to speed the adoption of new technologies and deliver consequent gains in productivity. However, in addition to these gains for the US economy achieved through the improvement of existing applications, unlicensed operation in the white spaces has the

[87] (Mishra & Sahai, 2009)
[88] (Bahl, Chandra, Moscibroda, Murty, & Welsh, 2009)

potential to unlock new applications that could have wider societal benefits, not just in the US but around the world.

8. Social benefits from the unlicensed use of the white spaces

The previous chapter examined the economic value that the use of the white spaces might generate in a mass market setting. In this chapter we briefly outline two novel unlicensed applications that might be enabled by the unique propagation characteristics of the white spaces: rural broadband and agricultural automation and monitoring. Although these applications may not generate the largest economic returns, they would appear to have the potential to deliver large social benefits.

Rural Broadband

The increasing importance of broadband

Broadband has become an essential means of social and economic connectedness, just as the telephone and transport links have been in the past: it is a central feature of modern life allowing people to interact, communicate, learn and engage in commercial activity. It is increasingly recognised by policy makers and politicians as an essential commodity without which individuals cannot participate fully in society. Indeed, a recent EU Ministerial Conference on e-Inclusion held in Vienna concluded:

> Broadband is becoming an "essential commodity" like water or electricity. It is today an indispensable service for the effective participation in the global trade, economy, education, culture, politics and society. As new broadband services are developed and new and more capable infrastructures are made available old gaps may get entrenched and new gaps may arise between those who have access and can successfully exploit it and those who do not have access or lack the ability to exploit it.[89]

The lack of rural availability

Although access to broadband is becoming more important it is far from universally available, even in developed economies. One of the most striking gaps in broadband availability is between urban and rural areas.

Addressing the lack of broadband coverage in the rural United States was one of the central planks of the American Recovery and Reinvestment Act. This provided $7.2 billion for broadband projects. However, one of the first hurdles that the US faces is the lack of existing information on its current availability[90]. Data collected in Europe is more comprehensive and is used in this chapter.

In their report for the European Commission in 2008, the consultancy firm IDATE conducted a thorough survey of broadband across the EU's 27 member states. From the collected data we can ascertain the following information about broadband coverage and availability in Europe.

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[89] (The Presidency of the Council of the European Union, 2008)

[90] The FCC, in 2006, classed an area as having broadband availability if a single user in a Zip code area had a broadband service. The definition of 'broadband' used by the FCC was one of 200kbps, which is very low. This level of speed is barely enough to stream low quality video. However, in response to this lack of data the FCC is now collecting data at the census block level (a level of geographic granularity of about 30 households) (FCC Form 477). The FCC's annual CMRS report already does this for mobile.

Figure 42 – The availability of >1Mbps broadband in urban and rural areas of the European Union

	Number (millions)	Percentage
Total population	466.2	100%
Urban population able to receive > 1 Mbps	325.2	69.8%
Urban population unable to receive > 1 Mbps	106.3	22.8%
Rural pop without BB coverage	34.7	7.5%

Source: Perspective analysis, IDATE data

IDATE's data show that over 34 million rural inhabitants of the EU surveyed do not have access to either wired or mobile broadband.

The role of unlicensed white spaces

White space enabled Wi-Fi could play an important part in reducing the costs of connecting rural communities. Whether, this connectivity is provided by fibre, wireless link or satellite, these white space using devices could play a complementary role by acting as a means of low-cost distribution. The diagram below illustrates how they might be used in conjunction with a fibre connection to provide connectivity.

Figure 43 – Indicative use of white space enabled Wi-Fi in delivering rural broadband

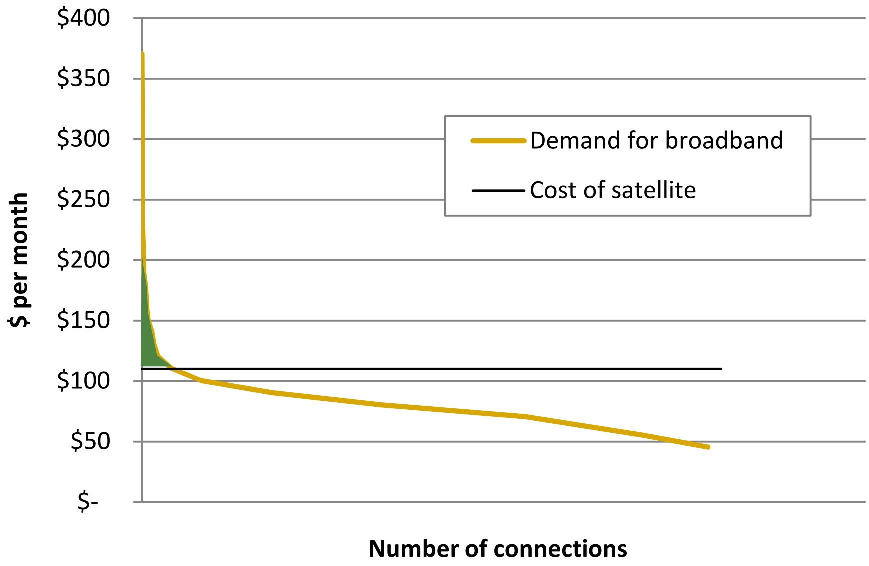
Source: Perspective analysis, IDATE data

Used in this way, the white spaces could be used to substantially reduce the costs of connectivity. Instead of each household installing a wired link to a fibre connection, or installing an external antenna, this method would utilise white space enabled Wi-Fi routers. This could greatly simplify the process of connecting more isolated communities. Furthermore, by being an unlicensed technology, this approach would be open to any organisation. It could just as easily be employed by major network operators seeking cheaper methods to fill in their existing footprint as by communities looking to self-deploy broadband.

The potential for value to be generated

Orszag et al (2009) found no difference between the willingness to pay for broadband in rural areas as opposed to urban areas. However, whereas urban areas often have a choice of low-cost methods of connecting to the internet, in some rural areas there is very little choice. Often the only method available is satellite broadband. The costs of this are high: even spread over a three year period they equate to around \$100 per month[91]. Below we reproduce the demand curve derived by Orszag, which aptly demonstrates the effect of such high prices on demand and consumer surplus.

Figure 44 – The effect of take-up if only high priced broadband is available



Source: Perspective analysis, Orszag et al

If broadband services are only available for sums greater than \$100 per month, take up will remain limited as only a very small number of households will be willing to pay such a price. Furthermore, the level of economic benefit derived, as measured by the consumer surplus, will be small[92].

Together with other technologies, white space spectrum could be used in a number of ways to help address the gap in rural broadband. To gain an idea of the magnitude of the benefits they could bring we can conduct some very approximate modelling of the benefits that would flow from cost savings in the delivery of broadband. We will take as our starting point, the costs of satellite broadband and construct three broad scenarios which relate to their potential effectiveness.

[91] The average cost of a Eutelsat Tooway™ system.

[92] Some governments around the world have been encouraging the take up of satellite broadband in rural areas through subsidies of the costs involved. This helps reduce the cost for the end-user, and so increases the usage of these services. However, this comes at a high cost to the taxpayer. For example, the Australian Broadband Guarantee provides a subsidy of over \$2000 over a three-year period for each household to be connected by satellite broadband. These costs are necessarily higher than the consumer surplus they create, and finding ways to reduce the costs of broadband without resorting to subsidies will prove beneficial to both underserved communities and to governments in the long-term. For communities, their access will be less at risk from cutbacks in governmental support, and for governments, their budgets will stretch further.

Figure 45 – Scenarios for modelling the impact of white space spectrum on rural broadband availability

Scenario	Description	Modelling consequences
1. Marginal cost improvements to satellite broadband	In this scenario, White Space Devices are largely used in conjunction with satellite broadband in order to drive down the costs of distributing satellite connectivity.	• 10% reduction in the upfront costs of satellite broadband
2. Competitive delivery at the margin	Benefits above + the use of White Space Devices allows the delivery of competitively priced broadband to 5% of the rural areas that did not previously have access to fixed line broadband[93].	• 10% reduction in the upfront costs of satellite broadband • 5% of rural population moves into urban category
3. Competitive delivery deeper in rural areas	Benefits above + use of White Space Devices allows for business models which can cover a larger amount of the rural population with competitive broadband.	• 10% reduction in the upfront costs of satellite broadband • 20% of rural population moves into urban category

Source: Perspective analysis

We have modelled the increase in both the number of internet users in the countries surveyed by IDATE and the resulting consumer surplus generated. We have used the IDATE data, in conjunction with the demand curve derived by Orszag (modified for a lower European GDP per capita). The results are presented below.

Figure 46 – Increase in broadband adoption and consumer surplus in the European Union in each scenario

Scenario	Increase in connections (millions)	Annual Increase in consumer surplus ($ millions)
1	0.78	$230
2	1.83	$750
3	4.97	$2,300

Source: Perspective analysis

This shows that the white spaces could connect a substantial number of people to broadband services if devices using this spectrum were able to reduce the costs of remote connection and extend urban coverage into neighbouring rural areas. Although these results relate to a European context, it is not inconceivable that similar results are achievable in the US.

Adapting to the effects of climate change

The use of technology has been proposed for both reducing the emissions which are resulting in anthropogenic climate change, as well as mitigating for the effects of changes already occurring and those projected to occur in the future.

Unlicensed wireless devices could play a role in many of the schemes devised to meet these ends. For example, we have already outlined above the role which applications based on 802.15.4 and Wi-

[93] In this scenario a variety of actors may be providing this access in a variety of ways. For example, it could be municipalities paying for the cost of fibre or microwave or small entrepreneurs extending connectivity from a larger town to a smaller unconnected one.

Fi are playing in smart metering and building automation applications. Devices using the white spaces could find uses in all these areas.

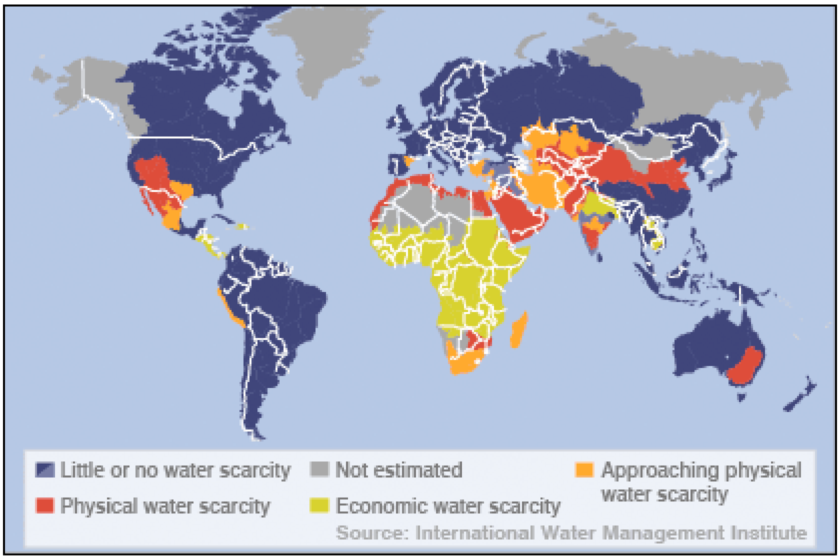
One area in particular in which white space enabled devices could have a significant impact is in the area of water saving, especially in agriculture.

Global water stress

The UN has warned that "water scarcity threatens economic and social gains and is a potent fuel for wars and conflict."

Large parts of the world currently experience water scarcity. The map below is taken from the International Water Management Institute's 'Insights' from the Comprehensive Assessment of Water Management in Agriculture[94].

Figure 47 – Water stressed regions of the world



Source: BBC

This shows that large parts of the world suffer from water scarcity. Areas of economic water scarcity are those where malnutrition exists but water resources are abundant, there being a lack of investment to take advantage of these resources for agricultural use. Areas of physical scarcity are those in which over 75 percent of river water is diverted for agricultural use.

Exacerbations through climate change

The combination of climate change and pre-existing physical water scarcity is likely to create significant water stress in the northern Mediterranean, which is the area most dependent on irrigation in the world. Giannakopoulos, et al (2005)[95] used sophisticated crop and hydrological modelling techniques to study the consequences for agriculture in the entire Mediterranean region in the event of a 2°C global temperature rise.

94 (International Water Management Institute, 2006)
95 (Giannakopoulos, Bindi, Moriondo, LeSager, & Tin, 2005)

> In some locations in the northern Mediterranean, the effects of climate change and its associated increase in carbon dioxide may have little or small positive impacts on yields, provided that additional water demands can be met. The adoption of specific crop management options (e.g. changes in sowing dates or cultivars) may help in reducing the negative responses of agricultural crops to climate change. However, such options could require up to 40% more water for irrigation, which may or may not be available in the future.[96]

It may well be possible for agriculture in the northern Mediterranean to adapt to the consequences of climate change, but at the cost of significant extra water resources. However, work by the UK Meteorological Office (Arnell, 1999) predicts that for this same period, rainfall will decrease substantially in this region. Therefore, under likely climate change scenarios, the northern Mediterranean region will have a significantly greater demand for water as well as a substantially lower supply, serving to increase water stress.

A key resulting challenge, endorsed by the European Commission, is that of conserving water resources.

The role of unlicensed white spaces

A comprehensive overview of the use of wireless sensor networks in agriculture and food production by N. Wang et al (2006)[97] clearly shows the potential for devices using unlicensed spectrum. Two examples in particular stand out:

> The Discovery Channel (2003) reported an application of a wireless sensor network in a vineyard in BC, Canada. Sixty-five motes were installed in a 1-acre land to remotely report temperature, moisture and sun light intensity to a central PC every 5 min. The owner could monitor each area of the vineyard in real-time to avoid frost, manage irrigation, determine fertilizer applications and arrange harvest schedule.[98]

> Damas et al. (2001) developed and tested a distributed, remotely controlled, automatic irrigation system to control a 1500 ha irrigated area in Spain. The area was divided into seven sub-regions with a total of 1850 hydrants installed. Each sub-region was monitored and controlled by a control sector. The seven control sectors communicated to each other and with a central control through a WLAN network. Field tests showed 30–60% savings in water usage.[99]

This paper also states the challenges of deploying these networks. These include:

- Propagation issues in large rural areas
- Off-power grid operation necessitating low power consumption
- Expense of equipment

White space enabled devices have the potential to meet these requirements. Firstly, the UHF spectrum has propagation advantages over other wide unlicensed bands. Secondly, the flip side of

[96] Ibid
[97] (Wang, Zhang, & Wang, 2006)
[98] Ibid
[99] Ibid

this lower-frequency is that less power is needed to attain the same distance. And thirdly, if well established unlicensed technologies adopt the use of the white spaces it is likely to result in economies of scale and low priced chipsets. There appears to be the potential to create sensor and control networks similar to those outlined by Wang using standards such as 802.15.4 enabled for white space usage.

Covering a small percentage of the irrigated land in northern Mediterranean countries[100] with automated irrigation systems has the potential to save large amounts of water. Figure 48 below shows the savings that could be made if these systems could make irrigation 30 percent more efficient, half the efficiency gain found by Damas et al (2006).

Figure 48 – Water savings from the application of wireless irrigation control networks to a percentage of irrigated land

Total irrigated land area covered with sensor networks and water control systems	0.5%	1.0%	2.0%
Land area (ha)	68,787	137,575	275,149
Water used (M m^3 $year^{-1}$)	210	420	839
Water savings (Mm^3 $year^{-1}$)	63	126	252

Source: Ecologic[101] and Perspective analysis

Chang and Griffin (1992) found net economic benefits of \$10 per m^3 of water traded from the agricultural to the domestic sector. Using this as rule of thumb, the indicative economic benefit from these savings could be in the order of \$600m to \$2.5bn per year in the northern Mediterranean.

The problem of water stress is not uncommon in parts of the United States; areas of California have suffered from three consecutive years of drought, which has caused billions of dollars in losses[102]. In 2009, up to a third of the 3 million acres normally irrigated with federally supplied water are due to be left fallow. The application of water saving technology is equally applicable in many parts of the world.

Summary

This has been a cursory treatment of some important issues. The modelling conducted above is merely indicative and, for innovative applications of a nascent technology, is likely to remain so. However, the combination of low cost equipment and the availability of lower-frequency spectrum such as the white spaces for unlicensed use might enable the successful application of this technology in areas such as those discussed above, and in many others which cannot yet be predicted.

[100] Cyprus, France, Greece, Hungary, Italy, Malta, Portugal, Romania, Slovenia, Spain.
[101] (Ecologic Institute, 2007)
[102] (Gorman, 2009)

9. Summary and conclusions

The approach of regulators, certainly in Europe and to some extent in the United States, has been to allow unlicensed usage of certain bands, where it could be tolerated – rather than actively seeking out spectrum for this purpose. Unlicensed spectrum has largely been an afterthought – 'junk' spectrum which cannot usefully be licensed.

The focus of regulators has instead been on licensed spectrum, and the intention has been to facilitate the creation of markets in national and regional spectrum licences. As yet these markets have failed to display the dynamism and activity that usually characterise competitive free markets. However, in the same period, a continuing effort in unlicensed spectrum – collaborative effort in setting standards and a competitive effort in the marketplace – has achieved a number of milestones.

As our analysis in Chapter 3 shows, a vibrant ecosystem of uses has developed in the unlicensed bands, across all sectors of the economy. Over the next five years it is likely that devices using only unlicensed spectrum will outsell those using only licensed spectrum, including such established widespread devices such as televisions, radios and some cellular phones. In many cases these methods of unlicensed connectivity are being integrated alongside licensed applications, such as in cellular phones, where the indication is that Wi-Fi is becoming a standard feature in any phone that can access the internet. However, in the majority of cases, unlicensed connectivity is being applied to devices that had previously remained unconnected.

It is the very success of unlicensed spectrum in enabling widespread and often specialist applications that makes the economic value it delivers difficult to comprehensively measure. Our analysis in Chapter 4 of only three unlicensed applications found that in total these might deliver $16 – 37 billion dollars of economic benefit annually over the next 15 years to the US economy. These applications are likely to represent only 15 percent of the total unlicensed devices that will ship in 2014. Consequently, our results might significantly underestimate the actual value that will be generated by unlicensed devices over the coming decade.

In chapter 6 we outlined the potential for innovation in the unlicensed bands. We found that many recent advances in wireless technology have first been applied to unlicensed technologies such as Wi-Fi. Moreover, as these advances have matured in Wi-Fi they have been adopted by the latest cellular standards, to be deployed in licensed spectrum. Unlicensed technologies have also been deployed to create radical innovations in products and services, from applications that can accurately locate users in cluttered urban canyons beyond the easy reach of GPS to pacemakers fitted with wireless connectivity. Unlicensed devices are also helping to usher in a revolution in ubiquitous computing, in which often everyday devices are connected together to allow new products and services.

Applications using unlicensed spectrum are currently restricted in their scope by the spectrum which they must use. For high data rate applications this is limited to high frequency bands which do not allow communication over distances longer than a couple of hundred feet, even in ideal conditions. There is no reason to suppose that permitting unlicensed access to lower-frequency bands, which allow communication over greater distances, will not lead to increased innovation and corresponding economic benefit. One such lower-frequency band is the television white space.

Our overview in Chapter 6 shows that few licensed uses could make use of this fragmentary spectrum. However, as we see in Chapter 7, Wi-Fi using the white spaces could generate $4 – 7 billion of annual economic value in the United States alone by improving a whole host of existing applications which use Wi-Fi. In Chapter 8, we briefly examined two new applications that could be enabled by Wi-Fi in the white spaces in a European context, and found the potential for substantial economic and social gains.

So far, unlicensed spectrum has had an accidental history. Had it not been for the serendipity of microwave ovens[103] and the foresight of a few individuals[104], the remarkable rise in unlicensed usage that we document in this paper may never have been experienced. However, to make the best use of this extraordinary mechanism for enabling innovation and economic gain requires policymakers and regulators to now take a more deliberate approach.

[103] Most commercial and domestic microwave ovens operate at 2.4GHz, and this had long been thought to render the band useless for communications devices (Carter, Laujouji, & McNeil, 2003)
[104] Michael Marcus, chief of the FCC's Technical Planning staff, pushed for the landmark decision to allow communications use of the ISM bands (The Economist, 2004)

Annex 1. The progression of spectrum management

Free-for-all

When radiocommunications were first developed they found an immediate military use, and in many countries the usage of radio was monopolised by the state[105]. In the United States under the Radio Act of 1912, and in other countries, private operators of wireless telegraphy services were permitted to operate in specific frequency bands if upon obtaining a licence. This situation persisted until the development of broadcast radio in the early 1920s. In the US, a large number of radio stations obtained licences under the Radio Act. Eventually the Commerce Department began to stop issuing further licences, under the express premise of preventing interference between stations. Due to this restriction, there was an active secondary market for licences, and in many cases these changed hands for hundreds of thousands of dollars[106].

However, in 1923 a US federal court ruled that the Secretary of Commerce had no legal basis on which to restrict radio licences, bringing to an end the restrictions on the number of broadcasting stations. Entities that previously had been denied a licence launched radio stations and existing licensees began to shift to different frequencies. The effect of this decision was to create a free-for-all which resulted in broadcasters engaging in 'power races' and 'frequency races' to drown out each others' signals and listeners were often only able to tune in to garbled static.

In response to this situation, existing broadcasters turned to the courts. Hazlett (1990) provides the fascinating details of the 1926 Illinois case of *Tribune Co. v. Oak Leaves Broadcasting Station*. In this case the presiding magistrate ruled that the broadcasts of the Oak Leaves Broadcasting Station, which prevented the reception of the Tribune Company's already established station, violated "a particular right or easement in and to the use of said wavelength which should be recognized in a court of equity and that outsiders should not be allowed thereafter, except for good cause shown, to deprive them of that right and to make use of a field which has been built up by the complainant at a considerable cost in money and a considerable time in pioneering."[107]

This judgment had the potential to create far-reaching implications. Hazlett reports that other stations which had faced a similar threat to the one faced by the Tribune Company responded by lodging similar appeals in state courts. Furthermore, the core of this judgment suggests an approach whereby a particular prior use of spectrum (broadcasting a radio station to be received by radio receivers on a particular frequency) would be protected by common law. This also had the potential to apply to the US Government; it would only have recourse to the law if external transmissions interfered with its own established operations but it would have no primacy or monopoly over radio transmission in general.

Hazlett presents this decision as a potential underpinning for the development of private property rights to spectrum. De Vries (2008), on the other hand, develops a different interpretation, in which the law would not have developed to grant entities rights over particular spectrum, but instead rights to a particular *usage* of spectrum[108]. This latter interpretation would appear to be supported by engaging in a thought experiment which varies the conditions of the Oak Leaves case. Would a similar judgement have been reached had the Oak Leaves Broadcasting Company transmitted

[105] (Hazlett, 1990)
[106] Ibid
[107] Ibid
[108] (de Vries, 2008).

signals, on the same radio frequencies, that did not interfere with the established usage? It is unlikely that a court would have upheld the claim from the Tribune Company, or even heard the case.

The development of this branch of common law was, however, cut short in the US by the Radio Act of 1927 which established radio spectrum as an inalienable public resource and gave over its management to the Federal Radio Commission, a forerunner of the FCC. Many other countries moved directly to this form of spectrum management, without the intervening period of free-for-all that for a time had characterised US broadcast radio. These actions instituted the beginning of governmental agencies tasked with the role of spectrum management.

Licensed spectrum usage

The majority of the wireless applications in use today occupy licensed spectrum and together they generate a huge amount of economic value.

The era of restriction

Once Governments had assumed the responsibility of spectrum management, specialised governmental functions evolved to carry out this function. The modern role of the spectrum manager is articulated concisely by Ofcom, in the executive summary of its 2004 Spectrum Framework Review:

> The role of the spectrum manager in outline is to ensure that no two users transmit on the same frequency at the same time and sufficiently close together that they interfere with each other. To do this, the spectrum manager does not give out "spectrum" but instead provides the right to transmit on a particular frequency over a particular geographical area. Such a transmission right is sometimes referred to as "access to the spectrum" and users will sometimes refer to having bought "spectrum at auction". There is often an international dimension to this as radio signals do not stop at international borders[109].

It is interesting to compare the role envisaged for the spectrum manager by Ofcom to the legal responsibilities espoused by the Oak Leaves judgment. Ofcom sees part of its responsibility as ensuring that only a single entity can "transmit on a particular frequency over a particular geographical area". However, this definition does not fully capture the central Oak Leaves concept, that it is only if the outcome is interference with a pre-existing user that there needs to be recourse. Furthermore, it is apparent that for Ofcom frequency is the key aspect for determining a license.

As radio broadcasting has been joined by television broadcasting and mobile two-way voice and data services, there has been a greater focus on the methods by which spectrum managers allocate the use of the radio spectrum.

In many countries lotteries were used as a major method of licence allocation, and in some cases they are still a preferred method of allocation; for example, in the distribution of community radio licences.

[109] (Ofcom, 2004)

However, it is clear that the gaining of a frequency licence can bring with it substantial commercial benefits, especially in sectors where licences are small in number relative to demand, and access to spectrum can command scarcity rents. This has led to a more common approach in recent years that of comparative selection, or 'beauty parade'. In this process multiple entities apply for a licence, and the spectrum manager selects the eventual licensee against a set of service criteria. In most European countries, broadcast licences and the first generations of mobile licences were awarded in this fashion.

The methods by which spectrum came to be managed was often termed one of 'command and control'. This referred not only to the means of licence allocation, but the conditions that were attached to the licences, such as a strict specification of technologies to be used and restrictions on transfer.

The era of liberalisation

Ronald Coase's seminal paper in 1959[110] laid out deficiencies in the command and control method of spectrum management. Coase argued convincingly that this method led to serious inefficiencies in the use of spectrum. Furthermore, he presented an approach based on property rights and market mechanisms which he believed could improve the allocation and utilisation of spectrum. Although these ideas were initially dismissed, over time they have been gained recognition, especially in the US and in Europe.

The extent to which Coase's ideas have been adopted varies across nations and spectrum managers. However, a number of components can be identified:

- Spectrum auctions – initially used to allocate spectrum. This is designed to ensure that those entities that value particular spectrum most will be able to gain access to it
- Secondary markets for spectrum – allowing the trading of spectrum so that entities can aggregate and disaggregate spectrum holdings according to their commercial needs.
- Liberalised use of spectrum – owners of spectrum should be free to change the use to which they put their spectrum, according to particular spectrum usage rules

Spectrum auctions also have an additional benefit in that they extract scarcity rents from particular applications and deliver them to the public purse.

The advent of liberalisation has led to a large number of spectrum auctions, and liberalised spectrum usage rights have seen many changes of technology in particular spectrum bands, especially those used for cellular communications. However, spectrum markets have remained undeveloped. A number of reasons have been postulated for the inactivity. Some have suggested that these markets will need time to develop, and that not enough tradable spectrum has been released into the market. More sceptical voices suggest that there is very limited substitutability between various spectrum bands, and that in very valuable spectrum bands, as long as utilisation remains high relative to capacity, spectrum will remain a core strategic asset, and is only likely to change hands when whole companies are bought and sold.

Unlicensed spectrum usage

[110] (Coase, 1959)

Although the licensed model has been employed to great success, in some circumstances it can prove a cumbersome method for enabling communications using radio spectrum. The development of the unlicensed model of spectrum usage can be traced back through amateur radio

Amateurs have experimented with radio communications since the beginnings of the medium[111]. However, once radio began to be used for military purposes, amateurs needed to obtain a licence to use the airwaves and were assigned certain frequencies upon which they could transmit. These licensing arrangements persist to this day for the use of the internationally harmonised amateur radio bands. Part of the licensing requirement for amateur radio operators is the taking of practical and theoretical tests which ensure that users do not interfere with others' communications.

However, amateur radio has never been a mass market phenomenon. The first two-way radio service that can lay claim to this was citizens' band (CB) radio. Originally introduced in the United States in 1945 for the use of private citizens, CB radio gained hugely in popularity in the 1970 due to lower price and increasing compactness of sets. Whilst there was originally a licensing requirement, as interest in CB radio spiked in 1975 the FCC couldn't keep up with the requests for new licences. In January 1976 alone, one million licensing applications were received, after several months averaging half a million requests[112]. In addition many users of CB were using their sets without a licence. Eventually, the FCC abandoned the licence requirement entirely. This resulted in an increase in interference within this band, as unlicensed operators largely ignored the politeness rules set down by the FCC as part of the licence condition.

Perhaps the first mass market consumer radio transmitting devices exempt from licensing requirements were cordless phones, which first appeared in the 1970s[113] and had become popular by the 1980s[114]. Spectrum was made available in countries such as the UK and the US at 39Mhz and 47MHz. In these bands cordless phones could operate free from licensing requirements. Even though the strict conditions set by regulators did not signify a return to a 'free-for-all', cordless phones suffered from many of the problems that economics would suggest as a result of the tragedy of the commons. The first analogue models were tuned to a limited number of channels, and so overheard conversations and tuning in to the wrong base station was a common problem; the only solution was to replace the phone with one using a different channel. The FCC even mandated a decrease in power levels to help alleviate the problems, and although this helped somewhat, it also had the effect of significantly reducing the range of cordless phones.

Perhaps the pivotal decision in the history of unlicensed usage of spectrum came in 1985, when the FCC ruled to allow the use of direct sequence spread spectrum (DSSS) technology for communications in the ISM bands in the US[115]. These bands were primarily used for non-communications industrial applications, and as such, were regarded as 'junk spectrum'. However, DSSS was designed to be resistant to noisy environments. Therefore, after significant periods of standards development two important uses of this band were launched; Wi-Fi and Bluetooth. It is now common to see a large number of Wi-Fi access points in densely populated areas of cities, these points are able to work well collaboratively due both to the use of DSSS and politeness protocols devised by the industry standards bodies, which can be most easily thought of as machine versions of the human rules which amateur and CB radio operators were expected to use. The economic importance of these standards is discussed in a later chapter.

[111] (Gernsback, 1909)
[112] (Bartlett, 2009)
[113] (Nicopolitidis, Obaidat, & Papadimitriou, 2003)
[114] (Radiocommunications Agency, 1999)
[115] (Marcus, 2008)

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