uk spectrum policy forum

UK Spectrum Usage & Demand

Second Edition - Appendices

Prepared by Real Wireless for UK Spectrum Policy Forum

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About the UK Spectrum Policy Forum

Launched at the request of Government, the UK Spectrum Policy Forum is the industry sounding board to Government and Ofcom on future spectrum management and regulatory policy with a view to maximising the benefits of spectrum for the UK. The Forum is open to all organisations with an interest in using spectrum and already has over 150 member organisations. A Steering Board performs the important function of ensuring the proper prioritisation and resourcing of our work.

The current members of the Steering Board are:

Airbus Defence and Space	Huawei	Sky
Avanti	Ofcom	Telefonica
BT	QinetiQ	Three
DCMS	Qualcomm	Vodafone
Digital UK	Real Wireless	

About techUK

techUK facilitates the UK Spectrum Policy Forum. It represents the companies and technologies that are defining today the world we will live in tomorrow. More than 850 companies are members of techUK. Collectively they employ approximately 700,000 people, about half of all tech sector jobs in the UK. These companies range from leading FTSE 100 companies to new innovative start-ups.

About Real Wireless

Real Wireless is the pre-eminent independent expert advisor in wireless technology, strategy & regulation worldwide. We bridge the technical and commercial gap between the wireless industry (operators, vendors and regulators) and users of wireless (venues, transportation, retail and the public sector) - indeed any organization which is serious about getting the best from wireless to the benefit of their business.

We demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless technology to create an effective wireless strategy, business plan, implementation plan and management process.

We have specific experience in LTE, LTE-A, 5G, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA, PMR, PMSE, IoT/M2M, Bluetooth, Zigbee, small cells, radio, core and transport networks – and much more besides.

For details contact us at: info@realwireless.biz

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Business Radio: Airwave Ofcom TETRA and Critical Communications Association (TCCA) Federation of Communication Services	**Short Range Wireless:** BAE Systems Sky
Meteorology: The Met Office	**Broadcasting & Entertainment** Arqiva BBC Microsoft BEIRG Sennheiser Digital UK Sky DTG
Public Mobile: EE Telefónica -O2 BT Three Ofcom Samsung Vodafone	**Fixed Wireless Access & Wireless Transport Networks** Independent Networks Cooperative Association (INCA) UK Broadband EE
Amateur Radio: The Radio Society of Great Britain	**Utilities:** Joint Radio Company

Contents

A.1. Introduction

1.1 Scope

This document provides detailed appendices to the main report and it suggested that the main report is reviewed first.

1.2 About the UK Spectrum Policy Forum

The UK Spectrum Policy Forum [1] is the industry sounding board on long-term UK spectrum issues to Government and Ofcom. Launched in September 2013 by Ed Vaizey, Minister for Culture and the Digital Economy, the UK Spectrum Policy Forum provides input and support to Government and Ofcom on future spectrum management and regulatory policy with a view to maximising the benefits – both social and economic - of spectrum for the UK.

The main objective of the forum is to harness industrial insights from across the diverse range of spectrum users, into the future developments in spectrum-based services and technology, the resulting evolution in spectrum demand, and the composition of fit-for-purpose spectrum policies and regulation. The key themes for the work of the forum are:

- provision of horizon scanning to review developments in (worldwide) wireless usage and develop a UK focussed assessment of future spectrum needs
- development of a strategic roadmap for the future use of spectrum, harnessing cross-industry insights
- informing future mechanisms for spectrum release, assignments and authorisation
- enabling innovative future applications from spectrum and access to public sector spectrum

The UK Spectrum Policy Forum is open to all and has over 100 member organisations. It is chaired independently by David Meyer, facilitated by techUK and supported by DCMS. A Steering Board comprises thirteen funding partners ranging from major multinationals to SMEs with representation from across the industry [2]. While the Steering Board provides coordination and support, all decisions are taken by the membership as a whole.

The work of the Spectrum Policy Forum is organised into three clusters, with other clusters under consideration. The clusters are:

- Cluster One: Spectrum Applications and Demand
- Cluster Two: Spectrum Access and Use
- Cluster Three: Economic Analysis and Social Impact

1.3 Scope of this document

The goal of Cluster One is to promote a joined-up understanding of current and future spectrum needs across UK users, thereby assisting in maximising associated benefits (social and economic) and ensuring spectrum supply can be efficiently matched to those needs.

This document has been commissioned by the UK Spectrum Policy Forum from Real Wireless to represent the work of Cluster One. It provides a snapshot of the current spectrum usage and expected long-term future needs of the major users of spectrum in the UK. It identifies the business and societal activities which depend on this spectrum and the associated drivers of value.

The audience for this document is threefold:

1. UK Government, to inform future spectrum and infrastructure policy
2. Spectrum users, to foster mutual understanding and cooperation amongst users with distinct needs
3. The other Clusters of the Spectrum Policy Forum, as input to their work on spectrum access options and economic and social impact.

1.4 Approach

This document has been prepared as follows. Representatives of several spectrum-using sectors were invited to give presentations and participate in panel discussions to the Spectrum Policy Forum at a series of events held from late 2013 to the end of 2014. Real Wireless then used this material and some wider sources to draft a chapter for each sector, with the following contents:

- Scope of the sector: What people, services and devices are included?
- Contributions to social and economic value: What are the sources of value and what is their magnitude?
- Current and recent past status: Any significant changes which have been observed in the market
- Sector trends: Future growth/contraction prospects, changes to delivery model etc.
- Usage of technologies and spectrum: Current status, expectations for the future, the range of potential options for change
- Expected changes to technology and spectrum in the near term (5 to 10 years)
- Longer-term (10-20 years) technology and spectrum needs and options: is the supply model for the sector expected to change, or have the potential to change, and upon what would these changes depend?

Once the chapter was drafted, representatives of each sector, including the original presenters and others, were invited to review the chapter and suggest changes which would provide a representative consensus view for the sector.

The document was then shared with the Steering Board for comment, subject to further review by representatives of each sector, and eventually approved by the Spectrum Policy Forum members as a whole. Each sector chapter therefore represents the views of the sector contributors, not those of Real Wireless or the SPF as a whole.

The document contents are structured as follows:

- Chapter A.2 provides a short general overview of how spectrum is managed in the UK
- Chapters A.3 to A.13 provide details of the spectrum needs of the sectors who contributed to the report

A.2. Spectrum policy in the UK and internationally

Spectrum is a national asset that is increasingly subject to international developments and which, if appropriately distributed and used, can yield substantial economic and social value for the UK via a wide range of services and applications.

Spectrum policy as a whole is the responsibility of the Department for Culture, Media and Sport, which works with other departments, notably the Department for Business Innovation and Skills. In 2014 DCMS published the UK Spectrum Strategy [3] which sets out a vision for spectrum to double its annual contribution to the economy from a base of over £50 billion a year by 2025 through offering business the access it needs to innovate and grow, and everyone in the UK the services they need to live their lives to the full. This document is one contribution towards achieving that vision.

More specifically we are concerned with the *electromagnetic spectrum* - the range of frequencies[1] of electromagnetic radiation between 9 kHz and 275 GHz which are useful for radio communications and for other industrial, scientific and medical applications. Since the characteristics of radio wave propagation and associated radio communication networks mean that radio coverage does not stop at national boundaries, international and national bodies have been formed to harmonise the allocation and assignment of radio frequency bands and to standardise the characteristics of the equipment used within them. Such decisions are not however purely technical, but relate to wider social and industrial policy so that spectrum policy is an important plank of national political and regulatory activities. Ensuring that the distribution of spectrum amongst users and uses maximises economic and social welfare is a key goal of spectrum policy.

At a global level, permissible usage of frequency bands is set by the creation of *allocations* by the International Telecommunication Union ("ITU"), which is an agency of the United Nations. An allocation is a designation of a frequency band to a type of service within a region. The Radiocommunication Sector of the ITU ("ITU-R") creates, via its World Radiocommunications Conferences, allocations of radio frequencies to different categories of radio service e.g. "fixed", "mobile" etc. Each band may have a single allocated radio service or multiple services which share the band, either on equal terms (*co-primary*) or with secondary services only permitted to transmit if they avoid *harmful interference* to receivers associated with a *primary* service. Spectrum allocations differ between three global regions. The UK and the rest of Europe are within Region 1[2] and adhere to the Region 1 allocations. At a national level, it is not mandatory for the entirety of the relevant regional frequency allocations to be implemented. Instead, each national administration draws up a national frequency allocation table, which is ordinarily a subset of the allocations for the region. The current UK frequency allocation table is available from Ofcom [4].

Spectrum within given allocations is made available to users by means of an *assignment* process, whether by the grant of exclusive licences to specific users or via operation under a licence-exemption regime where any user may use the spectrum within the conditions of the relevant *interface requirements* [5]. Increasingly, shared and concurrent models of

1 Frequency is one of the physical properties of an electromagnetic wave: It has units of hertz (Hz) where 1 Hz is one radio wave cycle per second.
2 Regulatory region 1 also includes, Africa, parts of the Middle East, and the former Soviet Union. Region 2 comprises the Americas, Greenland and some Pacific Islands, while Region 3 includes most of Asia to the east of and including Iran and most of Oceania.

spectrum assignment which are intermediate between licensed and licence-exempt are being considered. For some special purposes, such as radio astronomy, spectrum is set aside to be used only for receiving, not for transmitting. In the main, new licences are liberalised – that is they are not fixed to a particular technology or application except as required by the applicable international allocations.

In the UK Ofcom is responsible for authorising all use of spectrum except use by Crown bodies. Ofcom's statutory functions and duties with respect to spectrum are set out in the Communications Act 2003 [6] and the Wireless Telegraphy Act 2006 [7]. Particular duties of relevance to spectrum management under that Act include:

> "It shall be the principal duty of Ofcom, in carrying out their functions;
> (a) to further the interests of citizens in relation to communications matters; and
> (b) to further the interests of consumers in relevant markets, where appropriate by promoting competition"

Ofcom's role includes securing:

1. the optimal use for wireless telegraphy of the electromagnetic spectrum;
2. that a wide range of electronic communications services is available throughout the UK;
3. that a wide range of TV and radio services of high quality and wide appeal are available throughout the UK;
4. that sufficient plurality in the providers of different television and radio services is maintained;

In 2014 Ofcom published its spectrum management strategy, giving its approach to, and priorities for, spectrum management over the next ten years [8].

The UK spectrum management regime is also set by the European spectrum regulation process as managed particularly by the European Commission, CEPT[3] and ETSI[4].

Spectrum has a number of technical and economic characteristics which mean that specific spectrum bands may be more suitable – and hence more valuable – for certain applications. These characteristics include particularly:

1. The physical properties of spectrum change the coverage available from a given transmitter, with lower frequencies generally providing greater distances and deeper penetration into buildings
2. The quantity of spectrum (the bandwidth) affects the numbers of users which can be served and the quantity of service available to each. Higher frequency bands generally provide greater bandwidth.
3. The international use of spectrum bands affects its attractiveness, both because interference must be coordinated between countries, and because the wide use of the same band for a given purpose drives economies of scale in the equipment available for those bands.

Given these considerations, it is clear that spectrum policy is important, in that it impacts on national economic and social value; but it is also complex, in that it depends on many

[3] European Conference for Post and Telecommunications/Electronic Communications Committee
[4] European Telecommunications Standards Institute

technical, political and economic factors. To reach an appropriate view on long-term spectrum policy requires a full understanding of the potential uses of the spectrum and this document sets out to assist in that understanding.

A.3. Public Mobile

3.1 Scope of the sector

The public mobile sector comprises operators providing voice, text and data services over cellular mobile networks. Those core activities are the focus of this chapter, although it is worth noting that the cellular operators' platforms and businesses reach beyond public mobile services. Some, like EE, also deliver services over fixed lines as part of multi-play offerings, a trend which is expected to intensify in 2015; and over Wi-Fi in licence-exempt spectrum. These supplementary networks will only be considered here if they affect cellular spectrum usage and requirements.

The operators also may provide fixed wireless broadband over the same cellular connections as mobile, as well as private mobile services to industrial and public sector customers. These activities are covered in separate chapters. For this reason, operators which are currently focused on cellular fixed wireless alone, such as UK Broadband, are not included in this chapter.

The UK's public mobile industry really started in 1985, when BT Cellnet and Racal-Vodafone received licences to offer analogue mobile services, and later GSM (from 1994), in the 900 MHz bands. Three further licences were awarded in 1991, in the 1.8 GHz band, to Mercury, Unitel and Hutchison-controlled Microtel (Mercury and Unitel subsequently merged). Microtel, rebranded as Orange, and Mercury launched digital services in 1993. All four, plus new entrant Hutchison Three, gained 3G licences in 2000 and 4G licences[5] in 2013. BT also gained a 4G licence in 2013.

These operators have undergone a series of ownership changes. France Telecom acquired Orange while Deutsche Telekom bought Mercury One-to-One. The two European carriers subsequently put these two operators into the joint venture, EE. Meanwhile, Racal spun off Vodafone, and BT spun off Cellnet, which was rebranded as O2 and later acquired by Telefónica. That has left the UK with four national public mobile network operators – EE, Telefónica O2, Vodafone and Three[6]. These operators share significant amounts of their cell sites, base stations and other equipment – EE and Three via their MBNL network consolidation joint venture, O2 and Vodafone with an infrastructure sharing unit called CTIL (Cornerstone Telecommunications Infrastructure Limited).

There is already a large number of MVNOs in the UK. These offer public mobile services but do not have their own networks. Major players include Tesco Mobile, Virgin Mobile and BT, the wireline incumbent.

3.2 Contributions to social and economic value

The mobile industry is a significant contributor to the UK economy in terms of revenues and employment. In 2013, according to Ofcom, mobile retail revenues were £15.6bn, their highest level in any year except 2012, when they were £15.9bn [9]. Falling SMS messaging revenues were identified as the main factor for the drop-off. Active mobile subscriptions in

[5] More formally, the licence award in 2013 was technology neutral (liberalised) but the associated spectrum is being used entirely for 4G.
[6] At the time of writing both EE and O2 were takeover targets for BT and Three respectively.

2013 totalled 83.1m in the same year. The mobile operators employ about 55,000 people (excluding BT).

According to calculations by Analysys Mason, public mobile is the most valuable use of spectrum in the UK. It estimates a consumer surplus of between £24.2bn and £28.2bn in 2011, up between 7% and 25% since 2006, and producer surplus of £5.9bn, up 76%. For 2012-21, it calculates the net present value of direct welfare benefits from public mobile services to be £273bn to £341bn. [10]

About 60% of the total value of spectrum in 2011 (the last time such an exercise was carried out in the UK) derived from public mobile, according to the report, driven by the rapid evolution of mobile services – from simple voice to complex data and multimedia applications – and the associated increase in their value.

Mobile networks drive direct economic contributions through service revenues and through the operators' investment in network equipment and services (about £2bn a year), which affects a long value chain (though the majority of mobile devices and networks are supplied by non-UK companies). They also contribute through the operation of national chains of high street stores as well as call centres for customer service and sales. Mobile networks also enable indirect economic and social benefit by allowing businesses and consumers to engage in new activities, to increase productivity and to communicate more effectively. For instance, mobile networks are calculated to have enabled annual productivity growth of 0.267% [11].

As mobile networks are used for an increasingly wide range of functions, their economic and social impact should continue to rise. For instance, machine-to-machine communications are starting, in some applications, to require broadband speeds and mobility, potentially opening up a role for public mobile networks in the 'internet of things'. In a recent white paper by Cisco, it was estimated that M2M could generate cumulative economic value of $6,400 billion (£4,300 billion) for the global economy, over the next decade, which would equate to about €220 billion (£158 billion) a year by 2023 in Europe [12]. Plum Consulting attributes 40% of that economic value to mobile M2M services as opposed to Wi-Fi, fixed or proprietary networks. Public mobile networks are also expected to generate additional social benefit via support of the emergency services mobile communications programme (see chapter A.5 for further details).

3.3 Current and recent past status

The UK public mobile market has been in a state of significant change in recent years, and that looks set to continue. The changes have been in technology, business models and market structure.

There has been a massive rise in usage of mobile data including applications, streamed content and web services, stimulated by faster networks, improved mobile internet platforms and the introduction of smartphones, and later tablets, from 2007. Many activities which once took place on fixed terminals are now routinely conducted from mobile devices (though often while stationary), and many businesses are adopting mobile-first strategies.

This has meant that public mobile business models have changed significantly during the 3G era and those changes will be accelerated by 4G. Data has accounted for an increasing proportion of revenue, ARPU and profit over the past decade, and last year saw mobile data revenues overtaking those from voice and messaging for the first time in the UK.

The rise in mobile data and internet usage has driven the deployment of newer 3G technology releases, the complementary use of Wi-Fi for mobile data in the 2.4 GHz and 5 GHz bands and most recently the deployment of 4G/LTE networks, which have higher capacity and spectral efficiency than earlier technologies. However the availability of 4G increases the usage of data as well as supporting new services. While LTE enables greater usage, and to some extent drives it by allowing data to be consumed more quickly, it is also important to note that increased usage is also being driven by changes in data pricing and allowances, across both 3G and 4G services.

Commercial LTE services were first introduced by EE in 2012, followed by the other operators at various points in 2013. The UK had the highest number of LTE subscriptions in Europe as of October 2014, according to the GSMA's European Mobile Economy Report 2014. That number is expected to have exceeded 16 million at the end of the year, indicating a growth rate more than double that of 3G in its initial two years. 4G penetration in the UK should reach 20% in January 2015 and EE now reaches 80% of the population with LTE.

The UK's market structure is likely to change in 2015, especially as there is increasing convergence between fixed and mobile operators across Europe. Fixed-only or mobile-only providers are looking for partners and acquisitions in order to offer quad play services, as seen in Vodafone's purchase of Cable & Wireless Worldwide in the UK and several cable operators elsewhere in Europe. Vodafone and EE both have plans to expand broadband and TV services and offer the full bundle.

BT is re-entering the mobile market, having acquired spectrum in 2013 and signed an MVNO deal with EE to supplement its broadband and public Wi-Fi networks. It has also announced the possible acquisition of EE. Meanwhile Hutchison Whampoa, the parent company of Three, has proposed to acquire O2 in the UK. TalkTalk has also announced an intention to deliver 4G services direct to its broadband customers via residential femtocells.

3.4 Sector trends

The trends which have shaped the public mobile market in the first few years of the decade will continue to do so in the years ahead. In particular, the rising use of mobile data networks for every aspect of life; the increasing convergence of TV/content, access and computing services; and the need to invest in network capacity to support those key trends. On a global basis, there are expected to be 10.2 billion mobile connections by 2018, up from 7 billion in 2013 (Cisco Visual Networking Index 2013), generating 15.9 exabytes of traffic a month, up from 1.5 exabytes.

Telefónica O2's customers, as an example, are using 60% more data than they were 12 months ago, and 600% more than at the end of 2010. There has also been a change in the shape of data usage, which will affect network planning – for instance, voice-centric networks were built symmetrically, but the uplink:downlink ratio, in a data-driven network, is now about 1:7 (though social media usage may rebalance it somewhat with the amount of uploading that can entail).

That explosion of data usage impacts network design, and spectrum requirement, in several ways:

- Accelerates the need to expand 3G and roll out 4G, with consequent impact on capex budgets
- Increases the number of sites per network – the process of 'densification' to support high levels of data usage more than outweighs the decommissioning of sites because of network sharing
- Requires investment in additional backhaul capacity

In addition, from 2015 the broadband internet of things will start to evolve, putting further pressures on the carriers' networks, although of a different kind – less about huge volumes of traffic, as with video, and more about handling large numbers of smaller packets and connections, but with extremely low power and high reliability. LTE was not optimised for this type of usage, and so could find its role squeezed by Wi-Fi and specialised connections in important growth sectors such as the smart city, although 3GPP is working on new low latency, lower data rate specifications, under the LTE-M and Category-0 categories, to address this challenge. Overall, all wireless networks will be affected by the broad trend for virtually everything to become connected to other objects and the cloud.

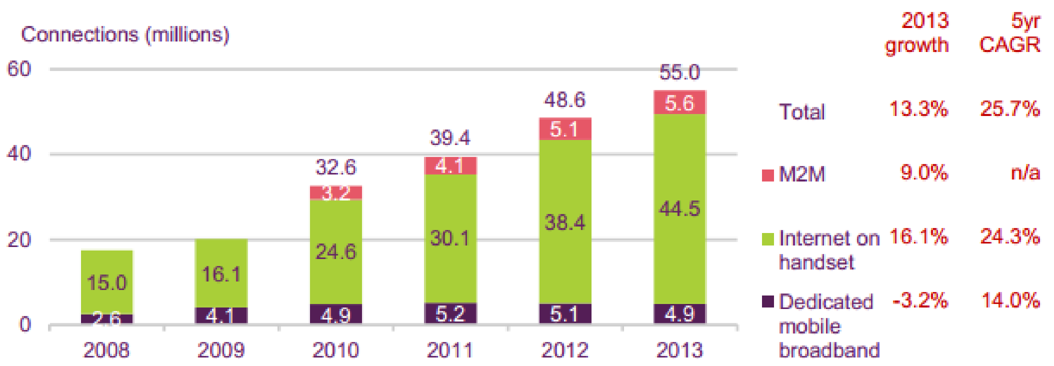


Figure 1: UK mobile connections by type. Source: Ofcom/ operator data [9]

Cloud-based services are the other major shift in usage for which operators will be adapting their networks, optimising them for constant streaming of data and content, rather than more periodic application and data downloads, for instance, as well as increasing the focus on uploading, especially for social media. The GSMA believes that mobile cloud traffic will account for 70% of the total by 2020, as compared to 35% in 2013 [13].

These trends will be driven and enabled by LTE, to a significant extent, and also by changes in tariffs, data caps, shared data plans and other developments. The introduction of LTE networks has been an important way to increase capacity and data rates, improving cost efficiency and quality of service for mobile data. However, LTE also drives a rapid increase in usage, so the pressure on spectrum and sites is not alleviated for long. While non-4G AUPU (average usage per user) is expected to double in the UK over the next five years, 4G AUPU will increase fivefold. In 2013, 4G AUPU was already 50% higher than that of 3G customers, but by 2018 the difference will be 6.3 times, according to EE (see Figure 2). O2's LTE network carried more traffic in its first six months than the carrier's entire network did between 2000 and 2008.

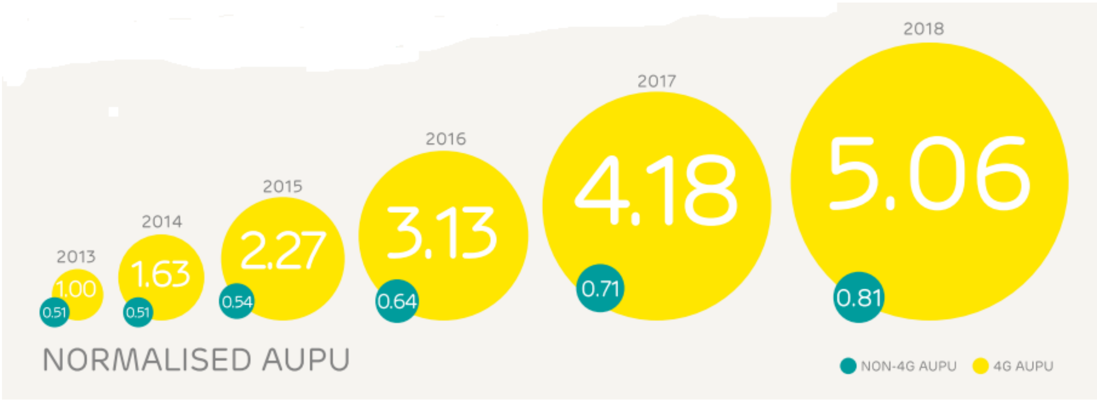


Figure 2: Trends in AUPU (average usage per user) on 4G and non-4G networks (Source: EE [14])

This means that the upgrade to 4G will not be enough on its own to support the rising volumes of mobile data and signalling, while also generating profits for the operators.

The UK MNOs are currently investing £2bn a year between them in expanding and upgrading their cellular networks to keep up with customer demand for higher data rates, larger data allowances and improved quality of service. However, core revenues have been stagnant - mobile retail revenues fell for the first time in 2013, by 2% on 2012, while average revenue per subscription also fell, from £16.13 per month in 2012 to £15.63 a year later.

The intensity of competition in the UK market means that data ARPU growth is slowing at an earlier stage than it did for voice or for 3G data, reducing the return on investment potential for the operators' 4G networks, especially as there is still significant capital spending ahead to expand and upgrade these. For instance, EE is already implementing elements of LTE-Advanced in order to boost capacity and keep a competitive edge, while Vodafone is spending £6 billion of the proceeds from the sale of its stake in Verizon Wireless on Project Spring, a massive LTE and fixed-line upgrade program across key markets including the UK.

Mobile operators also face competition from Wi-Fi-based wireless services offered by non-mobile service providers, but their challenges are not just about competition in wireless broadband access, but also the shift in the mobile value chain towards areas they do not control, such as applications and content. Over-the-top service providers can make significant revenues from apps or content which run on cellular networks, without contributing to the cost of the networks.

An important aspect of spectrum and network policy then is not just to make connections faster and more reliable, but to enable differentiation that cannot easily be matched by over-the-top rivals, thus helping mobile carriers to avoid being relegated to the role of 'bit-pipe'. Examples include investment in location-aware technologies which take advantage of the mobile network's inherent capabilities in this area, or in enterprise-class quality and value added services around voice, with the introduction of Voice over LTE (VoLTE).

As noted above, mobile operators are also working within a changing market structure as both fixed and cellular players move towards offering quad play services – bundles of access, content and data delivered to multiple screens (from TVs to handsets to cars), over both wireline and wireless connections. This approach can enable an operator to secure a larger percentage of an individual's or household's telecoms and media spending, even if the individual fees for each component service are lower. It may also allow a company to rationalise its networks, back office systems and personnel by converging fixed and mobile systems to create a single pool of integrated capacity.

All these pressures mean that operators have to be heavily focused on reducing their cost of ownership and squeezing as much capacity as they can from their spectrum and network assets. This has driven a trend towards new architectures which promise greater efficiency in cost, power consumption and spectrum usage, and capacity that can be targeted where it is required. Some of the important network trends, often in tandem with LTE roll-out, include:

- Mobile data offload: offloading low value data or 'greedy' users onto Wi-Fi. This is evolving into full integration of Wi-Fi, with its lack of spectrum costs, into the mobile core and back office systems, so it can be managed seamlessly
- Small cells: Using low cost, low power cellular or cellular/Wi-Fi access points to fill coverage gaps or to create dense zones of capacity where these are required, such as in stadiums, shopping malls or business parks
- Heterogeneous networks: Networks which use a flexible combination of different spectrum bands, cell sizes and technologies, including Wi-Fi
- Enhanced tools to automate network provisioning, to optimise delivery of multimedia content and to prioritise traffic and QoS levels, in order to balance customer experience with the most efficient use of resources
- Hardware virtualisation: networks are increasingly deploying network elements as software platforms on common IT infrastructure, replacing dedicated hardware/software network elements

Such changes do not just mean that mobile networks will need to continue to increase capacity while reducing cost of data delivery, but that operators' businesses will diversify as they seek additional revenue streams beyond mobile access. These may include cloud services, for consumer content or the IoT; big data analytics and marketing services; multiscreen video/TV; value added enterprise or vertical services.

3.5 Spectrum usage

Unlike operators in most European countries, which received 2G spectrum allocations in both the 900 MHz and 1.8 GHz bands, in the UK, BT Cellnet and Racal-Vodafone were assigned 900 MHz licences, while the 1.8 GHz licences were awarded to separate players – at the time, Mercury One-2-One, Unitel and Hutchison Microtel. After various changes in ownership of these players, the UK ended up with two national GSM900 networks, operated by Telefónica O2 and Vodafone, and one national GSM1800, operated by EE.

This dichotomy created some coverage challenges for T-Mobile and Orange, the firms which later made up EE, but the possession of 1.8 GHz 2G spectrum became an advantage at the 4G stage, since this had become a near-global band for LTE deployment. This enabled EE to re-farm some of its holdings in this band for LTE, and so gain a deployment head start on rivals with only 900 MHz, which has not yet developed into a mainstream 4G spectrum option. Ofcom permitted EE to start roll-out of its LTE1800 network shortly before other carriers were able to secure 4G spectrum, during the auction of early 2013 – a controversial decision.

During the 3G auctions of 2000, all the GSM operators secured licences in 2.1 GHz, as well as a new entrant, Hutchison Three. Unpaired spectrum in 1.9 GHz was also allocated to all the winners except Vodafone, but went largely unused.

In the 4G auctions, the four main players gained 800 MHz spectrum, with O2 and Vodafone winning the largest allocations, while EE and Vodafone also won chunks in the 2.6 GHz band, as did BT. Vodafone and BT additionally gained allocations in the unpaired portion of this band, which could be used for TDD-LTE, though the largest holder of unpaired spectrum is UK Broadband, with 124 MHz in the 3.4-3.6 GHz band. TDD-LTE in this spectrum is very immature in terms of ecosystem, but UKBB has launched limited fixed wireless services in parts of London and elsewhere, and in 2014 had the terms of its licence extended indefinitely.

Table 1 details and Figure 3 summarises the spectrum holdings of the major operators following the 4G auction and the divestment of 2x15 MHz of 1.8 GHz spectrum by EE, as a condition of its merger. This spectrum was acquired by Three.

The spectrum licensing environment in the UK has been somewhat liberalised in recent years, with Ofcom taking a European lead in areas like spectrum trading and opening up new licence-exempt bands. Its policy is to trust to a market approach where possible and only intervening where necessary. Licences for public mobile services are:

- Of indefinite duration and tradable
- Mostly technology and service neutral
- 900/1800 MHz licences are charged annually and Ofcom is in the process of revising the fees to reflect full market value as required by the WT Act 2006 (Directions to Ofcom) 2010 Order.

However, there have been criticisms with regards to LTE licensing and extent of the coverage obligation in 800 MHz. The operators call for a regulatory environment which encourages investment by providing stability – long-term licence durations and the guarantee of exclusive spectrum allocations in future being key - and there has also been considerable resistance to increases in the annual licence fees. The most important trend in spectrum usage in the past year has been expansion of LTE (see 3.3) and early moves to harness carrier aggregation in order to increase capacity without the need for new frequencies. This has been led by EE, which has also been undergoing the process of refarming some of its 2G spectrum for LTE. In addition, the operators continue to modernise their 2G and 3G networks – introducing more flexible and low power equipment; rationalising cell sites as a result of their RAN sharing initiatives; and improving rural coverage.

Table 1: Cellular mobile spectrum assignments UK (October 2015)

Primary technology	Frequencies	EE	Telefónica O2	Vodafone	Three	BT	UK Broadband
GSM	880.1-914.9 MHz/925.1-959.9 MHz		2x17.2 MHz	2x17.2 MHz			
GSM and LTE	1710.1-1781.7/1805.1-1876.7 MHz	2x45 MHz	2x5.8 MHz	2x5.8 MHz	2x15 MHz		
Low power GSM and potentially LTE	1781.7-1785/ 1876.7-1880 MHz	2x3.3 MHz shared by 12 licensees					
UMTS TDD	1900-1920 MHz (unpaired)	10 MHz	5 MHz		5 MHz		
UMTS	1920-1980 MHz/ 2110-2170 MHz	2x20 MHz	2x10 MHz	2x15 MHz	2x15 MHz		
LTE	791-821 MHz/ 832-862 MHz	2x5 MHz	2x10 MHz	2x10 MHz	2x5 MHz		
LTE	2500-2570 MHz/ 2620-2690 MHz	2x35 MHz		2x20 MHz		2x15 MHz	
TDD-LTE	2570-2615 MHz (unpaired)			20 MHz (+ 5 MHz restricted)		15 MHz (+10 MHz restricted)	
TDD-LTE	3480-3500 MHz, 3580-3600 MHz, 3605-3689 MHz (unpaired)						124 MHz
SDL LTE	1452 – 1492 MHz			20MHz	20MHz		

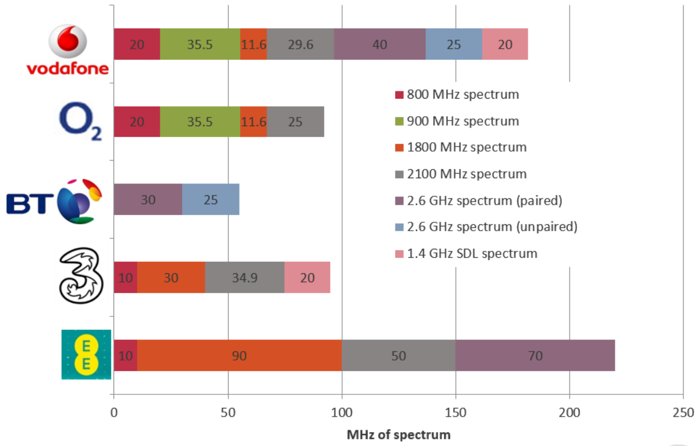


Figure 3: UK spectrum holdings after 4G auction, EE divestments in 1.8 GHz and trade of 1.4 GHz

Licence-exempt spectrum is also increasingly important in supporting public wireless services in the UK, usually over Wi-Fi. A study for the European Commission estimated that 77% of UK traffic from mobile devices would be carried on Wi-Fi in 2015 [15]. The opening up of new licence-free spectrum for mobile broadband has been an important feature of Ofcom's recent strategy, for instance in its consultations on the TV white spaces.

Wi-Fi services are sometimes offered by the mobile operators themselves – O2 has implemented free Wi-Fi hotspots extensively, for instance – and sometimes by fixed-line or pure-play providers. In the hands of a fixed-line operator, Wi-Fi can be a way to offer an alternative to the mobile services, at least for stationary or portable data usage (the most common form), especially as developments like Hotspot 2.0 allow for single sign-on, and seamless hand-off, between cellular and Wi-Fi. However, Wi-Fi still has challenges when it comes to full mobility and some voice services.

3.6 Expected changes to technology and spectrum

Over the next few years, the use of mobile internet and data services will continue to rise, and there will be radical changes to the user experience, which will put new strains on the cellular networks. Developments such as 4K video and beyond, augmented and virtual reality user interfaces, and hyper-personalised web services, will all require further progress in data rates, latency and QoS.

This data growth will need to be supported by spectrum, but also by upgrading and densifying cell sites, and upgrading backhaul. Network capacity can be increased without additional spectrum, by recycling it on more sites, though this entails new hardware and site costs. In the near term, the main network changes to support those changes will be based around LTE-Advanced, as well as increasing integration with carrier-class Wi-Fi as part of a HetNet strategy.

Some items on the menu of enhancements which comprise LTE-A will help to increase spectral efficiency and so help operators deliver more data in the same amount of spectrum. For instance, Coordinated Multipoint (CoMP) improves data rates at the cell edge by combining signals from multiple antennas, while carrier aggregation (CA) allows two or more interband or intraband carriers to be combined to increase bandwidth.

CA is being deployed most commonly by aggregating carriers from different standard LTE bands, usually with the focus on the downlink. For instance, EE has aggregated 20 MHz in the 1.8 GHz band with 20 MHz in 2.6 GHz, to enable downlink CA.

Other variations on CA may also become relevant to the race to boost capacity even when new allocations of spectrum are not imminent. Supplemental downlink (SDL) has been trialled by operators such as AT&T and Orange France, using L-Band spectrum formerly assigned to mobile satellite (1452-1492 MHz) for additional downlink capacity. LTE runs in these non-traditional bands but only as an adjunct to a conventional 4G network, not standalone (a downlink-only channel in the supplementary band bonds to the downlink channel in FDD spectrum). In October 2014, Ofcom proposed that 40 MHz of spectrum in the 1 470 MHz band, held by Qualcomm, could be used for SDL, in line with European harmonisation decisions, even though this would involve increasing in-band power limits and out-of-band emission limits. Qualcomm traded this spectrum to Vodafone and Three in 2015.

If the current asymmetry of networks continues to increase, it is possible that many future spectrum releases will be harnessed for SDL. This factor should also increase interest in TDD-LTE in unpaired spectrum, since the uplink:downlink ratio is flexible. Vodafone and BT both acquired unpaired 2.6 GHz spectrum in the 4G auction and there is rising global interest in the 3.5 GHz band, especially for small cells

Similar SDL concepts lie behind LTE-LAA (Licensed Assisted Access), a technology which is currently being developed for inclusion in 3GPP Release 13 (due to be frozen around March 2016). This allows LTE to run in 5 GHz licence-exempt spectrum, though only as a supplementary resource for a licensed network. The development has been controversial because some see it as the first step to a full implementation of LTE in a central Wi-Fi band, and therefore an attempt to squeeze the capacity available for Wi-Fi, using a technology only available to owners of licensed spectrum. Others have suggested that the LTE-LAA would access the spectrum on an equitable basis with Wi-Fi.

More generally, the tightening integration between licensed and licence-exempt spectrum and technologies will increase as service providers of all kinds look for more capacity. Wi-Fi is expanding into new bands as the 802.11 standards family defines extensions for the TV white spaces, 868 MHz and 60 GHz (WiGig), and Ofcom has consulted on potentially opening up more 5 GHz frequencies for licence-exempt use (which could include LTE-LAA as well as Wi-Fi), although international work expanding 5 GHz mobile allocations has encountered difficulties.

Other ways to maximise the usage of existing bands include greater sharing, either between mobile operators, or between different services in the same spectrum. Sharing, and the move towards dynamic spectrum allocation, are cornerstones of Ofcom's plan to open up more spectrum for mobile broadband, as outlined in its spectrum management strategy document in April 2014 [16]. Currently, around 29% of spectrum is shared between public and private sector users, and increasing that percentage is vital to achieving the government goal of opening up 500 MHz of new sub-5 GHz frequencies.

There are four main types of sharing, all of which are likely to play a part in future spectrum strategy, and all of which are supported by the mobile operators provided they are not a substitute for new exclusive nationwide allocations. Sharing can take place in licensed or licence-exempt bands, and on a geographic or frequency basis. The four options are summarised in Figure 4.

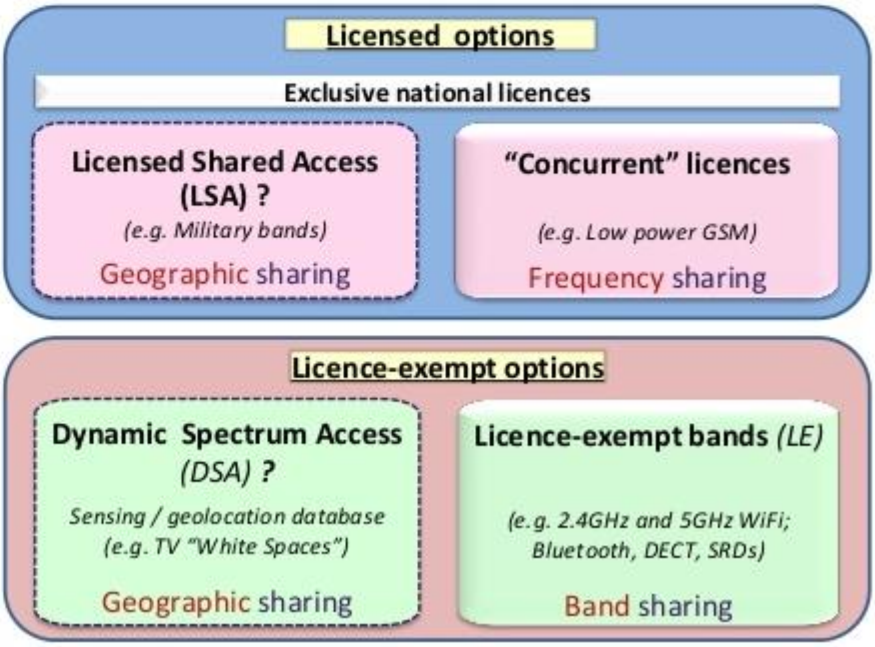


Figure 4: The four approaches to spectrum sharing Source: BT

The option with the greatest potential for mobile broadband capacity is DSA, but success will depend on the creation of a central public sector spectrum database that is dynamic and in due course accessible to the market, but this will be a complex and politically charged process. Additionally, the conditions attached to shared spectrum can degrade its value substantially, particularly with regard to uncertainty of access, which can make it difficult to ensure quality of service and wide geographical access (see study by Deloitte/Real Wireless for GSMA [17]).

As noted above, another source of spectrum which is currently underused, but is likely to form a more central part of LTE expansion in the coming years, is TDD. The unpaired frequencies in the 2 570-2 615 MHz range are acquiring a global ecosystem and roaming opportunities, thanks to the efforts of major TDD-LTE deployers such as China Mobile and Sprint/Softbank. In the UK, the only current TDD-LTE roll-out is in 3.5 GHz, by UK Broadband, but this type of spectrum has many advantages for data services, especially those which are asymmetrical (heavier on the downlink, in most cases), and for dense zones of small cells, which will be a characteristic of future LTE capacity increases. Vodafone and BT are the owners of TDD spectrum at 2.6 GHz.

Sharing, harnessing unlicensed bands, and squeezing more out of existing assets will all be important weapons enabling operators to support rising data demands and to upgrade to new iterations of LTE and HetNet. However, they argue that they will also need additional new sources of spectrum as well, at least by the end of the decade.

Ofcom is preparing, or consulting on, a range of options. The most immediate will be the auction of spectrum in the 2.3 GHz and 3.4 GHz bands in 2015-16 (see Figure 5). The former would yield 40 MHz in total, which is proposed to be auctioned in four lots of 10 MHz each, using an SMRA (simultaneous multiround auction) format (less complex than the combinatorial clock used in 2013). The main challenges have been seen in potential interference with Wi-Fi and other services in neighbouring 2.4 GHz.

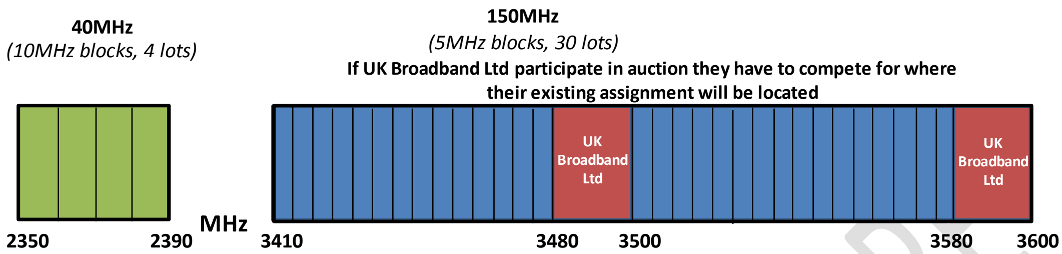


Figure 5: Ofcom plans to auction spectrum in 2.3 GHz and 3.4 GHz bands. Source: BT [18]

The latter includes 150 MHz of spectrum, arranged in two segments, 3 410-3 480 MHz and 3 500-3 580 MHz. These frequencies would be particularly well suited to small cell deployments because of their limited range, and would be compatible with the spectrum under review in the US as a potential shared band dedicated to small cells. If the US plans go ahead, the chances of 3.5 GHz becoming a near-global roaming band for small cells will be greatly increased, along with the value of the spectrum. In the UK, Ofcom proposes to auction the spectrum in 30 lots of 5 MHz each. The frequencies are bisected by the lower section of TDD-LTE spectrum owned by UK Broadband, whose holdings are at 3480-3500 MHz and 3 580-3 600 MHz. Although UKBB was recently given the rights to hold its licences indefinitely, if it participates in the 3.4 GHz auction, it would have to compete for where its existing assignments would be located.

The next major auction of mobile broadband spectrum is likely to be in the 700 MHz UHF band. This decision was controversial, not just because the incumbent broadcasters argue they need to retain much of the spectrum for digital terrestrial TV platform upgrades, but because other interest groups, especially in the machine-to-machine and PMR segments, are also keen to secure valuable low frequency assets. Ofcom is likely to auction this spectrum towards the end of the decade and free it up for use by 2022, behind some other countries such as France and Germany.

Some regions of the world, such as the US and many Latin American and Asian countries, freed up 700 MHz spectrum in their initial digital dividend, so the UK's decision will eventually bring it into line with those territories, which is significant for mobile roaming, a broad device ecosystem and other economic advantages. However, there is still significant work to be done on the band plan, and how far that can be harmonised with the Asia-Pacific 700 MHz plan without creating interference with existing services.

Other bands included in Ofcom's mobile data strategy as potentially being available by 2022 are:

- 1 427-1 452 MHz
- 2 GHz MSS
- 3.6-3.8 GHz

Others may also be added to this list, though there is currently more uncertainty about them, and they could come at a later date, or not at all. They include:

- 2.7-2.9 GHz
- 3.8-4.2 GHz
- 1 492-1 518 MHz
- Bands above 10 GHz and further unlicensed options

3.7 Long-term technology and spectrum needs and options

Operators' usage of 700 MHz frequencies might be very different from their patterns in the early LTE bands - the new spectrum could be part of new '5G' network deployments, or could be reserved for specific services, such as internet of things applications, rather than for mainstream consumer data. Emerging trends like the IoT will help generate new revenue streams and data patterns.

However, increasing network usage will still be driven mainly by two key factors – video and content streaming, and these activities will drive a continuing rise in mobile data traffic over the coming decades. There are various ways to model this trend as we approach mid-century, but nobody foresees a decline in traffic. Figure 6 summarises future data scenarios from Analysys Mason and Real Wireless, before offload is taken into account

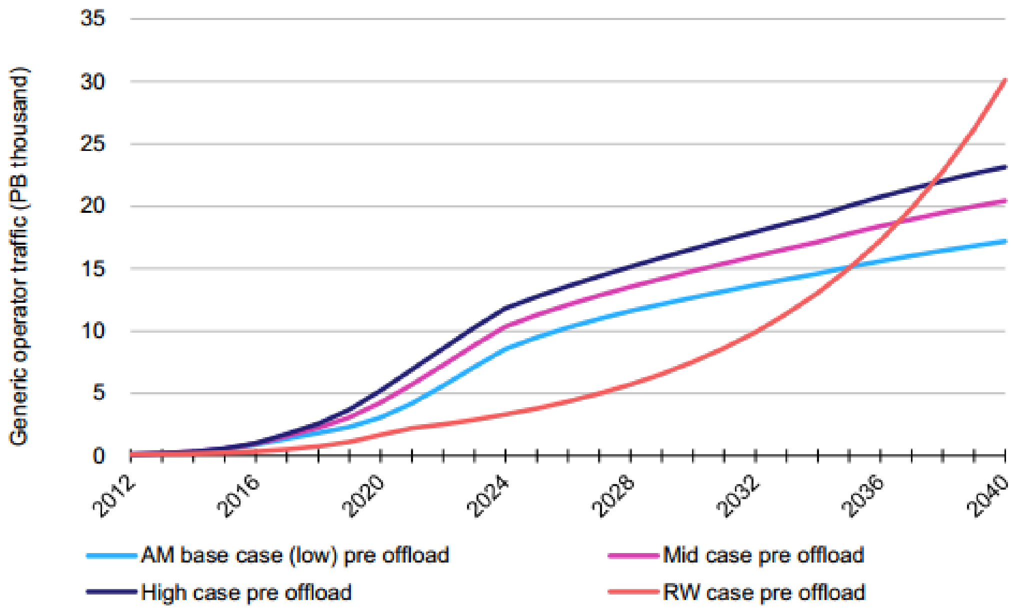


Figure 6: Modelled traffic, pre-offload, based on Analysys Mason and Real Wireless cases. Source: Analysys Mason [19]

Another forecast (see Figure 7) shows overall data demand rising by 22-fold in the UK between 2015 and 2030. By 2030, 76% of network traffic is expected to be video, with 10% of users already on 8K or UltraHD video resolution.

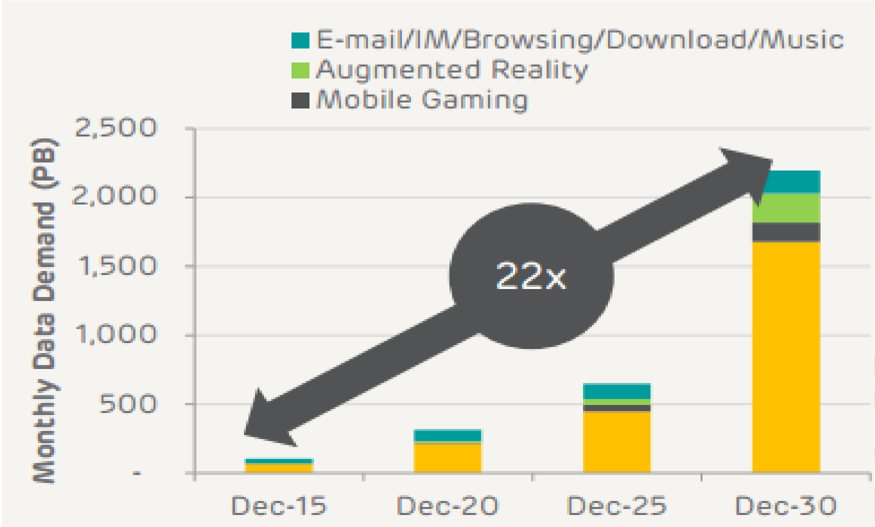


Figure 7: Anticipated growth in mobile data demand 2015-2030. Source: EE [20]

For all these reasons, by the time 700 MHz is available for mobile broadband, the industry will be into another wave of technology change, loosely labelled 5G. At this stage, no standards have been proposed, or clear concepts defined, for 5G, but it is possible that it will involve radically different network architectures, which use spectrum in new ways.

'5G' could be anything from an amalgam of current technologies; to a fully software-defined network enabled by emerging platforms like NFV (Network Functions Virtualization); to a whole new set of 3GPP air interface standards (or combinations of all of these). It will certainly only be deployed after the efficiencies of LTE and LTE-A have been fully exhausted – Figure 8 indicates the timelines for the next wave of LTE iterations, and for eventual 5G commercialisation.

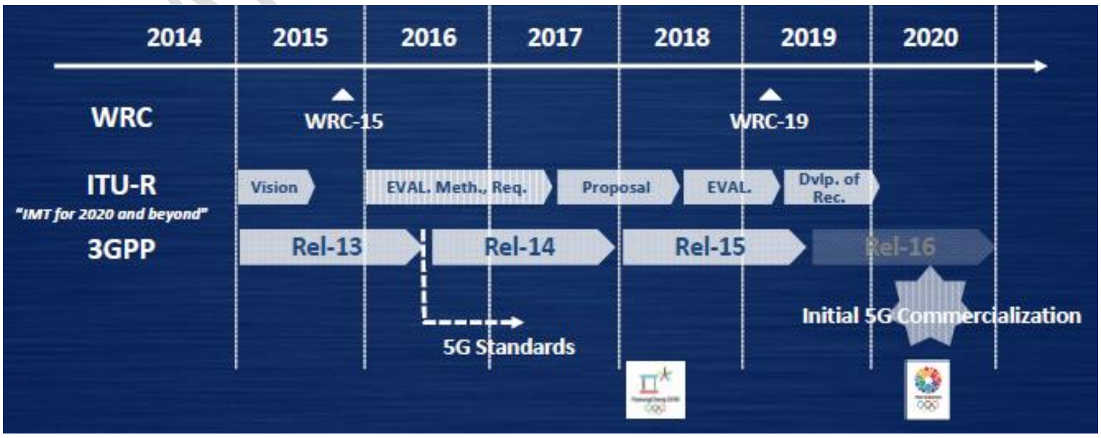


Figure 8: Likely LTE-A and 5G timelines

Indeed, many prefer to define 5G as a future user experience rather than a collection of technologies. Samsung sums that up as:

- Everything on the cloud – a desktop-like experience on the go
- Immersive experience – lifelike media everywhere
- Ubiquitous connectivity – an intelligent web of connected things
- Telepresence – real-time remote control of machines

On the network side, whatever the architectural choices as 2020 comes closer, certain assumptions can be made. To accommodate trends in data and M2M usage, and still enable viable business models, future networks will have to support:

- Ultra-low levels of latency and power consumption, especially to support the internet of things. Target air latency is likely to be less than 1ms, or 5ms end-to-end.
- Far higher data rates - vendors like Samsung foresee data rates rising from 6 Gbps in the early years of '5G' (from 2020) to over 50 Gbps by 2030.
- A dramatic increase in the number of connections, again largely driven by the IoT. Networks will have to be designed to accommodate between 50 billion and 80 billion (according to different estimates) by the turn of the century.

Whichever targets end up taking priority, it is clear that a new approach to network design and economics will be necessary and this will require new sources of spectrum, probably in very large swathes. In particular, there is interest in the use of very high frequencies to support very dense networks of tiny cells for very high capacity. The FCC, for instance, recently initiated an investigation into potential use of the upper portion of the SHF band (3 GHz to 30 GHz) and the lower portion of the EHF band (30 GHz to 300 GHz), with particular focus on licensing 24 GHz to 90 GHz for cellular broadband in future.

Pointers in this direction may well be seen at the World Radio Conference (WRC-15) this year. In preparation for this conference there is already discussion in regulatory bodies about the possibility to identify higher frequency spectrum for mobile broadband applications.

In January 2015 Ofcom published a "Call for Inputs" [21] on spectrum above 6 GHz for future mobile communications. This document seeks stakeholder input on spectrum bands above 6 GHz that might be suitable for future mobile communication services, often referred to as 5G (the 5th generation of mobile services).

The document considers filtering the spectrum above 6 GHz down to a smaller number of frequency ranges based on bandwidth and a current allocation in the Radio Regulations to the mobile service. It sets out the list of frequency ranges that results from that filtering process and asks stakeholders about alternative and additional criteria for narrowing down the range of potential bands, as well as views on specific bands.

The frequency ranges proposed for further consideration by stakeholders are within the overall range of 6 GHz to 100 GHz. There are many R&D projects focused on running mobile networks in millimetre wave bands.

A.4. Utilities

4.1 Scope of the sector

For the purposes of this report, the utilities sector comprises the generation, transmission and distribution of gas and electricity, excluding retail supply; the supply of water plus flood controls; waste water and sewage disposal. These segments have some things in common, including the challenges of managing national critical infrastructure, and of increasingly making that infrastructure 'smart'. All are at various stages in the process of deregulation, although the specifics of their regulatory and technology environments vary significantly. For completeness, smart metering is referred to where necessary, and is an energy supply obligation, but the communications aspects of domestic metering and home area networks are not dealt with extensively as these are not, in the UK, the responsibility of the energy distribution or transmission companies

In electricity, there are over 90 companies generating electricity though the 'Big Six' retail suppliers are also the biggest generators, controlling over 70%. This electricity is transmitted over the high power infrastructure owned and operated by National Grid, which also transmits gas supplies. There are also two grid organisations in Scotland, SP Energy Networks and SSE, but National Grid is the system operator for the whole of Great Britain. Northern Ireland has a number of distinct differences in regulatory structure compared to mainland Great Britain, and in terms of radio infrastructure must coordinate closely with the Republic of Ireland with which it shares a land border. To avoid excessive detail, this report focuses mainly on mainland Great Britain, so care must be taken in extending conclusions to Northern Ireland.

Distribution companies own and run the lower voltage/pressure networks which take the gas and electricity to homes and businesses (though actual sales to consumers are handled by separate entities). The UK has 10 electricity and five gas distribution firms.

The scale of the infrastructure can be seen in a few statistics. The electricity transmission system runs over 4,470 miles of overhead lines, 870 miles of underground cable and 329 substations at 400kV/275kV. The electricity distribution systems operating from 132kV down to 400V comprise approximately 288,937 miles of underground cables with 196,353 miles of overhead lines. The gas transmission system is similarly extensive, with 4,760 miles of high pressure pipe and 23 compressor stations and associated gas distribution networks. Annual electricity demand in 2013 was 347 terawatt-hours for electricity and 835TWh for gas [22].

There are 12 water and waste services organisations (formerly water authorities), arranged regionally across the UK, each with between 1 million and 8.5 million customers. There are also 30 water-only companies. These two tiers of organisations provide almost all water services in the UK. They are responsible for treating and supplying 17 billion litres of water a day in the UK, and collecting and treating 16 billion litres of waste water and sewage. The companies have to work closely with the Environment Agency and with Natural Resources Wales on challenges such as flood control, as well as with government agencies responsible for clean drinking water and other public health concerns.

4.2 Contributions to social and economic value

The reliable, efficient and affordable availability of energy and clean water has incomparable social and economic value in terms of health, hygiene and quality of living. Further, ready electricity supply enables businesses and consumers to adopt new technologies which further drive economic activity (e.g. computers) and quality of life (e.g. digital entertainment).

Depending how it is generated, electricity may support green programs, with their own social, environmental and economic benefits – for instance, in replacing petrol/diesel in vehicles.

The utilities support economic activity and employment in their own right as well as enabling the development of new businesses and social activities. In 2012, according to Energy UK [23], the energy sector provided £24 billion in direct economic contribution, an increase of £3 billion over the 2011 figure. It also contributed an additional £78 billion indirectly through the supply chain it supports. The sector directly employed 125,000 people in that year, up from 90,000 in 2008, and when combined with 539,000 jobs in its supply chain, it accounted for one in 45 of UK posts. It also created more jobs outside London and the south east than any other sector.

The energy sector invested £11.6 billion in 2012, about 10% of total UK investment, with about one-third of this related to renewables and other emerging energy sources, which may have additional economic and environmental benefits.

As for water and sewerage, the total economic impact of this sector was estimated to be £15.2 billion in 2012/13 by Deloitte [24]. The breakdown of this contribution is seen in Figure 9.

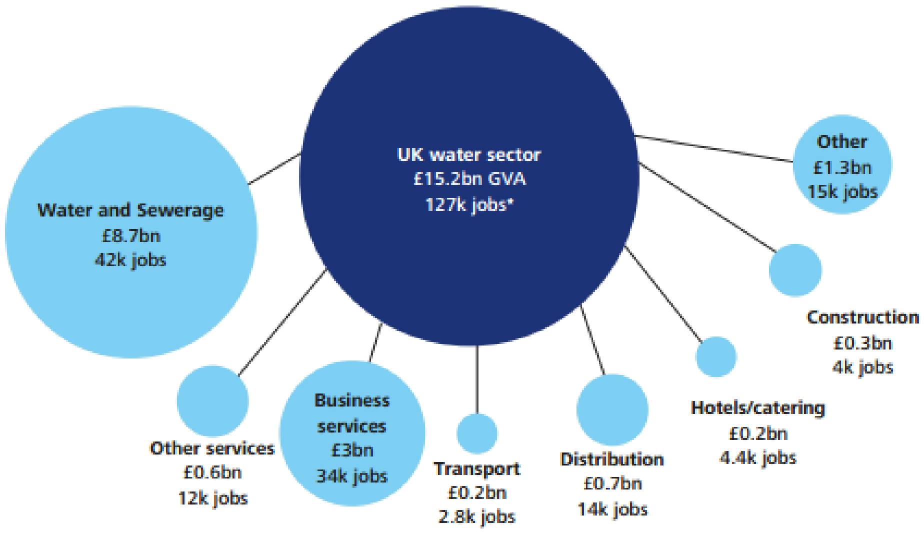


Figure 9: UK water and sewerage economic impact 2012/13: employment and GVA. Source: Deloitte/Water UK [24]

4.3 Current and recent past status

There has been significant investment in the fundamental infrastructure of the main utilities in recent years. Some of this has been essential to keep reliable supply going at all – replacement of Victorian water mains, for instance. Some has been geared to greater efficiency or capacity, or to supporting new energy sources such as wind farms.

In all cases, the organisations face the utilities' classic 'trilemma' of balancing sustainability, affordability and security of supply amid rising demand. This has become increasingly challenging because of:

- Increased business and consumer usage of power and water
- User expectation of the same, or better, quality with unfettered usage
- Society becoming increasingly dependent on a reliable supply of electricity to sustain almost every aspect of western lifestyle – transport, banking, a proliferation of gadgets, lifts for high rise buildings etc.
- The services are interdependent too e.g. gas heating, water supply and waste disposal require electric pumps
- Rising prices/dwindling supplies of fossil fuels
- Regulatory and public opinion pressure to invest in 'green' approaches and reduce carbon emissions
- Weather changes affecting usage (heating and air conditioning) and even security of supply (droughts and floods)
- The cost of utility services is becoming a political issue
- The security of supply is becoming an increasing cause of concern as application of technology makes networks more vulnerable to attack

A workable balance will require more than just modernised utility infrastructure such as water mains and power cables. It will also rely increasingly heavily on technology and communications to maximise the efficiency of distribution of power and water assets; to reduce total cost of delivery; to understand usage patterns better; to ensure security and stability; and to help suppliers and consumers to manage their usage.

In the past, the use of fixed and mobile telecoms was important to support the networks and allow employees to communicate; to back-up critical wireline connections to substations and other locations; and to support telemetry and PMR applications. But the utility networks themselves remained dumb.

Intelligence is just starting to be added to those networks via initiatives such as smart grid, but this can only be enabled with a massive increase in communications capacity. Much of this will be wireless, because of the highly distributed nature of the grids and networks; the need for flexibility and ubiquitous reach; and the timescales to replace fixed assets, which would be 50-100 years for a ubiquitous network.

That drives other trends and raises other important issues, including:

- Whether spectrum should be shared or dedicated, and if the latter, how it should be obtained and paid-for.
- The shift from merely connecting different elements of the utility network, to full integration with data analytics and critical applications, and how that is best achieved.

- How to meet increasingly complex and critical challenges related to cyber-security, physical security and privacy on the wireless networks.

The last point is increasingly a topic of debate. Those wireless communications systems will be as mission critical as the utility networks themselves, as they become essential to ensure the required power or water is always available where it is needed. Therefore there will be QoS requirements which will be comparable to those in networks used by emergency services such as fire and ambulance, which will have implications for future spectrum considerations.

Tim Yeo, then-chairman of the UK Parliamentary energy select committee, said in December 2013 that the power utilities were now “analogous to the emergency services” and, in the light of more extreme weather conditions, “have got to show they have got a proper plan which allows them to respond much more quickly when people are left without power”. This new flexibility and responsiveness will rely heavily on communications and smart networks.

4.4 Sector trends

The situation outlined above dictates that the most important sector trend in utilities will be the introduction of smart networks to increase the efficiency and flexibility of distribution of energy and water, since infrastructure upgrades alone will not be able to keep up with rising need for capacity, constant availability and security/stability. The pace of change in this respect is accelerating, driven by public concerns about energy prices, energy stability and environmental issues.

In the electricity and gas segments the primary development is the smart grid, and there will be parallel ‘smart water’ architectures. Simply put, the smart grid refers to the introduction of two-way communication between every element of the energy (or water) delivery network, to support intelligent applications such as flexible resource planning and on-demand distribution. Each device will be equipped with sensors and digital communications to collect data, which will be fed into complex analytics systems, and to allow for automation of many manual or currently non-existent functions.

According to the Smart Grid Forum, created by the Department for Energy and Climate Change (DECC) and utility regulator Ofgem [25], the key benefits of a UK smart grid will be:

- Reduced costs to consumers through savings on network costs
- Economic growth and jobs enabled by faster and cheaper connections to the network and an estimated potential £13 billion of gross value added, £5 billion of potential exports to 2050; and 9,000 jobs to 2030 associated with smart grids1
- Increased energy security and integration of low carbon technologies through greater monitoring and control of the network, enabling network companies to anticipate and identify problems more quickly and manage supply and demand at a local level.

These grid systems will help support the move of supply of energy and water from large centrally controlled systems towards widely dispersed, smaller scale sources with localised intelligence and more dynamic response. They will consist of several layers, each with wireline and wireless components, as illustrated in Figure 10.

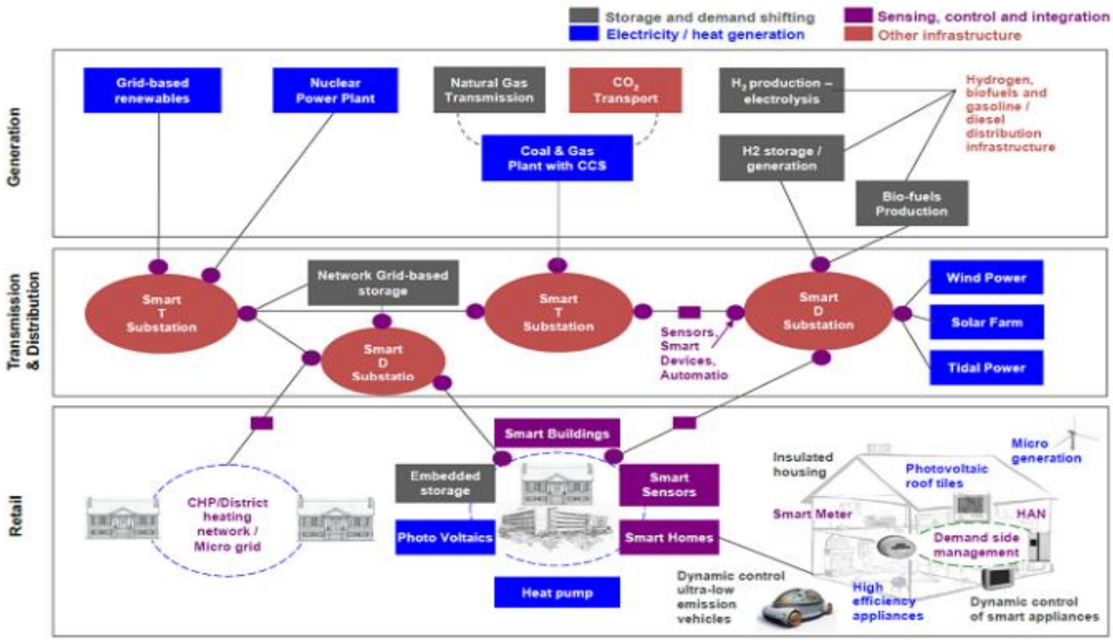


Figure 10: Roles and relationships of the different elements of the smart grid. Source: DECC [25]

At one end there will be interconnections between different utilities' grids and other critical infrastructure. As the Joint Radio Company points, out , interconnection of grids and interdependencies between critical national infrastructures will require more intensive deployment of telecoms, often by radio as fixed networks cannot be rolled out quickly enough.

At the other end will be the 'last mile' between the substation and the meters (in the electricity example), often called field area networks. These will be able to support automated distribution with advantages such as:

- Self-healing for greater reliability and fewer truck rolls
- Greater grid stability even in a distributed architecture
- Improvement in performance using tools such as power quality monitoring and distribution level sensing
- Increase in customer engagement through demand response and smart metering

From the inter-grid level to the national transmission system down to the last mile, there will be many wireless connections to accelerate roll-out, ensure flexibility and support remote or mobile elements.

As well as incorporating intelligent communications in the utility networks, there are other technology-driven initiatives to improve overall efficiency and value. These include:

- Improved systems for operators to share data on usage, supply and requirements
- Improved analytics for supporting near-real-time decision making based on that data
- Smart metering to monitor and potentially reduce energy usage in homes and businesses, often as part of a wider 'smart home' programme

- Increased use of wireless security systems, such as video monitoring, to secure key sites

In addition, IT and communications systems will have to be sufficiently flexible to support changing structures within the sectors, such as the OpenWater initiative, which will create a market-based approach for non-domestic water and sewerage services. To succeed in its goals of improved choice and better resource efficiency, this will rely on free flow of information within and between operators, advanced analytics and more automated business processes.

4.5 Spectrum usage

The utilities have already made extensive use of wireless networks, even before the advent of the smart grid. Their primary applications include telemetry, critical voice communications and PMR (private mobile radio), and SCADA (supervisory control and data acquisition) for machine-to-machine uses.

Most of these applications run in dedicated spectrum. In the case of gas and electricity, much of this spectrum is licensed or coordinated by the Joint Radio Company (JRC), a joint venture between National Grid and the Energy Networks Association, which represents UK gas and electricity transmission and distribution firms. Water companies have similar but separate arrangements co-ordinated through the Telecommunications Association of the UK Water Industry (TAUWI).

The JRC manages dedicated spectrum, and is responsible for radio link planning, as well as planning and commissioning telemetry and PMR services. It holds spectrum licences itself or manages them on behalf of its members. It also devised, and now manages and operates, a national cellular band plan for co-ordinating frequency allocation on utility and transport PMR networks.

The JRC currently manages just over 4 MHz of spectrum, of which 2 MHz is for automation and PMR (private mobile radio) applications, and 2 MHz for telemetry and telecontrol services. Its main areas of spectrum are:

- The JRC Mid-Band, made up of two 1 MHz blocks centred around 140 MHz and 148.5 MHz. This provides 78 national two-frequency channels of 12.5 kHz throughout the UK mainland for PMR and for resilient mobile communications for routine maintenance and to aid the restoration of supply after a major black-out or other critical event
- The JRC UHF Band Block 2, which consists of 20 two-frequency channels in the 456 MHz band paired with 461 MHz band. These channels are used for a variety of applications – primarily roaming and on-site communications with some telemetry systems
- JRC also has national licences for four 25 kHz channels used for data link applications and on-site TETRA systems
- The JRC manages the national cellular plan for coordinating frequency allocation within the ‘Scanning Telemetry Band’. This comprises 80 two-frequency channels in 457.50 to 458.50 MHz paired with 463.00 to 464.00 MHz. A major part of this spectrum (48 channels) is licensed by the JRC on behalf of the energy industries. A further 24 channels are used by the water industry and eight are for non-utility

telemetry use. The band is used by wireless SCADA networks which control and monitor critical infrastructure, such as gas and electricity plant, and provide reliable communications to remote and unmanned sites

Utilities also use fixed wireless links to connect all the elements of their highly distributed infrastructures, including ultra-rural locations and offshore sites such as wind farms. These usually run in microwave spectrum licensed from Ofcom directly or via a third party supplier, or the connections may be outsourced. Satellite communications are used in some cases to complement terrestrial wireless and fixed telecommunications, and are also used for very remote sites.

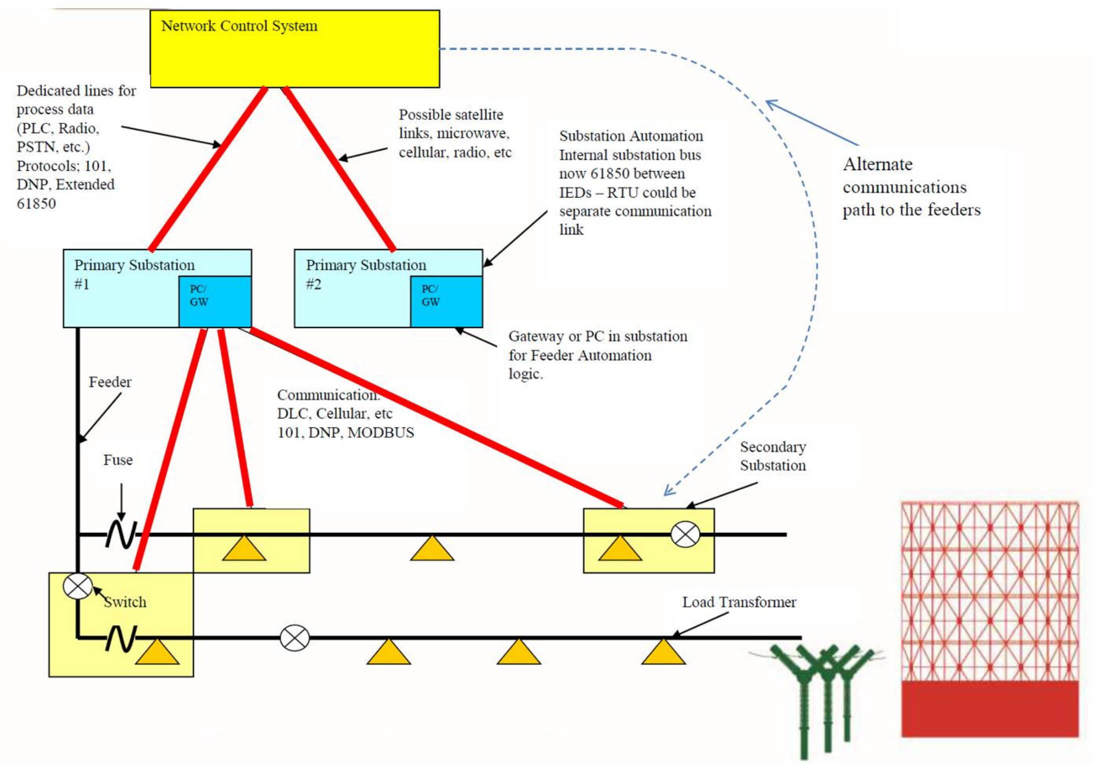


Figure 11: A conventional utilities architecture, with red lines indicating areas where radio links may be used. Source: EUTC [26]

4.6 Expected changes to technology and spectrum

The next technology developments in the utilities will be a mixture of brand new systems, like smart grids, and modernisation of existing platforms, like SCADA.

Some aspects of the smart, connected utility will mirror those of any large enterprise and can be supported by standard mobile networks. For instance, mobile enterprise systems – allowing remote or travelling employees to access the full range of corporate data and applications from smartphones or tablets – will support activities like field service management in the same way as they do in any distributed organisation.

However, there are also important differences between utilities and other businesses, which have a direct impact on the type of wireless networks they require, and their spectrum needs. These differences, and the criticality of some smart utility functions, may point to a dedicated network/spectrum for utilities, or a system of guaranteed access, similar to that envisaged for public safety/emergency services.

Smart grid:

This issue becomes acute with the introduction of the smart grid, which will rely on a combination of fixed and wireless links, with both being mission critical. The increasing penetration of distributed renewable energy sources such as wind generation and photo-voltaics is creating a dynamic grid with thousands more sources of energy than the grid was originally designed to accommodate. In addition, these sources are often intermittent in their operation, creating immense command and control challenges if the stability of the grid is to be maintained. The areas where utilities' needs diverge from the characteristics of public mobile networks include:

- A very high requirement for security of the network
- A similarly high requirement to protect the privacy of customer data. Utterly reliable performance for smart grid, since power and water are mission critical themselves and support other critical infrastructure such as hospitals
- More ubiquitous coverage than commercial mobile networks support, including high mobility for elements such as field service or emergency vehicles, and ultra-remote access for elements such as wind farms
- Data usage patterns are very different from those around which commercial public networks are designed. In particular, data rates are generally far lower and are not increasing in the way that consumer rates are; and data flows are upload-centric, in contrast to consumer patterns

These factors suggest that the mainstream mobile network is not optimal for utilities' mission-critical usage. Utilities are focused on resilience, ubiquity, security and uplink, rather than high speeds and large data volumes.

This has given rise to a debate about how far utilities should be awarded dedicated spectrum, or given guaranteed access on public networks to ensure resiliency and security for the smart grid and other critical applications. Many of the arguments focus on the coveted UHF band spectrum, whose propagation qualities are strong for ubiquitous coverage, including indoors, and so mirror those surrounding spectrum for emergency services (See chapter A.5).

Indeed the utilities sector regards the ESMCP (Emergency Services Mobile Communications Programme) as a good indicator for its own spectrum future, since the two segments share many requirements. Players see it as important that the electricity, gas and water industries present a united front on critical spectrum, as the various emergency services have done.

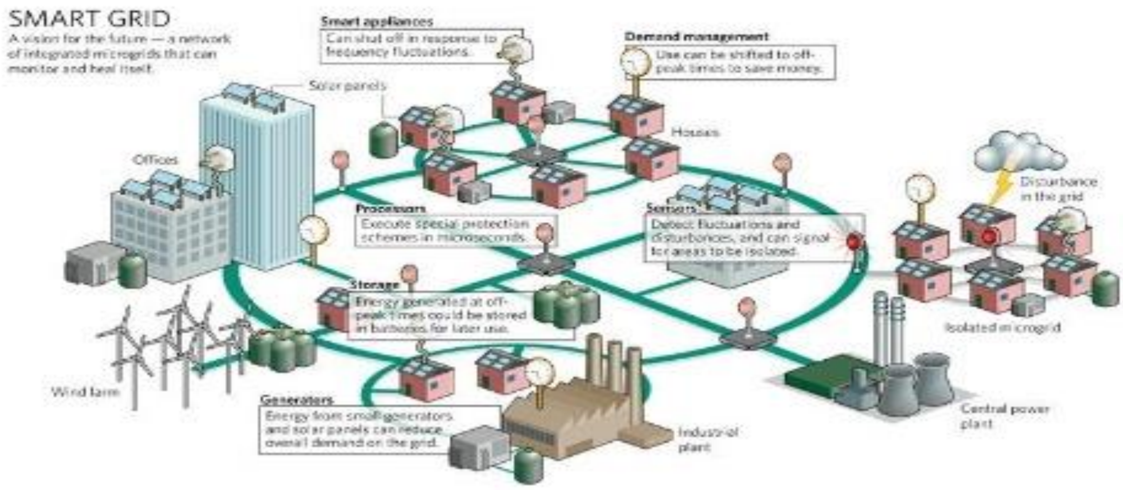


Figure 12: A smart grid architecture. Source: Consumer Energy Report

Early smart grid initiatives and pilots in the UK and elsewhere have tended to connect elements using unlicensed spectrum, the mobile phone networks or existing utility frequencies including microwave. However, many parties believe a national grid, with the critical cellular elements running in harmonised nationwide spectrum, will maximise the benefits and provide the security and resilience for these services as they become mission critical. Within Great Britain, communications to smart meters has been determined centrally by the Department of Energy and Climate Change (DECC). In the north of the country (Scotland and northern England), the chosen solution is a proprietary private network using licensed radio spectrum in the 410-430 MHz band. In the middle and south of the country (including Wales), the solution is based around a public cellular mobile phone network, supplemented by a low power mesh radio solution in the 800 MHz region.

The European Commission is considering the case for making spectrum available specifically for smart energy and smart water. In Article 8.2 of the European Radio Spectrum Policy Programme (RSPP), it states*:* *"*The Commission shall, in cooperation with the Member States, conduct studies on saving energy in the use of spectrum in order to contribute to a low-carbon policy, and shall consider making spectrum available for wireless technologies with a potential for improving energy saving and efficiency of other distribution networks such as water supply, including smart energy grids and smart metering systems." [27] These issues are also under review in Ofcom's spectrum management consultations.

Utilities argue that they need the security and QoS of licensed spectrum with dedicated or priority access. In some countries, utilities argue that they should receive this without licensing fees – because they could not afford to compete at auction with the mobile operators, and because their wireless systems would be justified in terms of cost savings from smarter energy and water management; the social and economic value of enhanced utilities; and the ability to ensure a secure and stable supply of essential services. However, in the UK utilities have accepted that, since other critical services, such as defence and the police force, pay for spectrum, they should do so too.

In 2011, the JRC conducted a socioeconomic study [28] of the use of spectrum to support utilities (updated in 2014), and the additional (non-quantifiable) benefits to society of incorporating advanced telecoms and intelligence into the passive grid. The report concluded that the socioeconomic value of a reliable electricity supply is at least 50-150 times the retail price of the electricity supplied. Using US examples, it said that the societal cost of a massive black-out is about $10 billion (£6.8 billion) per event [29], while smart grids could achieve a 12% reduction in electricity consumption and CO2 emissions by 2030. Although smart grids will not prevent outages due to severe weather, evidence from the USA suggests that more intelligence in the grid can reduce total outage duration by 50% and restoration time by 25%.

The EUTC's proposals to the European Commission, which are supported by many stakeholders for the UK too, ask for multiple small allocations in different but harmonised bands. As outlined in the previous section, major broadband capacity is not the issue, rather the ability to support many types of usage in a coordinated and secure way. The main spectrum recommendations are for

- VHF spectrum (50-200 MHz) for resilient voice communications and for distribution automation in rural and remote areas (2 x 1 MHz)
- UHF spectrum (450-470 MHz) for SCADA & automation (2 x 3 MHz)
- Lightly licensed or unlicensed shared spectrum for smart meters and mesh networks (870-876 MHz)
- L-band spectrum (1 500 MHz) for more data intensive smart grid, security and point-to-multipoint applications (10 MHz)
- Public microwave and satellite bands (1.5 GHz-58 GHz) for access to utilities' core fiber network or strategic resilient backhaul

There may be interest in the 700 MHz band depending on how it is released in the UK because of its propagation qualities and because it is likely to be relatively harmonised across the EU and even beyond. Ofcom's consultation on releasing this spectrum was concluded in 2014 though the licences are unlikely to be made available until 2022. In any likely EU band plan, the guard bands and duplex gap would be left open to national variations, with potential to be used for utilities and other machine-to-machine applications. These slivers of spectrum will be too small to support consumer mobile broadband but will be easily sufficient for M2M, and would also meet the utilities' requirement for some dedicated, quality-assured spectrum.

However, despite the suitability on paper, most utilities in Europe are pessimistic about being able to access the 700 MHz band and believe it will mainly be the preserve of the mobile operators because of their need for data capacity (and deep pockets for licences). Some may be allocated for emergency services (see section A.5), but with utilities only as secondary users.

The role of VHF spectrum is less clear, though the band in 143-169 MHz will be opened up by Ofcom in October 2014, having been returned by the emergency services for civil use. The foremost users are likely to be the PMR providers, which already operate in VHF, but Ofcom envisages new broader-band applications, of a new type in the VHF band, too. These would particularly be seen in the utilities sector for telemetry and M2M, and even what Ofcom calls "LTE-type" services. The regulator believes that the amount of contiguous spectrum being released will support new applications without harming existing users, but accepts that if demand is high, it may have to revisit its allocation procedures. The utilities sector remains uncertain of the importance of this VHF spectrum in its future spectrum landscape, especially the electricity sector as their own distribution equipment often generates high levels of background noise in the VHF bands.

The debates over critical spectrum requirements versus cost will spawn new alliances in the smart grid. Mobile operators may set some spectrum aside for dedicated or priority access for a utility customer, in return for providing a managed smart metering or smart grid service. This is particularly seen as an option when 700 MHz spectrum is auctioned, since the mobile operators, having already deployed LTE in 800 MHz, will have less urgent need of sub-1 GHz frequencies for consumer services. This approach is already seen in the Netherlands, where telco KPN and is to build and operate a dedicated wireless network in 450 MHz spectrum to support smart metering and other services for energy network provider Alliander. There are likely to be many examples where an MNO will harness some previously unloved spectrum, or even acquire new licences, specifically to support utility projects.

Smart metering and unlicensed spectrum:

Unlicensed spectrum will also have a role in smart metering, where there is less emphasis on ultra-high availability than the grid, but where the priorities are ubiquitous coverage and cost-effectiveness. Outside the UK, most utilities are supporting some form of sub-1 GHz mesh for metering purposes. The long range and indoor penetration of 800/900 MHz spectrum make it attractive, especially as, for now, it is uncongested compared to 2.4 GHz. However, most of the mainstream unlicensed-spectrum technologies are moving into 800/900 MHz, including Wi-Fi (802.11ah) and ZigBee, so interference may become an issue in future, especially given the limited capacity of this band. There are smart grid standards for the bands under development at the IEEE, TIA and ETSI. ETSI wireless mesh specifications have already been validated for the EC smart metering and smart grid reference architectures. In some countries, using the powerlines themselves for communications ('Power Line Communications' or PLC) competes with unlicensed spectrum for communications with smart meters and in home networks.

However, despite the interesting nature of some of these models, they are of limited relevance in the UK, since the regulatory structure does not allow them. DECC has awarded 15-year contracts for smart meter communications in Great Britain, so the only space for different approaches will be in water metering, or after the contracts expire. Nevertheless, some of the advances in licence-exempt bands may be relevant for other applications which impact on utilities, particularly in smart city roll-outs.

In 2013, Ofcom decided to open up the 870-876 MHz/915-921 MHz segments, which had been unused, for licence-exempt use. M2M applications, and particularly smart city uses like smart lighting, have been the main focus of interest. . However, in the UK, the regulatory structure means that utilities have far less incentive to drive smart city initiatives than in other parts of the world, and although they are often participants in such projects – and many benefit from aspects like intelligent street lighting - key drivers are likely to be local authorities or even central government.

Some argue that smart metering can deliver benefits, via cost-effective unlicensed spectrum, without the need for the full smart grid in its high value spectrum. However, analyses such as that by Ernst and Young [30] suggest that some benefits anticipated in DECC's smart meter plan would be at risk without parallel smart grid deployments, since the latter will be able to support a wide variety of additional applications to enhance the business and social case.

Anticipating that the use of licence-exempt but relatively uncongested bands will dominate smart meters, and extend to other elements of the smart utility, several companies have developed specific network technologies for these purposes. Designed for a wide range of M2M and 'Internet of things' use cases, these platforms often see utilities, along with city applications like intelligent lighting, as their initial markets.

One company which is active in the UK is France's Sigfox, which has a partnership with UK infrastructure provider Arqiva to build IoT systems in the licence-exempt 868 MHz/902 MHz bands. Another company which was active in this space was UK-based Neul, which developed the Weightless technology for IoT networks, initially in TV white spaces spectrum and then revised for operation in unlicensed bands. The Weightless standard is maintained by the Weightless SIG. Neul was subsequently acquired by Huawei Technologies in 2014. Huawei is currently leading the development of the NB-IoT standard at 3GPP for narrowband cellular IoT operation in licensed spectrum.

Sigfox, LoRa, Weightless and another IoT network specialist, Senaptic (a spin-out from Plextek) support the use of 'ultra-narrowband' (UNB) technology in 900 MHz, since it suits the utilities' data patterns (small packets with high reliability requirements). However, while their networks are dedicated to the use of their customers' meters or other 'things', the spectrum is unlicensed and so could be targeted by other applications and technologies, leading to congestion and poorer reliability over time.

In particular, the band may get more crowded as Wi-Fi devices supporting the 900 MHz 802.11ah extension become available in the second half of 2015. Some pre-standard silicon for this standard is already being demonstrated, for instance by Greece's Antcor. Its platform is targeting industrial and home automation, including meters, and will cooperate with Bluetooth and ZigBee for the 'last few centimetres' – likely to be a common pattern in the smart home. The 11ah specification supports data rates from 150Kbps in a 1MHz band to as much as 40Mbps over 8MHz.

The debate between licensed and unlicensed approaches for metering is seen in the UK contracts. Arqiva has secured, with BT, one of three contracts, awarded in 2013, to deploy smart energy meters. The partners will cover the northern region, and will rely on long range radio technology including UNB. Arqiva claims this is more secure and resilient than a cellular solution. Others support licensed spectrum networks – though not necessarily dedicated ones – for metering. The other two contracts, for the central and southern regions, went to mobile operator Telefónica O2, which is using its existing cellular network plus new street-level meshes to reach areas with poor signal. O2 said the contract was "a huge endorsement of cellular as the right communications technology" for meters.

Smart water meters will be separate devices from their energy counterparts and that industry is also currently considering two key approaches, short range mesh or long range 900 MHz radio.

4.7 Long-term technology and spectrum needs and options

In the medium to long-term, the complexity and challenges of the smart grid, for energy and water, will only increase. Although more fibre will be deployed to help meet these challenges, this will not keep pace with the need for flexibility, mobility and rapidly deployable links, so the reliance on highly reliable and secure wireless connections will remain high. The rising challenges will come from:

- Increasing variety of applications deployed on the smart grid
- Increasing use of big data analytics to improve service quality and network efficiency, and to improve customer response
- Increasingly distributed nature of the networks, especially electricity, to incorporate new and fragmented sources of supply. This will require more complex control and communication methods to ensure stability
- Increasing interchange of communications and data between different utilities, and between utilities and other networks such as telecoms
- Continuing rise in pressures to improve security, stability, capacity and energy efficiency

There will be a rising need to integrate private and public networks and their devices, and a wide range of spectrum bands and air interfaces, to support all these various requirements in a seamless all-IP environment. A commonly expressed vision revolves around a combination of existing PMR and telemetry systems, particularly to support the continuing needs for mission critical voice and low-rate telemetry; with the addition of UNB for mission critical data; and with an overlay of public LTE for broadband but non-critical data. With the possible addition of dedicated 700 MHz LTE in future, the priority will be for all these systems to be seamlessly integrated for the user (whether human or machine), and to connect to the networks of partners too.

Looking into the 2020s, far more of the network will become software defined and virtualised, as seen in Figure 13, a vision set out by communications and integrator group TTG.

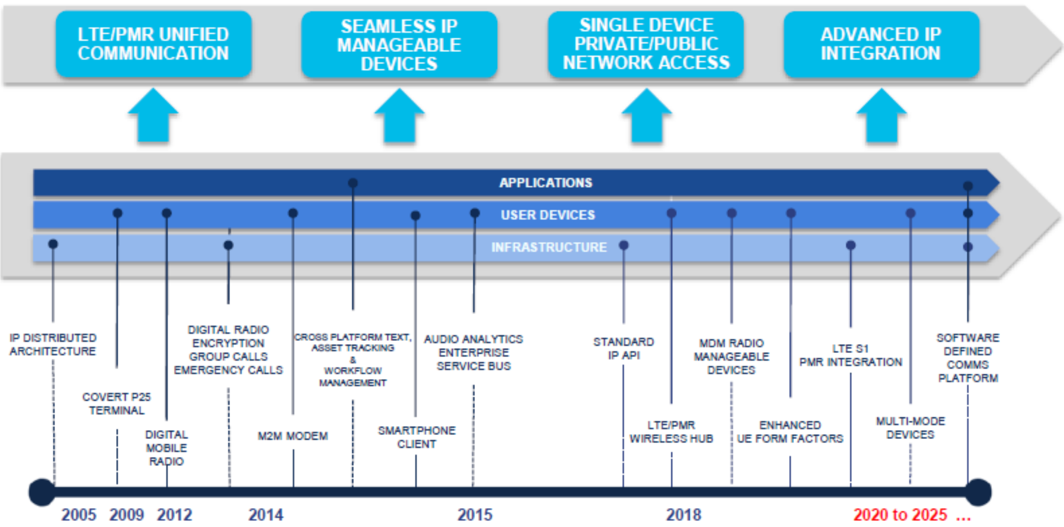


Figure 13: Technology roadmap for the utilities. Source: TTG

Although many of the initial elements of the smart utility systems will use unlicensed spectrum or higher frequency bands, the optimal frequencies will be those which are licensed (for security and QoS) and below 1 GHz (for range and penetration), and in which priority access for critical utility functions can be assured.

The availability of this licensed, low frequency spectrum will be increasingly low, and subject to competition from other potential users such as emergency services, commercial

M2M providers, enterprises and consumer mobile services (though with LTE built out in 800 MHz, the focus for consumer broadband is likely to shift towards higher capacity, and therefore higher frequency bands like 2.6 GHz). These factors make policy decisions about the 450 MHz and 700 MHz bands, and potentially VHF spectrum, critical to the utilities' wireless plans.

Internet of Things:

Apart from extending the functionality and resilience of the smart grid, there are other trends which will be relevant for the utilities. One is the emergence of the 'Internet of Things' (IoT), which has broader implications than just smart metering. As Figure 14 shows, a Machina Research calculation estimates that utilities will be the second largest sector in terms of M2M connections in the UK by 2020, with 59.5 million deployed.

Many of these will be meters, but energy suppliers could also link their systems to other smart home devices such as the smart thermostats popularised by Google's Nest. However, in the UK energy distribution companies are not allowed to have a direct relationship with the end customer, so the main movers here will be the home suppliers.

New and more intelligent uses of M2M will be important for internal efficiency for utilities, enhancing current machine-based functions and adding new ones. For instance, there will be new approaches to remote asset management, monitoring of substations and water mains, and delivering vital information to remote workers via smart clothing, in scenarios where the employee cannot have hands free to use a mobile device.

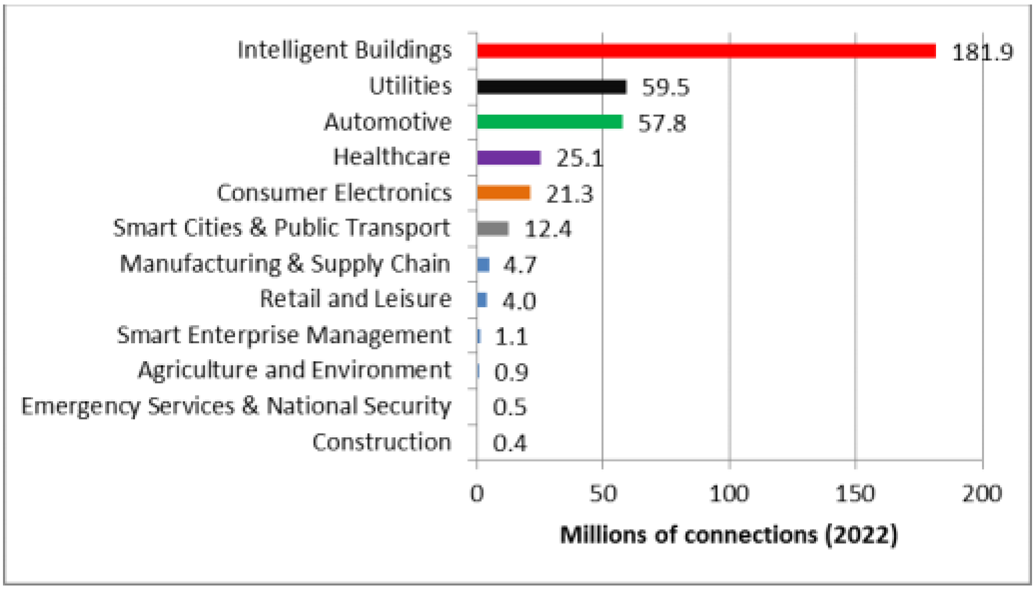


Figure 14: M2M connections in the UK in 2022 by sector. Source: Aegis Spectrum Engineering/Machina Research [31]

In the longer term, in many parts of the world, utilities will have a vital part to play in full smart city initiatives, which will look to coordinate, and intelligently manage, all kinds of resources such as energy, lighting, traffic, security, water and transport. In some cases, the utility, with its smart grid as a foundation stone, might become the prime coordinator and platform provider for a smart city. As noted above, however, the UK regulatory structure does not currently encourage this. Energy management is part of the UK's government's

Future Cities and Future Cities Catapult programmes, but not a primary goal, according to the Department for Business Innovation and Skills (BIS) [32], and the department is heavily focused on local authorities to be the main drivers.

According to the nature of the application, the IoT will run on a combination of networks and spectrum bands including:

- Wireless personal area network – Bluetooth, ZigBee, Z-Wave, Thread, 6LoWPAN, in various unlicensed bands, increasingly focused on 900 MHz
- Wireless LAN – Wi-Fi in 60 GHz, 5 GHz, 2.4 GHz and 900 MHz
- Wireless body area network – 802.15.6 (in the US, in a designated area of 2.3 GHz, elsewhere unlicensed)
- Application specific standards emerging for telematics, RFID, telemetry and others
- IoT-focused standards in unlicensed bands e.g. Weightless and Sigfox UNB, and LoRa, all in 868 MHz (900 MHz in the US), with Weightless also having an implementation for the TV white spaces
- Extension of existing short range device and PMR networks, in their current bands, for new IoT purposes
- Legacy cellular – M2M applications run on GSM, 3G and LTE. One cellular option discussed by some operators is to retain some GSM capacity in the licensed 900 MHz spectrum specifically for IoT, since GSM has many of the characteristics required for these connections (though is less power efficient than, for instance, UNB)
- LTE in 700 MHz and 800 MHz - the 3GPP is engaged in review of a new standard, LTE-M, which would be more optimal for IoT applications. This could be based on a new air interface, or on so-called LTE-M, which would adapt the current standards. Either could be deployed as a dedicated network or a cellular overlay
- CDMA in 450 MHz is also being promoted internationally for M2M but at present in Europe deployment is limited to the KPN utilities network in the Netherlands. In the UK, this would require reconfiguration of the band to align with the EU

Other bands may be released, with particular relevance for utilities and their potential IoT expansions. These include:

- The 870-875.6 MHz band, the subject of a recent European initiative for potential wide area use, on a licensed or licence-exempt basis.
- TV white spaces spectrum in UHF, which has low capacity in many areas, but long range, and so could support utility applications if priority access were allowed. Ofcom is the most active regulator, after the US's FCC, in approving trials in this spectrum, some of which have involved utilities, and it should be open for commercial use in 2015.
- The guard bands and the duplex gap between the base station and mobile transmit sub-bands in the 700 MHz cellular band, when that is released.

4.8 Conclusion

As a final point, the different utilities are progressing at different rates towards their smart network future, but all have similar overall aims, even if their regulatory and market pressures vary. However, it will also be increasingly important for them to interwork, and therefore it may be helpful to adopt a somewhat harmonised approach to spectrum and technology roadmaps.

Interworking may occur as part of broad smart city initiatives, whether driven by governments, local authorities or the private sector; as a way to save money through shared infrastructure (such as meters and cloud data centres), especially in under-populated areas; and because there is a tight economic relationship between water and energy. According to IDC Energy Insights [33], this 'energy-water nexus' occurs because about 15% of a water utility's O&M expenses are for power, while a large amount of water is used in the production of energy (cooling for power plants, fracking etc.). Both sides wish to reduce their consumption of the other's resources, which may be yet another stimulus for smart management of their resources and networks in future.

A.5. Business Radio

5.1 Scope of the sector

The Business Radio sector is highly diverse, covering a very broad range of applications and services, many of them vertical-specific or highly customised. Although it is not recognised as a single platform, because of this fragmentation, it underpins a huge range of critical business functions in many markets, and all of its elements do have some key features in common:

- Ultra-reliable and fully available communications
- Ubiquitous coverage in the required operational area, including locations which traditional wireless services rarely reach (e.g. underground and in very remote locations)
- Low latency and instant connections between users
- Enhanced support for group working including large numbers of people and/or machines
- Customised services to support a wide variety of businesses and activities, supporting construction, logistics, transport, farming, manufacturing and a wide range of other industries
- Services which are absolutely mission critical, and often essential to safety or even preservation of life.

Because of these requirements, Business Radio systems include several characteristics which are not usually supported by public mobile networks. In particular, they link groups of people or connected machines in peer-to-peer and point-to-multipoint fashion, supporting coordination of large numbers of users or objects. They also support pre-emptive priority for certain users, and direct device-to-device as well as air interface or end-to-end encryption, which are important in emergency services and other critical applications.

The main segments included under the umbrella label of Business Radio are:

- Emergency Services (police, fire, ambulance, coastguard etc.)
- Maritime mobile services, location, navigation and safety
- Private Mobile Radio (PMR). This itself provides critical and commercial communication services to a huge number of segments including
    - Public transport (railways, underground, buses, coaches)
    - Private transport e.g. taxis, fleets
    - Utilities
    - Petrochemical and biotechnology
    - Agriculture
    - Local authorities/municipal
    - Hospitals and healthcare
    - Underground activities (mining, car parks, basements)
    - Prisons
    - Environmental services
    - Manufacturing
    - Venues and outside broadcast
    - Aviation industry under-wing services

- Ports
- Nuclear industry security and transportation
- Events (sports, entertainment, both large and small)
- Operations in hazardous environments (e.g. hydrogen atmospheres)
- Any other businesses or activities requiring ultra-reliable, instant and ubiquitous communications.

In all cases, Business Radio systems provide levels of reliability, coverage and functionality which are not usually provided by standard mobile networks. As well as supporting activities where instant communications are essential, such as emergency response, they are also vital for coordinating large numbers of people or items in a timely way – for instance, managing the unloading of thousands of containers from a ship, or reconnecting electrical power to the grid after a black-out. The public mobile network may also be used for non-critical data services, but these activities are clearly separated from the critical communications over the BR network.

There are three main ways to deliver Business Radio services:

- The BR user buys and owns the radio assets – common among utilities or large venues
- The BR user owns the terminals but uses third party infrastructure and services (this is also known as PAMR or public access mobile radio, and is seen in the UK emergency services network for the police, operated by Airwave)
- The user outsources the entire service, including terminals as seen in the UK emergency services network for the fire and ambulance service, also operated by Airwave.

5.2 Contributions to social and economic value

Emergency Services:

The social contribution that emergency services make to society may seem obvious, just from quoting statistics such as ‘every six minutes, the emergency button is pressed in Great Britain’, or that the London Ambulance Service responds to 1.5 million emergency call-outs per year, reducing suffering and loss of life. The services are clearly driven by urgent need, not commercial models, and would not function without critical communications networks.

However, this value still needs to be quantified in order to justify the services’ costs against their benefits. In economic terms, as well as supporting large numbers of jobs and supporting industries, the contribution of efficiently coordinated emergency services can be calculated by, for instance, savings from reduced crime against the person or property, which in turn reduces the strain on other services like healthcare, and on insurance etc.

The socioeconomic benefits which are inherent in emergency services are enhanced by more modern and responsive communications, which therefore make a socioeconomic contribution in their own right.

One study by the London School of Economics, commissioned by the TCCA[7], estimates that the use of full mobile broadband by ambulance services could save 560 lives a year just by allowing ambulances to reach heart attack sufferers more quickly and with better

[7] Tetra and Critical Communications Association http://www.tandcca.com/

information [34], and this would translate to a socioeconomic benefit of £980 million a year. The same report quotes South Yorkshire Police, saying that the introduction of BlackBerry devices had saved 30 minutes per shift per officer, or £6 million a year, thanks to extra time spent in the community, the use of photo and CCTV evidence to help secure convictions, and other aids such as visual identity checks.

More broadly, the same study calculates a consolidated annual socioeconomic value of £5 billion that would accrue from the allocation of 2x10 MHz in the 700 MHz band specifically for PPDR (public protection and disaster relief) across the European Union. The calculations can be debated of course, but the general point illustrates the socioeconomic value of robust communications systems to support emergency services.

PMR:

Because it is not a homogeneous platform, the socioeconomic contribution of PMR outside the emergency services can sometimes be overlooked. However, by its nature it provides communications which are critical for either safety or business objectives, and it enables many commercial and public services to operate smoothly by supporting the so-called '5 Cs' of PMR - cost, coverage, capability, control and capacity.

As the TCCA puts it: "Mission critical users are those that are responsible for the health, safety, security and welfare of our citizens. Police, Fire, Ambulance, rescue services and specifically the Military would be classed as Mission Critical. Those that ensure the availability of Electricity, Oil and Gas, Water and Core Transport services, without which modern life would quickly degenerate, are also classed as Mission Critical…" (TCCA, 2013a). Beyond health and safety, mission critical operations are often defined as those which are essential to meeting an over-arching and important goal (such as getting a ship to sail on time, enabled by locating every last container on time).

The social contribution of many PMR-enabled services is often invisible, since systems that keep water flowing, goods delivered to stores or airports functioning are only appreciated if, on rare occasions, they go wrong. However, many of these services are as critical to normal social and economic activity as the ES sector.

Every major infrastructure project, for instance, needs access to PMR services, including railway build-outs, wind farms, nuclear power stations and so on. If they cannot access a reliable PMR service they may face greatly heightened risks and insurance bills (or denial of insurance), or have to invest in an expensive in-house system where possible.

Like emergency services, PMR supports essential functions rather than being a revenue model. Its main socioeconomic contributions are to improve safety and efficiency, and save money - it provides a lower cost option for many business functions than the public mobile network, since the infrastructure can be owned and controlled and therefore has no airtime charges associated with its use.

It does also generate income directly through commercial services, and the private aspect of BR was estimated to contribute net economic benefit of £2.3 billion in 2011, up from £1.2 billion in 2006 [35] (according to a study for Ofcom by Analysys Mason).

Such economic benefit calculations may even be under-estimates, since they may not measure the impact of BR being unavailable in a certain situation – the economic impact of the breakdown of UK ports because of lack of PMR capabilities would, of course, be far larger than the report's total figure.

Even using the narrow definition in the Ofcom report, the growth in direct contribution came during a period in which usage patterns and technologies did not change radically. Current trends, such as the inclusion of more data in PMR services, and the shift to digital technology, will enable new applications and may be expected to drive more rapid growth in this sector.

The introduction of digital technology throughout the chain (not just in the modulation) is ushering in radically different models. Many suppliers have taken the opportunity to invest in platforms which can host complex IP-enabled applications, optimised for many different users and functions. One company already has 4,000 apps partners whose specific operational solutions are hosted on the system.

In both ES and PMR, it is notable that while benefits may be enhanced by new spectrum, most of the benefits will generally not accrue to the organisations holding (and potentially paying for) the spectrum licences.

The FCS takes the view that solely economic models do not provide any realistic basis for calculating the value of Business Radio. For instance, the entity investing in the spectrum and networks is often not the same entity which derives the economic benefit, and there may be no clear connection between the two (insurance companies, for instance, are major beneficiaries of the investment by BR agencies in radio equipment which reduces burglaries or avoids accidents).

This is an argument deployed against any proposals that the ES sector, in particular, should have to secure its own spectrum at auction.

5.3 Current and recent past status

Emergency services:

Each emergency service originally had a separate wireless analogue network, but these were consolidated in the 2000s to create a single, national digital trunked radio network for police, fire and ambulance services. This service is currently delivered by Airwave using TETRA technology in 2x5 MHz of 380–400 MHz spectrum, managed by the Ministry of Defence but granted to the ES network until at least 2020. The narrowband network has enabled the main emergency services to inter-communicate, and it has greatly increased coverage (99% of GB landmass) and security compared to the legacy systems. It supports circa 275,000 ES personnel. In recent years, there has been rising use of data as well as voice for critical communications, some of this on the Airwave system, and some using conventional cellphones on 3G. The ES sector spends about £440 million a year on communications, including Airwave (about £400 million a year) and other wireless networks.

The various emergency services have very different mobile data agendas. Video and high-resolution images are important for law enforcement; real-time sensors and motion detectors are valuable for fire-fighting; video-equipped drones are on the roadmap for search and rescue, for instance.

The most important change currently taking place in the ES sector is the finalisation of plans to replace the Airwave public-private partnership arrangement. The overall Airwave contract ends in 2020 but many individual user contracts (e.g. that of the police) come to the end of their 15-year lives in 2015-16. The Emergency Services Mobile Communications Programme (ESMCP) is the Home Office initiative to replace Airwave with a new Emergency Services Network (ESN) for broadband public safety services, running on commercial LTE.

PMR:

There are two apparently opposing trends at work in the PMR sector. The number of PMR licences has been fairly static for the past seven years and in most areas, there is not excess demand for spectrum licences, though there are exceptions in some inner city areas. In fact, the number of PMR licences fell by 15% between 2006 and 2011, though that is partly because Ofcom simplified the categories. In the past two years, there has been an increase - as of the end of 2013, there were 46,294 Business Radio licences in active use, up from 43,000 a year before (see Table 2). In some metro areas there are concerns that the licences will simply run out if current rules are maintained.

Table 2: PMR customers and licences, Ofcom, December 2013

Licence class	Customers	Licences
Simple UK (light)	9796	10222
Simple Site (light)	4382	8009
Suppliers (light)	712	720
Technically assigned	13896	27095
Area defined	97	218
Total	**28883**	**46294**

By contrast with this relative stasis in licence numbers, the average number of users per licence has increased steadily, as have levels of usage, and that trend will only increase with the rising inclusion of data alongside voice.

Overall then, the Business Radio sector has been in expansion mode in recent years, despite cutbacks in the size or budget in some areas of the emergency services and commercial industry (indeed, recession-driven spending cuts may have increased interest in BR, and even led some users to return to it from 3G, since it is generally a more cost-controlled and less congested option than cellular for its target applications).

5.4 Sector trends

The general increase in expectation that everybody, and everything, will be always-connected has as much of an impact on Business Radio as it does on public mobile. At the start of the decade, only critical voice services might have been expected to be available everywhere, and all the time. Now that expectation has extended to data and to non-critical communications, as a result of changing business and consumer habits. The transition to data/voice rather than voice-only; to IP-based networks; and to broadband/wideband are the critical trends across all areas of BR, and are shaping the spectrum and technology requirements of the emergency services and the PMR sector.

Many organisations which previously tolerated key workers being out of contact in the field now need systems which enable their employees to communicate, and access company data, from all locations. More generally, that means that ubiquitous, reliable data is increasingly seen as mission-critical, to almost the same extent as voice in some cases, rather than a 'nice to have', and that changes the patterns of demand.

Further, functions that start being regarded as 'best effort' can, through repeated usage, become an integral part of the activity, and therefore graduate quickly to being regarded as critical.

All this leads to a rising demand for PMR systems, driven by:

- Heightened regulatory and public demands about safety and security standards (use of PMR for baggage handlers and security staff at airports or large venues, for instance)
- Adoption of mobile-first business models by many companies, which are now being extended to employees who may not be in easy reach of reliable cellular connections. Field support in remote areas such as oil-fields is an example
- Rising use of location awareness even in areas where there is not ubiquitous cellular or Wi-Fi coverage. For instance, real-time bus-stop updates as well as security applications.

Many of these trends are generic to most commercial and public organisations, but in many cases they are better supported by PMR than public mobile because of the ability to reach all locations in the required service area, and because of added value such as group calling and push-to-talk, for applications which involve coordinating large groups of people (security staff in a mall, crowd safety control in a stadium, warehouse workers).

The most significant usage trends in the sector are currently the migration to digital services, and to voice/data rather than data-only. The latter brings with it the associated demand for wideband or full broadband connectivity, and asset location services, especially in the emergency services.

Migration from analogue to digital was slow to start, especially in PMR, compared to public mobile networks, but is now well under way, with digital representing about 80% of sales of new or replacement PMR equipment, a CAGR of around 20% for the past few years. By 2017, it is estimated that about 70% of the migration will have taken place (Federation of Communication Services), although some important analogue uses will remain for the foreseeable future.

These developments will shape future technology and spectrum requirements for Business Radio (see section 5.6), but will also enable new commercial and public safety services, driving new usage patterns and revenues.

The key to those new applications will lie in the combination of digital/broadband/wideband data capabilities, with the unique attributes of PMR, notably its group coordination, instant set-up, low cost of usage, ubiquity and low latency. One of the biggest challenges for the sector is to ensure these advantages can be fully retained in a digital mobile broadband environment, in order to preserve the differentiation with standard cellular platforms such as public LTE.

Examples of new or enhanced services, achieved by combining PMR's capabilities with digital broadband, include:

- Instant transmission of images in public safety applications such as identification of suspects
- Real-time access to detailed and 3D maps and floor plans, for security and emergency use and customer service at venues

- Access to rich location and navigation services for transport workers
- Video group calling and conferencing, e.g. to offer high calibre remote support and guidance to on-site staff

The digital networks will also enable PMR systems to use some of the mechanisms which have changed the way people interact on public mobile services, notably the use of apps. The ability to download apps easily from a central store helps to expand the ecosystem and variety of uses of the network and encourage new innovations.

Perhaps the greatest medium-term opportunity for PMR lies in the expected explosion of the Internet of Things (IoT), a significant expansion of current M2M services, in which billions of previously unconnected objects are wirelessly linked to one another and the Internet. Many of these features are already available but usage is expected to grow, but this will see greater integration of PMR with VPNs and wider IP-based networks, in turn supporting new applications. The combination of PMR's existing capabilities for coordinating large numbers of people and machines, with its new support for data and IP, will put it in a strong position to underpin emerging IP-enabled IoT applications such as smart transport or new-generation factory control and supply chain monitoring.

5.5 Spectrum usage

Emergency services and PMR usage is mainly concentrated in the VHF and UHF bands.

Table 3: Key bands in use for Business Radio

Frequency band	Service
55.75 - 68.0 MHz	Private Mobile Radio
68.0 - 87.5 MHz	Private Mobile Radio
136 - 174 MHz	Private Mobile Radio
177 - 191 MHz	Private Mobile Radio
380 - 399.9 MHz	Terrestrial Trunked Radio (TETRA) or emergency use
425 - 430 MHz	Private Mobile Radio
430 - 440 MHz	Amateur radio (ham – 70cm band)
440 - 449 MHz	Private Mobile Radio
446.0 - 446.1 MHz	Private mobile radio
446.1 - 446.2 MHz	Digital private mobile radio
453 - 462 MHz	Private Mobile Radio
457.5 - 458.5 MHz	Scanning telemetry and telecontrol mainly for utilities
463 - 464 MHz	
606 - 614 MHz	Radio microphones and radio astronomy

The widest range of equipment, and best performance, tends to be seen in the higher VHF and UHF bands, so usage is concentrated there, though there has been considerable work done on harnessing additional bands.

Emergency services:

After the consolidation of individual services' networks to form a single, national digital trunked radio, all three services today use Airwave's TETRA technology service operating in paired frequencies between 380 MHz and 395 MHz, managed by the Ministry of Defence. The 380-385 MHz and 390-395 MHz sections of this band are harmonised across Europe for public safety. Emergency services also use a range of other bands for fixed wireless and wireless video communications, and airborne telemetry. Much of this spectrum is shared with the MoD. Higher bands in national use include 1 677-1 685 MHz, 1 790-1 798 MHz, 2 302-2 310 MHz, 3 442-3 475 MHz, 8 400-8 460 MHz, 10.25-10.27 GHz, 10.36-10.4 GHz, and 24.05-24.15 GHz.

The Home Office & Scottish Office also has significant spectrum holdings in the 435-470MHz band.

PMR:

A variety of bands is used for PMR, mainly in VHF and UHF2. Narrowband channels are used - Ofcom offers a range of channels for PMR, between 6.25 kHz and 25 kHz, with others assessed on request. The spectrum is lightly licensed and tradeable or leasable, but only certain portions are available in each PMR band, making them quite fragmented.

While the emergency services have migrated to digital PMR in the shape of Airwave's TETRA platform, other PMR segments have been slower to move. Many analogue systems, usually based on the UK MPT1327 standards, still operate (for instance on London Buses). Another digital technology in frequent use, mainly for smaller users for which TETRA would be unsuited, is DMR (digital mobile radio), an ETSI standard for narrowband PMR. This typically uses the same channel size, 12.5 kHz, as analogue PMR. However, channel size has been driven down to 6.25 kHz as spectral efficiency has evolved.

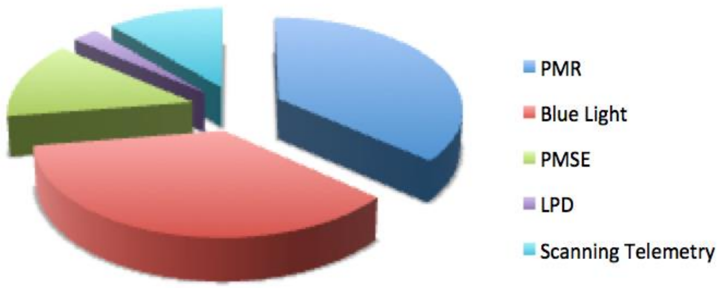


Figure 15: The UHF 2 spectrum available for various applications including PMR (Source: Ofcom)

5.6 Expected changes to technology and spectrum

The most important technology changes in the Business Radio sector are the migration to digital; to data as well as voice; and to mobile broadband. In all three cases, these transitions are more advanced in Emergency Services than most areas of PMR, but in both segments, these changes will impact on spectrum requirements and policy.

In particular, they are likely to drive a move away from a specific band dedicated to a specific technology (like TETRA) to IMT standards (LTE family) with flexibility on the band used (IMT supports a wide variety of bands, though the most relevant to PMR will be those below 1 GHz). In keeping with the key features of BR, it is likely that wideband services may require spectrum for certain critical operations. In particular, more spectrum will obviously be required, in bands where there is scarce supply relative to the number of potential services. That means that the key question underpinning the debate will be the right balance between spectrum sharing and possible trade-offs for ES and for critical PMR applications.

There is additional spectrum being released in traditional Business Radio bands. The greatest opportunity for new spectrum for Emergency Services is seen to be the likely opening of the 700 MHz band for LTE from 2018. However, for other parts of the BR community, access to this spectrum is likely to be effectively denied.

Despite the introduction of more efficient radio technologies and other improvements, current evidence appears to indicate that the introduction of advanced data services into BR user operations adds so much to the demand for capacity that there is a net loss of available spectrum capacity overall – a pattern also seen in public mobile.

The introduction of data to critical services:

The defining features of Emergency Services and Business Radio services are their instant call set-up, and high levels of availability and reliability. This has applied to voice and some forms of messaging, but will increasingly apply also to data, which raises a number of new debates over spectrum policy – in particular, whether that policy should aim to make data communications as failsafe as voice, which would impact on aspects such as sharing with commercial services, or whether voice should always be the fallback for critical services. Decisions on guaranteeing spectrum depend on the criticality of the service, and there is debate about whether data should be included in the highest level.

Although ES moved to digital at an earlier stage than other PMR networks, there is now a further requirement to migrate to full mobile broadband, in order to support higher data rates and more data-centric applications. A study conducted by Analysys Mason for the TCCA (TETRA +Critical Communications Association) [36] found that mobile video transmission is the key requirement, and would exceed the data capacity of current TETRA systems.

Commercial 3G and LTE networks already carry some ES data, but only when this is non-mission-critical. By contrast, many of the new functions which would be enabled by mobile broadband, such as precise location pinpointing (of disaster or accident victims, for instance), would immediately be considered mission-critical once introduced.

Similar issues are relevant in BR services, where these are mission-critical, as many increasingly are (keeping seaports open for instance). As in ES, services which are critical to safety or to business continuity increasingly rely on data as well as voice. This may often be 3G-based now, but the more the users depend on utterly reliable data, the more they will categorize this as critical rather than a 'nice to have'. In turn, that will increase demand for spectrum which can support higher levels of criticality than public mobile networks. There is no reason to think that BR will not see the same patterns as the 3G/4G operators – the more data capacity is made available, the more data is consumed. That could quickly put pressure on BR-suitable spectrum.

Two key issues then arise for ES and, in many cases, BR:

- Will data ever be as critical as voice, and if voice is always available as a fallback, does data need to be in dedicated, critical spectrum?
- Can shared or public spectrum and standard cellular technology, such as LTE, deliver the levels of availability, reliability and security to support critical data applications to the standard required?

New VHF spectrum for PMR:

The need to keep options open on licensing schemes, to accommodate currently unforeseen types of usage, was acknowledged by Ofcom in March 2014, when the agency issued proposals on the release of about 6 MHz of VHF spectrum in the 143-169 MHz band, being returned to civil use by the Emergency Services. (Spectrum between 143 MHz and 156 MHz in Scotland has also been returned by the Emergency Services, as has around 0.5 MHz of UK-wide spectrum in 168 MHz and 169 MHz.)

Ofcom acknowledged that the transition to wideband and broadband was likely to introduce new applications and technologies to this area of spectrum, in particular broadband-based telemetry, M2M and 'LTE-type' applications. Ofcom believes "these bands in the longer term may offer particular opportunities for new types of use that are not readily accommodated by the current licensing arrangement. The approach outlined in this document acknowledges that new demand may emerge and our proposed assignment approach is specifically designed to preserve future flexibility. If demand for wideband access or other technologies (such as M2M or 'LTE' type services) emerges, Ofcom may decide to review its assignment approach and may also consult on alternative allocation models, including an award of available spectrum."

The main proposed use for this sizeable chunk of contiguous VHF spectrum is to make the spectrum available on a first-come first-served basis through the existing Business Radio licensing scheme, which would be in line with EU recommendations to use this band for PMR. The situation is complex because of the rising number of critical applications supported by BR. For instance, there are strong proposals to support vital new operations for smart grid in this band.

In addition, 0.375 MHz would be allocated exclusively for maritime and land search and rescue, to support new technologies and protect those channels from interference. Any unused frequencies would be available on a temporary basis for amateur radio and PMSE.

Notwithstanding the VHF proposals, there are many demands for additional spectrum in the UHF 1 and 2 bands for PMR. As PMR services follow ES into the digital era, the rising use of data will put pressure on existing spectrum resources. However, as Ofcom puts it, there is “no obvious source” of new spectrum for PMR, therefore more effective use of the existing spectrum will be necessary. The rest of the UHF 1 band is constrained for civil use by MoD requirements and only one-third of UHF 2 is available for PMR (see figure 15). There is some migration of non-critical PMR users, such as taxi firms, to the public mobile network, though this is unlikely to offset the rise in broadband usage by those users who still require the particular capabilities of PMR networks.

Adoption of LTE:

The two key questions – is data as critical as voice, and can public spectrum and standard cellular technology support critical operations? – have informed the debate over whether a mobile broadband network for emergency services use should live in dedicated spectrum, or share with the public mobile services; and whether it should rely on a standard air interface like LTE, or a specialised technology.

The second question has been largely decided, with a rising consensus that LTE will be usable for critical data communications and broadband PMR, and that the sectors will benefit from the economies of scale and depth of ecosystem. This was confirmed when the UK government decided on an LTE network for the Emergency Services Network (see below), a decision which is likely to be very influential in other critical applications which use spectrum, and on policies in other European countries. However, there are still many significant and outstanding issues, especially with regard to voice services, which are likely to remain separated from data for years to come.

The US has been the leader in emergency services LTE, at least in setting policy blueprints for public safety networks, if not in their implementation. After years of wrangling, the US regulator, the FCC, issued an order, in January 2011, that effectively earmarked part of the 700 MHz band for public safety and required all public safety networks in that band to support LTE. The FCC had already allocated two blocks of 5 MHz in the 700 MHz band for public safety, and in 2012 it added two further 5 MHz blocks (the ‘D Block)and set up the FirstNet agency to build and operate the US’s first national public safety network, initially for group data services before adding the voice requirement

European governments are expected to follow this lead and base future emergency services networks on LTE, but their decisions are still dogged by the same dilemmas which delayed the US roll-out for so long:

- How to secure sufficient spectrum for public safety broadband use
- How to ensure availability and reliability if the most efficient way to allocate spectrum is to have it shared with commercial or other services
- How to increase the capabilities of the networks in the interim period, which may be five years or more, before LTE networks are fully able to support all the requirements of mission critical data and, even more problematically, voice.

On the last of these points, there are issues with the use of LTE itself for emergency services. The current 3GPP standards do not support some of the features required, such as group calling, priority access, direct device-to-device working and certain types of encryption. Work is in progress within 3GPP to consider how these PMR-like functions might be added to future LTE releases and the TCCA is a Market Representation Partner, contributing requirements and use cases and feeding inputs from the wider community. As Figure 16 illustrates, there needs to be a balance between minimising support for special functions and customisation (a key quality of PMR), in the interests of reducing cost and risk; and supporting as many operating modes and radio situations as possible.

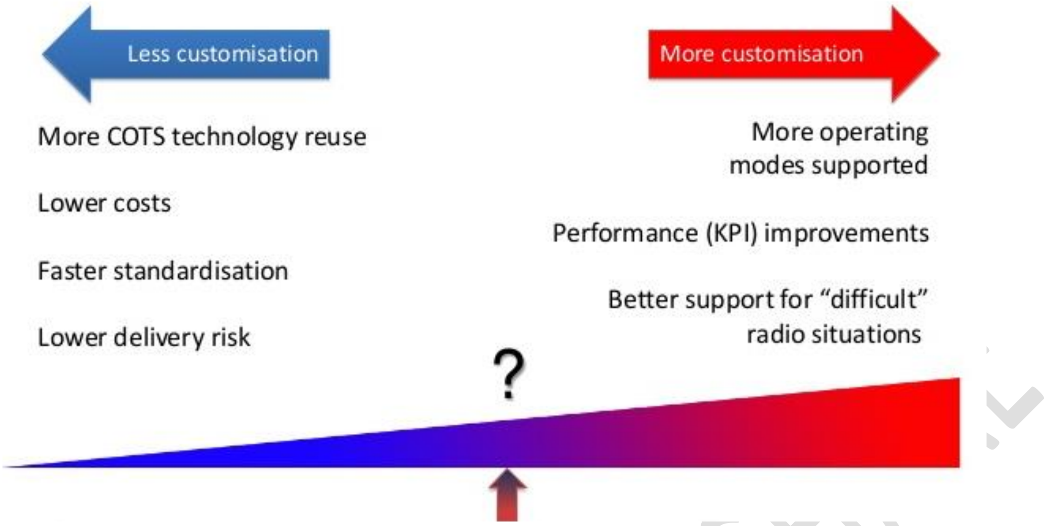


Figure 16: Trade-offs between customised and fully standard networks for critical communications. Source: 'Developing specifications for LTE', Mona Mustapha, chair, 3GPP TSG-SA WG1 [37]

The main work items for Release 12 are shown in the table below:

Table 4: Main work items for Release 12

System features	Proximity services (ProSE)
	Group call on LTE enablers (GCSE_LTE)
Radio layer features	Frequency band support
	Power level support
	Radio enablers for system features above

The critical communications enhancements are likely to be introduced over more than one 3GPP LTE release, with some appearing in Release 12, which will be frozen in Q1 2015, and others in Release 13 or even beyond. Release 13 specifications are due in 2016 but there will need to be additional work on detailed protocols and chipsets after that, so full LTE support for critical data functions may not be available in commercial equipment until 2018. Once standards are agreed, there is considerable extra effort to implement them – regulatory and legacy migration considerations, and the applications and device ecosystems, for instance.

However, countries like the US and UK are specifying their own pre-standard enhancements to support ES requirements in a shorter timeframe than the standards process will allow.

Such efforts raise the real possibility of a variant on the LTE standard emerging, specifically tailored to PMR and emergency services needs, and capable of supporting voice with no degradation of the reliability of current technologies. While rising data usage in ES and PMR sectors is the main driver for LTE adoption and for increasing capacity at reasonable cost, voice remains the most critical element of the services. Voice over LTE is immature even for the commercial market and for critical usage, there is real doubt over whether it will be adequate, even with proposed enhancements to the standards. The FCS comments: "Will the voice service arising from future enhancements of the global LTE standard be adequate to the purpose? The FCS does not know and the wider professional radio industry and user community will certainly need to see proper evidence of this before deployment in many environments.”

Hence the possible evolution of a variant standard, whether officially standardised or driven by industry and governments. The most common objection to this idea is that there would be limited economies of scale but advocates argue that, if the PMR sector worldwide were to unite on a set of specifications, this would create a sufficiently large ecosystem to drive costs down; and that anyway, PMR users will always need specialised terminals to support absolute criticality in voice services (for instance, to comply with the ATEX Directive). The latter points means it will not be possible to rely on mass market handsets and extra chipset costs must be accepted, if they are not excessive, in return for the benefits of the service. The FCS argues that the LTE variant being used in some mission-critical applications is far superior, for voice in particular, to the main standard, and that the question is “will there be an LTE standard that has sufficient uptake to support the necessary economies of scale? The FCS suspects that the variant may stand a very good chance of meeting this important criterion.”

Another potential outcome is that current PMR voice technologies continue to be used and enhanced for the long term, with LTE data networks kept separate for a longer period than is currently envisaged.

Dedicated or public networks?

In many countries, the decision still remains about whether the LTE ES network should run in its own spectrum or in public airwaves.

The decision to base the UK’s ESN on commercial LTE networks is an important precedent, but there are still ongoing discussions about European harmonisation. The TCCA’s stance is that critical communications must have guaranteed access to spectrum which is harmonised Europe-wide, if not further, but the emphasis is on ‘”guaranteed” rather than “dedicated”, except for the critical voice networks.

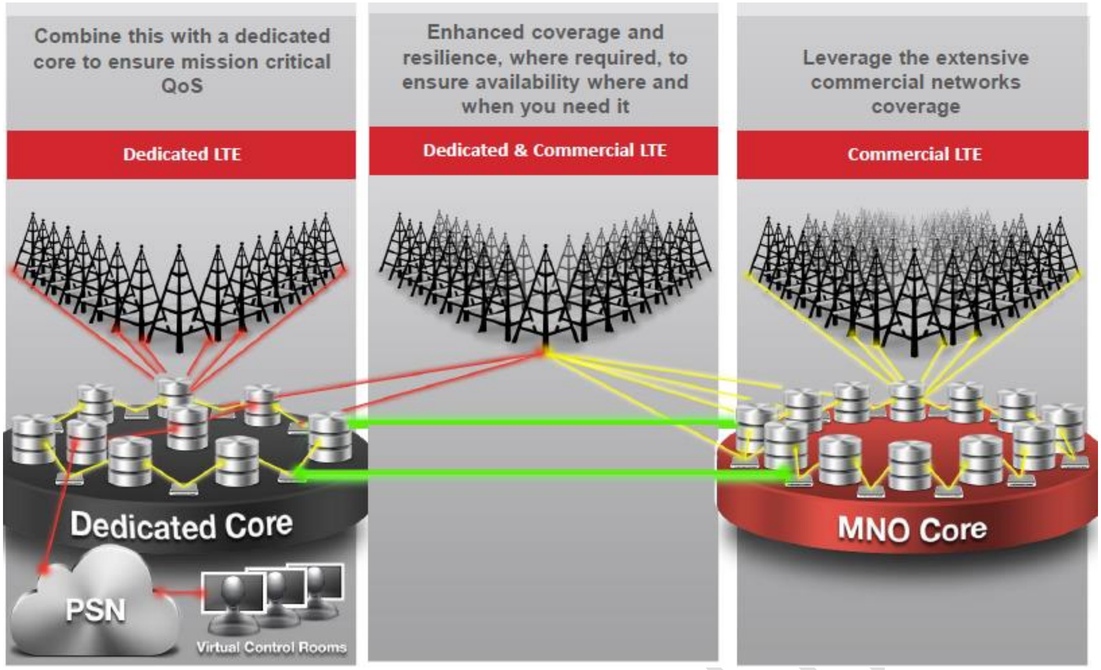


Figure 17: Architecture for a dedicated ES service delivered by a hybrid network topology (Source: Airwave)

Arguments for the fully blended commercial/ES network relate mainly to rapid time to market, economies of scale, cost efficiency. Arguments against relate mainly to the definitions of critical incidents – in other words, who would decide when a situation escalated to that level, how instantly would it happen, and more broadly, how would the requirements of 300,000 public safety workers weigh against those of 20 million mobile users for a commercial operator, most of whose revenues come from the latter.

The lower costs of using a blended commercial network are generally regarded as the key benefit, though it remains a complex debate because there will be the need to make the systems resilient for critical applications, which could be very costly (depending the degree to which the network is "hardened". Estimates from commentators in 2013 ranged from £700 million to £3.5 billion per public network. The lack of scale and of standards for these resilience specifications may push up costs. There will also be the issue of who will fund the exercise.

Current austerity programmes and the need to move quickly to mission critical broadband are scarcely compatible trends, but the European Commission is leaning towards the use of enhanced LTE as a fair compromise. In a study it commissioned from SCF Associates [38], the costs of five options were evaluated:

- Dedicated networks and dedicated specialised equipment
- Commercial MNO networks and commercial equipment
- Dedicated networks with commercial networking equipment
- Hybrid networks
- A common multi-purpose network, perhaps regional in scale

The study found commercial LTE operation was the cheapest in simple financial terms, but that other factors had to be considered to assess real value, including reliability and the degree of support for specialist requirements such as certain types of M2M data. So a hybrid network scenario had high upfront costs because of its architectural complexity, but offered high value because it allowed for flexible migration from existing systems and superior IT integration.

Table 5: Pros and cons of dedicated emergency services spectrum vs sharing with other services

Dedicated	Non-exclusive
Optimised in areas of particular value to critical communications e.g. ultra-low latency, direct mode	More accessible capacity, provided it is available where required
More stringent coverage obligations	Greater opportunities for spectral efficiency e.g. sharing
No interference or congestion risk	Flexible operation, though some flexibilities are missing, such as control of channels in specific situations
Stringent service management regime	Lower costs because of economies of scale, in certain circumstances (see above)
Ecosystem specifically focused on the devices and equipment required by BR	Shorter time to market
	Wider ecosystem supporting innovation and devices

The use of commercial mobile networks was concluded to be the best option when capex and opex are both considered, even though the dedicated network can have lower capex in the low frequency bands, such as 450 MHz, which require small numbers of base stations. Over a 10-year period, the opex costs of a shared commercial network are far lower, even when the commercial network is in a higher band such as 800 MHz. The report points out that, if the MNOs decide to support emergency services in the 700 MHz band when that is allocated, costs could be further reduced by as much as 20%.

The overall conclusion was that commercial mobile broadband networks could be used for mission critical purposes if various conditions were met:

- New regulations to ensure MNOs met commitments to resilience, and could not take advantage of their position to impose unreasonable price increases and other changes on the users
- Hardening and modification of networks to provide over 99% availability and extended coverage, including indoor penetration at relevant agreed locations
- No more should be spent on those modifications than would be spent on a dedicated LTE network
- The resulting network must be flexible enough to support the different services required by different mission critical ‘customers’ such as streaming video for police and low latency telemetry for utilities.

The ESMCP and ESN:

Notwithstanding the challenges in using LTE, as outlined above, it was selected for the UK’s Emergency Services Network (ESN). This will be used by the emergency services and 300 public safety-related agencies (sharers). It is being procured by the Emergency Services Mobile Communications Programme (ESMCP) to replace the current system.

The resulting network will serve 250,000 emergency services personnel, 44 police and crime commissioners, 50 fire and rescue authorities, 13 ambulance trusts, the National Crime Agency, the Police Air Service, the British Transport Police, the Ministry of Defence Police and the Civil Nuclear Constabulary. The 'sharers' will get lower priority, but will benefit from the high security of the platform. These could include customs or tax authorities, immigration agencies, local authorities, and postal and transport services – groups which need high security and critical services, but are not first responders. Many, such as ports and airports, are already heavy users of mission critical PMR services. ESN users will be divided between 12 regions, each of 11,000 to 50,000 users.

The framework will be divided into four lots - ESN Delivery Partner, ESN User Services, ESN Mobile Services and ESN Extension Services. The candidates to supply each aspect have now been selected and applications closed.

The UK considered the four options:

- stay with Airwave/TETRA
- use MNOs' LTE networks enhanced with hardening, uninterruptible power supplies, full coverage and diverse routing
- adopt a hybrid system combining a private LTE data network with an upgraded TETRA
- build a dedicated private LTE network in its own spectrum

The second option best met the business case and the migration from Airwave will start from 2016. The ESN will be based on build-out and management contracts and service level agreements using the two major LTE networks – one run by EE and the other by a joint venture between Telefónica O2 and Vodafone. These will share one another's networks, and possibly those of BT, to increase coverage and availability. However, since the Airwave network covers 98% of UK landmass and the MNOs cover 85%, the shortfall will have to be added as part of the Lot-4 contracts.

The ESN will be required to offer the same level of functionality and resilience as Airwave, along with additional data capabilities, all for significantly lower cost. It must support TETRA features such as group calling and push-to-talk for data as well as voice, and for vehicles as well as people on foot. The LTE priorities system will curtail the data rates of commercial customers to give ES priority for data and voice where needed. Emergency services will also gain pre-emptive capability, for priority access, with prioritised call queuing.

The emergency services will then invest in their own applications to run on this platform, which must support any commercial terminals they require.

Since new LTE standards for ES, and 700 MHz spectrum options will not be available until the ESN is well underway (2018 to early 2020s for the former; about 2018 for the latter), the project will rely on interim pre-standard specifications in areas such as resilience and group calling, as defined by the government. These additional interim standards have already been defined by the Home Office and will also cover the transition from TETRA. The initial roll-out will not use separate hardened network elements but will upgrade existing installed LTE base stations, with battery or diesel power back-up at cell sites. For the first years, it is envisaged that there will be a hybrid network, with TETRA continuing to provide ubiquitous voice and some critical data, and additional data requirements met via the new overlay. During migration and switchover, the Airwave and ESN networks will be active simultaneously and so will require real-time data interfaces, which will be deployed at control room level using an IP interface module.

ESMCP contracts will be re-tendered in 2021, and by then, the fully mission critical LTE-Advanced standards enhancements should be fully in place.

Proof of concept tests have been run in Mexico by Qualcomm and Huawei, using equipment based on LTE Release 12 standards. These showed the network supporting simultaneous call set-ups for 100 ES officers in the same cell while carrying heavier than normal commercial traffic.

Such results have convinced the Home Office that an additional network in dedicated spectrum is unnecessary and the existing capacity of EE and Vodafone/O2 will be sufficient for the foreseeable future. Both groups are building LTE out in 800 MHz (most relevant to ES) and 2.6 GHz, and in EE's case 1.8 GHz, and plan to aggregate these bands in future in various combinations, potentially also adding future allocations in 700 MHz, 2.3 GHz and others.

Ofcom says it is working closely with the ESMCP to ensure that UK spectrum rules and allocations support the programme's key objectives – to increase broadband capacity; converge the roadmap where possible with that of mainstream public mobile services; allow for flexible service provision, unconstrained by particular platforms; and reduce cost.

Spectrum efficiency options for PMR:

Across the European Union, sufficient harmonised spectrum has not yet been identified for mobile broadband for the ES segment, which makes the UK's ESN a closely watched project, and has also intensified interest in ways to use existing spectrum more efficiently

The EU has ordered studies to identify sub-1 GHz frequencies for public safety mobile broadband, and has called for a European standard to promote interoperability, economies of scale and roaming. The identification of this spectrum is part of the European five-year Radio Spectrum Policy Programme.

The Commission's statement of intent is: "The Commission shall, in cooperation with the Member States, seek to ensure that sufficient spectrum is made available under harmonised conditions to support the development of safety services and the free circulation of related devices as well as the development of innovative interoperable solutions for public safety and protection, civil protection and disaster relief."

CEPT has set up a project within its Frequency Management working group, called Project Team 49, to specify high-speed data applications and their harmonised spectrum requirements. This group estimates that a minimum of 2x10 MHz of spectrum is required for this purpose for PPDR (public protection and disaster relief) data functions alone, excluding some related activities like ground-to-air communications.

Options which are likely to play a role in the Business Radio area, across ES and PMR, include:

- Increase spectrum sharing, with government agencies or commercial users. The Ministry of Defence is offering some of its spectrum for shared use as part of

Ofcom's target to release an additional 500 MHz of capacity for wireless broadband purposes

- Reuse under-utilised portions of bands, and extend work to exploit additional bands
- Re-plan the UHF band to optimise the channel plan and make more available for PMR
- Change the assignment methods for PMR, to support more users per channel for instance
- Increase the use of AIP (Administrative Incentive Pricing), a fee charged to users of lightly licensed spectrum with the aim of encouraging efficient usage. An alternative which some believe to be more effective is to introduce more efficient field inspections
- Harness more precise engineering to match the coverage needed
- Support technology advances with greater spectral efficiency. This option is seen positively by the FCS, though it is in its very early stages – for instance, the DFS (dynamic frequency selection) systems used in 5 GHz band have technical problems which would make them inadequate for BR purposes

The debate about the balance between dedicated and shared spectrum is not confined to ES, but is important to all PMR applications which are mission critical. While some agencies still argue strongly that only dedicated spectrum can support the critical, ubiquitous and optimised networks their functions require, there is rising acceptance that guaranteed access within shared spectrum may be the only practical way to procure sufficient capacity for critical PMR.

5.7 Long-term technology and spectrum needs and options

As outlined above, there will be continuing developments in traditional PMR bands and technologies, because of the wait for fully capable LTE. However, spectrum needs to be identified for mission critical LTE, and this issue will dominate policy for Business Radio for the medium term.

At the World Radio Conference in 2012, the decision was taken to allocate the 694-790 MHz band for mobile use in Region 1 (EMEA), on a co-primary basis. This is seen as a significant opportunity for critical communications because it opens up more sub-1 GHz spectrum for LTE, and could make it easier for some governments, or individual operators, to dedicate some spectrum in this area to public safety, especially as the MNOs will already have the 800 MHz frequencies for commercial LTE.

This, of course, will continue the debate about dedicated versus shared spectrum, and the extent of guaranteed access for critical services. Ofcom wants the WRC 2015 to leave flexibility for each country to decide whether to allocate a sub-band within 700 MHz for ES. It will support the inclusion of PPDR services in the band in "as flexible a manner as possible without the need for an internationally mandated and exclusive allocation for PPDR", and will support LTE as a delivery platform for PPDR in any IMT band, not just 700 MHz.

Since many parties believe LTE will not be suitable for the critical aspects of Business Radio until 2018 and beyond, this timing could converge with access to the 700 MHz band and a more compelling case for a dedicated LTE-based sub-band.

The European public safety community, represented in the UK by APCO, gave a guarded welcome to recent recommendations from the EU's High Level Group on the future use of the 470-790 MHz UHF band – even though the body pointed out that the EU report made no specific reference to PPDR or PMR. However, the EU Council's Law Enforcement Working Party (LEWP), working jointly with CEPT-ECC, had previously concluded, in ECC Report 199 [39], is that a minimum of 2x10 MHz of spectrum in the UHF band is required for critical mobile broadband data services.

British APCO President Sue Lampard stated: "The PPDR community is arguably already at the point where data (as well as voice) is deemed 'mission critical'. This requirement will only grow over the next few years, and additional spectrum will be needed to support that growth. The 700MHz bandwidth is ideal for PPDR needs in terms of coverage over large areas and in-buildings. Release of 2 X 10 MHz will provide additional capacity required. Additionally, the opportunity for harmonisation to allow cross-border interoperability should not be missed."

The case for a dedicated 700 MHz sub-band is put by, among others, the LSE study, which states: "The consolidation of estimates on the utilisation of 700 MHz for mobile broadband on a more dedicated basis by emergency services indicates that they outweigh the opportunity cost of the 'one-off' sale of spectrum to commercial operators. The degree to which these potential benefits are realised depends on a range of factors including regulatory and licence conditions; the network mode of delivery; the speed of mobile broadband adoption; the nature of the services that are provided, and others." [40]

The next issue after LTE-based critical data is likely to be the future of voice. Voice is considered the most fundamental aspect of critical communications and, for emergency services, needs to be resilient, ubiquitous and to support the key features available in current platforms such as TETRA, Tetrapol and P25 (group calls, subscriber tracking, encryption etc.). With commercial Voice over LTE only in the earliest stages of implementation, all these specialised functions are unlikely to be supported in VoLTE until the next decade, although push-to-talk and other additions are being developed in 3GPP for Release 13, as is interworking with PMR/LMR voice.

Table 6: Work items for critical communications in 3GPP Release 13 Source: [41] 'Developing specifications for LTE', Mona Mustapha, chair, 3GPP TSG-SA WG1

Work Item	Work Item Document Reference
Study on Isolated E-UTRAN Operation for Public Safety (FS_IOPS)	SP-130596
Isolated E-UTRAN Operation for Public Safety (IOPS)	SP-140167
Mission Critical Push-to-Talk over LTE (MCPTT)	SP-130728

As well as the standards themselves, the migration and interworking issues for voice – especially between TETRA and LTE VoIP – are far more complex than for data, and far more significant to the robustness of the service.

Another longer term issue is future policy in the lower frequencies of the 470-790 MHz UHF band and also the 450 MHz band. Ofcom's spectrum management strategy document [42] concludes that the 470-694 MHz band will only be mainstream for mobile broadband use in the very long-term, and that there is very little interest in using the 450-470 MHz spectrum at all (Ofcom removed the work done on this topic from its 2014 report).

However, there are PMR and public safety players which believe these low frequencies are being unnecessarily sidelined in EU and UK policy, and they may come back into prominence in the long term. This is an especially important issue for the UK. There is a significant number of critical and non-substitutable services located in the 450-470 MHz band, so any international effort to harmonise usage around other applications – even in the long term – would present tough challenges. There are discussions about rationalising the fragmented 450 MHz band, which currently hosts an array of legacy analogue services and some CDMA, and even some spectrum in 380-450 MHz. In particular, there is interest in using such frequencies for new smart M2M/IoT applications, some of which will be highly relevant to PMR.

The SCR report for the European Commission concluded that the main TETRA band (380-420 MHz) was unlikely to be available EU-wide, especially not for LTE, and that 450 MHz was more promising, since more than half the member states were prepared to consider it.

Conclusion:

A statement from National Public Safety Telecommunications Council (USA) helps to sum up the difficult balance between maintaining and enhancing current critical communications and PMR networks, and migrating many data, and later voice, applications to a new mobile broadband LTE framework.

The US body, says: “There is much debate relative to whether broadband will eventually have the capabilities to replace current mission-critical public safety LMR systems, however the facts are clear that if this capability becomes reality it is not likely to happen in less than 10 years. Local, tribal, state, and federal public officials are urged to not abandon or stop funding their public safety voice LMR systems until such time as it can be demonstrated that broadband can safely and adequately provide public safety with the mission critical requirements currently provided by LMR.” [43]

A.6. Space

6.1 Scope of the sector

The UK Space sector is a genuine success story. It is responsible for world-class science in its laboratories and on international missions. The space sector is extremely varied, covering practically all of the applications and benefits provided by terrestrial services and more. Industries, government private institutions and the public all benefit from services available from satellites, either directly (e.g. the improved accuracy of the weather forecast), or through the provision of a commercial product (e.g. satellite television).

The inspirational "blue marble" image of the earth from space produced by NASA using the Terra satellite not only captures the public imagination but also demonstrates a different perspective: a global rather than national view.

All space services, their growth and their contribution to the UK economy, hinge on global availability and access to spectrum. A challenge is to demonstrate the benefits of spectrum use by space applications within a regulatory scheme dominated by telecommunications. Telecommunications are important space services, but the industries that monetise space touch almost every area of the economy. In addition to communications, the space sector enables services in finance, agriculture, transport, defence, planning, public protection, disaster relief and a host of other services. Related business interests range from the provision of ubiquitous satellite communications services, exploitation of earth observation data, weather forecasting, services based on navigation and timing and the advanced manufacturing of space hardware and ground segment.

Broadly, space activities can be classified into: Remote sensing, Science and exploration, Navigation and Communications services. The UK traditionally has significant involvement in all of these sectors, and maintains a prominent position in research, including pure science research, manufacturing and service provision. The majority of activities related to space are transnational or international by nature; therefore UK interests, either in science or communications satellite services, generally extend beyond domestic markets or institutions.

6.2 Contributions to social and economic value

Satellites are helping us to understand and address climate change, provide essential communications and information support for our armed forces, and deliver urgent aid when natural disasters occur.

Public perception of space services might be most strongly influenced by the services they encounter most frequently - satellite television, satellite navigation and satellite images in the weather forecast. However, many are also inspired by human spaceflight and probes sent to other planets. It is not generally known just how dependent modern society is based on less visible services delivered from space.

The national and international dimension of the space sector generates sizeable economic activity in the UK economy and in turn provides significant employment opportunities for very highly skilled personnel, most with a minimum of graduate-level qualifications, in research, development and service provision activities.

The Space sector contributes £11.3 billion a year to the UK economy and has been growing at about 7% each year throughout the recession. The UK Space Innovation and Growth Strategy, initiated in 2010 and refreshed in 2014 [44] [45] is targeting a fourfold growth in the sector by 2030, or 8.5% CAGR over those two decades.

About 80% of satellite services revenues come from TV while in 2012, satellite broadband saw the highest leap, at 25% year-on-year, and a 10% increase in subscribers worldwide, followed by remote sensing revenues, up 20%.

According to a 2012 report for the UK government departments of Business Innovation and Skills (BIS) and Culture Media and Sport (CMS), the economic value of spectrum to the UK economy was £52 billion in 2011, excluding contributions from the public sector and Earth Observation, with satellite services accounting for 7% of this figure and broadcasting (including satellite) for 20% [3].

The sector also supports thousands of jobs as a direct result of its activities, with employee productivity more than four times the national average. It consequently contributes some £145,000 per worker to UK GDP. Significantly, both manufacturing and operations are capital intensive and require highly skilled people resulting in graduates filling nearly two-thirds of all jobs.

UK industry and academia, assisted by the UK Space Agency, lead the Science and Earth Observation sectors, with much of the work being collaborative and led by the European Space Agency. Europe and European institutions are leading the development of improved satellite navigation systems and satellite meteorology. Satellite communication is now driven primarily by commercial satellite operators. In manufacturing, UK companies are big players manufacturing advanced satellites, payloads, components and systems for the global space industry. The UK manufactures many of the satellites surrounding the Earth, and has many experts in software design and systems integration.

The breakdown by sector is as follows:

Commercial Satellite Services:
There are two main actors in the commercial segment of the industry: Direct-to-Home and Communications Services.

Direct to Home (DTH) services: DTH providers generally utilise the satellite capacity available within UK and Europe to provide digital TV to users in the UK and elsewhere. These services bring further choice and innovative services to the consumers, and in turn set a broad base for further economic activity in related industries ('indirect impact') such as research in technology, programme making/content provision and terminal installation. All these activities contribute to the creation of job opportunities with substantial employment in the UK.

In addition to DTH, broadcasters rely heavily on satellite communications to make and distribute programmes internationally. The BBC World Service Group includes the multimedia international operations of BBC World Service. International production, news gathering and global distribution of programmes utilise satellite services in L, Ku, Ka and C-band[8], sometimes exclusively and sometimes as links in a more complex chain.

UK satellite service providers are at the forefront of deploying advanced TV formats such as HD and UHD, in some instances years ahead of the roll out of such developments by the terrestrial services. In addition to generating more economic activity, the availability of such services brings widespread educational and cultural benefits to society.

Communications services: UK satellite operators offer a diverse range of services in the UK and elsewhere in the world. These operators have deployed satellite networks (satellite networks include satellites in space and earth terminals) with either a single satellite or multiple satellites, and the collective investments made by them run into many billion pounds. The services offered range from broadband services and backhaul of cellular and internet services at one end, to provision of specialised services such as global aeronautical and maritime safety at the other. While these services are generally available to the UK consumers and customers, the bulk of the revenue for the satellite operators is generated from services provided to the customers elsewhere in the world.

The revenues from satellite services are healthy, and they make a positive contribution to the economy. In addition the satellite industry offers high end jobs in the UK employing those with minimum of graduate qualifications.

Science Services:
UK companies play a leading role in facilitating the applications within the Science sector that ultimately provide universal benefits to the society as well as contribute positively to the national economy. Many of these science services are offered either on a regional basis or on a worldwide basis with the involvement of international organisations such as the European Space Agency and Eumetsat.

UK companies participate in these programmes in many ways; they are either stakeholders in a European or a global programme, or commercialise the services available from such satellite systems. The revenues generated from these international programmes are large and UK companies, generally speaking, have a sizable stake in them of about 6%. The UK Space Agency's ambition is to grow this proportion to 10% by 2030.

Manufacturing

The UK has maintained its profile in satellite manufacturing despite some consolidation in this sector. The manufacturing base for small satellite technology is performing well in the UK. The rest of the UK industry has moved away from manufacturing large satellites to specialising in the manufacture of systems/sub-systems for both communications and other (science missions) satellites.

Summary of Downstream applications and social and economic benefits
The following table summarises the social and economic benefits arising from a selection of applications in the space sector.

[8] The frequency bands used in space services are defined in Table 9.

Table 7: Applications in the space sector contributing to social and economic benefits

Application	Economic and Social Benefit
Broadband services	Global Broadband coverage. Services to industry and individuals worldwide, services to maritime, aviation and defence. Broadband provision throughout the UK, complementing and competing with terrestrial provision benefitting rural businesses, educational opportunities, social justice
Broadcast services	UK Direct to home satellite services accounted for 70% of the Satellite Sector turnover of £8.2 billion (2010/11 figures) BBC World reaches an estimated global audience of 256 million. Sales for 2011/12 for BBC Worldwide totalled £1085 million, of which £216 million was invested back into the BBC
Corporate networks	Facilitate globalization and expansion of commerce by providing connectivity for enterprises and institutions (e.g. banks) that is essential for their daily operations
Emergency and distress communications	Mainstay of communications in major disasters
Emergency / distress alert communications to ships and aircrafts	Unique global services (e.g. GMDSS, managed by IMO and AMS(R)S, managed by ICAO)
Earth observation and Meteorology	This includes services ranging from Earth science to surveillance; facilitates management of disease, monitoring of environmental change, land management, agriculture, deforestation, ice caps, disaster recovery, weather forecasting and informs global security systems (surveillance) The UK share of the global market is predicted to grow from 6% in 2014 to 10% in 2030. Some examples of the predicted global revenue figures are: - Climate services market was worth £12.3 billion in 2010/11 and expects to be £16.2 billion in 2015 and £51.6 billion by 2030 [9, 10] - Revenue from geoservices is estimated between £90 billion and £162 billion worldwide per annum. The social benefit of EO is in its contribution to the understanding and stewardship of our natural resources and environment
Science	Radio astronomy - provides social benefit

Application	Economic and Social Benefit
	Space science and exploration – provides social benefit
Navigation, including Air Traffic Management (ATM), Unmanned Aircraft, Galileo PRS,	Navigation offers direct social benefits to the whole of the society. In addition the UK industry will be a major stakeholder of the Galileo GNSS service. The PRS receiver market is predicted to have a global value of between £1 billion and £2 billion by 2030. This is mainly positioning for blue light services and military. UK Share is expected to rise from £60 million in 2014 rising to £200 million by 2030.
Defence	See Defence chapter of this report.
Manufacturing	About 40% of the world's commercial telecoms satellites include a significant element of UK manufacture. The manufacturing sector also provides jobs for highly skilled graduate engineers.

6.3 Current and recent past status

There is an increasing involvement of the UK industry in the wider space sector. While government investment in space has often been squeezed since the 2008 downturn, there has been notable growth in commercial applications.

The main areas where there has been sustained growth in revenue in recent years are:

- Earth observation
- GPS-based navigation, location and timing services, for consumers and vertical markets
- Rising demand for broadband internet access in rural and remote areas throughout the world
- Mobile backhaul in remote areas, accelerated by the build-out of Wi-Fi and small cells in rural regions

According to the Space Foundation there were over 1,000 satellites operating at the end of 2012 - 38% are for commercial communications and a further 16% for government communications [46]. The global market had a value of $305 billion (£207 billion) in 2012 and an annual growth rate around 7% (see Figure 18). The satellite broadcasting and communication services market in 2012 was worth $110 billion (£75 billion).

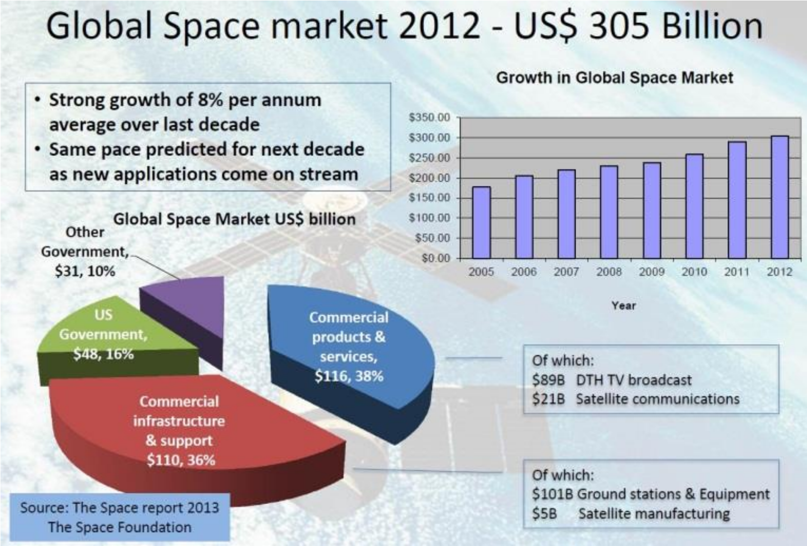


Figure 18: Global space market 2005-2012

Spectrum available for the Space sector is used for diverse commercial and scientific applications:

- Direct to Home (DTH),television and radio broadcasts, and national and international distribution of broadcasting content to terrestrial relays or cable networks
- Broadband services direct to consumers, primarily the Internet
- Video, voice and data applications direct to consumers, also mobile consumers
- Backhaul for Internet and cellular services
- Satellite news gathering from transportable and mobile terminals.
- Aeronautical services, including safety communications and In-flight services
- Digital cinema
- Corporate services
- Asset tracking
- Defence application
- Satellite navigation services to fixed, mobile devices on land, sea and air
- Police and emergency response services
- Communication services for ship operations and crew communications
- Earth observation, imagery and meteorological services
- Near Earth and deep space missions
- Radioastronomy

Satellite operators currently invest in new technology and markets; for example deploying additional satellites and utilising spectrum more efficiently, accessing spectrum made available for satellite services in the recent past, collaborating with ESA in deploying experimental payloads to assess the viability of satellite communications at higher frequencies. In other words satellite operators seek additional markets to further their expansion and growth, and invest in technologies for future deployments.

As in other areas of communications, mobile satellite voice revenues are flat or slightly declining, while data revenues rose by 5% in 2012 and that trend is expected to intensify as operators upgrade their fleets and bring on new services with faster speeds.

On the negative side, some factors have prevented growth being even faster. The biggest has been the slowdown in government and public sector spending in many countries, sparked by economic downturn. Innovation is allowing satellite communications solutions to become viable choices, in cost and performance terms, for a wider range of applications beyond the traditional rural/remote/ad hoc use cases.

6.4 Sector trends

Recent analyses have shown that the UK Space sector has continued to grow despite the downturn in the economy in the past few years [44]. Space sector revenues were estimated to be £9 billion in 2010/11, and the expectation is to grow from a 6.5% market share in 2010 to 10% by 2030 [45]. Market analysts predict that the global industry will grow at a CAGR of just over 8% between 2014 and 2018 [47].

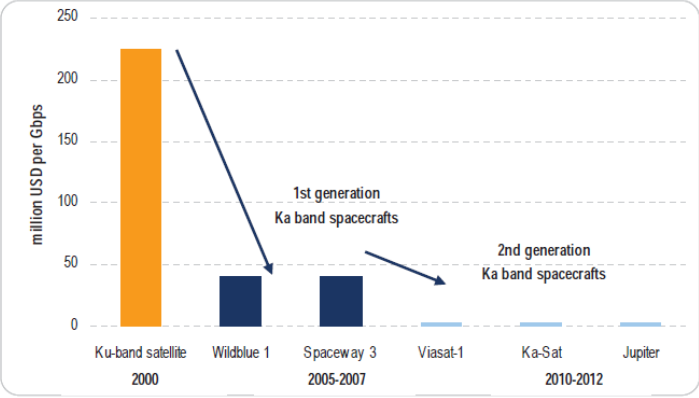
Whether it can continue that pattern in the years after 2018 depends on a range of factors, which may include the following:

- Maintaining the sector's current access to spectrum and meeting the spectrum demand for its growth
- Continuing innovations and expansion of applications and services, especially in non-traditional and consumer markets
- Remaining competitive in key markets against alternative solutions such as fibre-based IPTV and broadband
- Continuing reduction of costs of operation in order to drive down end user pricing
- Recovery or stability of government commitments to satellite in key markets
- Expansion of services ecosystem
- Partnerships with mobile operators to complement rather than compete
- Success of innovation in remote sensing based services, for example added value arising from explosion in availability of free datasets from Copernicus programme
- Continued innovation and developments to provide novel solutions to emerging requirements, threats and opportunities

6.4.1 Commercial Satellite Services

UK satellite operators provide a variety of services to address many different market segments, including mobile satellite services to land, maritime and aeronautical users, including safety services; and fixed satellite services that include applications such as broadband to both fixed and mobile users. These services are provided from satellites operating in the C band, L band, S band, Ku band and Ka band spectrum.

The Ka band offers much wider bandwidths compared to other satellite spectrum allocations at lower frequencies. In fact the Ka band satellites offer a ten-fold or more throughput when compared with Ku band satellites. These capacity increases lead to reduction in costs as depicted in Figure 19. These factors, coupled with the advancements of Ka band technology, have more or less made the Ka band the mainstay for satellite broadband services. The take up of Ka band is accelerating, and the UK operators are deploying regional and global systems to meet the demand for broadband, DTH and other applications throughout the world. The collective investments made so far by the UK operators in Ka band satellite systems alone run into US $5 billion (£3.4 billion).



Source: IDATE

Figure 19: Reduction in cost per Gbps for FSS broadband between 2000 and 2012 (iDate calculations [48]).

On the DTH side, the development of Advanced TV services is already underway. These will support far larger numbers of channels, Ultra-HD quality, 4K screens, interactivity, new advertising formats, multiscreen viewing and other changes. Despite the rise of broadband TV/video delivery, broadcast (using satellite or other methods) retains important advantages. Broadband systems still have a long way to go to deliver high quality video to a large share of the user base and at peak times. The continuing growth of DTH rests heavily on a model in which broadcast is optimal for the most heavily demanded content and for top quality linear video, while broadband is reserved for 'long tail' and user-generated content. In practice, this is being adopted by many service providers already.

An important trend, which in some regions will help expand the range of services satellite can deliver, while reducing costs to consumers, will be hybrid services, in which terrestrial and satellite spectrum and networks are combined. A similar, though less pronounced, trend will affect mobile communications services, in which mobile carriers may look to tap into satellite frequencies to expand their own capacity as well as extending their offerings into rural areas (see later section), or satellite operators may deploy terrestrial technologies in their own or partners' bands.

The appetite for fixed and mobile communications, data and TV will continue to increase, and increasingly this will mean pooling different types of network and spectrum capacity including satellite. However, the threat is that mobile or broadband providers will argue that some satellite frequencies should simply be turned over to their exclusive use.

There are other trends which threaten to limit the growth which those new satellites could drive, in particular the way that terrestrial services are encroaching on some of satellite's key differentiators.

Among these pressures are:

- Alternative solutions in conventional satellite markets like ultra-rural, including better economics for remote mobile coverage, e.g. in low frequency bands, and longer term, the use of satellites and drones (e.g. Google and Facebook) to expand coverage for broadband.

- Improving costs and service platforms for non-satellite TV solutions – fibre-based IPTV in urban areas, fixed 4G services in rural areas
- Changes in consumer behaviour, consuming TV over-the-top rather than via broadcast channels
- In some markets, satellite TV and communications providers are disadvantaged against telco competitors which can offer quad play bundles (fibre-based broadband and TV plus voice and mobile). It will be important for satellite services providers to be able to invest in, or partner to provide, broadband and mobile services, at affordable costs.

6.4.2 Science

Science sector encompass Earth observation, meteorological, remote-sensing, navigation and other satellites

Earth Observation (EO): EO Observation has advanced greatly over the last 30 years, meeting government objectives and generating wealth for the nation. During that time, EO science has revolutionised virtually all areas of earth, geophysical and environmental science - and the UK has become world class in several areas.

Today, EO derived data is widely available at greater levels of detail than ever before, and increasingly the public will expect EO information to be made widely available. There is an increasing market for EO data and it is expected that the sector will start to achieve commercial viability as the costs of the collection systems decrease and the number of applications for the data increase.

Globally, the public investment in EO equated to £4.2 billion in 2008, with Copernicus alone representing more than £1.5 billion investment in Europe. There are expected to be 360 EO-related launches in the next decade, up from 164 during the previous one. The estimated revenues of the EO services industry in 2013 are £1.4 billion in 2013 and the anticipated cumulative benefits of the EU Copernicus programme are up to £166 billion by 2030, with up to 83,000 high skilled jobs provided between 2015 -30 in Europe.

A specific theme in which the UK could establish a leading capability and that is expected to emerge in the 2010-2020 decade is the use of constellations – groupings of satellites operating together to provide significantly enhanced area coverage rates and timeliness of data delivery. These systems will be expected to open up significant markets which will be able to help both the development of the commercial markets and governments to deliver on the grand challenges imposed on society by changes such as climate, environmental stress and national & international security.

Thus, the vision for EO over the next ten years is to place the UK in a position to drive and benefit from the anticipated market growth. This will require the engagement of the investment community and non-space players and partners to unlock new markets, giving fresh impetus to market development through lower cost missions, more and better sensors and more capacity to handle and process ever increasing data volumes.

The availability of Earth observation data is expected to increase markedly through the European Copernicus programme, which aims to provide high quality EO data free of charge. The first satellite, Sentinel-1 was launched in April 2014 and carries a C-band Synthetic Aperture Radar. The Sentinel 3 satellite, due for launch in 2015 carries a dual frequency Ku/C-Band active altimeter, together with a passive dual frequency and highly sensitive 23.8/36.5 GHz radiometer (radiometric accuracy of 3K absolute, 0.6 K relative).

ITU Resolution 673 [49] recognizes that the use of spectrum by Earth observation applications has considerable societal and economic value and urges Administrations to protect Earth observation systems radio frequency requirements and before taking decisions that would negatively impact the operations of these applications.

All EO satellites (active and passive, radar and optical) require ever increasing bandwidths for data downlink. There is a drive for more frequent observations and persistent surveillance for security applications. This combined with the trend for EO satellites to become more affordable is leading to satellite constellations becoming more common. This results in a significantly higher bandwidth requirement, including permanent links at Ka band to satellites in Geostationary orbit such as the European Data Relay Satellite (EDRS)

NovaSAR

The UK has world-class capability in space based radar, and by combining this expertise with the capability in producing low-cost small satellites in the design of NovaSAR will provide a significantly cost differentiated space based synthetic aperture radar system, creating significant export opportunities.

NovaSAR-S uses the S-Band allocation of 3.1 to 3.3 GHz to deliver all weather medium resolution Earth observation data night and day at a price similar to traditional optical missions. It is priced significantly lower than any other SAR platform currently on the market, by leveraging highly efficient S-band solid state technology. The platform is sized for a range of low-cost launch options.

The UK government will provide the necessary seed funding alongside industry to develop and build the first NovaSAR demonstration satellite, enabling the UK to showcase the highly attractive technology to the global marketplace and initiate a constellation of NovaSAR satellites similar to the highly successful Disaster Monitoring Constellation.

MetSats

Met services require continuing protection of the current access to spectrum for the full range of observing tools (terrestrial as well as satellite borne) to allow both monitoring of the atmosphere in order to provide input to forecast models, as well as verifying forecast accuracy. This is equally valid for all ranges of forecasts from the weather broadcasts the public is familiar with on TV and radio, through to climate change predictions which feed in to government and international policy decisions.

Meteorology is a global science and as such much of the data is not limited to the UK, and therefore it is necessary to engage and keep abreast of international decisions on spectrum changes. Hence access to some bands is required even where there is no operational use of those bands within the UK.

6.4.3 Satellite Navigation

The EU is expected to spend approximately €7 billion (£5 billion) by 2020 on satellite navigation, and this investment is expected to reap considerable rewards. Independent studies show that Galileo will deliver around €90 billion (£65 billion) to the EU economy over the first 20 years of operation.

Today, positioning and timing signals provided by satellite navigation systems are used in many critical areas of the economy, including power grid synchronization, electronic trading and mobile phone networks, effective road, sea and air traffic management, in-car navigation, search and rescue service to mention but a few examples.

Like the Internet, a global navigation satellite system is a service enabler rather than a standalone service. It acts as a catalyst for economic activities, leading to the creation of added value and jobs in a wide range of sectors such as space, receivers and applications industries. It will also generate socioeconomic benefits for society as a whole, through for example more effective transport systems, more effective rescue operations, etc.

Galileo and EGNOS

EGNOS, the European Satellite Based Augmentation System, has been fully operational since 2011. It works to increase the accuracy of the USA's GPS positioning and provides information on its reliability, making it suitable for safety-critical applications. For example huge advancements in aviation were achieved by EGNOS – already available at more than 80 EU airports – enabling more precise landings, fewer delays and diversions and more efficient routes.

6.5 Spectrum usage

The ITU Radio Regulations, in their table of frequency allocations, list available frequency bands for the Space sector. International spectrum allocations for space services have been fairly stable since the foundations were laid at a special World Radio Conference in 1963.

Although most of the bands are allocated to Space services are shared with other radio services, necessary arrangements are made either on a national basis, regional basis (at CEPT for instance) or on international basis at the ITU, to establish suitable conditions for sharing with other services. In other cases arrangement could be either on a national or regional basis to access some spectrum on an exclusive basis to meet specific deployment requirements.

In contrast to some other spectrum users, the space sector requires most of the spectrum allocations to be on a worldwide basis. This allows satellites to be deployed to serve the global markets, and also to benefit from scale of production. The industry continually seeks the cooperation of spectrum managers to maintain international harmonisation in frequency allocation, and stop the position being eroded by any national plans that undermine international harmonisation.

The spectrum utilised by these sectors comes from many different categories of allocations made in the ITU Radio Regulations (RR). The most prominent of these are:

Table 8: Satellite services specified within the ITU-R Radio Regulations

Radio Service	Abbreviation	Details
Fixed Satellite Service	FSS	Allocations are for both Earth to space and space to Earth links, allocations from 2.4 GHz upwards
Mobile Satellite Service	MSS	Allocations are for both Earth to space and space to Earth links. There are also associated Maritime and Aeronautical Satellite allocations made in the RR.
Broadcasting Satellite Service	BSS	Allocations are for space to Earth links.
Radionavigation Satellite Service	RNSS	Allocations are for space to Earth links
Inter-satellite Service	ISS	Communication links between satellites
Earth Exploration-Satellite Service	EESS	Available for both passive and active observation of Earth from satellites, including meteorological satellite services
Space Research Service	SRS	Allocations are for both Earth to space and space to Earth links.
Space Operations Service	SOS	Allocations are for both Earth to space and space to Earth links.
Air Mobile Satellite service	AMSS	Allocations are for bi-directional communication between aircraft and satellites Also includes AMS(R)S – Air mobile satellite routing service – a safety of life service communicating via the satellites.

The spectrum for the Radio Services identified in the table above is only accessible through procedure stipulated in the RR, which generally involves the coordination of spectrum amongst other existing or planned users. The procedures set out in the RR are generally managed by the national administration of the party seeking access to spectrum.

Table 9 below summarises the frequency bands available for space services.

Table 9: Spectrum allocations for satellite services, global

Band designation	Approximate Frequency range (GHz)	Allocated satellite service	Other co-primary allocations in the RR
P	0.23-0.47	MSS, RNSS	Terrestrial mobile
L	1-2	BSS, MSS, RNSS	Terrestrial mobile, fixed
S	2-3	MSS, SOS, SRS	Mobile, fixed, EESS
C	3-7	FSS, MSS, EESS	Mobile, fixed
X	7-8	FSS (military), EESS, SOS, SRS	Fixed, radar
Ku	10-15	FSS, BSS, EESS	Mobile, fixed, radar
Ka	17.3-31.0	FSS, MSS, BSS	Fixed, radar
Q/V	31-52	FSS, BSS, MSS	Fixed, mobile, radiolocation
W	75-110	FSS, BSS	Fixed, potentially mobile

There have been some important changes in the regulatory framework for satellites, and they include:

- New allocations for RNSS and MSS at lower frequencies, to support new navigation services
- Increased flexibility in FSS rules, including the addition of reverse direction allocations and inclusion of mobility in the FSS (e.g. "Earth stations on mobile platforms")
- Permission to use certain BSS allocations for FSS
- Provision for non-geostationary FSS services
- New allocations in high bands for applications such as inter-satellite services
- Extension of applications using the higher frequency bands above 100GHz, especially for space research and Earth exploration

The UK allocations differ in some respects from the international table. There is no FSS allocation at 3.4 GHz to 3.6 GHz, or at 14.5 GHz to 14.8 GHz, in the UK, for instance.

Globally, space services have primary allocations totalling 30% of all sub-3 GHz spectrum, 65% of spectrum between 1 GHz and 10 GHz, and 82% of spectrum between 1 GHz and 100 GHz. However, only 3% is available on an exclusive basis for space/satellite services, and between 3 GHz and 10 GHz, no spectrum is allocated on an exclusive basis. Most commonly, there is sharing with fixed and/or mobile terrestrial services.

However, sharing is not feasible when earth stations of satellite systems are deployed ubiquitously, e.g. mobile satellite terminals or satellite television (TVRO) terminals

All spectrum users generally agree on technical sharing conditions to mitigate the possible interference between services. These conditions are usually agreed on an international basis at the ITU, or on a regional basis, i.e. at CEPT, by adopting regulatory instruments such as CEPT Decisions. A case in point is the CEPT ECC Decision (05)01 [50] which identified the band segmentation between FSS and FS for the Ka band, where both FSS and FS are co-primary.

The C and Ku bands are the most extensively utilised for commercial FSS services, while the Ka band is seeing rapid uptake and hefty new investments because the technological advances have helped the industry to unleash the full potential of available large bandwidths for high capacity systems. Increase in usage of these key bands is expected to continue at least until 2025, and to be particularly rapid in the Ka spectrum. An important trend will be the convergence of BSS, FSS and MSS services in all these bands. The C-band is likely to come under increasing pressure from terrestrial mobile, which means the satellite players are particularly keen to protect the C, Ku and Ka bands, now and for the future.

Protecting existing allocations in important bands is the top priority for most satellite stakeholders, given that most of them acknowledge that it is very challenging to obtain major new allocations, because of the amount of spectrum which already has a space service element, and the demands of other services. One compromise which is gaining support in the community is to review current arrangements where FSS shares with terrestrial services, in order to ensure FSS has priority. This needs to be a long-term guarantee, argue supporters, because of the huge upfront investments needed and the long lifespans of satellite networks.

Much of the emphasis is on FSS because of the importance of universal broadband. Much of the current emphasis has been on new allocations to FSS because of the importance of universal broadband. However spectrum requirements are continuously evolving; for instance in BSS, while some allocations are less used (in L-band), new requirements emerge in other parts of the spectrum e.g. in higher frequencies.

MSS, despite its high growth, is a tiny part of the overall mobile landscape and any search for additional allocations is complicated by the fact it needs to be global and virtually exclusive. The priorities for MSS, then, will be to use existing spectrum more efficiently via enhancements like spot beams, and to open up higher frequency bands, mainly used by the FSS for mobile satellite systems.

The main types of satellite orbit in use are:

- GEO (geosynchronous earth orbit) – support geostationary satellites which are good for broadcasting and fixed communications. Orbital height about 36,000km above the earth's surface, propagation delay 250ms, coverage of one-third of earth's surface.
- MEO (medium earth orbit) – orbital heights between about 10,000km and 15,000km, propagation delay of about 100ms, orbit periods of about 12 hours. Small constellations required, with each satellite covering about one-sixth of the

earth's surface. Main application is navigation, may be useful for future mobile systems.

- LEO (low earth orbit)- orbital height of 160km to 2,000km, taking 90-120 minutes to orbit the earth. Propagation delay about 50ms, covering relatively small areas of the earth's surface. Mainly used for mobile communications and earth observation.
- Elliptical - satellites can be directed to have visibility of different parts of the earth for different amounts of time. Main applications – earth observation, science, high latitude coverage.
  LEOs and MEOs are often used in constellations to expand their coverage progressively (e.g. for earth observation) or to global reach (e.g. Iridium).

EESS:
All EESS satellites (active and passive, radar and optical) require ever increasing bandwidths for data downlink. There is a drive for more frequent observations and persistent surveillance for security applications. This combined with the trend for EO satellites to become more affordable is leading to satellite constellations becoming more common. This results in a significantly higher bandwidth requirement, including permanent links at Ka band to satellites in Geostationary orbit such as the European Data Relay Satellite (EDRS)

Metsat:
The required satellite spectrum spans many differing frequencies, but of particular importance is the protection of passive bands (such as 1400-1427 MHz, 1068-1070 GHz, 15.35-15.40 GHz) so that the constituents and variables sampled in these unique atmospheric windows are able to be measured without any interference.

The Met Office has interest in the following frequency bands for UK use in the range up to 15 GHz from a satellite perspective:

- 1 217.6-1 237.6 MHz and 1 565.42-1 585.42 MHz for GPS water vapour sensing;
- 1 690-1 710 MHz for reception of polar orbiting met satellites at Exeter
- 5 200-5 300 MHz EESS active to provide info on sea level, wave heights and ocean surface winds
- 6 425-7 250 MHz for info on sea surface temperatures
- 7 450-7 550 MHz used for reception of data from geostationary met satellites
- 7 750-7 900 MHz used for reception of data from polar orbiting met satellites
- 8 025-8 215 MHz Terra and Aqua satellite data
- 10.60-10.68 GHz used to provide info on surface rainfall rate and precipitation over oceans
- 10.7-12.5 GHz Eumetcast & satellite TV reception
- 13.40-13.75 GHz to provide info on ocean surface winds

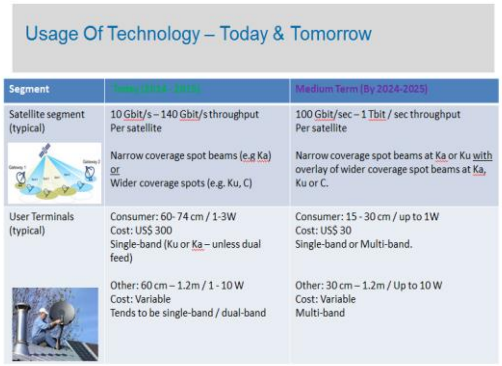
Additionally there are some frequencies which must be retained due to use in Europe by Met satellite operators. These are 1 675-16 90 MHz; 2 025-2 110 MHz; 2 200-2 290 MHz all of which are not used directly in the UK but must be protected.

6.6 Expected changes to technology and spectrum

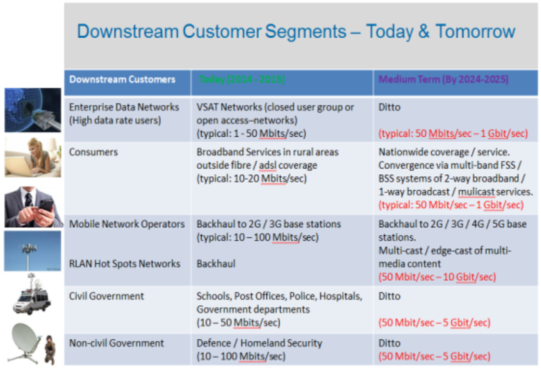
Like other wireless services sectors, the satellite industry is facing rising levels of usage, which will require additional spectrum and enhanced technologies.

The rise in demand for satellite services is being driven by:

- Demand for the provision of competitive broadband services in underserved regions of the world, including emerging economies
- Rising demand for satellite TV throughout the world and upgrade to high definition and ultra high definition
- Increasing capability of HTS FSS systems to support higher customer data rate requirements into the Gbit/sec range and smaller earth station terminals (see figures below).


Usage Of Technology – Today & Tomorrow

Segment	Today (2014 - 2015)	Medium Term (By 2024-2025)
Satellite segment (typical)	10 Gbit/s – 140 Gbit/s throughput Per satellite Narrow coverage spot beams (e.g Ka) or Wider coverage spots (e.g. Ku, C)	100 Gbit/sec – 1 Tbit / sec throughput Per satellite Narrow coverage spot beams at Ka or Ku with overlay of wider coverage spot beams at Ka, Ku or C.
User Terminals (typical)	Consumer: 60- 74 cm / 1-3W Cost: US$ 300 Single-band (Ku or Ka – unless dual feed) Other: 60 cm – 1.2m / 1 - 10 W Cost: Variable Tends to be single-band / dual-band	Consumer: 15 - 30 cm / up to 1W Cost: US$ 30 Single-band or Multi-band. Other: 30 cm – 1.2m / Up to 10 W Cost: Variable Multi-band


Downstream Customer Segments – Today & Tomorrow

Downstream Customers	Today (2014 - 2015)	Medium Term (By 2024-2025)
Enterprise Data Networks (High data rate users)	VSAT Networks (closed user group or open access–networks) (typical: 1 - 50 Mbits/sec)	Ditto (typical: 50 Mbits/sec – 1 Gbit/sec)
Consumers	Broadband Services in rural areas outside fibre / adsl coverage (typical: 10-20 Mbits/sec)	Nationwide coverage / service. Convergence via multi-band FSS / BSS systems of 2-way broadband / 1-way broadcast / mulicast services. (typical: 50 Mbit/sec – 1 Gbit/sec)
Mobile Network Operators RLAN Hot Spots Networks	Backhaul to 2G / 3G base stations (typical: 10 – 100 Mbits/sec) Backhaul	Backhaul to 2G / 3G / 4G / 5G base stations. Multi-cast / edge-cast of multi-media content (50 Mbit/sec – 10 Gbit/sec)
Civil Government	Schools, Post Offices, Police, Hospitals, Government departments (10 – 50 Mbits/sec)	Ditto (50 Mbit/sec – 5 Gbit/sec)
Non-civil Government	Defence / Homeland Security (10 – 100 Mbits/sec)	Ditto (50 Mbit/sec – 5 Gbit/sec)

Figure 20: Changing satellite customer segments and technology usage

- Mobile satellite, including broadband communications to ships and aircrafts, and other services such as navigation
- Increasing necessity of reaching every location on earth (broadband as a human right etc.)
- Upgrade of fixed and mobile broadband to higher data rates at reduced cost to users
- Improvements in Earth observation capabilities, including growth in numbers and sensitivity of active and passive RF sensors
- Bandwidth requirements of ever higher resolution remote sensing to relay observation data back to earth.
- Developments in lower cost launchers offering commercial access to space and consequent exponential increase in satellite numbers, especially in LEO

As well as greater spectrum capacity, these changes will require more efficient use of existing spectrum, as well as driving adoption of new technologies which support better price, performance and efficiency.

Important trends will include:

- Increasingly efficient use of lower frequency spectrum e.g. with multi-spotbeam/high gain satellite antennas (22m unfurlable antennas are already in use)
- Multiple satellites use the same spectrum and there are important frequency reuse techniques being adopted
- Increasing use of complementary ground components (terrestrial infill using ground based stations at fixed locations, in space spectrum, to increase availability). These can be simple satellite signal repeaters, but more commonly cellular base stations. Such techniques are being developed for the S-band MSS allocations in particular
- Terminal technology with very high pointing accuracy to improve mobile QoS and frequency re-use especially on ships and aircraft
- Increasing development of smaller terminals, consistent with conventional FSS VSATs, which in turn opens up the FSS bands for mobility, especially the Ka-band
- Rapid development of integrated circuit technology, smart terminals and low cost memory increasingly supports smarter and cheaper consumer equipment with more integrated functionality, though it is worth noting that the same trends also apply in terrestrial services, which have greater market size and economies of scale
- Drastic performance increase thanks to HTS (High Throughput Satellites) with multibeams payload and improved frequency reuse techniques
- HTS allows more flexible business cases as operators can decide whether to dedicate the whole satellite to broadband services or embark broadband-specific payloads.

Next generation HTS developments are targeting terabit/second capacity at costs to the user which are similar to terrestrial fibre, in the 2020 to 2025 timeframe, by harnessing improved reuse and spot beam technology (Northern Sky Research, Global Satellite Capacity Supply and Demand, July 2014). This would broaden satellite's addressable markets, especially when broadband is offered in a service bundle, though its sweet spot will remain the markets which are hard to reach by terrestrial. There are additional upfront costs for HTS compared to conventional satellite, but cost per bit is dramatically lower.

There are ongoing upgrade programmes for many commercial satellites, especially in the low frequency L and S bands, which are important for MSS (but also of interest to terrestrial mobile carriers).

There is a major process underway to upgrade satellites in these bands, LEO systems, as well as geostationary satellites in the L-band. The replacement programme will extend the life of the fleets by more than 15 years, but more importantly, will support new services. In particular, the new satellites will better equip operators to adapt to the trend for usage and revenues to be driven by data, not voice.

Meanwhile, L and S bands can be complemented by MSS services in the Ka band, if high bandwidth is required. The Ka band has several advantages to those operators which have rights there, such as Inmarsat with its Global Xpress offering. Ka-band has high capacity – and 2x500MHz of that is exclusive to satellite, with little potential for constraints from sharing with terrestrial mobile.

Improvements in spectral efficiency, and the capacity of this band, mean current ITU Region 1 allocations should be sufficient to support the expected services until at least 2025. There is interest in increasing use of the 17.7 - 19.7 GHz / 27.5 - 29.5 GHz band by Ka-band FSS systems, in bands also available for terrestrial P2P fixed services. This is technically challenging because of the density of fixed services in the lower of these bands.

As well as upgrades and new launches for broadcast and broadband, there will also be considerable evolution in other technologies including earth observation. For instance, 164 EO satellites have been launched during the past decade and this number is expected to grow to 360. About 80% are optical, requiring significant downlink capacity.

The evolution of hybrid services
An important trend, which in some regions will help expand the range of services that satellite can deliver, while reducing costs to consumers, will be hybrid services, in which terrestrial and satellite spectrum and networks are combined. The interworking may be at the spectrum level – satellite and terrestrial components sharing the same frequency bands; or may be at the network level – satellite and terrestrial components operating in a single integrated network, but each component operating in its own spectrum. This is already seen in some areas of the broadcast and broadband markets. Two examples are discussed below:

a) Hybrid S-band MSS / CGC Services

There have been many regulatory moves to allow terrestrial components in mobile satellite bands (e.g. Inmarsat and EchoStar/Solaris each won a selection process run from the EU in Europe for S-band spectrum, which are likely to have a complementary ground component (CGC)).

Following the EU authorisation, Inmarsat has significantly invested into the development of MSS services in the 1 980-2 010 MHz and 2 170-2 200 MHz frequency bands to provide high speed broadband services for aircrafts flying over the European landmass, supported by a CGC ground network. The project has been dubbed the European Aviation Network (EAN) and it seamlessly combines terrestrial LTE and satellite connectivity to ensure quality that will rival the broadband service experience achieved on the ground. Inmarsat recently announced a partnership with Deutsche Telekom and Lufthansa, thereby demonstrating its commitment towards launching the World's first LTE based ground and satellite network dedicated for aviation passenger connectivity. Deutsche Telekom will contribute to the project by developing and operating the terrestrial LTE ground network and Lufthansa will become the first participant of the EAN programme. Inmarsat aims to launch the EAN satellite program by the end of 2016, which will be followed by the launch of the Deutsche Telekom's LTE ground network in early 2017.

This emphasises the opportunity for satellite operators to have an important role in a '5G' hybrid network (see later section) both in air and on land, with the support and cooperation of terrestrial mobile groups.Such approaches are being discussed by satellite operators and regulators round the world but may be a double-edged sword for the sector. On the one hand, use of a complementary ground component gives MSS operators greater flexibility to deploy the most economically effective technology for a given service or market. The two types of delivery can complement one another, with satellite providing universal coverage and offload potential, and terrestrial delivering data and content at lower cost in densely populated areas. However, this enables competition between satellite and terrestrial mobile operators for the same spectrum as MNOs look to expand their data capacity as well as extending their offerings into rural areas

Such spectrum competition has already manifested itself through the discussions at the ITU Radio Assembly. The frequency ranges 1 980-2 010 MHz and 2 170-2 200 MHz, which are allocated for MSS in the ITU Radio Regulations, been proposed to be included in the channel plans of independent terrestrial LTE networks operated outside the EU. In response to this proposal, administrations as well as the satellite industry have voiced concerns that this may lead to significant interference that can harm or even prevent operation of MSS satellites in these bands. The matter will be further analysed over the next ITU-R study cycle and is a severe threat to the investment the satellite industry has already committed in the development of S-band services.

Hybrid Ku-band / Ka-band Satellite Services

An example of this interworking ‘4G’ hybrid network is SAT-IP that uses satellite broadband converted to IP traffic which can be distributed over any IP network using wireless (5G/ 4G, WLAN), powerline, wired Ethernet, or optical fibre. In a satellite IP environment any IP device (tablet, PCs, smartphone etc.) automatically gets enabled for satellite reception provided the right software is available.

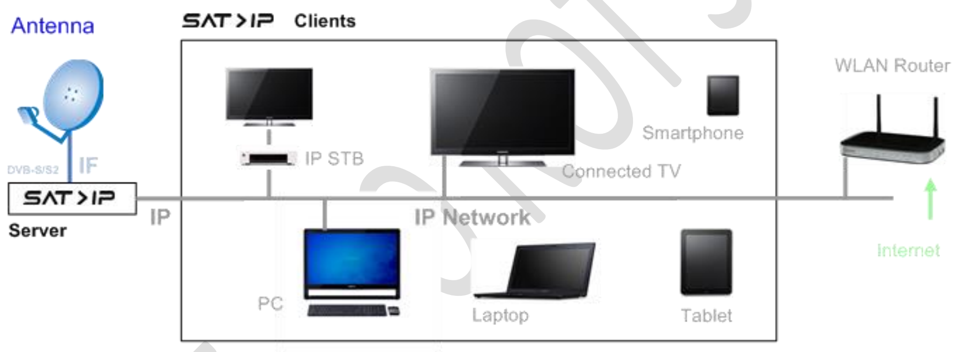


Figure 21: Satellite broadband provided SAT-IP clients with Connectivity

This opens up the opportunity for satellite to have an important role in a ‘4G’ or ‘5G’ hybrid network (see later section), though this may in part rely on cooperation with the terrestrial mobile, terrestrial fixed and terrestrial broadcast networks.

b) The route to 5G Hybrid Systems

As noted earlier, satellites can deliver very high data rate services (> 100 Mbps to 10 Gbps) in ‘Broadcast / Multicast’ mode to small, compact outdoor radio access points for:

- Direct delivery of linear, non-linear TV and IPTV services to in-building fixed customers
- Interconnect via 3G/4G/ RLAN wireless access networks (for in-home, in-building distribution) for service delivery to in-building mobile users.

Satellite can also deliver high capacity two way broadband services for complementary coverage to fixed or terrestrial wireless networks outside major urban and suburban areas.

Such novel satellite transmission technologies, spectrum utilisation technologies and receive/modem, network structures will rapidly mature and develop in the coming years.

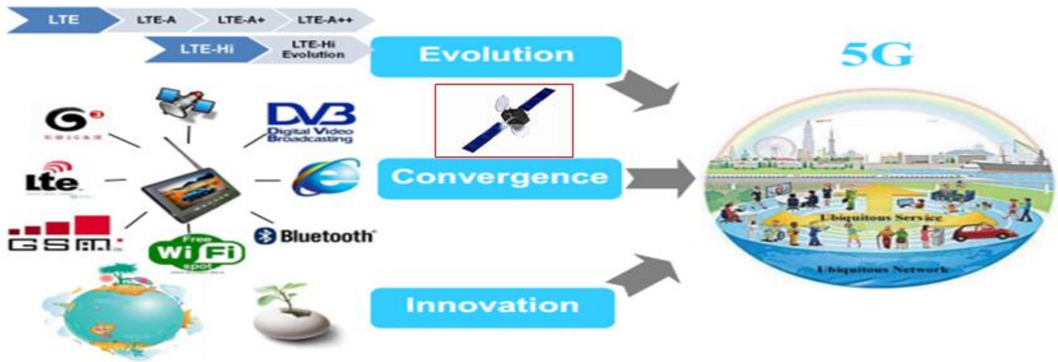


Figure 22: Satellite has a role to play in future 5G service delivery

An important outcome for the industry will be the extent to which satellite and terrestrial systems are inter-workable or partly or fully integrated at the network level. While there is an emerging trend to share separate networks, to improve coverage and capacity for broadcast and broadband, there is a far more ambitious vision in which satellite networks and terrestrial mobile networks are integrated or interworked via HetNets (heterogeneous networks), and inter-workable as a single pool of capacity. This would most likely be part of the as-yet undefined '5G' platforms, potentially expected to start to be commercialized from 2020, as depicted below.

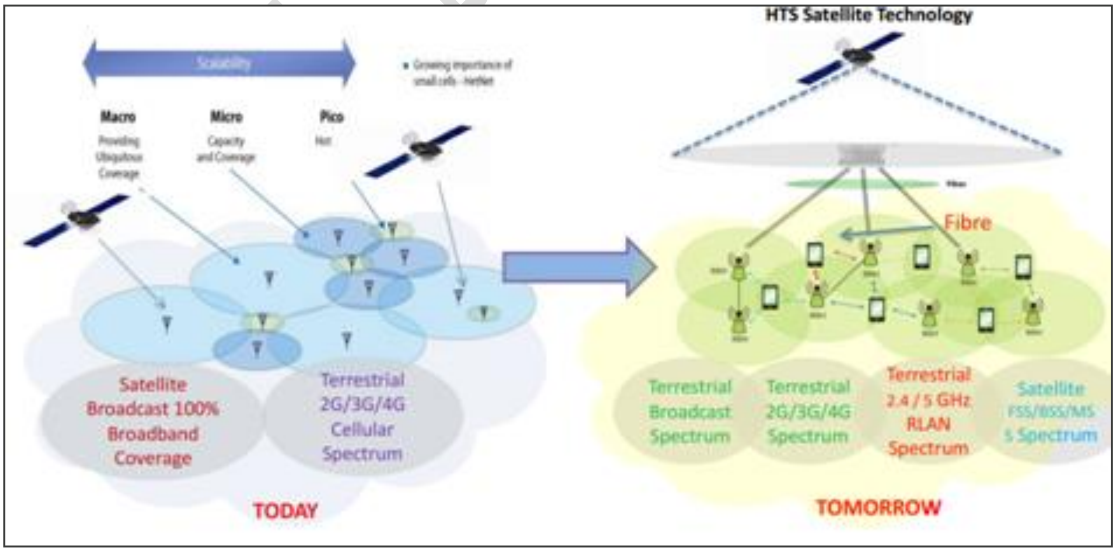


Figure 23: The convergence of satellite and terrestrial networks in a future HetNet

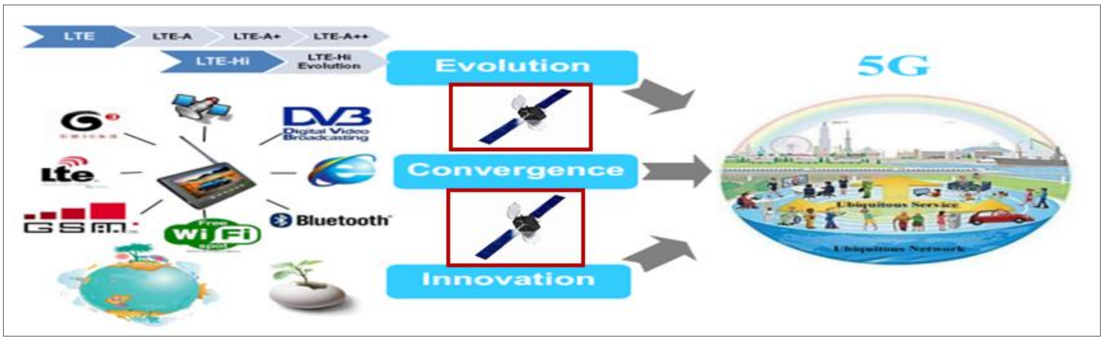


Figure 24: The convergence of satellite and terrestrial networks towards 5G

In the above vision, fixed and mobile broadband networks, and satellite communications networks, will converge, supported by multimode multiband terminals and seamless handoff technologies. ‘5G’ is widely expected to consist of multiple RATs, layers of cells and frequency bands, and satellite would be a candidate for inclusion. It would bring, in some scenarios, very high data rates (100Mbps to 10Gbps in multicast mode) and universal coverage, to complement the indoor penetration of terrestrial RANs.

There are various projects in this area, such as the EU-funded BATS (Broadband Access via integrated Terrestrial & Satellite systems). This addresses the EU Digital Agenda of making available more than 30Mbps data rates to 100% of users by 2020 and also looks to future applications in mobile ‘5G’. It is based on an ultra-high speed terabit satellite and combines with terrestrial delivery via an intelligent user gateway and diverse routing mechanisms.

This type of converged architecture would, if realised, be commercialised after 2020 and would guarantee satellite an important role in future 5G ecosystem including for content delivery and multimedia services.

Threats to the realisation of the social and economic benefits from space sector use of spectrum

The main threats to space spectrum, as perceived by the sector itself, are pressure at the WRC-15 to identify new primary global bands for terrestrial IMT. Specific bands under threat are:

- 3 400 – 4 200 MHz: potential reduced utility of the C-Band because of the identification of these bands for broadband mobile access. In the EU this has already lead some administrations to close parts of this band to new FSS earth stations. In many countries where WiMAX has been deployed in these bands, earth stations have suffered interference
- 5 250 MHz – 5 570 MHz: potential reduced utility of this spectrum because of WLAN. The impact would be on Earth Observation, particularly SARs in 5350 MHz-5470 MHz if this band is made an extension band for WLAN
- 1 400 – 1 427 MHz: unwanted emissions from adjacent allocations into this passive remote sensing band;
- 1 675 – 1 710 MHz bands used for meteorological satellite applications;
- 2 025 – 2 110 MHz and 2 200 – 2 300 MHz used for space research, EESS and space operation services
- MSS at 1 518-1 559 MHz and 1980 -2010 MHz used by Inmarsat, and potential interference from terrestrial IMT in the same and adjacent bands

- Potential impact on the satellite bands above 6 GHz (including in C-band, Ku-band and Ka-band) in the light of proposals from some mobile manufacturers to seek identification of more IMT spectrum in this range. Satellite / space entities have already communicated to UK Government and Ofcom their opposition to this in their response to the recent Ofcom consultation on WRC-2015 matters.

If the Ku-band or Ka-band frequencies were to be placed within the scope of any new IMT allocation, that act alone would create uncertainty for FSS/ MSS and BSS operators, their customers and their investors. FSS/ MSS and BSS systems may take 20 years from initial planning and funding, through to their end of life and during this period regulatory certainty is required. Such regulatory certainty would be undermined by such a new allocation to accommodate terrestrial IMT above 6 GHz.

Consequently, the satellite industry is concerned that spectrum that is currently allocated to the FSS, MSS or the BSS under the ITU Radio Regulations should not be identified as spectrum for future IMT-terrestrial services, since the satellite industry has no doubt that this would jeopardise and disrupt over $5 billion (£3.4 billion) in investment already made by UK-based satellite operator companies into Ka-band satellite systems.

Furthermore satellite networks also share with each other, in each satellite band in operation today much of the same spectrum is used, employing precise orbital spacing, coordination and directional antennas to avoid interference into each other. IMT services fundamentally break these carefully calibrated sharing assumptions and thus are not compatible with the existing intensive use of spectrum above 6 GHz by satellite services.

6.7 Long-term technology and spectrum needs and options

The increase in the range of satellite services, and the performance of those applications, can be assumed to continue throughout the period, driving further improvements in cost and spectral efficiency, but also requiring additional spectrum.

On the technology side, for instance, next generation HTS developments are targeting terabit/second capacity at viable costs in the 2020 to 2025 timeframe.

On the spectrum side, the satellite industry perceives three major challenges:

- To protect current spectrum users from harmful interference arising from sharing with other services, which would reduce the reliability of services, or removing access to certain bands entirely
- To ensure the continued long-term availability of *existing* primary or co-primary allocated satellite services or space services in for example L, S, C, X, Ku, Ka and Q/V bands to enable the continued development of new innovative satellite systems capable of offering a wide range of advanced services
- To acquire new spectrum, often in bands which are optimal for very specific applications. For instance, several frequencies are in demand to support next generation SAR for improved weather and interferometric services (40-50 MHz, 3.1-3.3 GHz, 13.25 GHz-13.75 GHz; 17.2 GHz-17.2 GHz; 35.5 GHz-36 GHz; 37.5 GHz-40 GHz; 94 GHz; 130 GHz-134 GHz).

Satellite players are calling on administrations to refrain from authorizing terrestrial use in some bands in future, since sharing may be impractical or harmful, and technology neutrality does not recognize the unique value and needs of certain services. They point out that demand for satellite services is increasing but without sufficient spectrum, costs will rise and QoS fall. They also argue that the data gathered by satellites is essential to preserving the environment and global security.

FSS / MSS / BSS Future Spectrum Needs

Satellite players aim to ensure the continued long-term availability of *existing* ITU primary allocated or co-primary allocated satellite spectrum to MSS, FSS and BSS in L, S, C, X, Ku, Ka and Q/V bands to enable the continued development of new innovative satellite systems capable of offering a wide range of advanced MSS / FSS / BSS services.

Satellite players also seek access to *new* primary or co-primary ITU frequency band allocations to support the development of new and expanded satellite services. A key goal is to obtain at ITU WRC-2015 additional co-primary spectrum at X-band, Ku-band and Ka-band for FSS use.

EO Future Spectrum Needs

During the last decade: 164 Earth observation satellites launched by civil government and commercial entities, of which around 80% are optical e.g. SPOT, PLEIADE, DMC (Disaster Monitoring Constellation). In the next decade the number is expected to expand to 360 satellites, with a corresponding increase in demand for bandwidth for data downlink:

Active sensors are used for applications such as altimeter and Synthetic Aperture Radar (SAR) and spectrum is also required for transmission of telecommand and telemetry (TC/TM), for both passive and active sensors.

Radar imagery is independent from weather conditions (e.g. clouds) or solar illumination on the ground and critical for many applications (e.g. crisis response, safety applications) Active sensors like SAR represent around 20% of the satellites launched and to be launched in the next 10 years transmission bandwidth and radar range resolution are mutually dependent

In the near term (in the next five years), as EO applications grow, there will be a requirements for use of X band EESS with an extended worldwide allocation up to 600 MHz by WRC 15 (AI 1.12), to provide higher resolution images in all weather conditions.

A proposal is to be made to WRC-15 (A1.1.11) to allocate the 7-8 GHz band to EESS Earth to Space for high rate payload control and data links given S band congestion.

In addition, the use of the 25.5 – 27 GHz band is proposed for EESS Space to Earth to provide an increased payload data downlink capacity. Both ESA and EUMETSAT (MTG) are already moving from X EESS to Ka EESS band.

In the longer term - in the 10-20 year timeframe - the spectrum requirements for data downlink will be driven by the very large data rates derived from 4D, very high resolution imaging.

Operation of active EO sensors will continue to move into the higher frequency bands (Ku, Ka, V and W) with SAR sensors operating in all-weather conditions.

There is a growing demand for very high resolution pictures produced by synthetic aperture radars (SAR) operating in the Earth exploration-satellite service (EESS) (active). This image resolution needed for global environmental monitoring can only be achieved by correspondingly transmission bandwidth.

A chirp transmission bandwidth of 1 200 MHz is to be available around 9400 MHz. Such a bandwidth requires an extension of the current EESS (active) allocation by 600 MHz to enable unprecedented features for long-term (4d, i.e.3d space dimensions and one-time dimension) global monitoring as well as for environmental monitoring and land use purposes.

It is to be recognised that the allocation to the EESS around 9 600 MHz combines the advantage of a largest possible bandwidth at the lowest possible frequency regarding propagation conditions.

Very high resolution mapping and monitoring is required by applications that provide substantial socioeconomic benefit:

- Disaster relief and humanitarian aid actions require ad hoc access to up-to-date geo-information, also to remote areas of the globe. Airborne imaging is very often limited by remoteness of the area to be observed and cloudy weather conditions. Today's radar satellites are too limited in resolution to allow adequate infrastructure damage assessment (and consequently a rough estimate of the number of affected people) to assist first responder activities. Also identification of trafficable roads, landing strips or suitable spaces to set-up first aid or refugee camps is limited by the resolution of today's radar sensors.
- Safety of energy supply: to ensure sustainable oil and gas production these sites need to be carefully monitored in terms of managing the extraction. In addition, vast pipeline networks require monitoring in terms of their integrity to avoid – or at least to detect – leakages and severe environmental pollution. For this, reliable and weather-independent monitoring is required.
- Cadastre: For city management and agricultural planning. Especially countries in the tropical regions suffer from substantial cloud coverage, some of these nations face rapid built-up area, growth and land cover and land use change. In addition, the growth of settlements and industry in quickly growing conurbations benefits from timely monitoring in support of spatial planning and associated public infrastructure programmes. All require an affordable, reliable and weather independent mapping capacity.

For the above-mentioned applications, given the object characteristics to be observed, a resolution below 20 cm is required. Satellite technology around 9-10 GHz is well suited to meet this need, provided that a transmission bandwidth of up to 1 200 MHz can be applied.

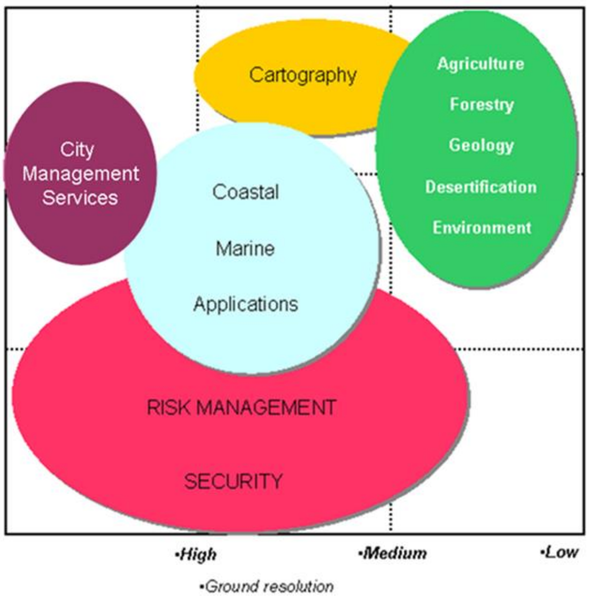


Figure 25: Ground resolution requirements in different application fields

Met Services

Future spectrum requirements for space observations for met services, the UK contributes to the EUMETSAT programme which benefits the whole of Europe in providing access to vital data from future planned missions, (such as the Sentinel series of satellites), any requirements for additional spectrum would need to be co-ordinated across Europe should future needs be identified. See further details of these services in section A.7.

Conclusion

Following a decade of UK consistent growth, the market for satellite services has distinguished itself within the UK by being recession-proof. UK-based satellite operators filing through the UK Administration include Avanti, DirectTV, Echostar, Inmarsat, Mansat, O3b, SES and Viasat. The current level of investment from these satellite operators in Ka-band systems alone is well over $5 billion (£3.4 billion) and that level of investment is expected to increase radically in coming few years.

To enable this investment to continue, the space sector argues that FSS/ MSS and BSS spectrum allocated by the ITU should not made available or identified to future IMT-terrestrial services, since sharing with IMT is not a practical proposition and would jeopardise the investment already made by UK-based satellite operators.

The navigation and timing services delivered from space have become an integral part of our national infrastructure and contribute strongly to the economy, especially but not exclusively in the finance, transport and agricultural sectors.

The UK has strongly invested in space science and Earth observation, both nationally and working with global partners and agencies. Services based on this investment are an important contributor to economic growth and social well-being. They are crucial to addressing key issues including climate change, population growth, building resilience and disaster relief. There are significant threats to the economic potential of the space science and Earth Observation sectors arising from pressures for more spectrum from other sectors, such as EESS arising from proposals to find additional spectrum for RLAN. The potential damage is significant. The total benefit of the space sector to the UK needs to be fully considered when decisions regarding allocation of frequencies are being made.

A.7. Meteorology

The following information on spectrum usage for meteorology has been provided by the Met Office.

7.1 Scope of the sector

The Met Office, as the UK's National Meteorological Service, is responsible for providing a wide range of weather forecast and warning services to the public, emergency responders, defence, aviation, industry and a range of other stakeholders across Government, underpinning the protection of life and property. Reliable access to key radio frequencies is essential for the remote sensing and communication of the global environmental information upon which operational meteorology and the monitoring of climate change depend. Indeed, almost all of the observational data that is received and used by the Met Office involves the use of the radio spectrum, with examples including data from meteorological satellites, weather radar, radiosondes, ocean buoys and windprofilers - all of which are coordinated within internationally agreed spectrum bands.

7.2 Contributions to social and economic value

Previous studies have been conducted to ascertain the economic value of weather services in the UK, the PA Consulting report from 2007 [51]suggests that the value resulting from the Public Weather Service was £614M compared to running costs of £83M per annum. Whilst this report puts a specific figure on the economic benefits, it is also important to stress that the overall value (encompassing the social benefits) can be expected to be many times more than this figure as the report stipulates that the Met Office additionally provides a service of invaluable proportions when it comes to issues such as climate change, military activity and human health.

7.3 Current and recent past status

The Met Office is a Government Agency, (part of BIS as from summer 2011), prior to this we were under the ownership of MoD, hence much of our historical access to Spectrum was through the MoD. There remains close liaison between MoD and Met Office to ensure we co-ordinate over spectrum frequencies to ensure that we do not cause one another interference.

7.4 Sector trends

The Met Office's relatively modest requirement for spectrum is not anticipated to change greatly in the coming few years. Whilst there will undoubtedly be greater data volumes from planned satellite missions we would hope to have sufficient capacity within the current bands to provide the levels of real-time data which will be required for future NWP modelling requirements. Further ahead, there may be scope for doing things differently as a result of technological advances but at this stage these are not yet fully understood, it would be hoped that technological advances will also lead to more effective us of the spectrum we currently utilise, thus balancing out the increases in volumes of data.

7.5 Uses of technologies and spectrum

7.5.1 Weather Radar

Weather radar is the key terrestrial remote sensing observing capability operated by the Met Office and the only means currently available for the measurement of rainfall and associated flash flood risk in real-time over large areas and also in critical rapidly responding catchments in urban areas. Radar is essential in monitoring the location and intensity of a range of weather hazards, including hail and snow, which can not only create significant disruption to transport systems and the economy, but also pose a significant threat to safety. Doppler radar functions are also used for the detection of dangerous wind conditions (e.g. wind shear) which constitute a hazard to aviation safety.

Radar data is not only used directly by forecasters and decision makers but is also ingested into meteorological and hydrological forecast models, underpinning the accuracy of warnings for severe weather and river/flash flooding events and other critical weather parameters. Radar-based services include warnings delivered to public partners, government agencies and Category 1 and 2 Emergency Responders. Weather radar output is used to directly inform (e.g.) COBR and local resilience fora decision making and both the Cabinet Office and Civil Contingencies Secretariat maintain access to weather radar products. The UK Weather Radar Network operates 24/7/365 and covers more than 95% of the UK land area in order to meet this requirement.

Weather radar can be operated as networks in the radiolocation allocations at 2.7-2.9 GHz (S-band) and 5.35-5.46/5.6-5.65 GHz (C-band). Non-network weather radars can also be operated at 9.3-9.5 GHz (X-band). The UK weather Radar Network is currently operated at 5.6-5.65 GHz

7.5.2 Satellite remote sensing & downlink operations

Meteorological satellite observations are a critical data input to both operational forecaster and Numerical Weather Prediction (NWP) supercomputer modelling requirements.

NWP is the primary tool for the provision of a range of key operational public services such as the National Severe Weather Warning Service (NSWWS), provided for the good of the UK on behalf of the Public Weather Service Customer Group (including the emergency services, EA, local resilience fora, CAA, MOD, etc). NWP (and therefore forecast) accuracy is founded on the reliable exploitation of satellite data underpinning safety critical services such as, in particular, aviation. Denying satellite data to NWP significantly degrades the forecast at all lead times, and has a greater impact than denying any other type of conventional observation as demonstrated by the following Hurricane Sandy case study on page 88.

Current and future meteorological satellite missions will continue to further improve our seamless understanding of global weather and climate at all timescales and thus assist Govt policy. For example, on seasonal timescales, satellite data is used to estimate ocean surface characteristics which are vital to the understanding of cyclical globally significant weather patterns such as El Nino/La Nina, bringing droughts to certain areas whilst flooding to others. Our greater understanding of these events and broader projections of climate through exploitation of satellite data, enable DECC and other government departments to influence global strategies for dealing with impacts.

Satellite Command & Control functions and downlink/uplink capabilities are vital to the operation of meteorological satellites and communication of their data. The Met Office represents the UK at EUMETSAT to exploit meteorological satellite capability, and also collaborates through the convention of the WMO to access global data from partners such as NOAA/NASA (US), JMA (Japan) and CMA (China). Whilst command and control and uplink functions are not used by the Met Office in the UK, it is still essential to protect EESS/Metsat downlink capability, notably at the Met Office's HQ in Exeter, which delivers the bulk of operational and time-critical data to our NWP supercomputer facilities. Some bands are protected by Ofcom under an award of RSA, whilst others fall under (eg) MOD-coordinated bands. Key bands include:

- 1690-1710 MHz (geostationary & polar-orbiting downlink data)
- 3600-4200 MHz (FSS EUMETCAST downlink)
- 7750-7900 MHz (polar-orbiting downlink data)
- 8025-8215/8400 MHz (environmental satellite data downlink)
- 10.7-12.5 GHz (EUMETCAST downlink)

7.5.3 Radiosonde data

Data from balloon-mounted radiosonde sensors collect and transmit temperature, wind and humidity data as they ascend through the atmosphere. As such, radiosondes are an important input to an accurate forecast and also used to verify NWP models. Radiosondes are launched several times per day from a number of different sites around the UK, as part of broader global programme for the collection of upper air meteorological and climatological data. This data is exchanged as an international obligation through the WMO to enable worldwide prediction capability.

Met Office operates radiosondes in the range 403-406 MHz. The lower part of the band (401-403 MHz) is also used offshore by meteorological buoys for the uplink of maritime data to relay satellites (Data Collection Platforms, DCP).

7.5.4 Wind profiler data

Wind profilers are Doppler radars pointing vertically and off-axis to provide an important 3D data source on wind speed, direction and turbulence within the atmosphere. The Met Office operates a number of wind profilers around the UK; the data is useful for NWP and (e.g.) aviation applications. These can be at lower frequencies for applications in the higher atmosphere (troposphere/stratosphere; 46-64 MHz) and higher up the spectrum for lower-level remote sensing (boundary layer; 915-921 MHz, 1290-1295 MHz).

7.5.5 Lightning detection

The Met Office's ATDNet lightning detection system is operated at various sites in the UK and overseas in order to monitor lightning strikes in real-time over broad areas of the globe. This is especially significant for aviation applications, but also for public service warnings in the UK. The frequency band 8.3-11.3 kHz is allocated internationally for this.

7.6 Expected changes to tech and spectrum

The Met Office needs to be vigilant to any initiatives which potentially threaten our ability to be able to carry out our public task of helping to protect lives and property. We are always keen to exploit new areas of science which help to advance our understanding of the natural environment. Government (through BIS) has recently announced investment of £97M to upgrade Met Office supercomputer capabilities, this combined with vastly increased data volumes from next generation satellites is expected to lead to incremental socioeconomic benefits of ~£2Bn from meteorological services and advice over a five year period once the new supercomputer is installed. The realisation of these benefits would be at risk if access to vital spectrum were to be denied or re-allocated to other users.

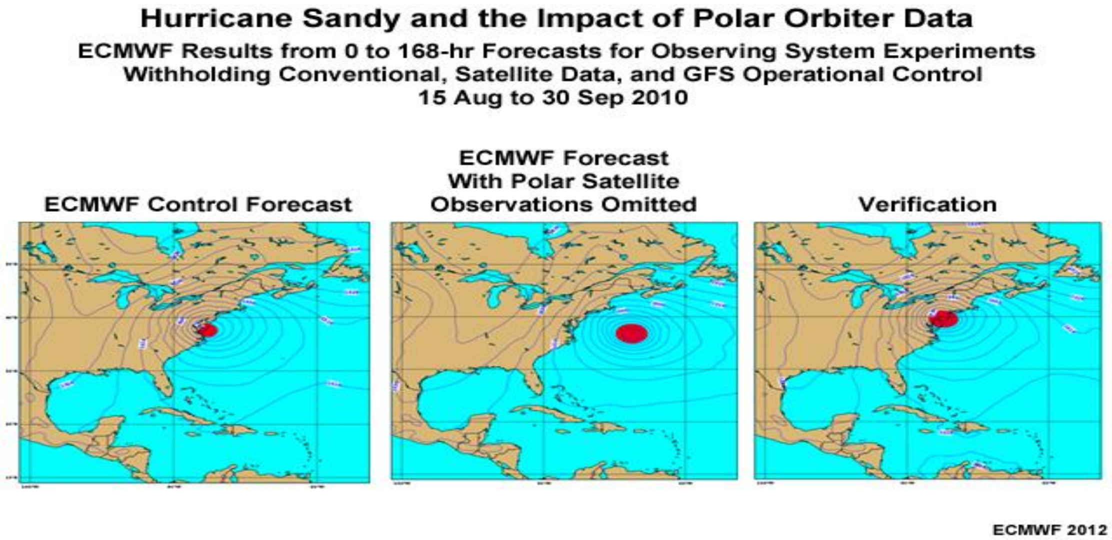
Examples where we could see detriment include:

- Increasing levels of interference to some of our key observing capabilities such as license exempt devices in the weather radar band of 5.6-5.65 GHz give us concern that soon those capabilities will become redundant, thus rendering the UK vulnerable to the full impact of life threatening floods and storms.
- Similarly loss of key bands for downlinks of satellite data into the supercomputer facilities at Exeter would set accuracy of weather forecasts back some 30 years or so, meaning that high profile weather events such as the St Jude's storm of Oct 2013 which was very well forecast several days in advance allowing emergency services to be prepared. The confidence levels in the forecast allowed train operating companies to cancel rail services for a specific period during the worst of the storm (although this caused significant disruption in itself, it was far better than having to deal with potential fatalities as a result of a train crash caused by debris of fallen trees on the lines, which became a major factor due to trees being in full leaf during that particular autumn storm).
- The impact of deterioration in NWP accuracy (by loss of access to spectrum bands which deliver vital wind and temperature profile information) would diminish the confidence in finely balanced weather events, such as the forecasting of storm surges in the North Sea. For example, the surge event of early Dec 2013 when many thousands of residents were evacuated from prone areas along the East coast, in the event several hundred homes were flooded in Boston Lincolnshire alone. The evacuation was both proportionate and effective in saving lives.

7.7 Longer term (10-20 year) tech and spectrum needs and options

As noted above in sector trends, the Met Office sees little change in its spectrum requirements even in the longer term, we believe that increases in data volumes (from future satellite missions etc.) which would suggest the need for more spectrum are likely to be balanced by technological advances and improvements in efficiency. Equally, if the technology and efficiency gains outstrip the levels of data increase then there would be a compelling case for reductions in the spectrum we require and we are quite open to this in principal, we are striving to ensure we continue to release any spectrum we no longer require (such as 137-138MHz) which is no longer used in the UK by the Met Office.

Case Study: Hurricane Sandy and the impact of polar orbiter data



Numerical Weather Prediction models require accurate and timely observational data in order to have any chance of producing an accurate forecast. Accurate predictions of severe weather several days ahead allow government agencies to plan for public evacuation if deemed necessary. In this New York case study mass evacuation and closures of key infrastructure such as subway stations meant that loss of life was much lower (50 or so deaths attributed) than otherwise would have been the case with no such warnings.

Satellite data omission case study from ECMWF (European Centre for Medium Range Weather Forecasting)

On 29 October 2012, Hurricane Sandy made landfall along the coastal areas of New York, New Jersey, and southern New England, causing storm surges of over ten feet. Six to seven days before the storm tore through the area, the ECMWF NWP model predicted that it would take a sudden left turn (turn towards the west), providing sufficient time to mitigate the loss of life and property.

*As part of an NWP forecast post-storm assessment, the ECMWF did an Observation System Experiment (OSE) in which it excluded **polar-orbiting satellite** observations from the analysis that provides the starting point for the forecast. The OSE was performed to see the impact of losing these observations on the forecast.*

The graphic shows the 168-hour (7day) operational and OSE forecasts, and the verification for Hurricane Sandy at the time of landfall. The control forecast included polar orbiter observations and had the hurricane making landfall near Norfolk, VA, with strong onshore winds expected north of the storm that would likely produce a storm surge up to the New York City area. Without the satellite data set (middle panel), the forecast only called for high surf and rip currents on the northeastern U.S. coast.

Photographs and aftermath of the Hurricane Sandy event can be reviewed at http://www.telegraph.co.uk/news/worldnews/northamerica/usa/9642239/Superstorm-Sandy-key-updates.html

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A.8. Defence

8.1 Scope of the sector

The defence sector consists of the armed forces, under the auspices of the Ministry of Defence, as well as all their suppliers and contractors. The MoD is the largest spectrum manager in the UK in its own right, and many players in the sector also use other spectrum – their own or public commercial frequencies – to support some of their services. Conversely other users, both public and private, use some MoD spectrum

The remit of the defence sector is summed up in the MoD's own words:

> "We protect the security, independence and interests of our country at home and abroad. We work with our allies and partners whenever possible. Our aim is to ensure that the armed forces have the training, equipment and support necessary for their work, and that we keep within budget." [52]

To achieve that, the MoD lists its seven **standing** tasks as:

- Defending the UK and its overseas territories
- Providing strategic intelligence
- Providing nuclear deterrence
- Supporting civil emergency organisations in times of crisis
- Defending our interests by projecting power strategically and through expeditionary interventions
- Providing a defence contribution to UK influence
- Providing security for stabilisation

The scope of the activities is very broad, and includes systems and operations on land, sea, air and space. In all these tasks, spectrum is increasingly important to success because of the rising reliance on wireless communications and surveillance. In recent times, there has been an intensifying focus on 'smart defence', which relies on sophisticated IT and big data systems; and on cyber defence and operations.

This is shifting the balance of deployments from physical resources and manpower which is reducing, leading to a greater reliance on technology and communications systems, without reducing overall capability. This means that cyberspace, and radio spectrum, must be thought of as operational environments. That, in turn, means there must be sufficient spectrum to conduct the operations successfully, with sufficient spectrum access to support goals such as training to fight, and freedom of manoeuvre.

8.2 Contributions to social and economic value

The primary social and economic contribution of the defence sector, as summed up in the MoD's seven standing tasks, is to support national, commercial and economic stability. Additionally, defence is an important UK industry in its own right.

The MoD, supported by 29 agencies and public bodies, has an annual budget of £14.88 billion for 2015-16 for defence equipment and support, a significant percentage of which is spent with UK companies [53]. The overall defence budget is the fourth largest in the world at £34.4 billion and this is also the fourth largest area of UK government spending, despite recent cutbacks. However, this figure is set against the context of a NATO recommendation that UK defence spending should be at least 2% of GDP.

The armed forces themselves employed 156,000 front line personnel as of the end of 2013, although following the defence review of 2010, numbers of full time service people are being reduced, especially in the army, and numbers of reservists are rising.

The MoD also employs about 40,000 civilian staff, and the defence industry as a whole employs over 100,000, plus a further 145,000 in the supply chain.

The sector's turnover is £22 billion a year with a rising percentage of that coming from exports, especially in light of spending cuts at home. The UK is the second largest exporter in defence products and services in the world, and has about 22% of the global market, or around £8 billion in annual sales. It is also growing its security export business, which was worth £3.2 billion, or 4% of the world total, in 2013. [54]

8.3 Current and recent past status

The period since the end of the Cold War has been one of profound change in the defence sector in terms of perceived global threats; approaches to warfare and security; and the use of new technologies.

In recent years, and especially since the 2008 crash, there has also been considerable pressure on the UK defence budget, and even questions about whether the scale of the country's defence resource can be justified (despite the NATO figure cited above). However, all that has come against the background of several recent campaigns and other military operations, in which the UK has been directly involved. The rising importance of cyber defence operations, plus the pressure on manpower and budgets, means that spectrum is more essential than ever.

These factors have led to greater cooperation, and sharing of expensive resources, with allies and to intense investigation of how technology and artificial intelligence can achieve defence and security goals at lower cost (financial and human).

Some of these changes include:

- New operational environments, with new communications challenges, including cyberspace and the 'war on terror'.
- Greater reliance on technology rather than armed personnel in some areas (e.g. UAVs, robotics). This in turn increases the need for additional bandwidth to support filling the gap.
- Greater emphasis on security of resources (e.g. fuel, water), not just territory
- Rising importance of 'warfare in the information age', harnessing communications and social media, and countering the use of those techniques by adversaries.
- New methods of gathering intelligence using deep learning and big data techniques.

8.4 Sector trends

The changes outlined above are reshaping many of the defence sector's practices. In particular, there is a greater premium placed on C4ISTAR (intelligence, surveillance, target acquisition and reconnaissance), which is heavily dependent on connectivity and real time data communications, potentially in harsh environments.

These new approaches are enabled not just by specific advances in defence and weapons technology, but in general trends towards information superiority, through a process of evolutionary change (e.g. many lessons from Afghanistan have been acted upon).

That presents major challenges in terms of processes, spectrum and security, because ISTAR demands resilient communications as well as fully protected mobile networks in sea, land, air and space.

The move towards information superiority drives the adoption of new tools and techniques. This has enabled the defence sector to operate unattended platforms and cope with the accelerating pace of operations and decision making.

The MoD's **Information Superiority** programme aims to achieve improved military results and efficiencies through evolutionary change as part of business as usual.

There is also the need for new skills and flexible working structures which can be adapted to new threats or methods of operation. This flexibility is even more important because of the increasing need to reduce overall costs dramatically, without compromising on national security; and to work closely with a diverse range of allies. The latter is, in itself, an efficiency move, but it means ensuring that all the partners' communications, data and intelligence systems can interoperate reliably whilst remaining secure.

The rate at which defence spending will continue to be squeezed will partly depend on developments in domestic and global politics which cannot be foreseen. However, the pressure to maximise cost efficiency will be a given for the foreseeable future and will drive changes such as greater use of commercial spectrum. This efficiency, as well as the new challenges of cyber defence/operations and shifting geopolitics, will shape the sector and its use of technology, including radio networks and spectrum.

8.5 Spectrum usage

Defence use of spectrum is extremely varied and in many cases, a complex capability such as electronic warfare, or large platform, such as an aircraft or aircraft carrier, can involve a large number of wireless applications in different bands.

Radio underpins many activities within the C4ISTAR platforms, the technology basis of all defence operations (C4ISTAR – Command, Control, Communications, Computers, Information, Surveillance, Targeting, Acquisition and Reconnaissance). That means that, in many situations, spectrum is considered a battle space, and acquiring and securing it can be as important as protecting land.

The Ministry of Defence is the UK's largest single manager of radio spectrum, with management rights to about 35% of the FAT (frequency allocation table). The frequencies employed range from kilohertz to gigahertz and some applications, such as radar, can span many bands.

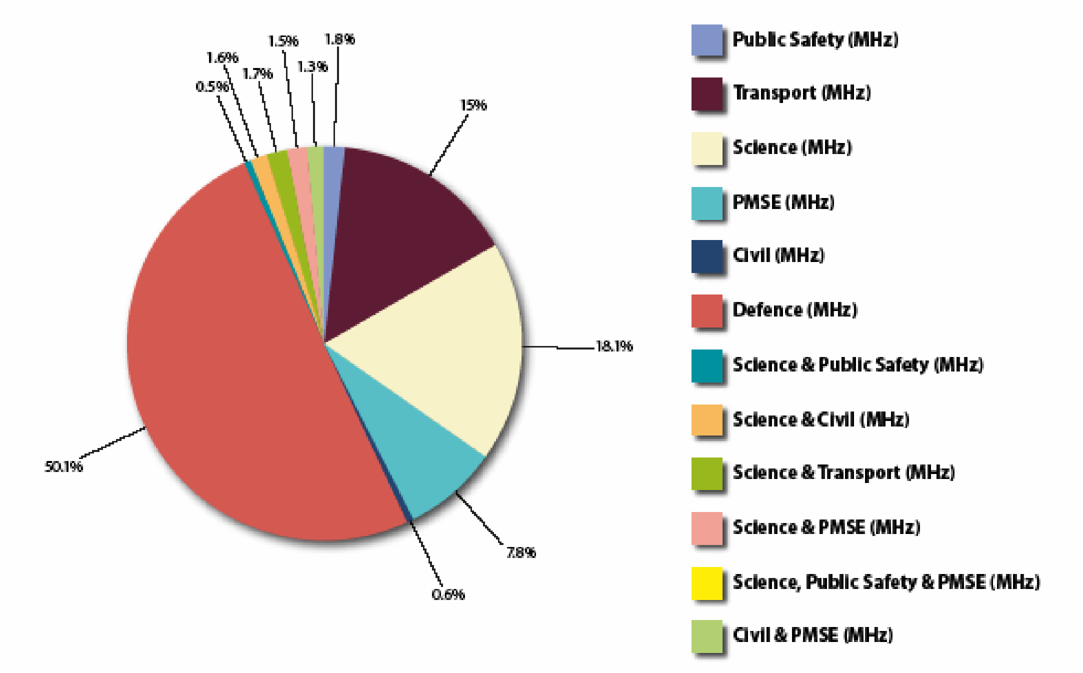

Figure 26: *Percentage of UK spectrum allocated to defence, compared to other segments.* **Source: Ofcom**

Some examples of defence usage of spectrum include:

Table 10: Examples of defence spectrum usage

Spectrum range	Example applications
LF spectrum (30 kHz- 300 kHz)	Submarine communications
HF spectrum (3 MHz – 30 MHz)	BLOS (beyond line of sight) communications over long distances or obstructed terrain
VHF spectrum (30 MHz – 300 MHz)	Tactical voice communications
UHF spectrum (300 MHz – 3 GHz)	Air-ground-air voice and data communications Personal management radios Ground-to-Air tactical data links Air navigation aids Geolocation systems
VHF/UHF	Tactical data communications
>UHF	Satellite communications
Millimeter wave	Weapon guidance radar Unmanned aerial vehicles (telemetry & data links)
Multiple bands	Air Surveillance and Control Systems (ASACS) Maritime navigation aids Electronic warfare systems Testing and training

Radar, which is used for a range of military applications, is one of the most significant users of spectrum – about 10% of that below 10 GHz, and about 25% of all military spectrum. Applications include tactical surveillance, maritime air defence and weapon guidance.

In addition to all these specialised applications, the MoD makes extensive use of services from other spectrum owners too, such as weather monitoring from the Meteorological Office; commercial radar and emergency services cooperation; and of course mobile communications over the public networks.

The defence supply sector:

It is worth noting that many defence suppliers and partners also use additional frequencies, whether private or commercial, in order to support both defence and other customers. Although not actually MoD spectrum, this does help enable some defence activities. The organisations which deliver spectrum-dependent systems to the MoD and other defence customers are represented by the Defence Manufacturers' Spectrum Forum (DMSF.

The members of the DMSF are:

- Chemring-Roke
- Rockwell Collins
- Ultra
- Selex UK
- BAE Systems
- Airbus Defence and Space
- Cobham
- MBDA Systems
- QinetiQ
- General Dynamics
- Thales
- Exelis Defence

These suppliers use spectrum for testing their platforms; for communications between people and objects such as vehicles; for tracking and monitoring; and for gathering data.

In their case, spectrum does not just support the MoD but international customers also. Many suppliers have become more dependent on exports, especially in emerging technology areas such as unmanned combat aircraft or robotics. Such technologies require **controlled and regulated, internationally harmonised** spectrum for full testing, as does one of the key growth areas for defence manufacturers, cyber-intelligence.

To develop, test and operate many systems before they are shipped to customers, vendors need a variety of spectrum-enabled capabilities. These include:

- Communications, which are increasingly complex and in which security is critical
- Support for **Information Superiority through a process of evolutionary change** and equivalent international programmes, which involves extensive use of sensors in many bands

- Navigation systems such as TACAN (tactical air navigation), VOR (short range system for aircraft) or ILS (instrument landing system)
- Identification systems such as IFF (identification friend or foe)
- Radar
- Electronic warfare support systems
- Telemetry

A vital aspect of spectrum usage by manufacturers is testing and measurement. In many cases, large items such as aircraft can only be fully tested outdoors and tests must be run in a wide variety of spot frequencies to ensure safety and reliability. Among the spectrum-dependent tests and measurements that might be run by a military equipment or aircraft supplier are:

- Electromagnetic hazards such as high intensity radiated fields or lightning
- Installed on-platform equipment performance testing, including wideband tests for electronic warfare systems
- Antenna performance measurement
- Radar cross-section testing (outdoor full-scale aircraft wideband measurements)
- Interoperability testing required to qualify for international orders

8.6 Expected changes to technology and spectrum

As noted in section 8.4, the changing nature of operations and defence will radically change, and often expand, the use of radio spectrum. For instance, the **Information Superiority** initiatives will often rely on wireless connectivity; and the increased emphasis on unmanned weapons, robots and cyber-operations will inevitably require new spectrum. At the same time, while the defence sector's use of spectrum is diversifying, there is increased pressure to use it more efficiently to reduce costs, and to free up or share spectrum, where applicable and practical, recognising that the rising demand for mobile broadband and other applications is increasing

One of the challenges is that it is difficult for the MoD to predict future changes in its spectrum needs, especially as it has a long equipment cycle (in some cases 10 years for procurement of kit which then lasts 30 years). In addition, most of its equipment has to be used overseas and so must conform to the spectrum policies of host nations and being able to operate in the relevant spectrum environment.

The MoD has shared some of the spectrum it previously managed. In the 2 025 MHz – 2 070 MHz band, where security of tenure has been granted to other services – notably, it now has formal recognition for PMSE air-to-ground usage – and that will count toward the 500 MHz being relinquished. There is already significant sharing of defence spectrum with other crown bodies and private sector users, with more under discussion. This sharing may be permanent – for instance, PMSE (programme making and special events) is a secondary user of some MoD spectrum – or temporary, as when the MoD provided spectrum for the Olympic Games in London and the Commonwealth Games in Glasgow, sharing military frequencies with police and other civil agencies for these events.

However, there will inevitably be divisions of opinion over how far and fast further sharing plans should be introduced, and at what point there is the risk of compromising military effectiveness.

This was recognised by the government in a March 2014 report, The UK Spectrum Strategy, in which the Department for Culture Media and Sport, which is responsible for most commercial spectrum, said:

> "At the same time as MoD is looking to release some spectrum, it is experiencing an increasing number of new demands for spectrum, particularly at a time when manpower is reducing and the hi-tech equipment that enables the Services to operate with reduced numbers is becoming ever more spectrum reliant. Balancing these competing demands requires careful prioritisation, planning and preparation. Value to society as well as the market place must be taken into account." [55]

Ofcom began its reviews of military spectrum as far back as 2002, and in October 2013, it announced that the MoD would release 190 MHz of spectrum to be repurposed, in many instances for mobile broadband (LTE). The frequencies in question are:

- 40 MHz in the 2.3 GHz band, between 2350 MHz and 2390 MHz. This will be released on an exclusive basis, although CEPT wants it to be a licensed shared access band.
- 150 MHz in the 3.4 GHz band, above 3410 MHz and below 3600 MHz

The regulator will manage the allocation of these licences, planning for FY15/16, and is likely to pursue an unpaired band plan as close as possible to international norms.

The Ministry of Defence has also relinquished spectrum in the 870–872 MHz paired with 915–917 MHz band. This was initially earmarked for sharing, but was released to Ofcom in 2013 and will be opened up for licence-exempt short range devices, smart grid and RFID, in line with EU harmonisation processes.

In November 2011, the MoD also outlined plans to open up some of its bands for sharing with public or private sector organisations (updated in December 201256. This will be an important element of the UK government's pledge to release 500 MHz of sub-5 GHz spectrum by 2020, mainly for mobile broadband use. Work is ongoing to achieve the Government's spectrum release targets. A review process will establish which bands may be suited to sharing, and what the terms are, and once agreed, Ofcom will be responsible for any issuing and charging for licences.

The objective is to make parts of the MoD bands where there is spare capacity, because an application is only required in certain locations – available for sharing, provided defence capabilities are not impacted. There has been discussion about clearing certain frequencies altogether, but the MoD argues that this would have to be at no cost to itself. Clearing of spectrum, as seen in the 2.3 GHz band, can be very costly, with the costs potentially outweighing the potential revenue, as the US found in its deliberations on whether to clear some of its AWS band.

The most important factor in these discussions will be ways to allow defence frequencies to be shared, without risk of interference to the incumbents.

As the DCMS report pointed out, this is particularly true when defence requirements for spectrum are growing and changing. New spectrum-based technologies will be harnessed to meet several important demands over the next few years, including:

- More agile decision making and response based on C4ISTAR principles, often enabled by wireless communications
- Flexible and reconfigurable systems to improve effectiveness and prolong the life of key assets
- Greater efficiency required by reductions in permanent staff
- Support for emerging unattended and unmanned platforms
- Support for the Land Environment tactical communications system
- Rising traffic generated by new intelligence gathering systems and by greater use of data communications between soldiers and other personnel

At the CeBIT trade fair in March 2014, Prime Minister David Cameron said the government's strategy for spectrum was a "gradual move away from exclusive use to shared use of frequencies". As the largest manager of spectrum, the MoD and its supply chain will come under pressure, and the MoD says it is fully engaged in that process.

Cameron said sharing would be a key enabler of the goal to double the economic benefits of spectrum to the UK economy, as estimated by Ofcom, to £100 billion by 2025. The government has invited a panel of experts to advise on options such as dynamic spectrum sharing mechanisms, and this will publish its conclusions in July 2015.

Many countries are having similar consultations about sharing military and other spectrum with commercial providers, notably the USA. There is particular interest in technologies – such as some types of radar – which use large amounts of spectrum, but on a geographically limited basis; or others which need their frequencies only occasionally.

Mechanisms are sought which would allow secondary users to take advantage of these frequencies where or when they are not being used by defence systems. Some of the pioneering work has been done in the white spaces within the TV bands (TVWS spectrum), which the US, UK and others are opening up for secondary use by licence-exempt wireless broadband or M2M providers. Some of the lessons could be applied to certain military frequencies, although with even greater safeguards against interference, security breaches and congestion.

The ability of mitigation tools and techniques to provide the necessary protection for military radio communications and location systems is the subject of study and investigation by ITU-R and CEPT. Areas covered include geolocation databases, which secondary user devices must consult before connecting to locate vacant channels; and 'detect and avoid' technologies incorporated into secondary devices. DCMS is looking at geospatial databases and other dynamic methods amid concerns that such techniques will not provide adequate protections. For instance, many spectrum assignments in this sector are not geospatial (most of the towers are mobile).

There is much detailed work to do, and in the meantime new technologies and standards will evolve around sharing in general – for instance, in the area of cognitive radios, which would enable more dynamic shared access in future, but remain several years away from standardised, certified devices.

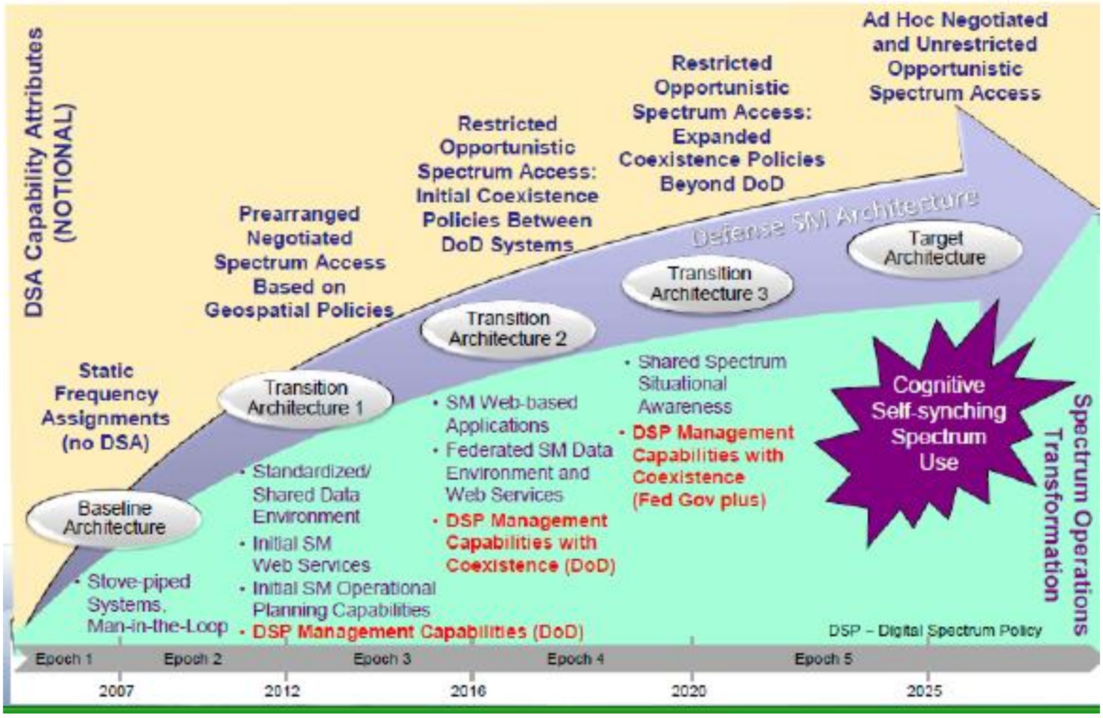

Figure 27: *United States Digital Spectrum Policy roadmap. Source DISA (Defence Information Systems Agency)* [57]

Figure 27 indicates the way that the US government is thinking with regard to dynamic sharing and cognitive radio. The Defense Information Systems Agency, which – among other responsibilities – manages spectrum for the Department of Defense, foresees a 20-year progress from current static frequency assignments, via the current approaches such as geospatial databases and policies, towards more dynamic opportunistic access and eventually, the ultimate goal of fully ad hoc, automated platforms to allocate and synchronise frequencies on demand.

Sharing is being considered in some critical frequencies, as shown by some of the tests carried out on both sides of the Atlantic in recent years. Many challenges remain, particularly in the areas of security, trust and guaranteed quality of service for the primary user, especially for critical applications. For instance, in August 2013, the US Navy carried out tests with its AN/SPY-1 radar system, part of the Aegis anti-missile platform, running in the same 3.5 GHz band as an LTE base station. However, significant concerns were raised about interference with the radar by LTE [58].

The defence sector accepts that there is pressure being brought to bear for more sharing of its spectrum in future. However, as the primary user, the MoD, needs robust protection, there must be sharing mechanisms in place to ensure that. The MoD also calls for recognition that it will need continued spectrum access to support information superiority.

Some stakeholders believe smarter ways to share access could include a UK register of usage, so that decisions would be based on real time usage information; a catalogue of emissions, acting like a fingerprints database for wireless; and an extension of the geolocation database concept to a full ‘sandpit’ of spectrum, with far more granular data on time, channels, location and other aspects. The MoD acknowledges this initiative but has not yet had the reviewed the concept, as Spectrum Release business has taken priority.

8.7 Long term technology and spectrum needs and options

In the longer term, there is only likely to be greater pressure for defence agencies to be very efficient with their spectrum so that more is available for commercial purposes. That pressure could intensify when the UK starts to move towards '5G' mobile networks which, though entirely undefined as yet, are likely to start trials from around 2019. Many believe 5G will make greater use of high frequencies such as millimetre wave, which are suited to very dense networks of small cells, and so the call for sharing could move up the spectrum from the current mobile sweet spot below 3 GHz, to higher MoD bands.

Radar spectrum will also come under scrutiny, as indicated by projects to investigate techniques like 'passive radar', which could free spectrum for '5G'. For instance, last year saw Thales working with UK civilian air traffic control provider NATS and R&D organisation Roke Manor on investigating the use of existing TV signals to locate and track aircraft using passive radar, an old but currently less used approach. That could potentially free up ATC spectrum. The system works by measuring the timing of TV signals reflected from aircraft to determine location and, by measuring the Doppler shift of the signal, to track speed and direction. However, there are major doubts over whether the range and types of defence radar would be able to adopt such an approach, particularly given the substantial investment in a complete overhaul of MoD ATC systems and the unique role of Air Defence Radar systems.

Since radar is a significant user of the spectrum, the release of even a small percentage could provide significant gains for other sectors. The Civil Aviation Authority is carrying out a feasibility study, for instance, in 2.7 GHz-2.9 GHz, though there are no conclusions yet on the practicality or potential applications. However, many radar players believe there will be limited opportunity, if any, for sharing this spectrum, even in the longer term, as radars cannot tolerate significant in-channel interference without noticeable loss of coverage coupled with system degradation not being observed by the operator creating the risk of a potential operational cliff edge. Moreover, radar signals are inherently broadband and therefore likely to cause interference to any collocated radio system.

Perhaps the biggest reason to be cautious about widespread sharing is that spectrum will not just be necessary to support new defence activities in the next decade, but could potentially become a battle space in its own right, as unmanned and cyber technologies take centre stage, and warfare becomes more dynamic and, in many cases, more 'virtual'. This raises issues around usage and security which are unique to this sector, since with many of the key emerging technologies, such as ultra-precise weaponry, it is not yet clear exactly how they will use spectrum.

Figure 28 shows the direction in which defence industry spectrum roadmaps and R&D programmes are heading. Over a period of perhaps two decades, the industry and armed forces in many countries will develop new command and control systems which rely heavily on radio technology to support unprecedented levels of rich intelligence and dynamic operations – the two critical enablers of a lean, agile framework for decision making and action. Just as the defence processes themselves have to become agile and dynamic, so will the spectrum and radios that enable them.

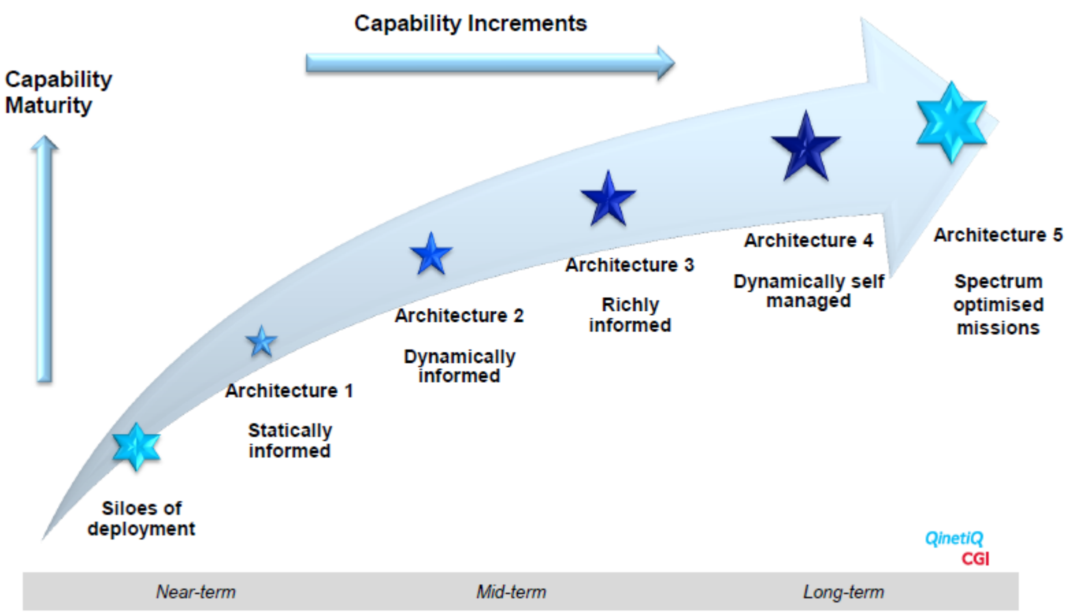

Figure 28: *Spectrum research roadmap for defence usage* Source: QinetiQ [*59*]

A.9. Transportation

9.1 Scope of the sector

The transport sector comprises services and equipment for carrying goods and people on aircraft (private, commercial and defence aviation), trains, metro/city transportation systems, ships (including fishing), and road vehicles. This chapter does not cover the automotive manufacturing industry except in terms of the adoption of intelligent transport systems. Nor does it cover in detail wireless smart city systems, although these often have a transport element (such as smart traffic management), as these will be covered elsewhere.

All these forms of transport are increasingly dependent on wireless connections for communications, customer services, navigation, security and safety, and automated control. A commercial jet, for instance, has about 30 antennas.

There are multiple layers of spectrum-using organisations needed to support any one transport service, notably:

- The public or private service and vehicle operators e.g. airlines, train and bus operators, shipping lines.
- The agencies providing and supporting the infrastructure for those operators e.g. Network Rail delivers train signalling and communications; Transport for London (TfL) supports real time passenger information and driver communications in the bus, Underground and riverbus networks; and so on.
- Transport authorities e.g. the UK Department of Transport centrally manage intelligent transport and road toll systems; the Civil Aviation Authority (CAA) regulates aviation safety and air traffic control; the Highways Agency uses road traffic telematics and road toll systems.

Because of the mobile nature of the vehicles, there is significant intervention by international (in the case of aviation and maritime) and national agencies to ensure harmonisation of radio usage when trains, ships and aircraft are moving into different regions.

In addition to their dedicated wireless networks, the focus of this chapter, all these transport organisations are also significant users of services which are covered in other chapters, particularly those in licence-exempt spectrum, including Wi-Fi, PMR (private mobile radio)/TETRA and short range devices for applications like metering and monitoring.

9.2 Contributions to social and economic value

Transport is a significant contributor to the UK economy and the aviation industry alone accounts for about 4% of GDP or £64.5 billion [60]. This sector (including storage) employed 1.4 million people and carried 197 million passengers in 2012.

The railway sector employs 212,000 people and its tax contribution, of £3.9 billion in 2013, offsets government funding for the industry almost precisely. The sector calculates that it delivers £13 billion a year in benefits to passengers and freight users, and £10 billion of additional GDP through its supply chain and impact on stimulating other economic activity.

The maritime industry makes a direct contribution to the UK economy of between £8 billion and £13 billion, according to 2013 government figures. More than 90% of global trade is carried by ship, and 99% of UK trade by weight [61].

As well as contributing directly to the economy, the transport industries stimulate productivity and GDP increases in other sectors by enabling greater efficiency. For instance, at the start of the Crossrail railway project, the GDP benefit for the UK was estimated at £20 billion and the welfare/social impact benefit at £19.9 billion – many of those benefits resulting from shorter journey times [62].

The same mixture of direct and indirect benefits is true of the wireless networks that support the transport sector. In spectrum terms, the government deliberately steers away from placing a value on spectrum usage when it is primarily for social value, as in transport control systems [63]. In a March 2014 study on spectrum valuation for DCMS (Department for Culture Media and Sport), it stated: "In parts of the transport sector, such as aviation and maritime, major contributions are made to the UK economy not only through the direct value of these networks but also in the support they give to the economic viability of many other service industries. Maritime for example contributes £14 billion and aviation £50 billion each year to the economy and rely extensively on radio and radar systems to ensure safety."

9.3 Current and recent past status

The transport sector touches on almost all aspects of social and economic activity and so its usage and investment patterns are complex. It includes public, private and hybrid operations; commercial and social objectives; for-profit and subsidised models; local, regional, national and international governance. Different transport methods may compete for some business while also cooperating to create integrated transport networks, especially in cities. Transport is also a highly political issue, involving large sums of taxpayers' money, issues of public service levels and social justice, and some flagship UK corporations such as British Airways.

The requirement for all kinds of transport has grown steadily along with key trends such as:

- Increased consumer spending, and rise in globalised trading, driving freight transport by sea, road, air and rail.
- Urbanisation, putting pressure on metro transport resources.
- Rise in international travel, especially leisure and long distance travel. The number of air arrivals and departures in the UK peaked in 2007 but the trend turned up again in 2013, when 228 million terminal passengers were recorded.
- Rise in car ownership – cars, vans and taxis accounted for 83% of distance travelled in the UK in 2013, up from just 27% in 1953. That has been somewhat offset in the past six years by rising fuel costs and green concerns, which has shifted traffic primarily to the railways.

In 2010, 22 billion tonne kilometres of domestic freight were moved within the UK, about the same amount as in 1990 but down 14% from the 2005 peak because of recessionary factors and increased international trade [64]. About two-thirds of this travelled by road, 19% by water and 9% by rail (and 5% by pipeline).

In recent years, the rise in energy costs, because of increased oil prices and taxation, and the increased interest in green issues, have led to an intense focus on energy efficiency to reduce costs and emissions. After a peak in 2008-9, energy usage has been falling in the transport sector even though usage has grown (Figure 29). This has happened because of efficiency measures, and shifts in the pattern of transport – for instance, from cars to trains and buses; from road to rail freight or air to sea [65].

Railway usage is increasing – passenger journeys have risen by 115%, and the amount of freight transported by 70%, over the past 20 years. The current rate of passenger growth, of 1.5% to 2% a year, is likely to continue for the foreseeable future as train usage is driven by faster services and new routes, the cost of petrol, green considerations and other factors. Rail passenger journeys in the UK have doubled since privatisation in 1994-5.

Use of public transport has risen for the same reasons, especially in major cities. In 2013, light rail and underground journeys were at their highest level ever and bus journeys rose after six years of stability, with London accounting for 50% of the total.

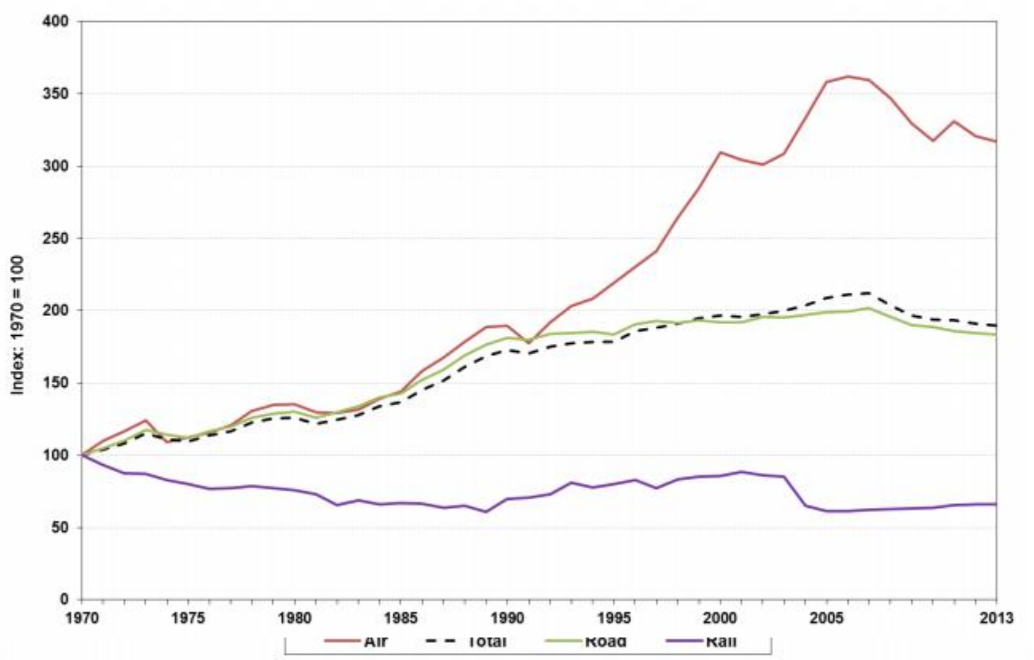

Figure 29: Patterns of energy consumption by the UK transport sector, by transport type. Source: DECC July 2014 [66]

9.4 Sector trends

These trends in usage drive several trends which are common, to some extent, to all transport methods, and which then place new burdens on wireless networks and spectrum. These include:

- Ever-growing safety and security expectations, among the public and regulatory agencies
- Need to alleviate transport congestion and improve levels of service (eg timeliness) with the use of wireless monitoring and planning systems
- Environmental pressures

- Rising use of data, and rising criticality of some data applications, in transport communications
- Rising customer service expectations

In most areas of transport, there are growing numbers of routes as well as passengers, requiring larger or more complex wireless management systems (new railway and Tube lines, airline and bus routes). For instance, an increasing number of train lines plan to use in-cab signalling or ETCS. Expansion of the systems can also raise safety concerns, driving investment in wireless technologies which can reduce risk, often based on radar (anti-collision systems for aircraft, cars and buses, for instance).

Passengers demand new services such as on-board Wi-Fi and real time travel updates, and freight customers also want to be able to track their consignments at all times. Transport operators in competitive areas like passenger flights or cross-Channel links are always under pressure to improve customer satisfaction and increasingly that revolves around mobile apps and information. Government agencies also harness technology to improve satisfaction levels to justify tax support for transport, and to introduce efficiencies such as NFC-based ticketing (on London transport and elsewhere).

The trend towards greater use of machine-to-machine communications, and the progress towards an IP-based 'internet of things', is starting to be felt across the transport sector for a wide range of purposes, from tracking the vehicles themselves, to monitoring on-board conditions and identifying possible faults or safety risks, to supporting ticketing systems.

From the technology point of view, the combination of increased customer demand, and rising pressure to save cost and fuel, is driving investment in 'smart transport' systems in most segments. These use many types of sensors to monitor fuel efficiency, traffic patterns and so on, and to automate formerly manual processes, the eventual endpoint perhaps being the driverless vehicle (already here in light railways and drones, a distant prospect in passenger aircraft). Transport is an important element of any smart city project.

However, there are significant barriers to adopting new technologies rapidly in the transport sector, especially when it is international, because of the need for global consistency. Infrastructure takes many years to plan and build, safety testing is rigorous, and the environment is heavily regulated.

So for instance, commercially, the aviation industry is developing quickly, with rising levels of passengers and freight. However, its adoption of new technologies has not matched this evolution, because of the wide array of regulations which govern new developments, as well as the long timescales for developing, testing and introducing new technologies.

As well as the CAA, aviation is governed by at least eight international agencies, alliances and standards bodies including, on the radio front, the ITU, CEPT and ETSI; and on the aviation side, the ICAO (safety, interoperability and general principles), the RTCA/EUROCAE (minimum operational performance standards), Single European Sky (SES) and its associated air traffic management research (SESAR) programme and EASA (European Aviation Safety Agency).

The same issue affects maritime usage, with limited freedom of action when choosing radio equipment or spectrum bands, since global harmonisation is important. The main regulators are the International Maritime Organisation, which collaborates with the ITU on spectrum matters, while the IMO's SOLAS (Safety of Life at Sea) convention defines much of the radio gear.

In addition, timescales for aircraft and ships are very long compared to other wirelessly connected objects such as smartphones or even cars, so there can be no rapid adoption of new technologies or spectrum rules. For instance, while the availability of a new spectrum band might take 3-4 years, based on the World Radio Conference schedule, aviation standards cycles are typically more than five years (e.g. ICAO), while the development of a new aircraft can take up to 10 years from concept to commercial flight. Once in the sky, it can be in service for 40-50 years. There is a seven-year notification period for aircraft modification, and the most significant type of maintenance process, the D Check (which would be necessary to fit a new antenna), takes place only every six years and can leave an aeroplane out of service for two months – a serious commercial consideration. In addition, operational use can frequently only be delivered once a sufficient percentage of equipage on an international scale has been achieved necessary to maintain safety.

The implementation of modern technologies in railways has also been relatively slow because of regulatory, economic and safety pressures.

9.5 Spectrum usage

Aviation:

Without spectrum, aeroplanes cannot fly – a modern jet has about 30 antennas for communications, navigation and surveillance. Figure 30 indicates the wide variety of antenna types, applications and spectrum bands which will be in use.

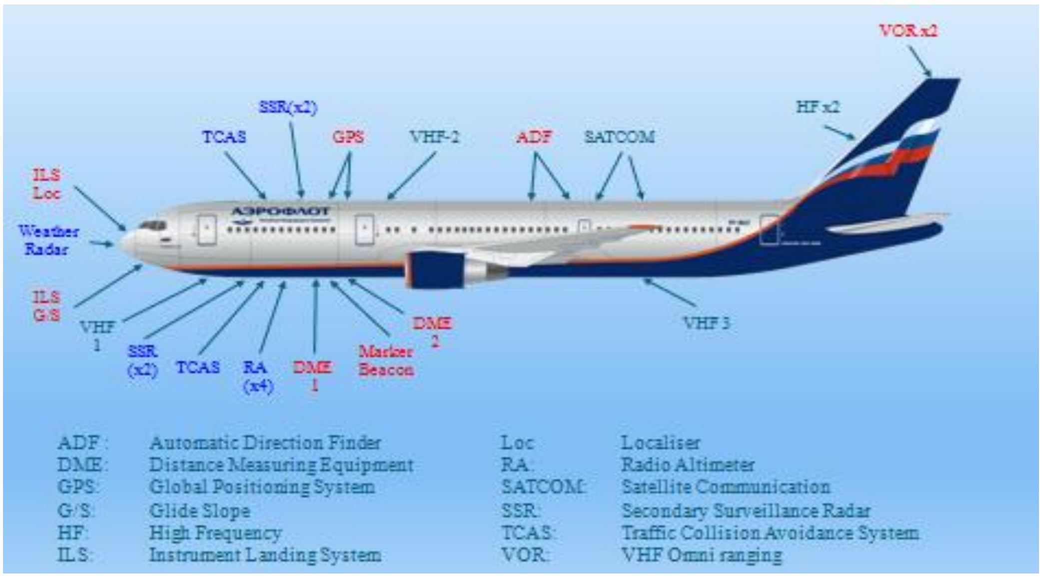

Figure 30: Typical antennas in modern commercial jet. Source: CAA

Frequencies in use by aircraft range from 100 MHz to 100 GHz, and services include:

- Air-to-ground communications in MF, HF and VHF bands plus satellite
- Ground-based navigation systems such as beacons and landing systems, supplemented by satellite

- Ground-based radar for air traffic control support and to monitor movements around airports, in the L-, S-, X- and Ku- bands.
- Airborne applications including weather radar, in-flight communications, in-flight broadband, altimeters
- Distress and safety systems

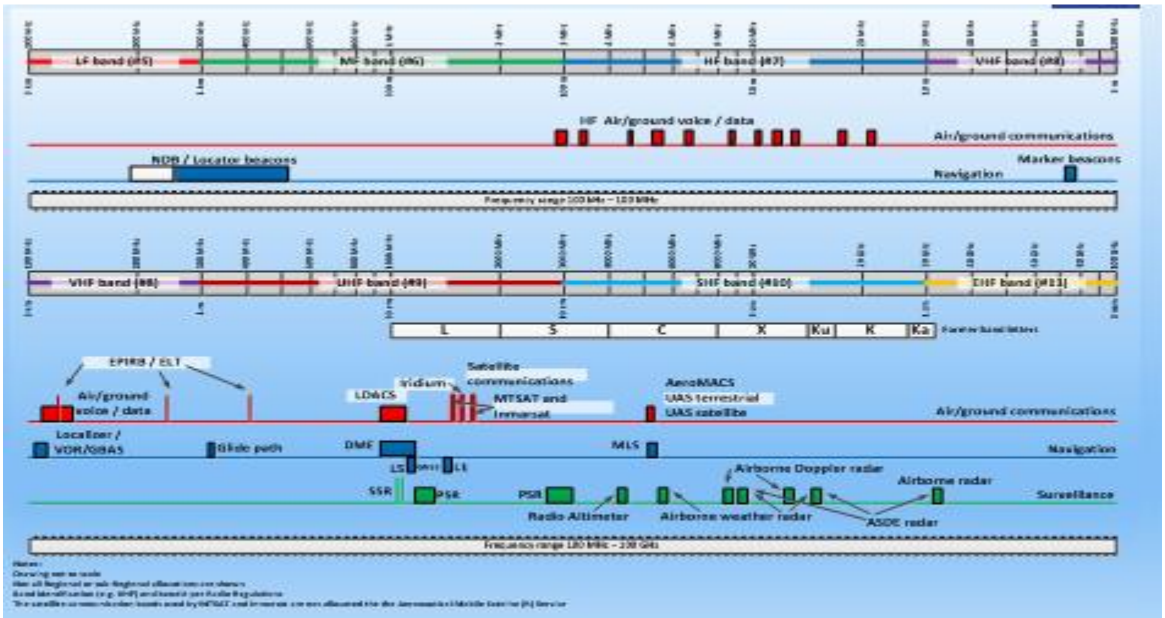

Figure 31: Global allocations of spectrum to the aeronautical sector. Source: CAA

Because of the global nature of the air transport industry, many areas of frequency planning are internationally harmonised, particularly for safety, communications, navigation and secondary radar. In areas of intensive activity, such as the European Union, further coordination of spectrum usage is required, and this is achieved by national regulators via Eurocontrol and ICAO systems. The UK's Civil Aviation Authority issues spectrum licences to commercial aircraft services on behalf of Ofcom. In many cases, aviation bands are shared with other users, such as the Ministry of Defence. In addition to sharing, MOD is a joint user of aeronautical spectrum to support common systems carried on defence aircraft to maintain safety through interoperability.

Rail

The sector is steadily replacing the fragmented older systems for train-to-track communications with GSM-R, which is now mandated and makes the UK railways EU-compliant. Deployed by Network Rail, it runs in the 900 MHz band. Its primary application is voice communication for drivers and other crew. In the southern region, GSM-R's predecessor, the National Radio Network (in 200 MHz) has already been turned off and other regions will follow. Other legacy systems which will be phased out include Cab Secure Radio in 450 MHz and the Radio Electronic Block in 200 MHz.

An important change is the steady replacement of trackside signalling infrastructure with in-cab signalling, supporting real-time intelligent traffic management. Other innovations in control systems since 2007 include:

- Commissioning of the first European Rail Traffic Management System (ERTMS) project Initiation of Network Rail’s control centre consolidation strategy
- Pilot projects for Driver Advisory Systems (DAS)
- Automatic train operation (ATO) on Thameslink and Crossrail

Beyond in-cab signalling, control systems and voice, there are many other types of communication used in trains, as seen in Figure 4.

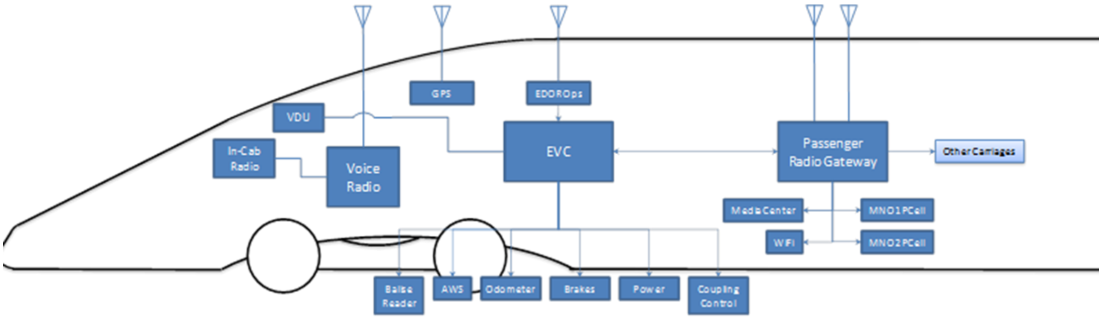

Figure 32: The wide range of communications used in trains. Source: Network Rail

There is a wide range of communications to be carried to and from drivers, on-track maintenance staff and signallers, both for emergency response and day-to-day information. In-cab signalling is also an important application and trains are starting to feature more passenger wireless services, such as in-train Wi-Fi (which may be backhauled by cellular or satellite).

Unlicensed spectrum is also commonly used for support purposes such as connecting CCTV security cameras on tracks and stations.

The London Underground has particular communications needs to link its stations and trains (some of them driverless), and has its own Airwave Tetra network for communications to its 125 below-ground stations, and particularly for emergency response, an issue which went up the agenda after the 7 July 2005 London Tube and bus bombings.

Maritime:

Like other transport methods, ships of all kinds use spectrum for a wide variety of purposes, many of them mission critical and some internationally harmonised. These include:

- Safety – distress and SAR (search and rescue); collision avoidance
- Navigation – position fixing, maritime safety information, beacons, radar, differential GPS
- Security – vessel monitoring, anti-piracy
- Operational – on-board passenger management and communications, fire-fighting, port operations, commercial management
- Social communications for crew and passengers using satellite/VSAT
- Shore-based and ship-based radars for vessel traffic services (S-band and X-band)
- Ship-to-shore communications

Assignments for shore-based services are carried out on a national basis by Ofcom, and a ship's one-off lifetime licence covers all maritime radio systems. Maritime radar often operates in spectrum shared with the CAA and MoD.

Radio communications in the low frequency UHF and VHF bands are particularly important since the signals can penetrate ship elements like the bulkhead, while keeping them water-tight (a significant risk of installing cables). The maritime sector sees this as an important argument for retaining or increasing its allocations in the UHF band and says that there have already been problems in some ports in states where UHF spectrum has been released to other users. It is also becoming increasingly difficult to make new VHF assignments to ports.

The maritime sector continues to roll out additional functions within the IMO's GMDS (Global Maritime Distress and Safety System), which will be in use for at least another two decades. Its basic functions are alerting, search and rescue coordination, safety information broadcasts, locating, and bridge-to-bridge communications. Key elements include the EPIRB (emergency position-indicating radio beacon) in 406 MHz, the Navtex information broadcast system in 519 kHz, Inmarsat C satellite services, high frequency radiotelephony with digital selective calling, and other elements which will be mandatory on vessels above a certain tonnage.

Road

Road-based public transport, mainly buses and trams, are significant users of wireless systems. Private vehicles have not generally needed dedicated spectrum, and where they have relied on wireless communications, these have been over the public mobile or PMR networks (the latter for applications such as taxi dispatch or road freight monitoring). However, this situation will change with the rise of smart transport, often within smart city programmes; and intelligent vehicles. Both these related trends may require dedicated frequencies, and/or put increased pressure on existing licensed and licence-exempt bands (see below).

For now, the heaviest road users of dedicated spectrum are the bus networks, especially in London, which has 9,000 buses. These vehicles and their crews are managed by 43 dispatch and control centres. The main wireless network connecting all these elements is the MPT 1327 analogue trunking radiocomms network, powered by 10 radio sites and 66 traffic channels. This supports voice and data, emergency calls from bus operators, route control and the AVL (automatic vehicle location) system.

The buses are equipped with radios and interfaces to the AVL system, which since 2008 has been known as iBus. This tracks the position of the buses for the purposes of service management, planning and emergency response. Increasingly, its positional data feeds into passenger services such as real time bus arrivals boards, and it can integrate with smart transport systems, for instance to trigger priority at traffic junctions.

9.6 Expected changes to technology and spectrum

Aviation

The use of wireless technology will only increase in aircraft, which could create new demands for spectrum, at a time when the industry will also be under pressure to use what it has more efficiently, to share it or even to release it. Some transport agencies already share spectrum with other government bodies, especially defence (GSM-R is deployed in 900 MHz defence spectrum, and transport applications could use some of the bands which the MoD is considering for release).

Such sharing will be extended to commercial mobile services in future. As part of the UK government's programme to free up 500 MHz of public sector spectrum for commercial use, the Department for Transport and the CAA are leading studies into the possible release of 100 MHz in the 2.7-2.9 GHz band, in the 2016-2020 timeframe. This band is currently used for civil and military aviation radar but could be attractive for mobile broadband as it is next to the 2.6 GHz LTE band.

The studies are examining the potential to refarm this spectrum by retuning radars to operate in the upper end of the band, or in 2.9-3.1 GHz. In parallel, they are assessing whether there is potential to replace existing radars with new technologies in other bands, and the broader issues of future aviation surveillance needs.

The initial results of these feasibility studies should be known soon, and depending on the outcome, more detailed field testing will commence, as well as studies into the possible uses of the frequencies, and into coexistence with users in nearby bands. Ofcom says a limited release might be possible before 2017 through refarming, but the full release would likely rely on new technologies [67]. Despite the challenges, 2.7-2.9 GHz may be considered as a candidate band at this year's World Radiocommunications Conference (WRC-15).

In other spectrum areas, the aviation industry may require more spectrum, be more creative in how it uses its existing allocations, or will use technologies in additional bands. Some of the expected developments which will have an impact in the next few years are in wireless avionics, where increasingly there will be replacement of wires with radios; and additional sensors to support more complex applications with increased diversity of routing. These activities are accommodated by existing spectrum allocations to the industry but are likely to see rising usage.

The same is true of new uses of radar, including plans to use radar on aircraft wing-tips, particularly to avoid collisions during taxi. One of the agenda items for the WRC-15 conference is the possible reuse of automotive radar in the same spectrum for this purpose.

Because of rising aviation activity, increasing numbers of wireless applications, and the level of sharing, congestion is being seen in some bands, notably in VHF. Some remedies have been actively explored, such as fitting aircraft with narrowband VHF radios (8.33 kHz rather than 25 kHz, phased in since 2007).

Conversely, there has also been discussion about releasing some of the spectrum used by aviation, especially in the S-band radar band, as new and more spectrally efficient technologies are phased in. However, this is only practical when it is coordinated with other countries, and when there is no risk of the new radar technologies interfering with services in nearby bands.

Rail

In the railway sector, the eventual goal would be to get rid of lineside telephones and theft-prone copper wires, and as well as increasing reliability, a radio solution would enable new applications, such as proactive maintenance (monitoring trains and infrastructure to detect in advance what might develop a fault), which would further improve efficiencies and passenger service quality. There is increasing use of machine-to-machine technologies for purposes such as monitoring conditions in the train, but little availability of equipment in the GSM-R band, which limits the economics.

In the next few years, GSM-R will become universal on railway lines, but will also be evolved in terms of improved coordination throughout its band. The use of GPRS on the system will increase its functionality, especially related to in-cab signalling and improved passenger communications.

There will also be increasing use of gateways on trains to support Wi-Fi or cellular services for passengers.

As in other transport sectors, there is already discussion of how increased data usage will be supported, and what the future railway control and communication system will look like (see next section for details). Figure 33, a routemap from the rail industry's Technical Strategy Leadership Group (TSLG), indicates the ongoing evolution of railway systems, the complex range of technologies they involve and the long planning timescales.

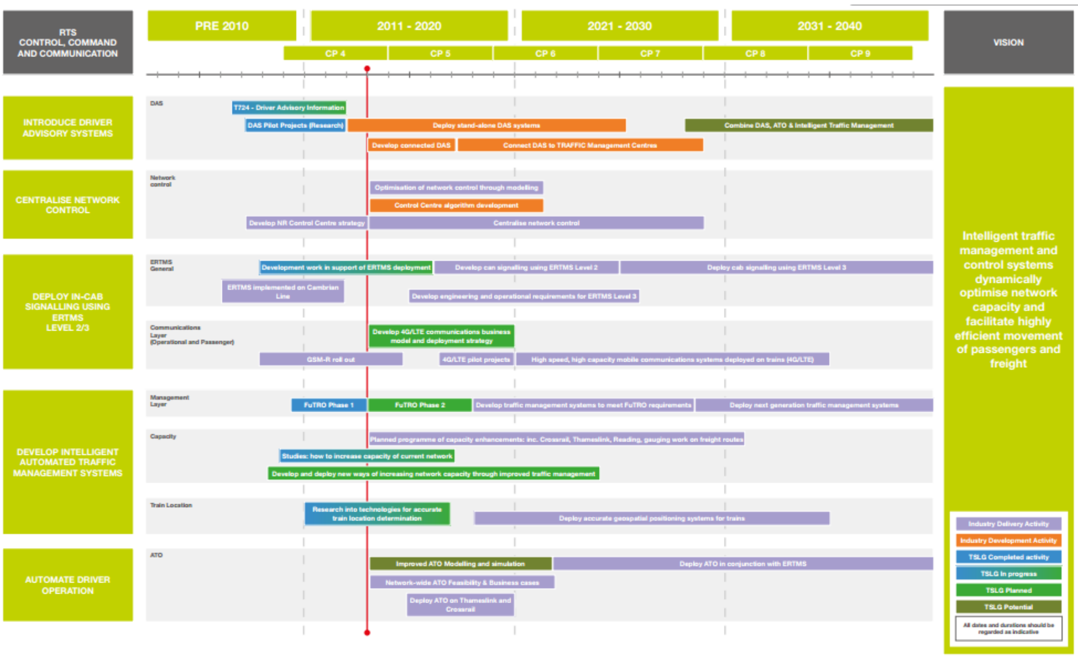

Figure 33: Routemap for control, command and communication, TLSG [68]

As on the above-ground railways, the London Underground needs to plan for higher levels of data usage in future, and for some data applications potentially becoming as critical as voice. The Home Office is currently evaluating possible successors to the current Airwave Tetra system for use after 2019, when the current PFI contract expires.

The Tetra system is connected to a fiber SDH backbone so that any staff at any station can communicate, but like GSM-R, it has challenges with data performance. London Underground wants to support faster data channels for applications like fault detection or proactive maintenance, based on information from trains.

One choice, as with other public transport data systems, is to use LTE, either the public network, or in a modified form in dedicated spectrum. However, no mobile operator has yet built out a cellular network to reach into the tunnels, which include the deepest in the world and are a challenge for mobile coverage. LUL wants to negotiate with Ofcom to receive additional spectrum which would support a wireless data network that would be effective in supporting data to and from underground and overground trains and stations, plus portable handheld devices, in-cab CCTV and other connected equipment.

Maritime

In the maritime sector, the most important trend in the near future will be the transition to digital, which will create spectral efficiencies and support new services, notably E-navigation for decision support systems and 'single window'.

Other developments will include additional service provision in GMDSS (global maritime distress and safety system), as well as improved, and increased, usage of on-board UHF communications.

As in other areas of transportation, there is already some interest in the application and the spectrum impact of unmanned craft.

There will be a rising number of data-intensive applications which may require new additional spectrum or heavier use of public networks, but will also drive more efficient ways to use existing frequencies. The migration to digital is an important aspect of this, though it remains an area of debate whether the efficiency of digital systems will create sufficient additional capacity to avoid the need for new sub-1 GHz spectrum allocations in the short to medium term.

Also boosting spectral efficiency, there has also been a move from duplex to simplex channels in some areas where this is possible under international harmonisation rules. About half the VHF channels assigned to the aeronautical and maritime sector are UK-specific and so can be subject to efficiency measures[69]. New radar technologies are also seen as an important ongoing study for potential spectrum efficiencies, provided interference concerns can be addressed.

Road

For the buses in London, and some other heavily used urban networks, the current wireless communications system is in need of upgrading to ensure efficient service control as well as safety levels. The current London system was designed a decade ago with the assumption that there would be 30,000 calls a day, but the current average is 55,000, with a peak of 65,000, especially during major events or disruptions, or industrial action.

Over the next five years, the bus services will be expanded by at least 5% to keep up with an anticipated increase in passenger demand of 7%, which means there will be even more dispatchers and calls stretching the capacity of the radio network. In addition, TfL (Transport for London) expect levels of intervention by bus service controllers to rise as the organisation tries to meet more stringent targets – for instance, keeping excess waiting time below one minute – and because of major road infrastructure projects which cause diversions and other issues.

The current system cannot handle many more dispatchers and by the end of 2016, it is expected to have reached its ceiling in terms of call volumes, with possible effects on quality of service. There are also issues around the complexity of a network which needs to support the mobile radios in buses as well as the hand portable devices, delivering the same communications – there are already 300 of these in use and more will be introduced, mainly in bus stations but potentially on a far wider basis.

More capacity will be needed, and there are various options under discussion for upgrading the system. One is to use commercial LTE, but with additional mechanisms to guarantee coverage, availability and public safety. That would entail more redundancy mechanisms than are usual in commercial LTE, plus guaranteed access. Some aspects of the future bus communications network appear not to fit well with LTE in its current form, such as the large number of broadcast calls made to all drivers (though LTE-Broadcast might help with that, if implemented in London).

Another possibility is to carry the AVL data on the London Bus private network, either primarily, or as a fallback for LTE. Since the move to a digital PMR (private mobile radio) network will double channel capacity that could avoid the need for brand new spectrum, at least for a while. However, existing digital PMR functionality will need to be enhanced if it is to be the primary system. The requirements of the next generation bus network are complex and stringent, including:

- Support for all current functionality and the AVL interface
- Open interfaces for the bus radio
- Dynamic route call groups
- Increased data bandwidth for foreseeable and future needs
- Dynamic network management and optimisation
- Support for an all-IP connection in the bus

In addition, the migration has to happen on a fleet and network which must continue to operate 24/7, and must be implemented across a large number of vehicles with specific antenna challenges.

Intelligent transport

The other major issue on the road is intelligent transport. There are many developments in this area, with input from the automotive industry, wireless and applications service providers, local authorities in smart city initiatives and device manufacturers. Much of this takes place in public mobile or licence-exempt spectrum – IVI (in-vehicle infotainment) and other connected car services, some city-driven applications like smart parking, often using unlicensed 868 MHz spectrum.

However, one aspect that affects current and future spectrum policy and will require new frequencies is the Intelligent Transport System (ITS), which is designed to improve road safety and includes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications. In 2009, Ofcom published its regulations for ITS [70], in line with a European Commission Decision of 2008 to mandate harmonised use of the 5875-5905 MHz band for the safety-related applications of ITS. The decision had to be enacted by member states by 5 February 2009. Safety-related, vehicle-based ITS applications were to be licence-exempt, but for safety-related ITS infrastructure, and non-vehicle installations, licences would still be required.

In 2009, the US Department of Transport and the EC's CONNECT directorate general agreed a coordinated research programme around V2V, on the basis that these systems would enable safer, less congested and more energy efficient road transport via functions like collision avoidance and emergency vehicle access. One of the key goals is to harmonise over-the-air interfaces and protocols.

Most of the ITS work in the EU and US has focused on Wi-Fi, particularly a special variant, 802.11p, devised for dedicated short range communications and operating in 10 MHz bandwidth in the 5850-5925 GHz band. There are also systems which use 3G or LTE, and because of the best effort nature of 802.11p, ETSI has also considered a proposal based on an alternative MAC (medium access control) protocol, STDMA (self-organised time division multiple access). In either the 11p or STDMA case, some analyses have suggested that, in dense traffic environments, more than 80 MHz of bandwidth would be required to achieve 99% reliability, far more than the 10 MHz set aside in Europe and the US [71].

9.7 Long term technology and spectrum needs and options

Aviation

Major new aviation systems are by their nature long term because of the timescales involved. For instance, an important goal is to create a global air traffic management system in future, which could monitor aircraft on a global basis and would be very effective at finding missing planes, as well as helping to standardise the radios and equipment used round the world. However, this would need to be planned for 40 years' time, given the development cycle and lifespan of aircraft, so would be in operation around 2060 or beyond.

Remotely piloted aircraft is a much discussed development but in order to coexist with manned aeroplanes, and achieve the same levels of reliability required of those, it would need "many zeros after the decimal point for link reliability", as the CAA puts it, and about 150 MHz of additional spectrum for command and communication. In the nearer term, before the entirely unmanned jet appears, there are steps on the way which increase spectrum usage and may require new tests and regulations. These include higher levels of automation within conventional aircraft, reducing the number of pilots per plane; and the use of small commercial drones. In addition, the European SESAR programme is actively investigating system automation opportunities.

Another high profile development is the space plane, such as Virgin Galactic, and the type and quantity of spectrum that would require, in commercial use, is currently being investigated. These aircraft fly about 120 kilometres up, which puts them above terrestrial, but below satellite altitude. It is possible that astronomy or space research bands might be appropriate, but far more studies are needed of propagation, interference risk and other aspects.

Another interesting application which is in the early stages of evaluation is the use of mesh networking – where aircraft act as nodes and create ad hoc wireless networks in the sky – as an alternative to satellite communications.

Rail

Although GSM-R is only just becoming almost ubiquitous, the system's own life will expire and there is already debate about what should replace it. It is likely to become obsolete by 2024, according to the rail industry's UK Technology Strategy Leadership Group (TSLG) [72].

Many of the arguments mirror those in London bus and Underground transport, though with longer timescales for migration. As in most areas of transport, the trade-offs between the pain and risk of migrating a huge and critical system, and the benefits of more modern technology, have to be closely assessed.

One of the important issues is that the applications, many of them mandated (for instance a red emergency button in the driver's cab), usually last longer than the network itself. The industry is keen that, whatever radio technology might be adopted in future, it would not force the reinvention of the wheel in terms of user interfaces and applications.

There is early-stage discussion of the potential of moving to LTE. This could be as a replacement for GSM-R, or – perhaps in a shorter timescale – as a data-driven complement to the voice-optimised GSM system. The 3GPP initiated a work item in 2012, called 'Moving LTE Relay', which focuses on high speed group mobility in trains, up to 350 kilometres per hour. Train operators could potentially migrate their GSM-R base stations to LTE, or colocate the two networks on GSM-R towers.

However, a dedicated 'LTE-R' network would require new spectrum - one suggestion is that spectrum adjacent to GSM-R (872-876 MHz paired with 917-921 MHz), might be allocated in future, or alternatively some of the frequencies in the hotly contested 700 MHz broadcast band, when that is freed up around 2018-2020; or options in 400 MHz. However, at least 10 MHz of spectrum would be needed, which would be an expensive option in the low frequencies, and would be subject to debate over who would pay for it.

It is possible that a railway LTE network could run on the existing network and spectrum of an MNO, but only if that option could support the mission critical nature of in-cab signalling (ETCS). That would mean the operators guaranteeing that they could meet five key conditions:

- New regulations to ensure that MNOs deliver the required level of criticality for mission critical traffic, as well as preventing them from imposing unreasonable price increases or lock-ins
- 'Hardening' of the commercial networks to support over 99% availability, with a target of 'five nines', and to extend coverage and indoor penetration as required by critical applications
- Assurance that modifying and hardening the commercial network would not cost more than building a dedicated railway LTE system
- Ability of LTE to support many types of services based around different network behaviours. This would be especially important if, as many argue would be positive for spectrum and cost efficiency, the railways shared the modified LTE network with other mission critical users, notably PPDR and the utilities. These three segments have different needs – streaming video and database access for public safety; low latency telemetry and real time control for transport and utilities.

- Agreement of the member state government to put a public safety network in commercial hands.

As in-cab signalling is increasingly used for safety purposes, voice will become less critical and could be run on the public network in future, keeping a dedicated or hardened LTE system for critical data. Regardless of spectrum/network choices, there is likely to be development of the radio technology as ETCS becomes increasingly central to railway safety and efficiency – on the wishlist is an ETCS-optimised, ultra-robust radio delivering 10-20kbps at speeds of 500 kilometres per hour.

Road

The longer term roadmap for bus transport is towards an open all-IP system which can support a wide range of wireless connectivity options, in order to harness the most appropriate standards and spectrum bands for any particular need, current or future.

As in other sectors such as railways, LTE may become more suitable for public road transport as new features and operator SLAs evolve. In the medium to long term, commercial LTE networks could be the primary ones for data, and the fallback for voice, while a single private radio network might serve the whole of Transport for London (or other major cities), as the primary voice system and the fallback for data.

Another concept may be a hub device within each vehicle, which could provide communications regardless of the network used, or support various connectivity methods for different purposes (PMR, cellular, Wi-Fi and future standards).

The biggest changes to road transport of all kinds will be driven by smart transport and connected vehicles developments. Vehicles will be equipped with rising numbers of sensors in order to communicate automatically with one another, with central management systems, with roadside infrastructure and with the internet. This will support, proponents claim, more efficient traffic management, greater safety levels, the rejuvenation of congested city centres, new driver and passenger infotainment services and the increased use of driverless vehicles.

A.10. Broadcasting and entertainment

10.1 Scope of the sector

The broadcasting sector consists of TV and radio broadcasters delivering programming content to consumers via terrestrial radio transmitters, satellites, cable or fibre TV networks, or the Internet. As well as programming, these companies increasingly offer video-on-demand and catch-up services.

For the purposes of this chapter, the scope will be limited to broadcasters delivering radio or TV programming over terrestrial radio networks (digital terrestrial TV or DTT), since cable and IPTV providers do not use TV spectrum; and mobile and satellite delivery of TV is addressed in the relevant chapters.

However, services are increasingly converging at a service device and (to a lesser extent) infrastructure level and traditional broadcasters may be delivering add-in services over mobile or Wi-Fi spectrum. For instance:

- Pay-TV broadcasters offer ‘quad play’ services in which TV, broadband access, telephone and mobile offerings are bundled.
- Broadcasters offer ‘TV everywhere’, delivering programmes to mobile devices as well as PCs and TVs.
- Broadcasters support IP-based services, such as catch-up, interactive content or even additional channels, to complement their core offering.

These trends are mainly seen in the pay-TV sector (satellite and cable), but the DTT and the free-to-air operators are starting to consider them too, as seen in the Freeview Play initiative, which launched in October. And further down the line, there is discussion of converged platforms combining broadcast and mobile broadband activities (covered at the end of this chapter), although it is worth noting that there are serious question marks over the technical and commercial viability. In 2013, the European Commission made it clear that LTE/DTT convergence was a long term option, with significant technical and commercial uncertainties to be addressed

In the UK, there are over 100 TV, radio and interactive DTT channels, the majority of them free-to-air. These are carried on the multiplexes, which use the DVB-T technology under the Freeview service. Three multiplexes use DVB-T2 (see later section). Many of the channels are also carried on other platforms.

The major content providers include[9]:

- The BBC, which is funded by the licence fee and offers eight (reducing to seven) main national TV channels over the DTT network along with children’s channels, BBC News, BBC Parliament, Alba and many regional offshoots and radio channels.
- The three other former analogue terrestrial channels – ITV, Channel 4 and Five - and their regional offshoots. These have public service obligations but are commercially funded, mainly by advertising.

[9] Additionally, there are Broadcast data services, such as *The Engineering Channel* on PSB1, managed by the DTG, carrying software updates for DTT receivers etc.

- Other commercial broadcasters such as UKTV, a joint venture between BBC Worldwide and Scripps Network Interactive, and offering channels such as Dave.

The UK also has one of the world's largest DAB digital radio networks with about 250 commercial stations plus 34 BBC stations. As of the end of 2012, there were also over 540 analogue radio stations, mainly on the FM band. The migration from FM to digital radio is likely to take place in a staged process, which will begin after a 50 per cent listening threshold is reached.[10]

The DTT sector shares spectrum with some PMSE (programme making and special events) users. This contains providers and operators of audio equipment for public events, mainly wireless microphones and in-ear monitors. The PMSE sector also comprises providers and operators of video equipment notably wireless cameras. PMSE equipment is used for a wide and diverse range of cultural, entertainment and educational purposes, including film, TV and radio production; news gathering; theatres and other cultural venues; live broadcasts; events such as sports games, concerts or political rallies; use by businesses and religious institutions. Beyond that, PMSE is essential to content creation, in an era when high quality live content increasingly attracts the largest viewing figures and revenues, and manages to avoid some of the fragmentation of the video content 'long tail' by uniting consumers around a one-off event.

10.2 Contributions to social and economic value

The UK television industry generated £13.2bn in revenue in 2014, an increase of 3.1% year on year, and 92% of people watch TV each week, down slightly from 93% in 2013 [73].

The rise was driven mainly by growth in subscriptions and net advertising revenues. These offset a slight decline in publicly funded programming since 2012, which had the exceptional factor of the London Olympic Games.

Over a five-year period, TV industry revenues have experienced a compound annual growth rate of 2.8%, also the highest in the communications sector. Drivers behind this five-year pattern have included:

- a strong bounceback in the TV advertising market after the slump of 2008-2009
- resilience of pay-TV revenues.
- Rise in number of TV channels and especially the impact of Freeview.
- Rise in number of TV households, and particularly in households with multiple TV screens.
- Adoption of HDTV and the rise in premium HD content.

TV content and services have grown slightly in relation to total GDP, reaching 1.14% in 2012, according to Deloitte [74]. TV also drives revenues for other sectors by supporting advertising; content production, aggregation and distribution; through content payments to other industries, e.g. for sports rights; and through TV-related items like books and music; as well as equipment manufacturing. The total broadcasting value chain supports about 40,000 UK jobs.

10 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/270375/Digital_Radio_Action_Plan_v10__5_.pdf

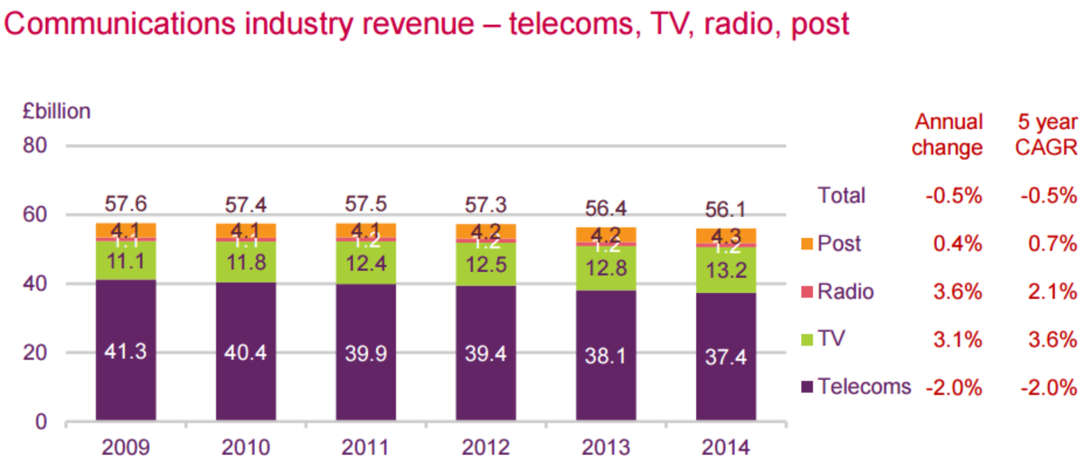

Figure 34:TV industry revenues as a percentage of total communications industry revenues in the UK 2014. Source: Ofcom [75]

The average UK citizen devotes about one-quarter of waking time to TV content (although not all that is DTT-delivered). TV makes a social (and often an intangible economic) contribution by

- Providing a platform for educational content.
- Enabling virtually all the population to access news, information about many topics, and important updates such as weather reports.
- Providing an important leisure activity at low cost to the user.
- Providing an important outlet for creativity.
- Providing a platform for debate and free exchange of ideas.

The BBC's official mission statement perhaps reflects the best aspirations of broadcasting – "To enrich people's lives with programmes and services that inform, educate and entertain."

When judged in narrower spectrum terms, broadcasting emerges as one of the largest components of the total economic value of UK spectrum, which totalled £52 billion in 2011. In a 2012 report for the Department of Business Innovation and Skills, Analysys Mason calculated that the economic value of spectrum usage by TV and radio broadcasters was £10.8 billion as of the end of 2011, up 79% for TV and 35% for radio compared to 2006. This was second only to public mobile communications. [76]

Another report, produced for Digital UK by Communications Chambers in 2014, argued that DTT has a higher marginal value than public mobile. Among its conclusions, it stated that the economic benefits of DTT are higher than previously estimated, and that DTT delivers more value than mobile broadband, when the amount of spectrum used by the respective services is taken into account [77].

As for PMSE, it is an essential enabler of a creative sector which totals £71.4 billion in revenues and employs 1.7 million people. It directly employs over 150,000 people in the entertainment industry, according to BEIRG (British Entertainment Industry Radio Group) and all citizens benefit from the high quality content which PMSE technology enables. Over

90,000 requests for PMSE spectrum are made to Ofcom each year in the UK, an indication of the significant level of activity in the sector.

10.3 Current and recent past status

The broadcasting industry has been undergoing significant market and technology change for almost two decades, as viewing habits have altered; the number of channels has exploded; and HDTV has become increasingly mainstream. Many of the changes have been driven or enabled by the transition of TV (and some radio) to digital platforms.

Although pay-TV – mainly delivered by cable, satellite and IPTV – has been the largest source of revenue growth, according to Ofcom, DTT remains a significant element of the UK TV landscape. It is now the largest single viewing platform (see Figure 35), as it is in some other European countries such as Italy, Spain, Portugal and France.

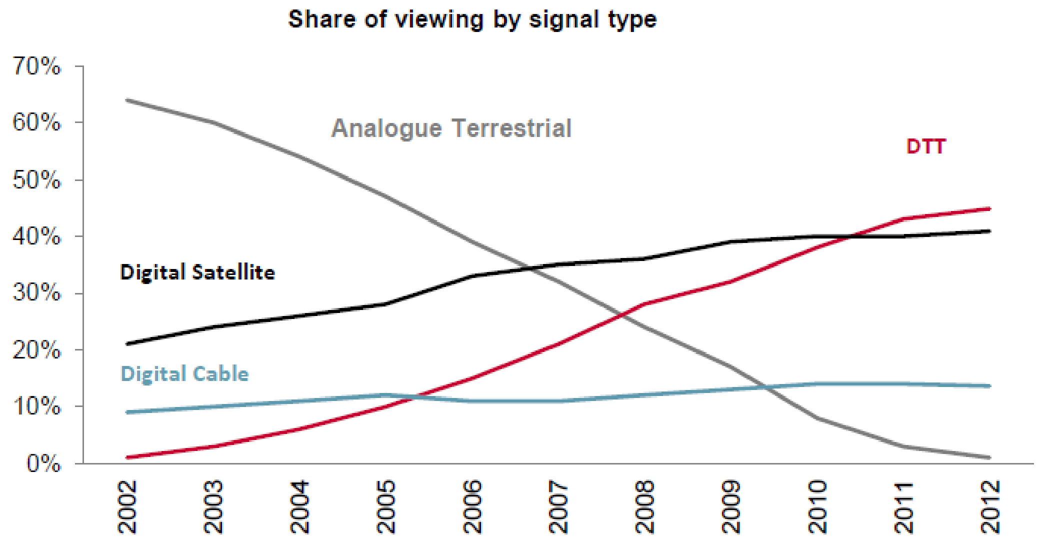

Figure 35: Share of TV viewing by signal type in the UK. Source: Ofcom Communications Market Report 2013 [78]

By contrast, it is a minor part of the mix in countries like The Netherlands and Germany. These variations create complications when attempting to create pan-European spectrum strategy for DTT (see Figure 36). However, a significant attempt at this was made in 2014 by Aetha, in a report on the future use of the 470–694MHz band, produced for Abertis, Arqiva, BBC, BNE, EBU and TDF. This assessed the spectrum use of DTT compared to mobile across all 28 EU Member States and argued that there would be no case, at WRC-15, for co-primary allocation of the band and that any loss of UHF would jeopardize the quality of TV services in Europe and undermine the case for future investment by DTT operators [79].

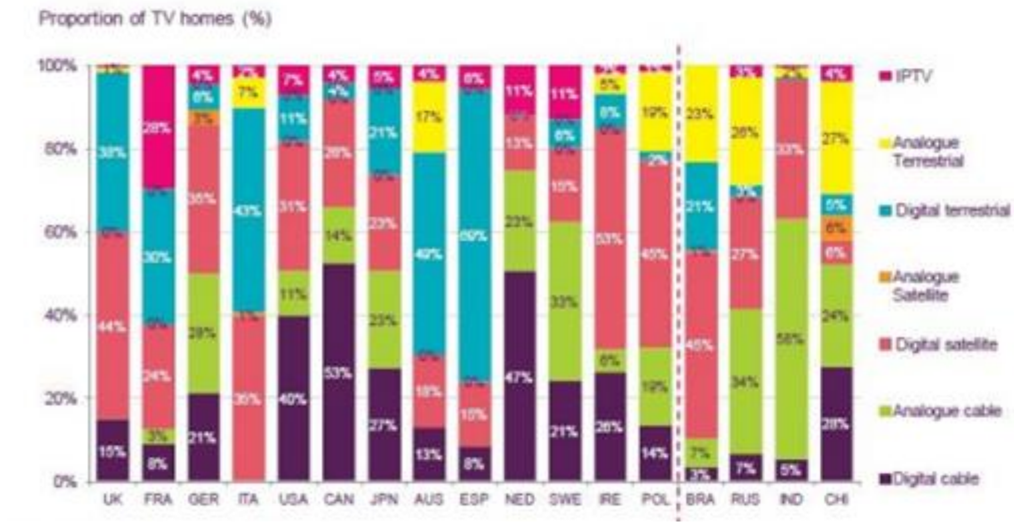

Figure 36: Uptake of DTV by platform and country, 2011. Source: Ofcom/iDate/industry data

The digital switchover of satellite broadcasting was accomplished in 2001. Digital switchover for terrestrial TV was completed in October 2012. The later date was because the latter came with far broader social and policy implications, and involved many stakeholders rather than just one. Transition took place in stages from 2008 to 2012 and resulted in DTV Services – a joint venture between the BBC, ITV, Channel 4, BSkyB and Arqiva - being the only free-to-air DTT service, with the Freeview and Freeview HD brands.

The technical specifications and conformance testing regime for Freeview are published and maintained by the DTG, the centre of industry collaboration in the UK. The base technology is DVB-T, which uses COFDM modulation to carry compressed digital video, audio and other data. In late 2009, Freeview was the first operational TV service in the world to use the DVB-T2 standard, which has far higher capacity – roughly double that of DVB-T on a single multiplex. That allows a mux operator to carry more standard definition channels, or to carry some HD channels. It requires a DVB-T2 tuner in the set-top box or TV.

There are eight DTT multiplexes[11] (blocks of channels) underpinning the services (see Figure 37). Three of them carry the free public service channels of the BBC, ITV, Channel 4, S4C (Wales) and Five, plus some other services from those broadcasters, and guarantee coverage to 98.5% of households. The other three carry purely commercial broadcasting and reach at least 90% of households. The technical platform management and electronic programming guide are the responsibility of DigitalUK, which is co-owned by the firms running the multiplexes – the BBC, ITV, Channel 4 and Arqiva.

DAB radio stations are also broadcast in multiplexes. The most far-reaching ones are the BBC's national DAB multiplex for its own stations, and Digital One, owned by Arqiva, which supports commercial stations reaching over 85% of the country. The new Digital Two national DAB multiplex is due for launch in 2016.

[11] Nine muxes when local TV is included.

I

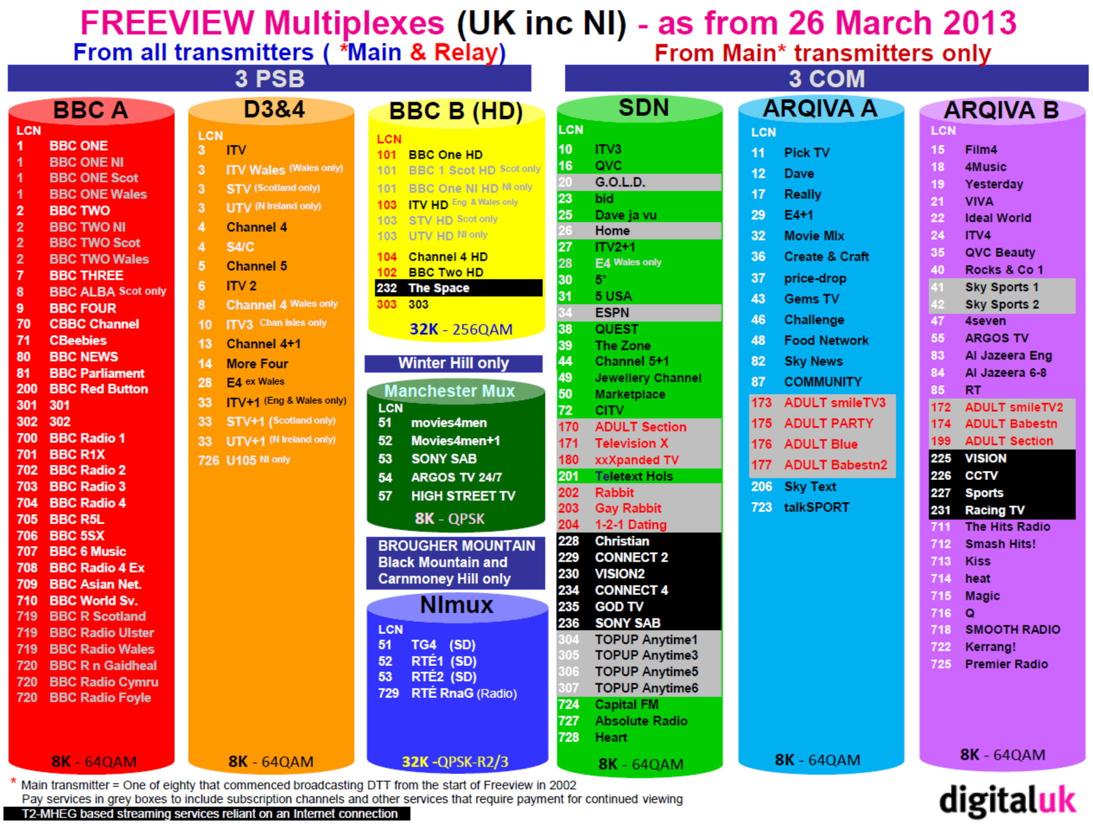

Figure 37: The UK DTT multiplexes in 2013 – not this does not include the two additional interims. Source: DigitalUK

10.4 Sector trends

Now that TV in the UK is fully digital, some in the industry are heavily focused on whether it will be possible to sustain recent revenue growth, once the effects of digital and HD upgrades start to level off. Apart from digitalisation, there are other important trends in the broadcast TV sector, some of which present significant challenges to future growth, though some, like IP convergence, also bring significant potential opportunities.

The audio-visual sector is competitive. Aside from DTT it includes:

- Pay-TV options, mainly satellite (Sky) and cable (Virgin), but increasingly IPTV-based (e.g. BT TV has IPTV options on top of its terrestrial service).
- Delivery of free-to-air (FTA) TV by other methods such as Freesat, Freesat-from-Sky or hybrid (YouView).
- Over-the-top services such as Amazon Prime and Netflix, which are increasingly commissioning original content – though from a very low base compared to the public service broadcasters, and currently these services are seen complementing rather than replacing DTT
- Use of wireless networks, especially LTE and Wi-Fi, to deliver TV services, though this is currently very low (23 seconds a day per person on average according to one estimate by Plum Consulting)

- Connected TV services, which deliver content – including on-demand and catch-up – over the internet, to PCs, smart TVs or mobile devices. These have been important ways for these services to compete with Freeview, prompting Freeview's stakeholders to launch their own free version, Freeview Play.

More broadly, there is competition to broadcast TV from alternative delivery mechanisms, and to all forms of TV from other uses of consumers' time, whether that involves non-TV video (such as YouTube); alternative screen-based pastimes, like gaming or internet surfing; or wider trends such as reduced viewing time because of longer working hours.

In the UK, the level of competition amongst all services for consumers' TV viewing hours is particularly intense. Some operators are increasingly seeking to build quad play services in order to seize a larger percentage of each household's telecoms/media/internet spend, as individual rates for those services are falling. Virgin, BT, mobile operators EE and Vodafone, and broadband provider TalkTalk are all planning quad plays with TV as a heavy part of the proposition, and Sky will certainly respond.

That market battle does not directly affect the DTT services, whose business models are based on advertising or licence fees, but it does intensify the competition to their offerings, as the quad play firms, and even the over-the-top players like Amazon, continually make their TV services more tempting in content and price.

The DTT sector, like all TV platforms, is constantly incentivised to enhance its own offering. At present the BBC licence fee is under review and TV advertising rates are volatile. In that context the stakeholders in Digital UK are investing significantly in Freeview Play, which will offer connected TV services. It will be a rival to YouView, which is distributed free by BT and TalkTalk with certain bundles, and is credited with those providers' increase in TV market share at the expense of Freeview.

In 2012, broadcast TV (including satellite and cable) accounted for 92% of all viewing (including YouTube etc.), with IPTV representing the rest (only 1% of that to TV sets). In 2020, according to some projections, those percentages will not have changed too dramatically – Enders Analysis projects that broadcast TV will be 80% of viewing, IP to TV 4% and IP to other screens 16% [80]. Ofcom found that "Watching programmes previously recorded on devices or through catch-up services (time-shifted) among all individuals has grown over the same period (from 17 minutes a day to 27 minutes a day), but the main way people watch programmes continues to be at the time of broadcast (88%)" [81].

Although broadband penetration is rising in the UK, reliable and high quality TV experience relies on speeds of at least 30Mbps, which will be less common, as Figure 38 illustrates. In many cases, IP-based viewing remains a secondary activity in a household whose main TV device is still a TV set with an aerial, dish or cable.

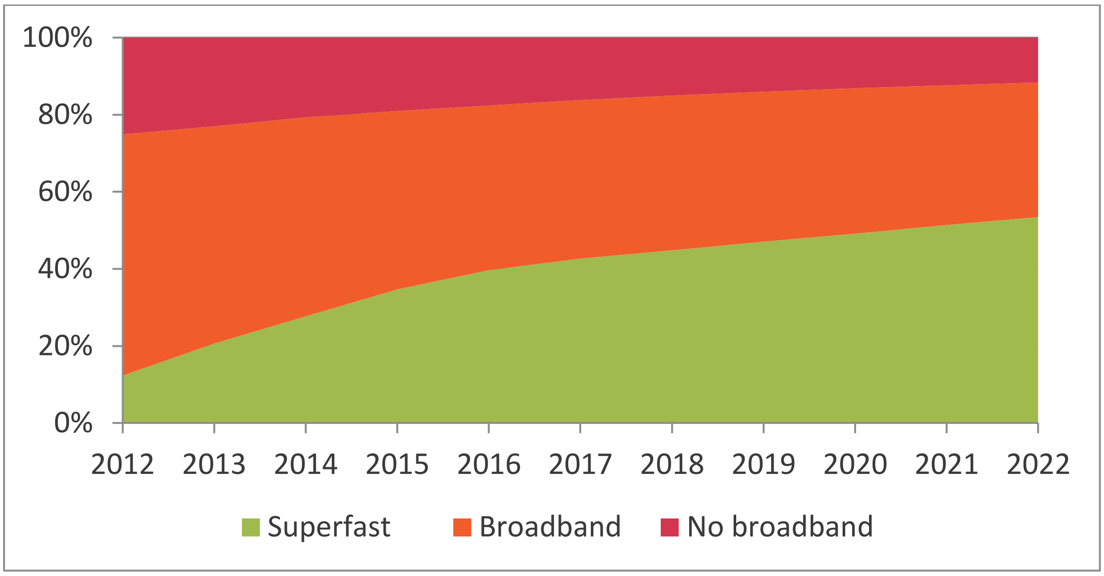

Figure 38: Broadband penetration projections UK. Source: 3Reasons LLP, spring 2013 model

The trend in the PMSE sector is one of growing demand on a yearly basis as producers and consumers raise their expectations of live content quality, and as live content is increasingly the leading revenue source for musicians/record labels and others. As events get more spectacular, larger numbers of units are required (104 wireless microphones in the 2012 Eurovision song contest, for instance, compared to 54 in 2004).

10.5 Spectrum usage

As outlined in the previous sections, the broadcasting sector has gone through a dramatic change in its spectrum usage thanks to the transition to digital services. Since digital TV typically requires about eight times less spectrum to transmit an equivalent signal, compared to analogue, the transition has allowed more channels to be transmitted; has supported new services, such as HD (which still requires less than 20% of the spectrum of an analogue signal); and has freed up spectrum in the 800 MHz band for mobile broadband (the digital dividend).

Digital switchover cleared the 800 MHz (790-862 MHz) band, which was auctioned for LTE use, and the 600 MHz band (550-606 MHz), which is licensed on an interim basis to Arqiva for mainly HD services, incentivising consumer take-up of DVB-T2 receivers. DTT and PMSE remain, in the whole UHF spectrum between 470 MHz and 790 MHz, thanks to the Ofcom decision to license the 600 MHz band to Arqiva. However there are likely to be further changes to how DTT uses this spectrum in the coming years (see Figure 39). The 700 MHz band (694-790 MHz) cleared to allow further mobile broadband use around 2020 in the UK. Regarding the spectrum between 470-694 MHz the EU supports the Lamy Report proposal that says DTT access to sub 700MHz (470-694 MHz) should be ‘safeguarded’ until 2030.

Converged mobile/broadcast spectrum usage and/ or new spectrum options may be considered in the very longer term, as described in later sections, though any significant changes are very far from certain.

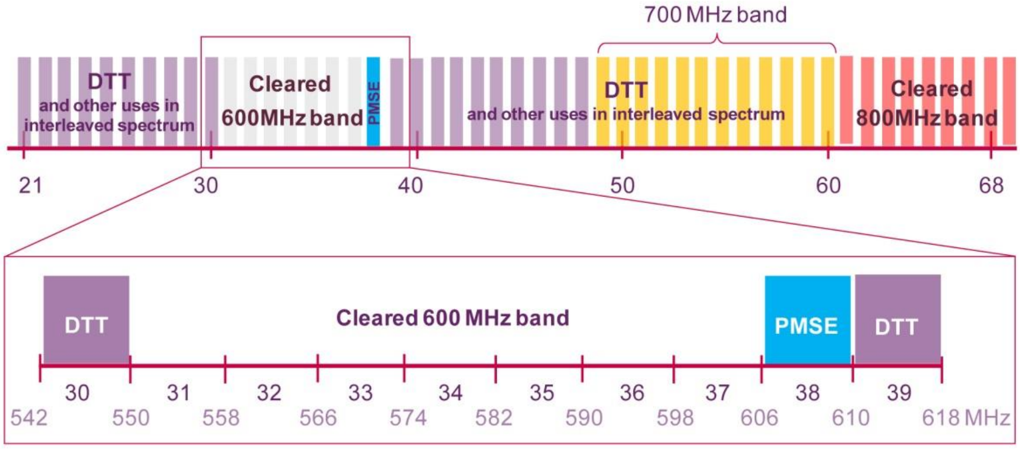

Figure 39: The UHF spectrum band after digital switchover in the UK

The digital dividend

Freeview is now using spectrum harmonised with the rest of Europe, since the UK decided to bring its 800 MHz mobile broadband band plan into line with the EU – in 790-862 MHz or UHF channels 61-69. That was achieved after a successful major infrastructure project and a customer retune in 2013. The UK initially leapt ahead of the EU in identifying its digital dividend frequencies, deciding as far back as 2003 to release 112 MHz as a result of digital switchover. At the time, the dividend spectrum consisted of a small upper band of 48 MHz at 806-854 MHz (channels 63 and 68), and a lower band of 64 MHz at 550-630 MHz (channels 31-35, 37 and 39-40). Subsequently, aeronautical radar was cleared from channel 36 and radio-astronomy from channel 38, creating an extended lower band of 128 MHz.

However, the band remained out of line until, in 2009, Ofcom decided to align itself with the EU to achieve the benefits of a common mobile base, for roaming and device economics. That meant moving DTT users out of channels 61 and 62 and into channels 39 and 40, and PMSE users in channel 69 down to channel 38. The final dividend comprised 550-606 MHz (channels 31-37, the 600 MHz band) and 790-862 MHz (channels 61-69, the 800 MHz band).

This process incurred additional costs, although Ofcom estimates those to have been outweighed significantly by the additional benefits of harmonisation. It reduced the total amount of spectrum available for DTT and PMSE, but again, Ofcom deemed that disadvantage to be justified by the additional spectrum for LTE.

There was also the risk of interference with Freeview signals higher up in the DTT portion of the band, once 800 MHz LTE services were launched. This was one responsibility of DMSL (Digital Mobile Spectrum Limited), set up by the government and funded by the mobile operators which had won dividend spectrum at auction, to plan the 4G roll-out. Ofcom estimated that about 960,000 households would be affected though at this point, post-release, it seems that the figure will be lower.

The 600 MHz band

In September 2011 Ofcom announced plans to award spectrum in the 600 MHz (550-606 MHz) band, with the intention of using channels 31-37 for DVB-T2/MPEG-4 Freeview HD services and white space services, allowing for future migration of DTT out of 700 MHz, to open that band up for mobile broadband. The 600 MHz spectrum was allocated on an interim basis to Arqiva in July 2013. The single licence supports three new digital TV multiplexes – channel 36 as a national single-frequency network; plus two multiple-frequency networks. The new multiplexes broadcast to up to 70% of the UK population (above the 50% minimum set by Ofcom). The licence can run until 2026, but with a break clause which could be invoked as early as 31 December 2018, and with a 24-month notice period.

There was criticism of the award from some parts of the broadcasting sector, which believed its allocation was being tied into a clearing of 700 MHz for mobile broadband, before that step had been fully agreed. However, Ofcom said the primary area of "substantive challenge" to its 600 MHz allocation conditions was that the interim DTT licence might limit the ability to start clearing the 700 MHz band for mobile before the end of 2018. To address that, Ofcom added a clause in the Arqiva licence which allows it to "vary or substitute the frequencies awarded in the 600 MHz band, as necessary, ahead of the end of 2018, in order to facilitate any transition of DTT from the 700 MHz spectrum".

PMSE

The 600 MHz band will also be used by PMSE and by emerging white spaces applications (see note in final section). However, BEIRG (the British Entertainment Industry Radio Group, which represents the audio PMSE equipment sector, argues that the loss of the 800 MHz band, and the likely loss of 700 MHz, is creating significant uncertainty, which affects investment in the area and increases the likelihood of spectrum shortage for major events. One of the spectrum issues for PMSE is that almost all (99.9%) of its equipment in the field is analogue, with a 200 kHz mask per link. Digital PMSE equipment does exist but it introduces latency, which is completely unacceptable in live audio transmission, and, as BEIRG puts it, is "not the silver bullet that regulators or others would like to believe".

10.6 Expected changes to technology and spectrum

The broadcast industry will soon start to undergo the next major wave of change. Significant technology shifts may be driven by further spectrum reallocation. Important developments will include:

- Further reallocation to mobile, with much of the 700 MHz band (694-790 MHz, channels 49 to 60) likely to be cleared for mobile broadband use in many countries, including the UK.
- Further implementation of technologies to support HD content, interactive services and greater spectral efficiency, particularly DVB-T2 and MPEG4 compression.
- Increased reliance on internet-delivered video and services, and potentially mobile TV, to complement DTT. The latter gives rise to the idea that broadcast and wireless broadband services and spectrum need not be mutually exclusive in the way they have been in 800 MHz, with more TV travelling over LTE (as well as Wi-Fi). That, in turn, is leading to exploration of possible future converged platforms.

Technology upgrade

On the technology front, DVB-T2 enables a capacity improvement of at least 50% over DVB-T, through use of improved Forward Error Correction (FEC), not counting the impact of H.264/MPEG-4. The UK has been one of the first countries to implement it widely, and the broadcast sector is already trialling the next wave of technologies to improve user experience, such as 4K Ultra HD, and spectral efficiency, such as H.265/HEVC compression.

Harmonized standards are not fully completed yet, though in July 2014 the DVB Project announces its Phase 1 specifications, for UHD standards to be deployed in 2014 to 2016. Unlike HD, its successor is fixed at a single resolution, 2160p (2160 x 3840 pixels). To cope with such a big increase in resolution a significant improvement in compression efficiency is essential to keep the bit rate down and this has been achieved using H.265 or HEVC (High Efficiency Video Coding), which has been incorporated into the Phase 1 UHD spec and is the successor to MPEG-4. HEVC will increase efficiency, compared to H.264/MPEG-4, by as much as 65%.

Along with UHD Phase 1 the DVB has also approved technical protocols for companion screens and MPEG-DASH, both important for the emerging ‘next generation’ of TV experiences, in which users simultaneously view and interact on, for instance, a smart TV set receiving a broadcast over the air, and a tablet receiving the same programme, or related content, over a high speed IP connection. This is enabled by the DVB’s specification, ‘Companion Screens and Streams, Part 2: Content Identification and Media Synchronization’; while MPEG-DASH is important for supporting adaptive bit rate (ABR), which maintains a consistent viewing experience when bandwidth fluctuates.

In August 2013, DTG’s UK UHD Forum was set up to coordinate the UK industry activity and understand the challenges for production and delivery in 4K UHD, high frame rates and high dynamic range. The group is chaired by technology chiefs from the BBC and Sky and includes studios, broadcasters, TV manufacturers and retailers.

4K broadcasts are unlikely to become mainstream in UK services until 2016 or beyond, partly because 4K televisions are still only in a small minority of homes (penetration is expected to reach 10% in western countries only in 2018 [82]. Nevertheless, there is pressure to move quickly on the content and broadcast sides. Over-the-top TV service Netflix has already released the second series of its flagship original TV series, ‘House of Cards’, in 4K. The BBC ran a trial at the 2014 World Cup in Brazil, broadcasting and streaming live 4K UHD coverage of three games as part of its ongoing series of tests. The footage was transmitted over satellite to the UK and then distributed via DTT as well as streamed over high speed broadband links to test TVs.

This was the first UK demonstration of over-the-air UHD, and the first trial of simultaneous distribution over DTT and IP – an important step towards convergence between broadcast and IP, including LTE.

Another potential step forward in spectral efficiency is the gradual move from higher power multiple frequency networks to single frequency networks (SFNs) which may increase the number of channels which can be transmitted in a given piece of spectrum, although the scale of their impact is disputed. According to one assessment, by Farncombe [83], if SFNs and HEVC were used throughout a country like the UK, six multiplexes or 48 MHz of spectrum would be needed, compared to 240 MHz with current systems, which have repeat patterns of around 5. However, this is disputed by other stakeholders due to international harmonisation challenges.

LPLT (low power low tower) networks allow the use of SFNs with shorter guard intervals, maximising the data-carrying capacity of the system. This also reduce the interference zone between areas of different content from 50-100 kilometres to maybe just 5-10 kilometres, which may make it practical to deploy them in most areas - though there are still significant issues around boundaries between different editorial areas (including along regional and national boundaries). Furthermore, there is a significant cost attached to moving to LPLT and risks of disruption to the viewers involved.

The 700 MHz band

In November 2014, Ofcom announced its intention to free up the 700 MHz band (694-790 MHz), somewhere between 2019 and 2021. This was the result of the decision at WRC-12 to make the 700 MHz co-primary for broadcasting and mobile in Region 1 from WRC-15 to bring it into line with Regions 2 and 3.

Some regions of the world, such as most of the Americas and many Asian countries, allocated 700 MHz as their first digital dividend. The release of 700 MHz for mobile broadband in ITU Region 1 (EMEA) has been driven heavily by Africa, since in many countries on that continent 800 MHz is tied up with other services. This led to an agreement, at the World Radio Spectrum Conference (WRC-12) in 2012, to open up 700 MHz for mobile use across Region 1 (EMEA).

Some in the broadcasting community have argued that this WRC-12 decision reneged on the earlier agreements by the European Commission to reserve enough spectrum for broadcasters to develop advanced HD and 3D services. The mobile community retorts that further sub-1 GHz spectrum could be liberated for its services, while still keeping EC pledges, as a result of efficiency improvements in DTT transmission such as the better FEC employed in DVB-T2 and the move to SFNs.

However, some broadcasters and PMSE players believe the second dividend will be a cut too far, and make their platforms unsustainable, even with the move to the new spectrally efficient technologies, since they will also need to create more multiplexes to carry additional digital channels and increased HD content, in order to remain competitive with other delivery platforms. There will also be a significant cost attached to the retuning of the DTT network, and procurement of new consumer equipment. The DTT sector is seeking to minimise disruption to ensure that customers are not incentivised to adopt alternative TV platforms.

Ofcom, on announcing its plans, pledged that “the UK will retain a competitive terrestrial television platform”, and that it would inform the PMSE community next year which frequencies will be available to it.

However, there are limited options for adding new frequencies to PMSE’s allocations. Some PMSE options are currently being assessed by Ofcom.

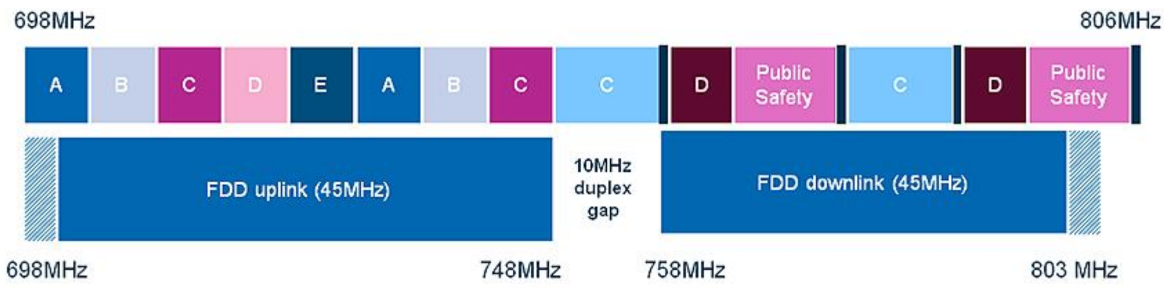

Figure 40: The main 700 MHz band plans (USA above, Asia-Pacific below). Source: Analysys Mason 2012

The GSM Association has called on the EU to release 700 MHz spectrum in the 2018-2020 timeframe, rather than "from 2020", the target set by a Digital Agenda proposal submitted in August 2014, in a document by former European commissioners Pascal Lamy. The EBU responded that the 2020 timescale is too ambitious, saying: "The danger that this will not give broadcasters and viewers enough time to adapt to appropriate spectrum arrangements and ensure the necessary upgrade of DTT networks and consumer equipment, especially in countries where DTT is the main TV platform."

Broadcasters called for a full "stocktake" of spectrum holdings and requirements to be conducted before any far-reaching decisions are made, something on which Lamy agrees, proposing a review of the sub-700 MHz spectrum by 2025 to provide a "factual basis" for future policy decisions. In the meantime, Lamy proposed that broadcasting should retain access to 470-694 MHz until *at least* 2030.

Broadcasters also argued that, since the mobile operators gained access to 800 MHz spectrum, it was unclear how critical further frequencies were to their future business cases. It can be argued that the rise in use of mobile data will create a shift towards capacity-driven build-outs, which are better supported in higher frequencies such as 2.6 GHz (reference public mobile chapter). In the meantime, technologies such as TV white spaces can make use of the propagation benefits of UHF to help extend broadband coverage, especially in rural areas.

When it comes to radio, digital switchover faces different pressures than TV, because it uses far less spectrum and there has been little clear alternative use for those frequencies although Internet of Things applications have been vaunted.

Convergence:

However, since Ofcom is clear that it wants to release 700 MHz for mobile use, and this will also be a Europe-wide direction, the more realistic debates may focus on how broadcast and mobile can effectively co-exist in terms of spectrum usage. Some have suggested that broadcasting content could be delivered on mobile (and Wi-Fi) spectrum. This is not without problems from a spectrum efficiency point of view as spectrum removed from broadcasters would likely go to mobile operators using arguably less efficient technologies to deliver the same broadcaster services.

The emergence of converged DTT/fixed IP and DTT/mobile platforms are shifting the terms of debate. Initially, the talk has been about harnessing IP channels as an adjunct to DTT, with convergence at applications or service delivery level. HPHT (high power high tower) infrastructure, in common with satellite, was designed for one-to-many delivery with limited ability to support two-way interaction, feedback or user-controlled scheduling or content – all hallmarks of the modern viewing experience. Hybrid approaches have been developing, such as HbbTV (hybrid broadcast broadband TV) and Youview. A similar scenario is envisaged by the UK public service broadcasters, who have invested in hybrid DTT-IP platforms YouView and Freeview Play.

Broadcasters have the option to accelerate their use of hybrid IP/free-to-air platforms, and their efforts to attract households to IP and to work with internet players investing in new multicast IP services. Some channels could be converted to IP-only (as is already planned for BBC3).

In many cases, the IP aspect is mainly supported by fixed line connections, especially where full HD and UHD are concerned (mobile screens are already starting to support 4K, but their connections are generally not fast enough, on a consistent basis, to provide a good viewing experience). Convergence, then, is often not a spectrum issue, but the rise of mobile networks capable of supporting a full TV experience will make it one.

One proposal put forward is for a fully converged network – at infrastructure or platform level. That might enable a single infrastructure (transmitters and backhaul) and spectrum band to support mobile services and broadcasting, with devices capable of receiving both broadcast- and IP-delivered content. That would enable flexible spectrum use for linear and non-linear broadcast content, in broadcast (broadcasting), multicast (IPTV) or unicast (VoD) mode as required. However, many technical and public policy issues remain unresolved (see next section).

PMSE

The future is even more uncertain for the PMSE industry, at least until Ofcom identifies the new frequencies it might be allocated. EC proposals suggest a minimum of 60 MHz is made available, but some studies indicate that busy cities, or times of peak demand such as major events, may require over 100 MHz some of the time. As with DTT, demand is predicted, by the industry, to outpace the efficiencies achievable through new technology, which are limited anyway in PMSE because of the analogue nature of many of its activities.

Possible options suggested by the EC, CEPT and national regulators for audio PMSE include duplex gaps in the 700 MHz, 800 MHz and 1800 MHz bands; sharing with mobile downlink and other services at 1427-1518 MHz; sharing in 960-1350 MHz and 1525-1710 MHz (all of these subject to local regulatory variations). However, PMSE bodies argue that in most cases they would be sharing with LTE, whose high out-of-band emissions could cause interference and a failure to meet QoS requirements.

According to Farncombe, if all current use were displaced from UHF spectrum, the cost of replacing current equipment throughout the EC would total up to €700m. Aside from the cost of migration, BEIRG says its members are being forced to consider how to deal, in future, with a ‘dirtier’ operating environment, with greater congestion and interference from nearby LTE. It said: “We foresee a situation whereby secondary status is no longer suitable – there is a need to upgrade PMSE to co-primary status.”

Wireless cameras and video links have also been impacted by a reduction of available spectrum. In 2014 Ofcom published a statement on a strategy to ensure users of wireless cameras and video links in the programme making and special events (PMSE) sector continue to have access to sufficient spectrum to support their activities [84]. This follows a likely reduction in spectrum available to these users after the proposed award of spectrum in the 2.3 GHz and 3.4 GHz bands. The approach suggested included a preferred resource of a PMSE allocation at 7 GHz, a secondary allocation at 2GHz for applications that cannot be supported at 7GHz and occasional borrowing of non-PMSE spectrum to meet specific demand.

10.7 Long term technology and spectrum needs and options

In the longer term (2022 to 2030), as in the nearer term period, the potential for a major platform migration and a major spectrum change will be considered, the two being closely interrelated.

One platform issue, as mentioned in the previous section, is the potential migration to a converged mobile/broadcast network, sharing spectrum and infrastructure and using either DVB-based, LTE-based or hybrid/greenfield standards. This remains a highly uncertain outcome, but is worth considering in this report since, if commercially and technical viable, it would have a major impact on spectrum usage. Key platform issues also include other potential developments in DTT technology, including the hybrid DTT-IP platforms; whether mobile proves to be an effective substitute for DTT and/or fixed IP; and whether mobile-fixed networks converge to create seamless consumer platform experiences.

Convergence

The discussion about convergence is being driven, in part, by the competing claims for spectrum, but also by the increasing overlap between mobile and TV services. This is illustrated by:

- Rising percentage of TV consumption on mobile devices. Currently these are often acting as a second screen for the TV, but the rise of 'TV everywhere' as a value added service is driving expectation that TV must be available in all locations, which requires mobile connections.
- This shift is being enabled by the parallel introduction of very high resolution mobile screens, smartphones with high performance processors, and LTE-Advanced to enable a mobile video experience comparable to that on a larger screen.
- The increasing operator interest in LTE-B (LTE-Broadcast) which provides a mobile multicast and broadcast platform that does not require dedicated infrastructure (as the failed DVB-H and FLO standards did). This will enable more broadcast-suitable content actually to be broadcast, rather than unicast, as now, which is spectrally inefficient.

There are many scenarios for convergence, with different balances between DTT and LTE spectrum allocations. At one extreme DTT could be switched off altogether, freeing most of its spectrum for mobile services, including broadcasting. It is unclear, however, whether mobile services could deliver TV content in a more spectrally efficient way than DVB. That being the case, there may well be no spectrum efficiencies in a move to mobile delivery and no clear rationale for such a move.

At the other, DTT could continue to expand, and incorporate its own mobile and Wi-Fi options, limiting the role for LTE operators. However, this outcome is dependent on the broadcast sector maintaining sufficient spectrum to keep its services competitive with those delivered by the pay-TV sector over cable/fibre or satellite (sectors which are also developing mobile and Wi-Fi services or alliances to add value).

Any scenario where DTT disappears in the medium term (early 2020s) has been discounted in the UK, which has high penetration of DTT, and the outcome will be partly a matter of public policy, and partly of technology evolution. Any benefits of convergence are likely to be in countries where there is low DTT penetration and high usage of over-the-top and IPTV offerings, although some argue that moving to free-to-air DTH satellite, like Freesat, would generate comparable benefits.

The key challenges to any platform change reflect a mixture of these concerns:

- Optimal use of VHF/UHF spectrum
- Availability of compliant end user devices
- Flexibility to support changing TV consumption patterns
- Ability to support convincing business models and attract investment
- Support for TV's role as a public medium
- Ability to enhance European content production business
- Ability to offer full coverage to fulfil social obligations
- A viable commercial model to realise returns for content providers who would likely face enormous additional infrastructure investment

Technologies which will help enable convergence are emerging from both sides. The key issue is whether DVB or LTE standards will dominate for broadcast transmission. LTE-Broadcast, based on the eMBMS (enhanced multimedia broadcast) standard, is limited in functionality but its successors, which are already being developed, may make it easier for DTT and mobile services to share the same UHF spectrum and delivery infrastructure. Meanwhile, DVB technologies are also evolving to support mobile consumption with activities like DVB-T2 Lite and DVB-NGH (next generation handheld), and have fewer migration issues. DVB transmission would mean moving DTT to the LTE towers; with LTE, it would mean integrating all broadcasting onto LTE-B. In either case, mobile unicast would provide capacity and additional services with supplemental downlink, so LTE will always have a role.

In simple terms, the comparison may be between simple transition (DVB) versus greater convergence benefits (LTE), as seen in Table 11).

Table 11

Table 11: Comparison of LTE-based or DVB-based solution for converged network

LTE	DVB
Unified network in LPLT	Better rural coverage
Better support for interactive services	Support for unregistered users
Optimised for mobile use, which is increasing as a percentage	No upgrade costs for TV receivers

LTE	DVB
	Potentially higher spectral efficiency (>3.5bits/Hz compared to >2bits/Hz) [85]

The architectural approaches under discussion include:

- Cellular broadcasting in broadcast spectrum. All TV content delivered over IP-based cellular systems, enabled by LTE-B/eMBMS over a single frequency network. This complete replaces DVB-T/T2.
- Hybrid network. This envisages cooperation between DVB-T2 and LTE-B, harnessing their synergies to reduce network costs and optimise spectrum use. One proposal in this area was developed by a team led by prominent DTV scientist Ulrich Reimers [86] and suggests a tower overlay system (see Figure). This allows video content to be transmitted either via the HPHT network or via the underlay LPLT network. LTE signals are broadcast multiplexed within a DVB-T2 frame, using the latter as the physical carrier. And LTE-B receivers could also detect and decode the content contained in the frames. This is supported by the 'future extension frames' (FEF19) element of the DVB-T2 standard, but this remains untested.
- Common Broadcast System. This would create a single broadcast system allowing the two networks to cooperate, delivering content in either way according to its nature or popularity. This would be helped by the fact that both DVB-T2 and LTE are based on OFDM principles and the DVB standards family contains mobile extensions such as DVB NGH (next generation handheld).

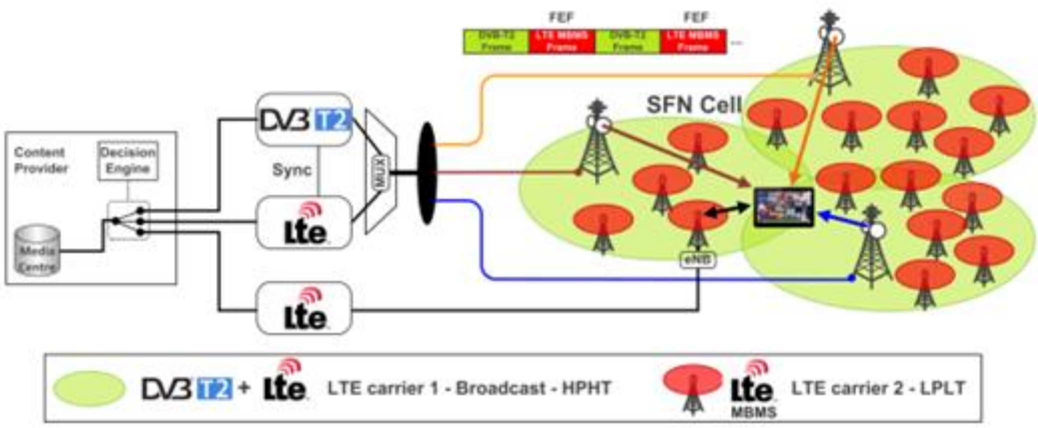

Figure 0: A possible hybrid network approach using eMBMS and DVB-T2. Source: EBU Technical Review [87]

However, there are significant barriers to convergence, particularly in terms of transition issues and timing.

- Overnight transition to convergence will be impossible while maintaining required coverage for public service broadcasting, as well as avoiding excessive disruption for users. So simulcasting will be necessary for some years, which will require additional spectrum, especially if all services are available on both platforms.

- Technology issues and full standardisation will be complex and contentious to address and a fully commercial platform with a broad device ecosystem may not be ready for many years.
- Any option which involves a new network will be time-consuming as well as costly (this would likely cost several billion pounds) to bring to market.
- There will be cross-border issues in the sub-700 MHz band to be addressed via international regulation, before a broad and harmonised ecosystem is achieved.
- There will be costs to create the new platforms and to migrate infrastructure and end user equipment. Some early modelling suggests that, while the costs are likely to fall on the DTT sector – unless they are shouldered by government – the main benefits accrue to the mobile sector, which gains additional spectrum and improved mobile services.
- That will make clear definition of business models – and confidence in them on both sides – essential for investment. This will mean clearer ideas of who will own and operate the converged platform, what type of service providers will use it, and how they will all share the proceeds.
- There may still not be enough spectrum to meet rising mobile and TV requirements, even when the two are sharing some or all of the band.
- Currently, the costs of migration to a converged platform are far more clearly demonstrated than the benefits, whether from enhanced services or the value of released spectrum.

UHF spectrum changes

Many decisions about future platforms will be influenced by eventual UK and EU policy on the sub-700 MHz UHF spectrum. The Lamy report of September 2014 addresses both the 700 MHz band (694-790 MHz) and the lower UHF band (470-694 MHz). While proposing relatively rapid reallocation of the former spectrum for mobile broadband, it recommended that the lower band should be retained for broadcasting until at least 2030.

Lamy stated: “The EU should adopt a common position against the co-primary allocation of the core audiovisual band (470-694MHz) to the mobile service at WRC 2015”. The GSMA responded, calling for a review process for sub-700 MHz spectrum no later than 2020 and a more aggressive timescale, arguing that the EU’s mobile operators could end up at a competitive disadvantage to those in other regions with lower-band frequencies.

The EBU hit back with its own report, commissioned from Aetha, and supported by the BBC, Arqiva and other groups. This claimed the cost of migrating the sub-700 MHz band from DTT to mobile services over the 2015 to 2030 period would be at least four times greater than the benefits accrued. The report estimated the costs of migration at €38.5 billion, including €19.7 billion for the consumer equipment required, €10.8 billion for setting up a new free-to-view platform and €14.2 billion arising as a result of reduced competition in TV platforms, but minus the €6.2 billion saved through no longer having to run DTT networks. Its calculation of net gain to mobile services was €10.5 billion. [88]

Ofcom is broadly supporting the Lamy position and said in a recent consultation document: “We see an important role for digital terrestrial television in the UK for many years. We are monitoring developments carefully but our current expectation for WRC-15 is that we would resist a co-primary mobile allocation in this band.” [89]

As the UHF policies will influence convergence, so the choice of converged platform (if any) will influence spectrum allocation. The details of such options remain to be determined.

Applying the TV white spaces

If converged platforms may make conventional arguments about mobile versus broadcast redundant in time, so new approaches to spectrum may change attitudes to coexistence within key bands. In particular, there is growing interest in dynamic sharing of spectrum, and much of the initial real-world work has centred on the TV white spaces (TVWS) in the UHF band. This is because of its favourable propagation characteristics as well as its global applicability.

The US and UK have been the frontrunners in opening up the TVWS. Building on the groundwork in these countries, a global industry association, the Dynamic Spectrum Alliance (DSA) is helping to progress the development of the technology and best practice enabling regulations. DSA members include Facebook, Google and Microsoft, as well as universities and silicon suppliers.

At this point in time, geolocation databases are being used to avoid interference with incumbent services. Dynamic spectrum access is expected to develop further over time, applying spectrum sensing and other cognitive radio techniques to enable greater spectrum sharing efficiency.

Access to the TV white spaces is licence-exempt, and so available to a range of technologies (Wi-Fi, 802.15.4, 802.22, specialised systems for machine-to-machine use) and applications (rural coverage including TV, additional Wi-Fi hotspot capacity, connecting up smart cities, enterprise connectivity, flood defences etc.). In Scotland, TVWS technology has been used to extend broadband to rural communities (Isle of Bute and Annan) and to ferry users (in the Orkney Islands). It has also been applied to flood detection around Oxford and to remote monitoring of animals in London Zoo.

As a result of the DSA's work, TVWS technology is enabling the benefits of broadband to be extended to rural communities in Africa and Asia. Singapore is leading the way in urban Internet of Things applications.

Being licence exempt (LE), there are no restrictions on who can use TVWS technology or for what purpose. It therefore provides excellent scope for experimenting with new approaches to take advantage of the improved propagation (compared with higher frequency LE bands, such as 2.4 GHz). Finalisation of the IEEE 802.11af standard, in 2014, added TVWS to the bands available for Wi-Fi applications. Work at the University of Strathclyde, sponsored by BSkyB, has demonstrated the coverage efficacy of TVWS (802.11af), alongside established Wi-Fi bands (2.4 and 5 GHz) – in home network scenarios, using the first triple-band Wi-Fi units in the world.

There are constraints on TVWS capacity linked to DTT and PMSE protection requirements. For this reason, the number of channels available, as well as the maximum power levels, can vary significantly from one location to another.

TV white space technology is an important first step towards the broader application of dynamic spectrum access (DSA). In the US, which enabled TVWS back in 2010, DSA is now being applied to the 3.5 GHz band.

On the downside, widespread introduction of TVWS below 700 MHz would significantly limit the opportunities to migrate the use of that spectrum to LTE. Future capacity is uncertain given that the amount of white space will diminish as the broadcasters use the 470-790 MHz band more efficiently, and PMSE continues to have priority in locations with theatres and studios. The vast majority of the landmass of the UK is hardly touched by PMSE use, though there are temporary outdoor uses in certain locations.

Potential further contraction of broadcast spectrum below 694 MHz in the UK and EU seems to be many years away and DTT network changes tend to be slow. So geolocation databases enabling TVWS spectrum use to be adjusted in a matter of minutes, mean that TVWS should be well-placed to facilitate any future ‘furniture moving’ that may be required in the UHF bands in the years to come.

A.11. Short range wireless (SRDs and Wi-Fi)

11.1 Scope of the sector

This chapter covers two sets of technologies which overlap in terms of spectrum allocations, and sometimes in terms of application, especially as they meet one another in the expanding 'Internet of Things' (IoT) market. However, except that they live mainly in licence-exempt frequencies, Wi-Fi and SRDs (short range devices) otherwise have more differences than similarities, but may find themselves seeking additional spectrum in the same bands.

Wi-Fi has been an extraordinary success story in terms of global adoption and its rapidly expanding set of use cases. Its core technology goes back to cash register systems invented by NCR in 1991, but the base IEEE 802.11 standard was released in 1997, providing a set of physical layer and MAC specifications for a wireless LAN (local area network). Its remit quickly expanded from enterprise-focused WLANs to home networks, but the real catalysts for adoption were two parallel developments heavily driven by Intel – the embedding of Wi-Fi into consumer devices, initially laptops and later handsets, cameras and tablets; and the creation of public access points or hotspots, to support broadband access on the move.

Other enhancements are stretching Wi-Fi's functionality into new application areas, well beyond the WLAN. These include long range, low power broadband (draft standards 802.11af and 802.11ah), for applications such as rural access and smart cities, harnessing sub-1 GHz frequencies. Individual operators and vendors have also adapted the base Wi-Fi platform to support additional use cases such as fixed broadband wireless, mobile backhaul, public safety, vehicular communications and many more.

The Wi-Fi ecosystem has therefore expanded to create a broad sector which encompasses:

- Radio, chipset and component makers
- Wi-Fi enabled device vendors
- Suppliers of consumer, enterprise and carrier equipment
- Wi-Fi service providers, including aggregators, wholesalers, venue owners, mobile operators, fixed-line operators, enterprise providers etc.
- Suppliers of Wi-Fi enabled content and applications.

The second group covered in this chapter, short range devices, has an even broader scope and the SRD ecosystem includes suppliers of chips, devices and equipment; and specialist service providers and integrators, for a host of applications. All of these have certain characteristics in common:

- Very low power consumption (typically 10-100mW depending on frequency band).
- Consequently short range, usually up to a few hundred meters depending on band and application.
- Almost all are in licence-exempt spectrum because their low power levels limit the risk that they will interfere with others.
- Most are for terrestrial use only.
- They operate on a non-protected, non-interference basis, which becomes a vital consideration when they are used for critical purposes such as security.

- Most use 12.5 kHz channels though 25 kHz is permitted for some higher bandwidth applications.
- Wide range of data rates, typically from 1 bps to 1 Mbps.

Some SRDs connect using standards like ZigBee and RFID, while others use proprietary radio designs.

These devices are used in a wide range of sectors including transport, avionics, supply chain management, industrial control, the smart grid, emergency response and medical monitoring.

The categories of SRDs outlined by Ofcom include:

- Industrial control and telemetry
- Medical implants and medical body area networks (MBANs)
- Short range indoor data links, e.g. for smart home connectivity
- Railway identification and vehicle-to-track communication
- Road transport and traffic telemetry
- RFID
- Metal detectors
- Alarms
- Licence exempt radio microphones (not requiring a PMSE licence)
- Assistive listening devices
- Wireless video cameras
- Vehicle radar
- Ground probing radar

11.2 Contributions to social and economic value

Wi-Fi supports a broad ecosystem, as outlined above. Most of the suppliers of equipment and components are located outside the UK, but Wi-Fi nevertheless creates economic value

- Directly, for Wi-Fi service providers, integrators and distributors
- Indirectly, by enabling revenue-generating services which would otherwise have been absent, or less available.

For instance, the ready availability and affordability of public Wi-Fi have driven greater usage of on-the-move data and content than would have occurred without Wi-Fi. Without it, users would have been limited to cellular (more costly and, until the advent of LTE, slower) or Internet cafes (inflexible). In 2012, over 80% of smartphone-originated traffic in the UK ran over Wi-Fi rather than cellular [90] according to market research by Nielsen, and when users were at home, the percentage was even higher, as Figure 1 illustrates.

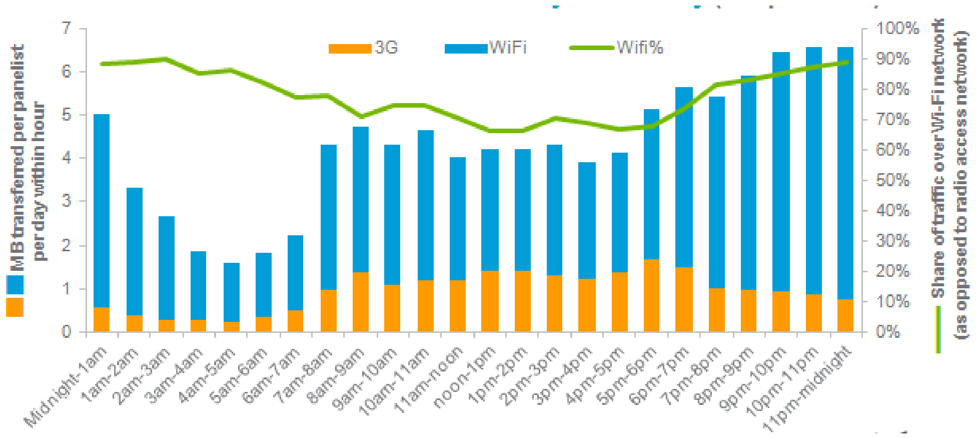

Figure 41: Wi-Fi and cellular usage patterns (Mbytes per hour) based on a panel of UK Android smartphone users, Nielsen, September 2012.

Some of this data would, if Wi-Fi did not exist, travel over other networks, in some cases generating higher revenues (the high usage of Wi-Fi is partly driven by low cost or free services). However, many high value services would not be able to exist if they had to rely only on mobile networks, because of capacity constraints – for example, BSkyB's SkyGo 'TV anywhere' offering is enabled by the fact that about 60% of its data can be offloaded to the provider's 'The Cloud' Wi-Fi hotspots.

In social terms, Wi-Fi has made it more affordable for people to adopt many new working practices and leisure activities, which can be argued to be beneficial to productivity, social connections, communication and cultural life. These include communication on the move, which aids social relationships and work productivity; new types of high bandwidth content services such as multiscreen video; access to information and entertainment from any device or location.

Meanwhile, SRDs have a far lower profile in terms of their economic contribution, but enhance efficiency, productivity and even safety for a wide range of industries and consumer applications. Greater intelligence in industrial networks, supply chains and in vehicles, for instance, supports new revenue-generating services, as well as cost efficiencies for those sectors.

Part of the value of SRDs relates to their efficient use of spectrum resource. For instance, in research commissioned in 2006 by Ofcom from Aegis and Ovum, it was calculated that RFID, a particularly efficient SRD technology used for telemetry and smart barcoding, could contribute about £620 million per MHz to the UK economy over 20 years, while broadcasting and mobile communications would each contribute less than £30 million. Arguments like these lead SRD sector lobbyists to suggest that their services would be a better economic use of additional spectrum in the 5 GHz band than expanded Wi-Fi capacity.

Also, SRDs are used in a widening range of critical applications, which help to improve safety, security and public health – medical monitors, devices to locate injured people, and radar landing aids for air ambulance helicopters are just some examples.

The innovative ecosystem which unlicensed spectrum often encourages has led to the SRD community creating new technologies, which have gone on to be valuable to the broader wireless world. These include ad hoc mesh, new security protocols and trusted network discovery mechanisms. The need for devices to be very low power and low cost also means that the SRD providers have helped drive the overall reduction in prices and size of devices across the wireless board, right down to sensors.

The economic value of Wi-Fi and SRDs, then, is tied into the broader value of unlicensed spectrum in driving high usage levels and innovation, as well as the creativity in business models which those enable. Many of the most detailed studies of the economic contribution of licence-exempt spectrum have been done in the US, where the most recent report, focused mainly on Wi-Fi, calculated a figure of $140.2bn for the US alone [91] . Plum Consulting estimates that the value of improving Wi-Fi's capacity and quality of service, through additional spectrum, would be worth €16.3bn to the EU economy.[92]

In the case of SRDs, much of their future contribution will be related to the growth of the Internet of Things in unlicensed spectrum. By 2020, the economic potential of the IoT is calculated to be over $1.4 trillion a year, or five times the economic contribution of the Internet today [93], and unlicensed spectrum could support over 90% of the billions of devices which will be connected. This will have social benefits in terms of new services, smart cities, improved health monitoring and others.

The value of Wi-Fi and SRDs can also be seen in the context of the overall Internet value chain, which a study by AT Kearney estimated to be worth £82 billion a year in 2012 [94], with mobile and wireless connections accounting for 16% of this. Connectivity is the largest element of internet capex (about 72%) but on the wireless side, the bills can be reduced by omitting spectrum fees.

11.3 Current and recent past status

The Wi-Fi market has gone through significant changes, in technology and usage patterns, in recent years. Some indications of its growth are seen in the following statistics:

- Wi-Fi traffic will exceed wireline by 2018 (Cisco Visual Networking Index 2014) and cellular by 2015 (Juniper) on a global basis. In the UK, according to Cisco, mobile and Wi-Fi traffic will reach 88.6 petabytes in 2014 and grow to 445 petabytes in 2018, with at least 60% of this being carried over Wi-Fi (see Figure 42).
- The UK has over 200,000 Wi-Fi hotspots, and this figure will grow to 494,000 by 2018 (Rethink Research 2014, Figure 43).
- Almost 57% of mobile data is offloaded to private or public Wi-Fi networks (Juniper Research 2013)
- About 20% of UK users' data consumption takes place away from the home or office.

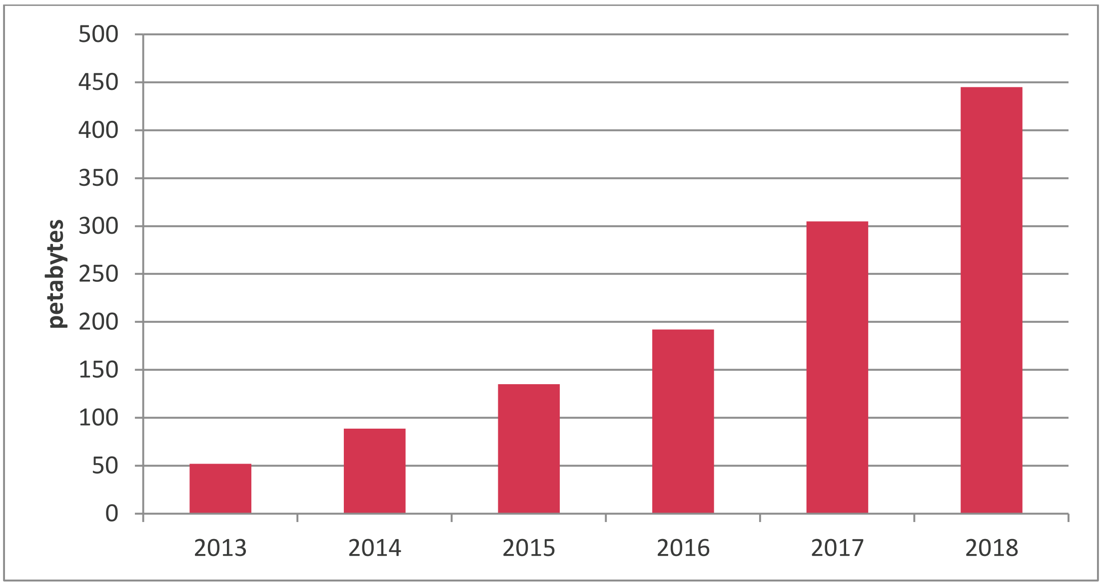

Figure 42: Mobile and portable data traffic in the UK 2013-2018. Source: Cisco VNI June 2014.

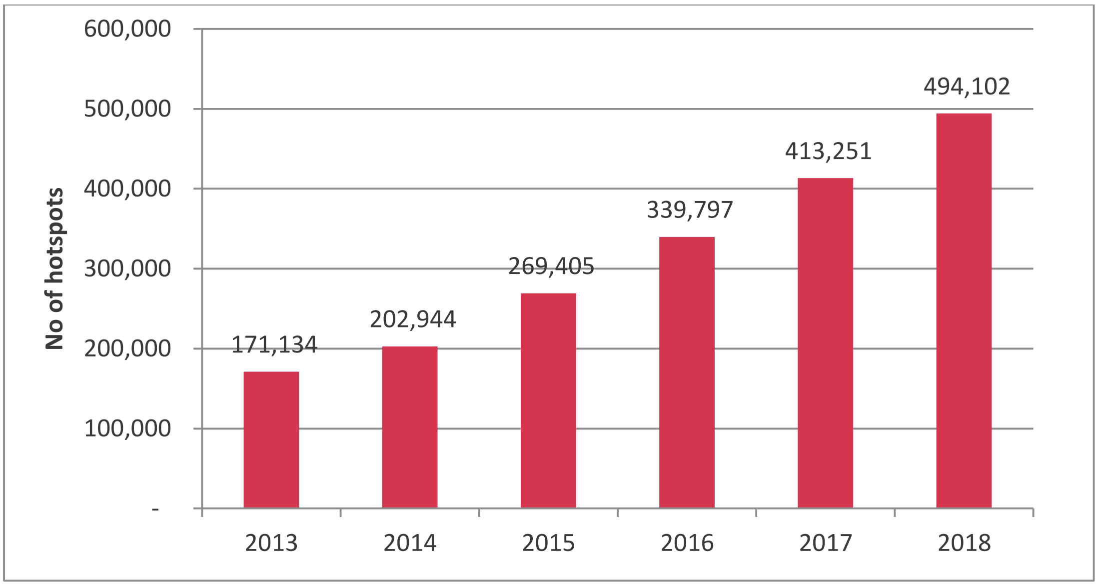

Figure 43: Number of public Wi-Fi hotspots forecast to be deployed in the UK 2013-2018. Source: Rethink Technology Research October 2014

Trends like these are driving technology improvements, notably the adoption of higher speed 802.11ac system, as well as growth in the services sector. Comparison of today's Wi-Fi with that of a decade ago illustrates the rapid pace of its evolution (see Table 12).

In 1999, the Wi-Fi Alliance was formed to promote, trademark and test/certify equipment and devices based on the 802.11 family of standards. That family has grown rapidly, with 12 mainstream additions to the 1997 specs either completed or in the works, plus extensions for specific purposes such as security (802.11i/WEP) and quality of service (802.11e). Some of the new extensions have been geared to increasing peak and average data rates, as well as range, to support broadband applications (802.11b, the first fully commercial version, boasted peaks of 11Mbps; now 802.11ac is being deployed commercially and supports gigabit-plus data rates; a future iteration, 802.11ax, aims to quadruple those speeds and provide better stadium-area coverage).

Table 12: The main Wi-Fi standards

Standard	Frequency band	Bandwidth	Modulation	Peak data rate
802.11-97	2.4 GHz	20 MHz	DSSS, FHSS	2Mbps
802.11b	2.4 GHz	20 MHz	DSSS	11Mbps
802.11a	5 GHz	20 MHz	OFDM	54Mbps
802.11g	2.4 GHz	20 MHz	DSSS, OFDM	54Mbps
802.11n	2.4 GHz, 5 GHz	20 MHz, 40 MHz	OFDM	600Mbps
802.11ac (waves 1 and 2)	5 GHz	20 MHz, 40 MHz, 80 MHz, 80+80 MHz, 160 MHz	OFDM	6.93Gbps (with wave 2 specs)
802.11ad	60 GHz	2.16 GHz	OFDM single carrier	6.76Gbps
802.11af	TVWS	5 MHz, 10 MHz, 20 MHz, 40 MHz	OFDM	12Mbps
802.11ah	800 MHz, 900 MHz	1 MHz, 2 MHz, 4 MHz, 8 MHz, 16 MHz	OFDM	40Mbps
802.11ax	5 GHz	40 MHz, 80 MHz, 80+80 MHz, 160 MHz	OFDM, OFDA	>6Gbps

However, rising speeds and usage are putting intense pressure on available spectrum capacity, risking a backlash against Wi-Fi if quality deteriorates as a result.

The same issue faces the SRD sector, which runs the risk that growth in usage will outrun the allocation of new frequencies. In the case of SRD, this is not about soaring data rates or traffic volumes per user, as in Wi-Fi, but about rising numbers of devices which need to be accommodated, increasingly with very low tolerance of interference (for instance, in safety applications or heart monitors).

The scale of the sector, even before the IoT in its modern definition has taken off, is seen in an estimate of the minimum number of SRDs sold annually in the EU for the 863-870 MHz band. According to CEPT's ECC Report 182 [95], conservative estimates of these numbers (in 2012) were:

- All kinds of metering >10 million
- Home automation >10 million
- Alarms >10 million
- Automotive >5 million
- Industrial >2 million
- Audio >2 million
- RFID >100,000 readers
- Social/personal alarms >100,000 units

As Figure 44 shows, machine-to-machine (M2M) connections already account for almost 8% of total wireless connections in the UK (as of the end of 2013), the ninth highest figure in the world, and a high percentage will be enabled by licence-exempt SRDs (though it is worth noting that smart meters have been the most significant growth factor for unlicensed M2M connections in many countries, such as world leader Sweden, whereas in the UK, smart metering is being supported in licensed bands by Arqiva etc).

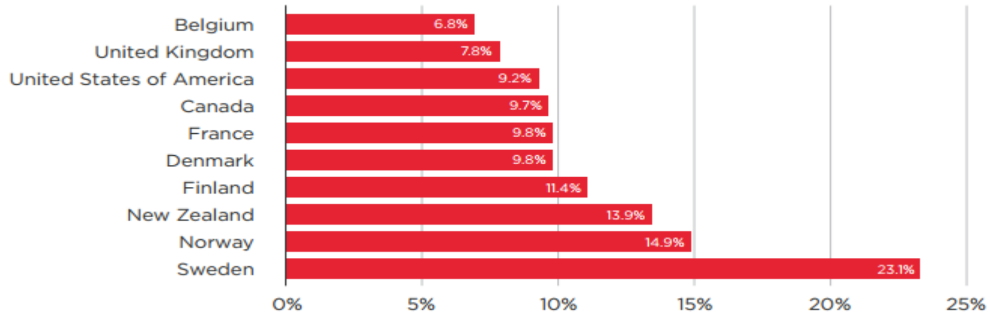

Figure 44: M2M connections as a percentage of all wireless connections, by countries with highest penetration. Source GSMA [96]

While Wi-Fi has a unified family of standards to support it, SRDs support a wide range of protocols, all of them devised for short range, low power applications such as WPANs (wireless personal area networks) or M2M. The diversity is seen in the number of standards battling in the smart home market alone, each driven by different companies and interest groups.

Table 13: Some of the key standards-based protocols for SRD

Protocol	PHY Standard	Spectrum band(s)
Bluetooth Low Energy	IEEE 802.15.1	2.4 GHz, 868 MHz (Europe), 900 MHz (US)
ZigBee 6LoWPAN Thread	IEEE 802.15.4	2.4 GHz, 868 MHz (Europe), 900 MHz (US)
Z-Wave	Proprietary	868 MHz (Europe), 900 MHz (US)
ANT+	Proprietary	2.4 GHz

There are also many proprietary and specialised protocols for specific applications, especially in sensors. A large percentage of SRDs run proprietary radio technologies specifically geared to ultra-low power consumption, which avoid the overhead of a protocol stack.

Any of these connections will often link one or more devices or sensors to a gateway, which will then be linked to the internet or cloud server by a long range, low power network, which could be Wi-Fi, cellular, or a narrowband technology such as Plextek UNB, Sigfox or Weightless, depending on the application. With the exception of cellular, these long range IoT networks usually operate in unlicensed 800 MHz band UHF spectrum.

11.4 Sector trends

As well as the increases in usage, traffic volumes and data speeds outlined above – all of them putting pressure on available spectrum capacity – there are other important trends shaping the Wi-Fi and SRD sectors in the UK and beyond.

One of the most important, in both cases, is the increasing emphasis on higher quality of service (QoS). In the case of Wi-Fi, this is seen in the shift of infrastructure deployment and services towards carrier-grade networks, which aim to support a user experience close to that of a cellular network in terms of reliability, consistency and quality, not just speed. This is driven by users' rising demand for higher consistency, particularly because an increasing percentage of online time is spent consuming streamed content such as video, which is QoS-sensitive. Operators believe they will be better able to monetise Wi-Fi if they can promise a premium experience and many are progressing from using Wi-Fi mainly to offload mobile data, to supporting full 'anywhere' content services, as seen in SkyGo.

This is being enabled by several factors:

- New industry specifications such as Next Generation Hotspot and Passpoint/HotSpot 2.0, which support single log-in, seamless roaming between different networks (including cellular).

- Integration of Wi-Fi into an operator’s mobile or fixed-line core networks and OSS/BSS systems, to support carrier-class services.
- Future standards which focus on consistency and coverage as much as raw speed (e.g. 802.11ax).
- Emerging work, by the Wi-Fi Alliance and others, on intelligent access control, so that users receive the most appropriate connection in relation to their application or other criteria.

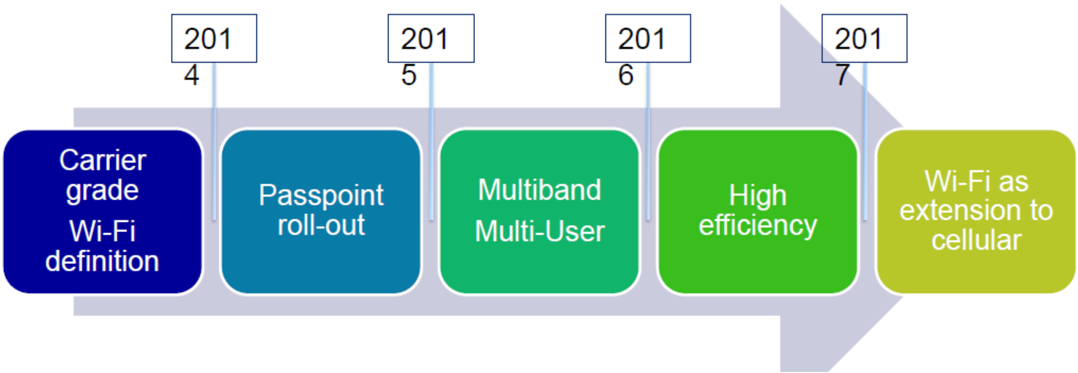

Figure 45: Evolution of Wi-Fi capabilities to support new types of services. Source: BSkyB/The Cloud

For SRDs, the need to pay greater attention to reliability and quality is arising because, as outlined above, more of the applications they support are becoming safety-critical, or essential to the smooth functioning of a business (monitoring of freight or vehicles, for instance).

For both sectors, interference and congestion are therefore becoming increasingly destructive to their business cases and future growth, making the availability of additional spectrum essential.

11.5 Spectrum usage

Both the Wi-Fi and SRD segments are focused on a dual strategy when it comes to spectrum – to campaign for additional licence-exempt allocations, and to use existing frequencies more efficiently by harnessing intelligent mechanisms. As Sami Susiaho of BSkYB/The Cloud expressed it: “Our priority outdoors is intelligent channel selection, because we’re out of spectrum.”

As in any licence-exempt bands, the devices have several key challenges:

- Securing sufficient interference-free capacity to support rising usage
- Mitigating the QoS impact of congestion as usage rises or becomes more quality-critical
- Avoiding interference with primary user technologies, where relevant
- Behaving ‘politely’ to other licence-free users nearby, even where new technologies are entering the band.

Wi-Fi currently operates in two main bands, and is developing standards to move into more, subject to regulatory approval (see below). SRDs operate in a wide range of frequencies, depending on application, and the terms of usage for some of these categories can be strict.

The first spectrum band to support Wi-Fi was the 2.4 GHz ISM band, and many devices still support only this option. Because it has minimal regulation, 2.4 GHz houses a large number of technologies coexisting in a spectrum 'free-for-all'. This is leading to congestion and interference, particularly for outdoor and public Wi-Fi (where usage levels are variable and often unpredictable), but also even in the home, where other protocols such as Bluetooth and ZigBee may be operating, as well as other devices such as baby monitors and microwave ovens. In some parts of the UK, according to operators, there is virtually no 2.4 GHz spectrum left that is usable (e.g. in the City of London).

Although there is just over 80 MHz of spectrum available in 2.4 GHz, this translates into just three 20 MHz channels because of how the band is planned in the US (and therefore how equipment is designed).

As far back as 2000, Ofcom was looking ahead to likely congestion in 2.4 GHz, and commissioned a study by Aegis Consulting. As Figure 46 indicates, the main casualty, in terms of performance, is outdoor usage.

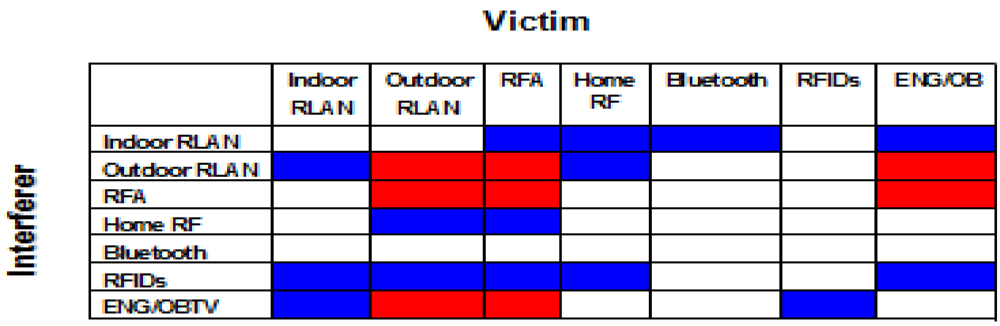

Figure 46: Potential congestion in the 2.4 GHz ISM band UK. Source Aegis Systems [97]

The second main Wi-Fi resource is the UNII 5 GHz band. This is split into two main blocks – 200 MHz between 5150 MHz and 5350 MHz; and 255 MHz between 5470 MHz and 5725 MHz. The former block is also split in half, with the lower section being for indoor use only, and the higher 100 MHz being subject to mandatory DFS (dynamic frequency selection) mechanisms, to avoid incumbent radar users. The higher 255 MHz block is also subject to DFS. Guard bands reduce the total amount of usable spectrum to 19 channels of 20 MHz and because the band is split, it is only possible to form two contiguous 160 MHz channels (the high speed 802.11ac standard uses these wide channels to achieve its maximum data rates, combined with MIMO and other techniques).

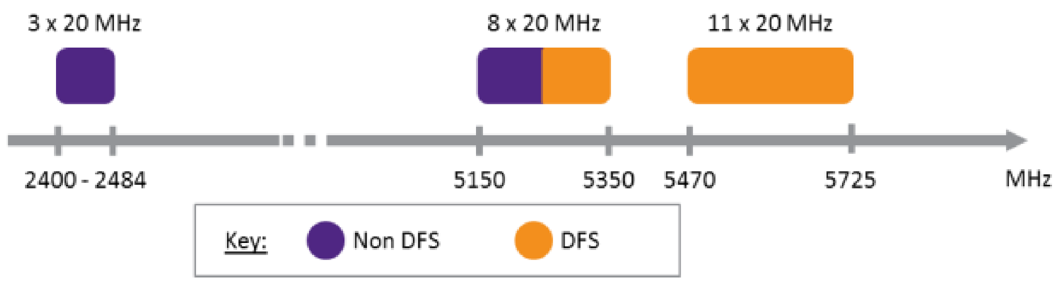

Figure 47: Current spectrum availability for Wi-Fi in Europe. Source: Plum Consulting

The use of the 5 GHz band is increasing as device support grows and the 2.4 GHz spectrum becomes overloaded. For instance, on The Cloud's hotspots, 5 GHz usage started to rise significantly in 2013 and now accounts for two-thirds of the data, and 51% of the sessions, on the network.

For SRDs, European frequency allocations went a long way to harmonisation in 2006 when the European Commission published its Decision on SRDs, which the EC said were playing "an increasing role in the economy and the daily life of citizens".

The key bands currently in use, or in the process of being opened up, are:

Table 14: Key SRD bands in Europe. Source: CEPT, BAE Systems

Band	Main SRD application	Issues
433 MHz	Key fobs, energy meters etc	Limited bandwidth, in same band as high power military devices as well as cheap, low quality receivers. Best avoided
UHF 863-868 MHz	Medical alarms, RFID, smart home, mesh, sensors, smart grid	Extensively used but risk of congestion and issues with LTE in nearby frequencies
UHF TV white spaces	UK trials for applications like smart metering	Better suited to long range, not available across EU
920 MHz (US ISM/RFID band)	RFID	Economies of scale with US devices, but scarcely regulated
2.4 GHz	WPANs eg Bluetooth, ZigBee, smart home	Very congested
2.3 GHz		LTE concerns once Ofcom auctions some 2.3 GHz for cellular

Band	Main SRD application	Issues
2.48-2.5 GHz	Medical applications (MBANs, implants)	Coexistence with satnav systems, allowed because MBANs ultra-low power
4 GHz	Wireless avionics (WAIC)	
5 GHz (5725-5875 MHz)	Generic usage eg industrial or home automation	
5.9 GHz (5875-5925 MHz)	Car-to-car ITS (intelligent transport systems) band	Shared with fixed wireless and fixed satellite primary users
60 GHz	Intelligent transport, industrial automation	No DFS, spectrally efficient and high bandwidth
77 GHz	Radar sensors especially for transport eg cars, aircraft	Was a free-for-all like 2.4 GHz but now needs better planning to support critical applications like air ambulance

Although SRDs require limited bandwidth and have a range of bands at their disposal, there are still rising concerns over congestion and QoS because of the sheer numbers of devices which will be implemented for IoT applications. As with Wi-Fi, the SRD sector faces the key dilemma of licence-exempt spectrum, the trade-off between the flexibility and creativity of the free-for-all, as in 2.4 GHz, and the need for stricter rules to ensure quality of experience, especially for critical applications like transport safety, rescue helicopters or MBANs.

In 77 GHz, for instance, a 'tragedy of the commons' situation is threatened, where various groups of users have all pursued their own agendas, leading to the depletion of the spectrum resource, to the benefit of nobody. New control will be required because the band supports transport radars, which include car safety and air ambulance applications.

One approach may be to categorise users in the unrestricted bands, like 2.4 GHz, according to the relative transmit power of the devices, which some are recommending for the UHF spectrum as it becomes congested.

One of the most attractive emerging sources of SRD spectrum is the 60 GHz band, which is well suited to applications such as industrial automation, where larger quantities of data may increasingly be transmitted than in classic SRD applications. Availability of CMOS chipsets has brought down costs, and the development of intelligent antennas now supports the ability to transmit large amounts of data round corners and walls. There is no DFS requirement as the spectrum is unoccupied and so the band is easy to engineer, flexible and spectrally efficient.

Some SRD advocates argue that their technologies would be more suited to some applications, including in industrial automation, than the 60 GHz implementation of 802.11, WiGig (see next section), and could solve some of the problems, such as penetration throughout buildings, which Wi-Fi faces at high frequencies. However, they acknowledge that high frequency spectrum is not suited to all types of short range devices and functions, and want to see low frequency options with similar freedom and simplicity to that in 60 GHz (a dream unlikely to come true, given the competing claims for the sub-1 GHz bands).

11.6 Expected changes to technology and spectrum

The social and economic impact of unlicensed spectrum and low cost broadband access, particularly as enabled by Wi-Fi, has been strongly recognised in recent years by governments and regulators round the world. This is resulting in new spectrum options being considered by those bodies to add Wi-Fi capacity. These often do not go far enough for the industry heavyweights such as Google and Microsoft, which are campaigning for accelerated action to release new or shared spectrum, especially in the US, and which are creating ecosystems around new frequencies such as the TV white spaces (TVWS) in UHF/VHF bands, and 60 GHz.

The main sources of new spectrum for Wi-Fi in Europe in the rest of this decade will be:

- Additional 5 GHz frequencies for conventional Wi-Fi/802.11ac. Most of these will be made possible by new spectrum sharing techniques, which make it more practical to have Wi-Fi (and other licence-exempt technologies) coexist with licensed incumbents such as radar.
- Other shared spectrum options. The TVWS spectrum is just one example, and is proving an important testbed. The emerging 802.11/Wi-Fi standard for TVWS is 802.11af (also known as White-Fi).
- Expansion into bands currently used by SRDs and others, notably 863-868 MHz, with the 802.11ah extension.
- Expansion into 60 GHz spectrum courtesy of the WiGig standard (802.11ad).

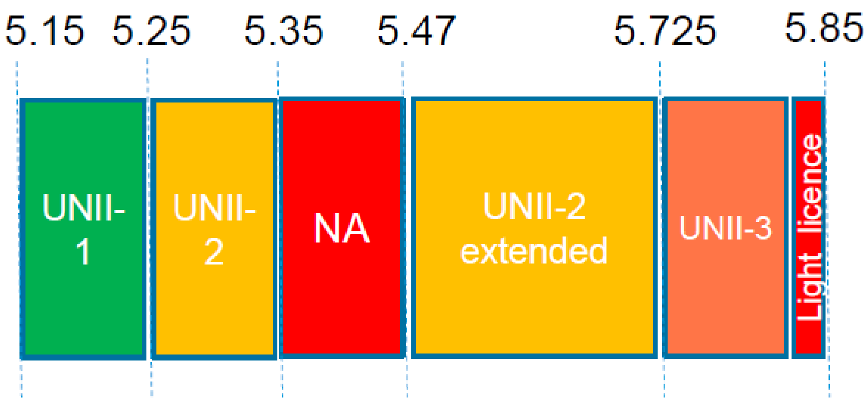

Figure 48: The layout of the 5 GHz band, including new allocations in UNII-3.

The existing 455 MHz of 5 GHz spectrum in which Wi-Fi can operate is shown in Figure 11, along with an additional tranche (UNII-3) in which authorities on both sides of the Atlantic propose Wi-Fi should be able to share with incumbents. The whole area from 5300-5900 MHz is used by meteorological and military radars as well as maritime surveillance and these have primary use rights (Wi-Fi's detect and avoid mechanisms have proved effective in UNII-2).

In September 2012, the European Commission issued a Communication favouring shared spectrum use, noting: "A new generation of RLAN equipment (known as 802.11ac), expected to be on the market by the end of 2012, could approach the user speeds of fixed line networks. While depending on existing RLAN spectrum at 5 GHz, such developments will require very broad frequency channels that are currently limited in number."

Ofcom opened a consultation in August 2013 on shared use of the extended 5 GHz band.

Dynamic spectrum allocation (DSA) techniques will help to make this a reality. Some have been pioneered in the TV white space spectrum, which has proved a useful testing ground for mechanisms such as geolocation databases, to enable licence-exempt devices to identify vacant channels and avoid interfering with primary users. However, where existing users are from government or space sectors, there will be particular sensitivity about interference risks, and the industry is under pressure to develop ever-more sophisticated spectrum sharing tools.

This is because there is relatively little virgin spectrum left, at least in the lower bands, and usage is rising quickly. Wi-Fi operators say they will run out of UNII 5 GHz spectrum in many markets well before new bands are opened up – likely to be in 2-3 years' time. That urgency will be heightened as Wi-Fi extends its range of applications further, in areas like smart cities; as quality of experience expectations rise; and as, in some cases, providers switch off the 2.4 GHz option altogether for QoS reasons.

The rise of 'Wi-Fi first' mobile services in the US is one example where the balance of usage is being pushed even further from cellular to Wi-Fi, even though, some argue, cellular is in a stronger spectrum capacity position than Wi-Fi.

In such environments, Wi-Fi will, in the near term, run out of the capacity to support the data rates required. Various calculations indicate this, including some carried out by Plum Consulting [98, 99] (see Figure 49).

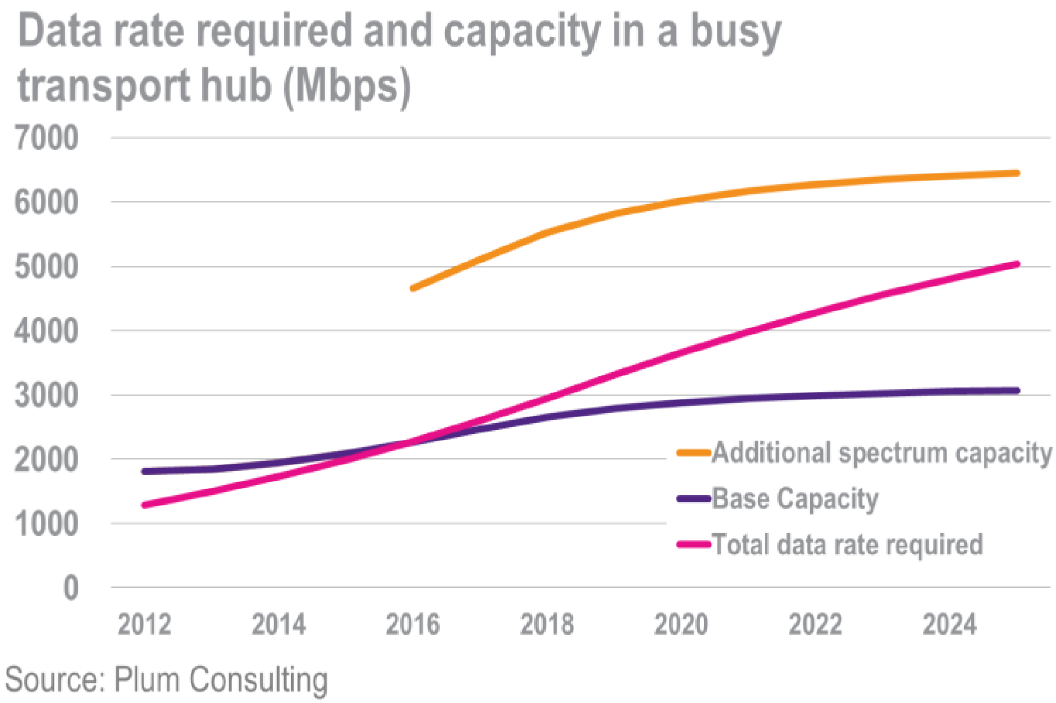

Figure 49: Without additional 5 GHz spectrum, Wi-Fi capacity will be inadequate to support desired data rates in busy areas such as transport centres, as early as 2016.

This study calculated that the benefits of additional 5 GHz allocations would be worth €16.3 billion to Europe in net present value terms (€12.3 billion in improved speeds for residential users, with associated additional fees; €4 billion from increased mobile data offload, saving cellular network costs).

Additional 5 GHz spectrum could also benefit some SRD applications, particularly wireless industrial automation (WIA), delivering large-scale and reliable communications and sensor networks to factories, refineries and utilities. CEPT working groups have been looking at the potential of the 5725-5825 MHz spectrum for large networks supporting over 1, 000 devices in an environment such as a factory.

The sub-1 GHz bands:

As noted above, Wi-Fi extensions are being devised for three further bands, and more may be added in future. The 802.11ah specification for UHF spectrum will be ratified in early 2016, and is likely to be targeted mainly at machine-to-machine applications since it will be sharing the limited capacity of the 800 MHz frequencies with many other eager contenders.

That capacity is increasing however (see Figure 50 and Figure 51). The 7 MHz originally available in 863-870 MHz is being expanded to a total of 20 MHz, (adding 862-863 MHz, 870-876 MHz, and 915-921 MHz). That is a significant resource for SRDs (and other users) and brings Europe into line with US allocations, creating global harmonisation for applications like RFID. That is important to support international monitoring and supply chain applications such as transport, freight and aviation).

Following the EC decision to make the additional spectrum available, ETSI will revise its standards (EN 300 220 for SRDs and EN 302 208 for UHF RFIDs) by early 2015. Additional new harmonised European standards are under development in ETSI, such as EN 303 204 for network-based SRDs, which can work together to form meshes, or topologies for metropolitan/rural area networks.

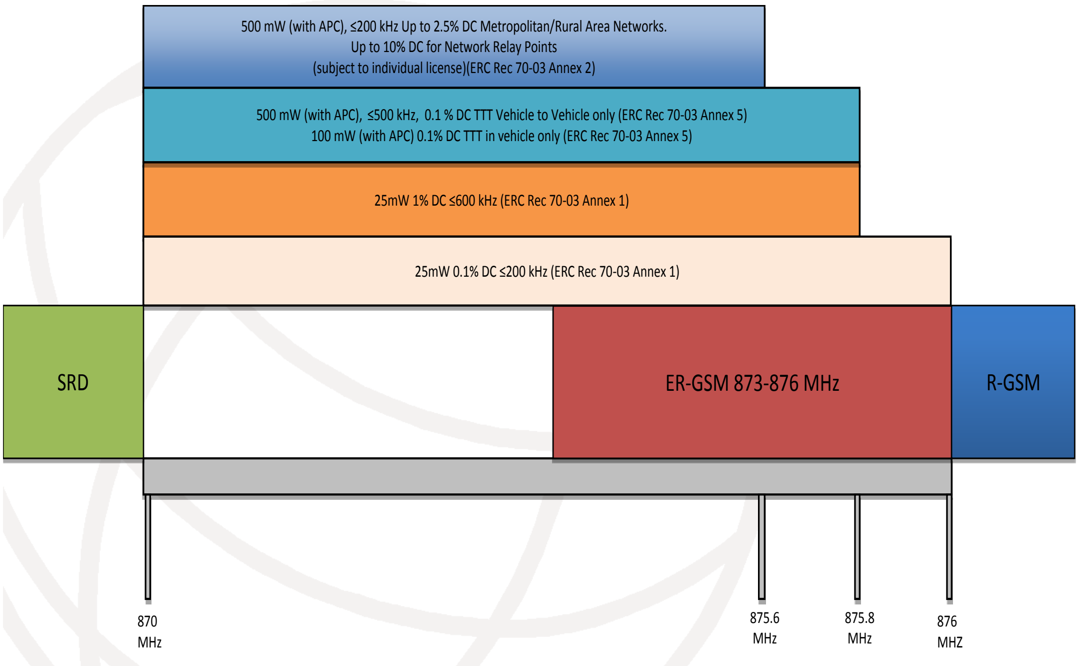

Figure 50: Allocations in the 870-876 MHz band (ECC Recommendation 70-03 February 2014)

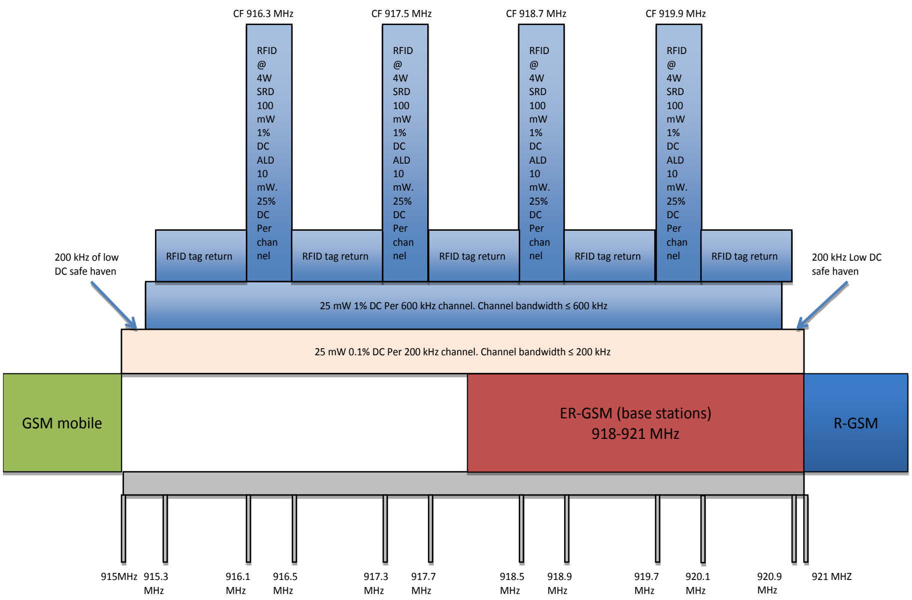

Figure 51: Allocations in the 915-921 MHz band (ECC Recommendation 70-03 February 2014)

The overall increase in capacity in this part of the band will also be important as some SRD applications grow their bandwidth, and as techniques like machine meshing are adopted – both these trends would soon stretch the limits of the original 7 MHz allocation.

There are still challenges, including the need for better ad hoc protocols and receiver performance, and more robust wireless security for critical applications.

Benefits of UHF, such as good indoor penetration, also apply to the TV white space, although these are far more immature in terms of available devices. Ofcom has been one of the most enthusiastic regulators about opening up these neglected scraps of spectrum, and trials have focused on rural broadband and M2M. However, a device ecosystem will be hard to build up until there is more global approval.

High frequency spectrum options:

A promising area of spectrum for high capacity Wi-Fi is 60 GHz. The 802.11ad standard is addressing this, implementing a Wi-Fi-like PHY and MAC in the high frequency band. This was originally a separate effort under the brand name WiGig, but was merged into the Wi-Fi Alliance's activities in 2012, enabling a broader ecosystem and greater harmonisation with mainstream Wi-Fi. Certification will start in 2015 but pre-standard equipment has already been produced, mainly to support high speed connections between PCs and peripherals. In future, 11ad is expected to support other applications requiring very high data rates over short distance, such as hotspot access or last meter backhaul; in-home HD media transmission; meshes to provide dense capacity in small urban zones. Most expect 11ad to complement its longer range cousin, 11ac, and most chip suppliers are planning multimode products supporting 2.4/5/60 GHz.

The SRD sector is already using the 60 GHz band (see previous chapter) and is looking further up the spectrum too, in particular at 77 GHz, where the main application is radar sensors. While 24 GHz has largely been abandoned for wideband radar, EU legislation has forced the pace of adoption of 76-77 GHz for long range radar (cruise control) and 77-81 GHz for short range radar (smart braking etc). New radar/sensor permutations include fixed infrastructure (roads, tunnels, level crossings), aircraft wing tips during taxi, and helicopter landing (e.g. roadside rescue).

There is still a complex process of testing all the various permutations of radars and equipment in 77 GHz, as is already ongoing in 60 GHz. These are under the auspices of the CEPT SE24 group.

There are other emerging options under consideration for various SRD purposes. One is to harness some underused cellular bands such as 1900-1920 MHz and 2010-2025 MHz –the Draft CEPT Report 52 proposes the expansion of SRD and DECT in these areas.

Even higher up the spectrum than the car radars, 122 GHz could be used for high resolution sensors and other general purpose devices, while the huge swathe of spectrum between 200 GHz and 600 GHz is the subject of a proposal to ITU WP1, to use it for extremely fast intrachip communications at speeds of 100Gbps and more.

The solution to Wi-Fi's rising capacity needs will not only be to secure more spectrum. There will be technology remedies too, on the network and device side. These will include:

- Algorithms supporting more intelligent decisions about the best connection to make, according to various criteria such as the type of application in use.
- Standard or proprietary enhancements to Wi-Fi to reduce its ‘chatter’ and make it behave more efficiently.
- Dynamic bandwidth allocation systems, which assign connections between Wi-Fi, cellular and other options on-the-fly, optimising the use of all available capacity.
- More sophisticated access control mechanisms, which should be incorporated in Wi-Fi Alliance standards and certification in 2016-2017. These will enable providers to measure QoS and decide on appropriate access levels.

The same is true of SRDs. It is essential to use existing bands more efficiently, for instance with continued development of better receivers (more selective receivers are now mandated by the new EU-RED). Developing for a new band may entail high expense and, in the end, be less effective than using existing, well-understood frequencies more effectively (the virtual failure of the huge industry push behind UltraWideBand is a good example, with UWB pushed back to a few niche uses).

11.7 Long term technology and spectrum needs and options

In the medium to longer term, there are likely to be changes to the entire way licence-exempt spectrum and services are treated, as most useful bands become more congested. More licence-exempt spectrum is set to be released by authorities round the world, and the traditional system of allocating long term licences to a single operator will probably come under review, especially with the rise of virtualised networks, dynamic bandwidth allocation and other new approaches to the use of capacity.

Ironically, though, another potential direction is that the unlicensed spectrum becomes more rigidly policed, with certain frequencies being reserved for specific services in a manner more familiar in the licensed world.

Some of the SRD community is already calling for a less laisser-faire approach from regulators, even in unlicensed spectrum. The days of a spectrum free-for-all being workable are ending, they argue, and call for regulatory moves such as band planning based on compatible power categories, in all frequencies.

They question whether the diverse applications all seeking to use bands such as 5 GHz and 800 MHz can really coexist peacefully, given their very different bandwidths, power levels and duty cycles, and the different way they deal with interference. There are fears in some quarters that the universal usage of Wi-Fi will allow that technology to dominate UHF and 5 GHz licence-exempt frequencies, even where other technologies such as ZigBee, RFID and other SRDs might generate greater economic value if allowed the freedom to operate optimally.

The case for industrial automation versus consumer access in 5 GHz is a good example of this type of debate, with strong arguments on both sides, and it is not a question of which application is superior, but of more rigidly allocating certain frequencies to each one so each can perform effectively. This is likely to be a key discussion point for the future.

There will also be increasingly blurred lines between licensed and unlicensed bands in many regards, especially when it comes to mobile broadband. For instance, mobile operators are increasingly integrating Wi-Fi into their ‘heterogeneous networks’ harnessing techniques such as seamless hand-off and converged mobile cores to create a single pool of capacity. Conversely, an LTE technology called LAA (Licensed-Assisted Access) is under development for the 5 GHz band, effectively co-opting some of that spectrum to support supplemental downlink for LTE networks in licensed bands. Some see that as a first step to a fully blown unlicensed LTE technology, though even LAA will take some years to reach the mainstream, partly because it does not currently support neighbourly relations with Wi-Fi.

If LAA does gain traction, it will be one more technology fighting for space in 5 GHz and other popular bands, and such trends will only intensify the focus on dynamic allocation, cognitive radio and other techniques which are likely to become significantly more sophisticated over the coming decade, supporting unprecedented levels of flexibility and coexistence in unlicensed bands.

While many of the changes in regulatory and technology approaches to unlicensed spectrum will be driven by broadband, an even greater change – in business terms, if not capacity pressures – will be created by the emergence of the Internet of Things over the next decade. This will to a great increase in the number and variety of SRDs, and the type of spectrum they will require.

A.12. Fixed Wireless Access and Wireless Transport Networks

12.1 Scope of the sector

This sector includes any provider which delivers services over a fixed wireless link i.e. with no mobility for the end point (although increasingly both fixed and mobile services may be supported on the same network, for example in the case of LTE).

The main segments to be covered in this chapter are

- *backhaul* for cellular networks and Wi-Fi base stations;
- *broadband access* over fixed wireless links;
- and various kinds of enterprise and public sector *private networks*.

Fixed wireless has not historically played as significant a role in broadband access in the UK as it has in some other markets, partly because of the country's small geographical size and relatively high investment in wireline technologies for telephony, internet access, backhaul and broadband. However, it is very important in the mobile backhaul arena, where about 60% of cell sites in Western Europe were connected to the core by microwave links in 2014, according to Ericsson [100].

In both access and backhaul, many network operators will use a combination of wireline and wireless technology to balance capacity, reach and cost. For instance, fixed wireless is used to extend broadband access into rural communities and also into white spots in dense urban areas.

Important emerging business models relate to machine-to-machine (M2M) applications, especially smart cities; and backhaul for new mobile network topologies such as small cell HetNets (heterogeneous networks) and Cloud-RAN. There is also the mandate to extend true broadband speeds to the entire population, some of which will rely on wireless links.

For all of these, wireless technology may be economically viable in some situations where fibre is not, and so there will be new opportunities for fixed wireless providers, with a resulting impact on spectrum requirements.

It is therefore arguable that, as fixed wireless technology evolves, it may become more important in the coming years than it has been historically, to support dense mobile networks, smart cities and universal broadband access schemes – or at least that, though some usage will shift to fibre as this becomes more widely deployed, new applications will emerge to fill the gap.

In terms of service providers, there is a wide range from community access providers and WISPs to national operators like UK Broadband. In addition, cellular operators may provide fixed access or small cell/Wi-Fi backhaul services over LTE, and wireline providers may supplement their offerings with fixed wireless technologies. For instance, mobile operator EE has offered fixed wireless broadband over LTE in rural areas since 2013.

Service providers may offer a combination of retail, wholesale and private managed networks (UK Broadband, for example, has all of these offerings).

For backhaul, mobile operators will typically deploy their own wireless links, though some may be leased or shared, and for small cells, there may be a shift towards hosted 'small cells as a service' platforms, in which MNOs share sites and backhaul. The operators' links may be in their own block allocated spectrum or Ofcom assigned channels (leased).

12.2 Contributions to social and economic value

It is hard to quantify the social and economic value of the fixed wireless sector specifically because this goes beyond the direct revenues attributable to fixed wireless providers and equipment makers. Fixed wireless underpins the mobile network industry, and therefore contributes to the revenues and growth of that sector, as well as delivering efficiencies for some enterprise and public sector activities.

In a study of the economic value of spectrum, conducted for Ofcom in 2006 [101], it was estimated that fixed wireless (including wireless broadband) contributed 10% of the total value, or £4.2 billion of net benefit to the UK economy. This was up from £3.8 billion in 2002, though that figure was higher as a percentage of the total (14%). In a 2012 study by Analysys Mason [102], the net contribution (though assessed with a somewhat different methodology) was £3.3 billion or 6.3%.

However, these conclusions relate just to direct revenues, not to the indirect, and less tangible, contribution made by supporting the mobile industry. In 2012, the top five national mobile and fixed broadband providers accounted for 85% of fixed wireless usage, making the sector highly concentrated.

By enabling these providers to deliver services and/or backhaul base stations in difficult terrains, fixed wireless technologies allow mobile and broadband to reach remote areas – with all the known social and economic benefits that brings – and also at a viable cost for the operator. With universal access requirements becoming more stringent in terms of guaranteed speeds, fixed wireless's role in rural and remote services will remain significant. Microwave backhaul also has an important role in some urban and suburban areas. A balanced portfolio of fibre and wireless backhaul is essential for commercial reasons, for optimal TCO, and also for practical considerations. For instance, it is a challenge to run fibre through buildings to roof tops, particularly if diversity is required. Similarly, there are types of networks which can only be deployed using fixed wireless, including some used in emergency situations, which have clear social benefits that are not related to revenues.

There are also new applications emerging for fixed wireless networks, particularly in machine-to-machine (M2M) markets, as some of those systems migrate to broadband. In a recent white paper by Cisco, it was estimated that M2M could generate cumulative economic value of $6,400 billion (£4,300 billion) for the global economy, over the next decade, which would equate to about €220 billion (£158 billion) a year by 2023 in Europe [103].

Taking such factors into consideration, Plum Consulting estimated the economic value of fixed wireless links in the European Union to be €27.8 billion in 2013, rising to €30.3 billion in 2023, mainly because of additional backhaul links [104].

12.3 Current and recent past status

As outlined above, the main situations in which fixed wireless technologies are currently used are:

- To backhaul cellular base stations, connecting them to the core network. Wireless links may be used for the last mile, to connect the base station to an aggregation point, or all the way to the switching centre or point of presence.
- To backhaul public Wi-Fi access points. This usually involves shorter links with lower capacity.
- To provide links between enterprises, base stations (for instance, in a relay) or other fixed entities. These may include very long distance and multihop connections, and trunking. They may also use ultra-low latency technologies to deliver ‘faster than fibre’ performance, typically for the financial services.
- To deliver fixed broadband services where fibre is unavailable or where customers require flexibility and low cost.
- To provide redundant back-up for wireline links in mission critical applications such as power plant monitoring or cloud data provision.
- To support network infrastructure where wireline is impractical because of cost or terrain e.g. in the utilities, emergency services, broadcast content distribution, CCTV, other private and dedicated networks.
- To support temporary networks for disaster response, PMSE, building sites, temporary offices, military use etc.

Most of the use cases above rely mainly on point-to-point (P2P) links but broadband access networks for homes and businesses, and some backhaul links (especially for small cell networks) may be point-to-multipoint (PMP) and multipoint-to-multipoint (MPMP). Temporary and city networks will also often rely on PMP, MPMP or mesh topologies.

The biggest market for fixed wireless is mobile backhaul. On a Europe-wide basis, Analysys Mason estimated in 2011 that microwave accounted for 55% of backhaul links, a figure that could rise to as high as 70% in 2015 [105] because of the move to denser networks and the shift away from copper leased lines. As those copper contracts expire, a combination of fibre and microwave is emerging as the option providing the best balance of capacity and cost, whether on a leased or purchased basis. Ericsson says the figure for Western Europe was 60% in 2014, while Plum Consulting believes that 50% of new base stations in the EU will be backhauled by microwave up to 2023.

Fixed wireless also has a role in broadband access services, mainly for rural or deep infill (filling white spots in difficult urban terrains) applications. This could help the government to hit its universal service commitment of 2Mbps and to comply with the European Union’s NGA (next generation access) targets. These mandate the delivery of at least 30Mbps download speeds to every citizen by 2020, all of which cannot be achieved over conventional copper lines, but requires new generation technologies such as fibre, G.fast or wireless, or satellite connections

According to INCA (the Independent Networks Cooperative Association), which represents alternative providers of NGA networks, of its 65 members, 46 are operating NGA services over most of the UK, creating an ‘altnet’ accessible to more than a million premises.

12.4 Sector trends

There are several important trends which will shape the fixed wireless sector in the coming few years and present new opportunities and challenges.

Many of these trends are, as in other wireless sectors, driven by the continuing increase in data traffic, the growing demand for data, combined with rising user expectations of speed, quality of service, availability and affordability.

The pressure which those factors place on cellular networks is well understood, and that creates new challenges in the access network and for backhaul, especially when fibre is unavailable or uneconomic.

The growing need for additional data capacity on a localised basis is leading wireless operators increasingly to use small cells for dense coverage (see section 3.6 and 12.6). Wi-Fi is playing a greater and greater role across the industry, becoming heavily used in the home as an offload from cellular and through Apps such as eWi-Fi. Wi-Fi is blurring the distinction between fixed and cellular access (see section 3.6 and 12.6). Use of Wi-Fi and small cells in the access network mean that the "last mile" is becoming the last few metres. This will have implications for backhaul and increase demand for wireless backhaul. This will have implications for spectrum demand and utilisation.

The rise in data usage affects other fixed wireless businesses too. In broadband access, neither governments nor end users will be satisfied with 'best effort' rural services any more, and there will be rising pressure to deliver fibre-class experience over wireless as part of universal access programmes. This presents opportunities for the fixed wireless 'altnet' providers, in rural coverage and also in 'deep infill' in urban areas and other areas of concentrated demand.

An important step forward has been approval of fixed wireless access as an NGA technology by the European Union (DGCONNECT and DGCOMP), albeit "with a defined evolutionary path to fibre when economically viable", though there is little definition of what 'economically viable' might mean. Many smaller providers have demonstrated a sustainable business case using a combination of fibre-to-the-premises and fixed wireless, with the last 10% of rural links profitably served by wireless. UK Broadband is delivering the Swindon Borough Council Superfast Broadband contract for 20,000 premises with fixed wireless using LTE technology and licensed spectrum. Other superfast broadband contracts have been awarded to operators using wireless access technology.

In technology terms, important trends include the densification of the cellular network (see 3.6) which will have a profound impact on backhaul; and the shift, in access networks, from proprietary or legacy protocols to standards, notably LTE (see 3.5). The latter is not just true of consumer broadband, which is seen shifting from 802.11 and even 802.16 to LTE, but of private and mission critical networks, as many of these migrate towards broadband and IP, and as LTE evolves to meet the particular requirements of markets like transportation (LTE-R), PMR and PPDR (eLTE) and M2M (LTE-MTC).

A migration towards LTE for access applications (not backhaul except in limited circumstances) can improve the economies of scale of fixed wireless and better enable service providers to expand into new areas, such as smart cities, because they can support standard endpoints. UK Broadband, for instance, will unveil LTE-based smart city, smart campus and smart rail offerings in the UK from 2016, introducing services first launched by its sister company, HKT, in Hong Kong.

Among smaller providers, INCA says only 1% of its members' connections (excluding UK Broadband) were LTE-based at the end of 2014, but it expects that to change during 2015 as the capex cost comes down (which may be accelerated after 2016 if LTE options for unlicensed spectrum move into the mainstream).

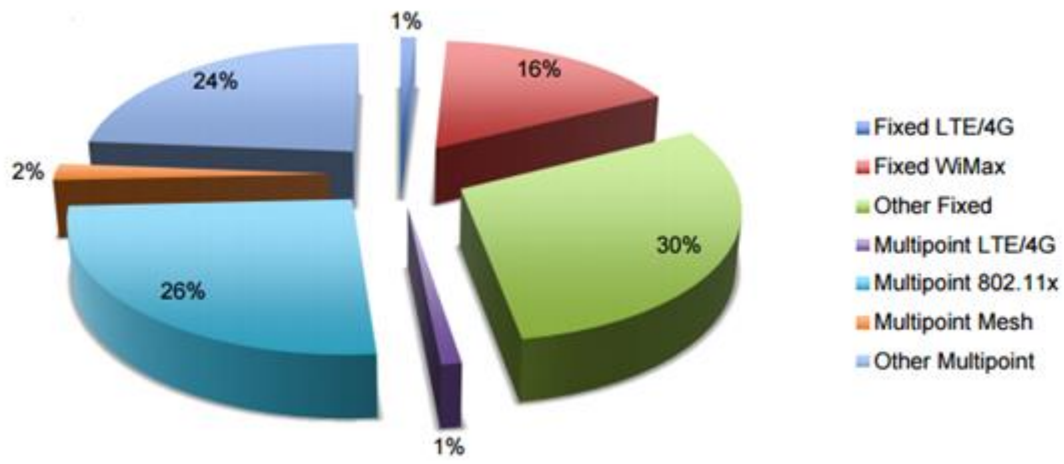

Figure 52: Fixed wireless connections by technology among alternative network providers. 'Other' generally refers to proprietary or legacy technologies. Source: Ofcom and INCA [106]

Another emerging opportunity for fixed wireless operators is in wholesale data capacity. They may offer this to MNOs which require additional capacity in certain areas such as venues or downtown city districts; to fixed-line operators which want to offer their subscribers wireless coverage on the move; or to vertical or over-the-top service providers on a virtual network operator (VNO) basis.

12.5 Spectrum usage

Spectrum for fixed wireless falls into three main ranges (see Figure 53: Bandwidth available in the three main ranges of terrestrial wireless spectrum in the UK Source: Ofcom []

Below 6 GHz, common bands in use for fixed wireless are unlicensed 2.4 GHz and 5 GHz; lightly licensed 5.8 GHz; licensed 2.6 and 3.4-3.6 GHz. All of these can also nowadays be used for mobile or portable services. Key access technologies include Wi-Fi and TDD-LTE (in 3.5 GHz and 2.6 GHz). For backhaul, there are 802.11-based platforms as well as proprietary OFDM-based technologies for sub-6 GHz non-line of sight connections.

Fixed links may also be supported in spectrum that is primarily considered mobile, as when an LTE network in 2.6 GHz, 1.8 GHz or 800 MHz is also used to deliver fixed broadband services to the home. These cellular bands are rarely used for wireless backhaul as they are expensive and so are reserved for the more lucrative mobile access services. A future exception may be self-backhauled small cells (see section 12.7). The Electronic Communications Committee (ECC) has also proposed to harmonise technical conditions for Mobile / Fixed Communications Networks in the 450 – 470 MHz band.

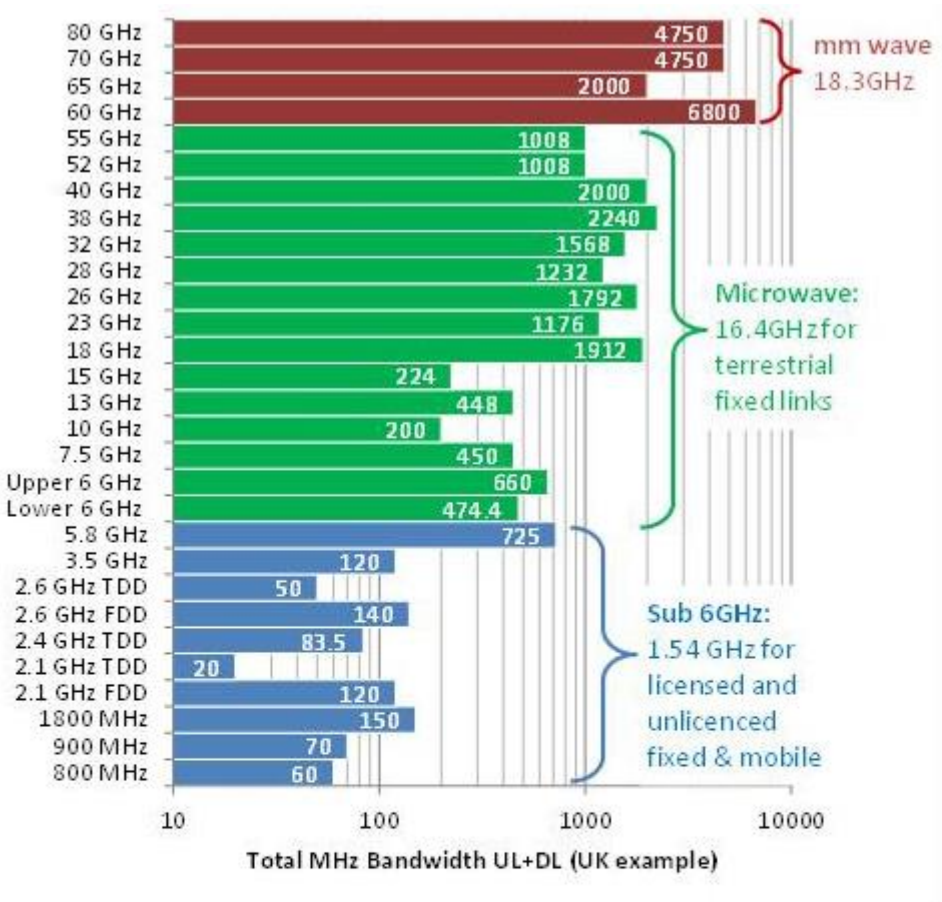

Figure 53: Bandwidth available in the three main ranges of terrestrial wireless spectrum in the UK Source: Ofcom [107]

The ‘workhorse bands’ for wireless backhaul are the microwave frequencies from 6 GHz to 55 GHz, and despite the emergence of new options, most studies assume that they will remain the most heavily used well into the 5G era. In the UK, these bands are all licensed, on an area basis for point-to-multipoint (PMP) and a link basis for point-to-point (P2P). Below 11 GHz, the frequencies can support long hops of 10-50 kilometres, suited to macro layer backhaul and rural or suburban sites. From 11 GHz to 23 GHz, medium haul links of -20 kilometres are typical and larger RF channel bandwidths are possible, supporting traffic requirements in most areas outside dense urban centres. The highest portion of the microwave band is best suited to urban backhaul and to smaller cells.

From 55 GHz to 300 GHz is the millimetre wave region of the spectrum, where there is a combination of unlicensed (notably in 60 GHz) and lightly licensed schemes. These are of increasing interest though technologies are immature and there are few economies of scale as yet, while licensing regimes remain fragmented (see 3.6).

At the current time, MNOs and others with spectrum licences concentrate their usage in the microwave bands, while smaller players, primarily use lightly licensed 5.8 GHz and unlicensed 5 GHz and 2.4 GHz. They mainly use point-to-point (P2P) topologies, though there is also some use of point-to-multipoint (PMP) or mesh, especially for community networks, as these options are often cheaper than P2P, but have lower capacity. So far, there is little activity in millimetre wave bands, though a few INCA members are testing in V-band.

Within the UK there are four main spectrum access approaches for point-to-point fixed wireless services (see Table 15)

- Ofcom Co-ordinated: A fully and centrally co-ordinated approach based on predefined criteria with individual licences issued on a per-link basis.
- Licence Exempt: Spectrum access via a simple set of rules which, once met, do not require the equipment to be individually licensed.
- Self Co-ordinated: A form of 'light licensing' where the licensee carries out the co-ordination rather than Ofcom. Spectrum access is on a first come first served basis and based on date/time priority.
- Block Assigned: Blocks of spectrum made available, mainly by auction. This mainly applies to the 10 GHz, 28 GHz, 32 GHz and 40 GHz bands, which were auctioned in 2007 and can be used for various purposes including fixed wireless and backhaul.

In the third and fourth cases, link operators are responsible for all aspects of frequency co-ordination and link planning.

There is also point-to-multipoint usage in 3.5 GHz and 3.6 GHz.

Table 15: Fixed wireless bands by access mechanism. Source: Ofcom

Ofcom Co-ordinated Bands

Band	Bottom (GHz)	Top (GHz)	Bandwidth (MHz)
1.4 GHz	1.35	1.517	2 x 24
4 GHz	3.6	4.2	2 x 180
L6 GHz	5.925	6.425	2 x 237.2
U6 GHz	6.425	7.125	2 x 320
7.5 GHz	7.425	7.9	2 x 224
13 GHz	12.75	13.25	2 x 224
15 GHz	14.5	15.35	2 x 112
18 GHz	17.7	19.7	2 x (715 + 203)
23 GHz	22	23.6	2 x 560
26 GHz	24.5	26.5	2 x 896
38 GHz	37	39.5	2 x 1120
52 GHz	51.4	52.6	2 x 504
55 GHz	55.78	57	2 x 504
70/80 GHz	71.125	83.125	2 x 2000

Ofcom Licence Exempt & Self Co-ordinated Bands

Band	Bottom (GHz)	Top (GHz)	Bandwidth (MHz)
60 GHz	57	64	6800
65 GHz	64	66	2000
70/80 GHz	73.375	85.875	2 x 2500

As in most wireless markets, there is a move to support greater spectrum sharing, in order to improve the usage levels in each band and open up more capacity for each service. Most FWS bands already share spectrum allocations with other services, working within the technical and regulatory framework set out by the ITU Radio Regulations. At national UK level, sharing is established with services such as Satellite Service Permanent Earth Stations in bands including 4 GHz, 6 GHz, 7.5 GHz, 13 GHz & 17/18 GHz.

Another way to boost spectrum availability through sharing is to adopt a light licensing approach, implementing interference mitigation techniques such as dynamic frequency co-ordination or cognitive radio. Light licensing is considered in the 65 GHz and 70/80 GHz millimeter wave bands where the large amount of vacant capacity, and the short range of each link, lowers interference risks. This must be balanced against an increasing need for ultra-reliable networks as operators evolve from best effort mobile services to critical applications. The correct mix of fully licensed, light licensed and unlicensed spectrum is essential.

12.6 Expected changes to technology and spectrum

Given that mobile backhaul is the largest use case for fixed wireless, the most significant changes in technology and spectrum will be driven by the needs of mobile operators and others requiring backhaul.

Mobile and other wireless operators are searching for architectures, enabled by LTE, LTE-Advanced and future 5G technologies, which will help them to support far greater capacity per MHz of spectrum, at lower cost. Important developments – some of which will enhance fixed wireless access as well as mobile – include MIMO (multiple in multiple out) antenna arrays to create parallel data paths; advanced modulation schemes such as 512QAM (1024 and even 2048 are in the lab while some vendors have a roadmap to 4096QAM and beyond); XPIC (cross-polarisation interference cancellation) to double channel capacity; carrier aggregation to create 'fat pipes' even across non-adjacent frequencies; co-ordinated multipoint (CoMP) and many more.

In particular, fixed wireless will have the opportunity to enhance the economics of two major new mobile architectures, small cell HetNet and Cloud-RAN. Both these architectures might ideally use fibre everywhere for backhaul and fronthaul, but that will often be commercially inviable, so the evolution of strong 'wireless fibre' alternatives will be critical to the business case [108].

The adoption of these approaches is, of course, being driven by the overall rise in data usage, which will require greater capacity and spectral efficiency on the wireless backhaul link as well as the access network. So these architectures will, in turn, intensify interest in new spectrum options to deliver that capacity, some of which – notably the millimetre wave frequencies, may be readily usable for the first time.

Small cells:

An important way to increase capacity and spectrum reuse, and to lower total cost of ownership, is to densify the network with large numbers of low power small cells. In a HetNet, these may be a mixture of cellular and Wi-Fi (or multimode), and in future of LTE-Unlicensed. They will often work in a separate spectrum band from the macrocell and they will be highly automated.

However, they raise new challenges for the backhaul. The network will include a far higher number of transport links (potentially several hundred per macrocell in a very dense environment). In many cases, fibre will be impractical or unaffordable to backhaul every cell, and wireless can provide a lower cost option which can be deployed quickly and flexibly. However, the small cell sites will typically be close to the ground, and so the backhaul links will have to operate in the urban clutter, making line of sight very difficult.

In addition, while the small cell market remains immature, it is hard for backhaul vendors to drive the costs of their equipment down as far as it needs to go to support the business model for operators, especially if they are developing kit for the new millimetre wave bands, in which there is significant fragmentation and very little scale.

In this situation, fixed wireless offers clear advantages and there is even talk of hybrid access/backhaul in small cells at the 5G stage. It is typically less costly to install and run than supporting fibre to every small cell site. It is quick and flexible to deploy, and can be used for a short hop from the cell site to a fibre-connected aggregation point, or for longer links. Since small cells typically require less capacity than a macrocell, they do not need the bandwidth of fibre to every site. However, using access spectrum for backhaul can greatly reduce available access spectrum, even more so when daisy chained, and could negatively impact on quality of service in the access network if over used.

Cloud-RAN:

Another important new architecture is Cloud-RAN or virtualised RAN. This has evolved from the common 'base station hotel' approach, in which the functions of the base station are split between the antenna (at the top of the mast), the radio head (at the base or integrated with the antenna), and the digital baseband processing functions. These are centralised in a single box which can be shared by several of the remote sites, connected to them by fibre.

In Cloud-RAN, this architecture is evolved several steps further (see Figure 54). In its purest form, the baseband functions (and the packet core) are run as virtual machines on cloud servers, and can support hundreds of remote sites. The links between the cloud server and the remote radio/antenna units are called fronthaul.

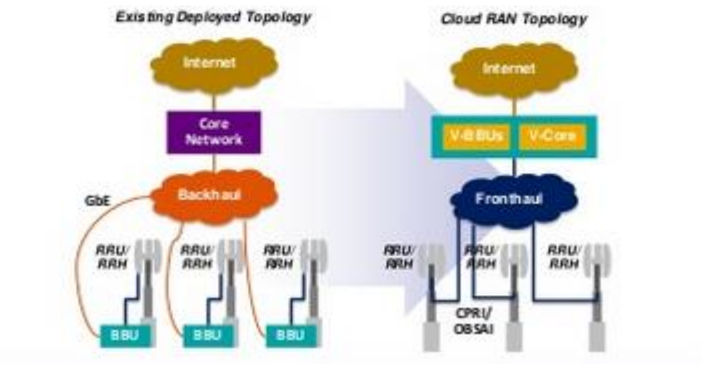

Figure 54: Comparison of traditional and C-RAN topologies. Source: Oi [109]

In reality many operators plan to implement less dramatic versions – for instance, with up to 20 radio/antenna sites connected to a switching centre or even a macro site within a few miles' distance. The ability to adopt full Cloud-RAN is partly determined by the cost of the fronthaul links, especially if these are to span long distances. They require far higher data rates, lower latency and tighter synchronisation than traditional backhaul and so fibre has been considered the only practical option.

FW Solutions:

As in conventional backhaul, there are many cases where fixed wireless technology is more economical and effective than fibre, but these two architectures present particular challenges. In small cells these mainly revolve around scalability and flexibility, as well as overall capacity; in Cloud-RAN the challenges lie in range, latency, reliability and capacity.

However, FWS technology is evolving rapidly in terms of reach and capacity, providing a whole range of range:bandwidth options which will increasingly be able to meet the needs of small cells and C-RAN. At one extreme, in terms of range, NEC recently deployed a 176-kilometre microwave link in the 4 GHz band. At the other, some millimetre wave solutions can achieve over 4Gbps over very short ranges (InterDigital's EdgeHaul, as an example, uses the 802.11ad WiGig standard in unlicensed 60 GHz, with highly directional antennas to mitigate interference, and claims total bandwidth of 4.5 Gbps over short hops and 2.5Gbps over 100 metres).

In C-RAN, companies are starting to develop wireless fronthaul solutions, usually running in millimetre wave or 28 GHz bands. These have been pioneered by companies like EBlink, Fujitsu, Ceragon, E-Band and Solid Technologies but the challenges are significant. Whereas a single-sector LTE 2×2 MIMO base station in a 20 MHz channel might require peak backhaul throughput of 180Mbps, fronthaul based on the CPRI standard requires constant capacity of 2.457Gbps, according to the NGMN Alliance [**110**]. That figure can be reduced to 1Gbps by better compression of CPRI traffic. However, as the case improves in one way, it worsens in another, particularly as operators deploy CoMP (co-ordinated multipoint), which requires very low latency (less than 1-2 microseconds) to deliver its full benefits.

Wireless fronthaul relies on the same kind of high end microwave links that are evolving for high capacity backhaul and could bypass the need for optics at every macro antenna. This will be helped by the new implementation of the CPRI standard over microwave. Such approaches would reduce the primary cost of the C-RAN approach and, as in backhaul, a hybrid system combining microwave and fiber would give many carriers greater flexibility in cost and capacity for C-RAN.

For instance, NTT Docomo of Japan has trialled a 'Hethaul' topology in which multipoint-to-multipoint wireless fronthaul links are used to connect many ultra-low power cells to a 'master cell', which then connects to the cloud via fibre.

Millimetre wave:

The millimetre wave bands are seen as the primary source of new spectrum for fixed wireless in the backhaul and fronthaul segments. Their high bandwidth over short range makes them well suited to small cells and to 'last hop' fronthaul as described by Docomo and others.

There has been a decade of effort in developing wireless fibre equipment, especially in the US where the FCC opened up the 70 GHz and 80 GHz bands in 2003. This has mainly been proprietary and very expensive, targeted at applications like super-fast connections between two enterprise locations. Recently, more widely applicable technologies have started to develop, boosted by the emergence of the WiGig/802.11ad standard (in effect an implementation of Wi-Fi in 60 GHz spectrum), which is already achieving a broad ecosystem – although one in which the emphasis has so far been on access rather than backhaul.

Such developments are making the millimetre wave bands of increasing interest to standards bodies and the wireless ecosystem, as capacity requirements increase and the traditional microwave bands become saturated. The main millimetre wave bands for which equipment has been developed are the V-Band (57 GHz to 66 GHz), which includes the 60 GHz licence-exempt spectrum where the 802.11ad standard sits; and the E-Band (71 GHz to 86 GHz). Other important bands for expanding backhaul are the W band (75 GHz to 110 GHz) and D band (110 GHz to 170 GHz).

Higher bands up to 300 GHz are the subject of many R&D projects and regulatory discussions, particularly around 5G. ETSI set up an MWT (millimeter wave transmission) ISG in 2014. The work items on its agenda range from investigating use cases for E-Band and V-Band, to technical work in areas like active antennas, to exploring 5G options and frequencies up to 300 GHz.

Proponents believe that mainstream commercial use of the millimetre wave bands could address the 'capacity crunch' in access and backhaul. Although these high frequencies do not allow for long range links or penetration through walls, they do lend themselves to small cells in various topologies, including mesh, and to applications from single-room high speed wireless transmission, to 'wireless fiber' point-to-point relays, to small cell backhaul.

Benefits include:

- High capacity
- High frequency reuse
- Sub-band free
- Low or no licensing costs
- Uncongested

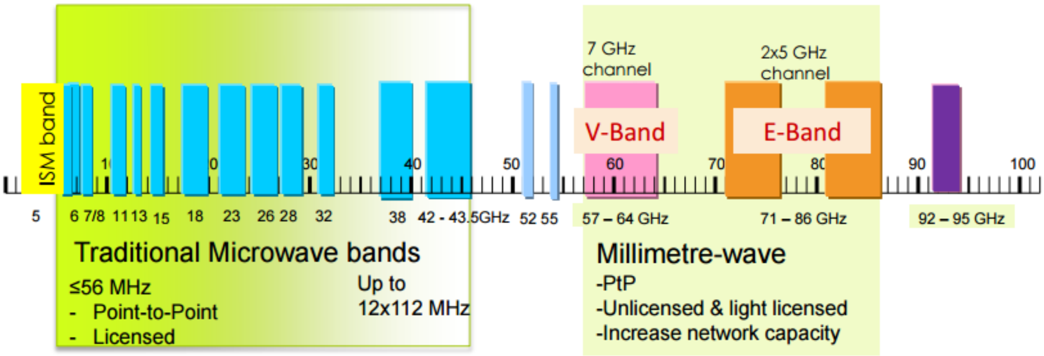

Figure 55: The microwave and millimetre wave bands with RF channel arrangements. Source: ETSI MWT ISG and EBlink

However, licensing and regulatory policy around the world is fragmented, which reduces the potential for economies of scale in equipment and devices. Figure 56 is an example (in the V-Band) of how regulations differ, even between different EU countries, and even more dramatically between the UK and the US, China or Australia. Similar issues affect the E-Band.

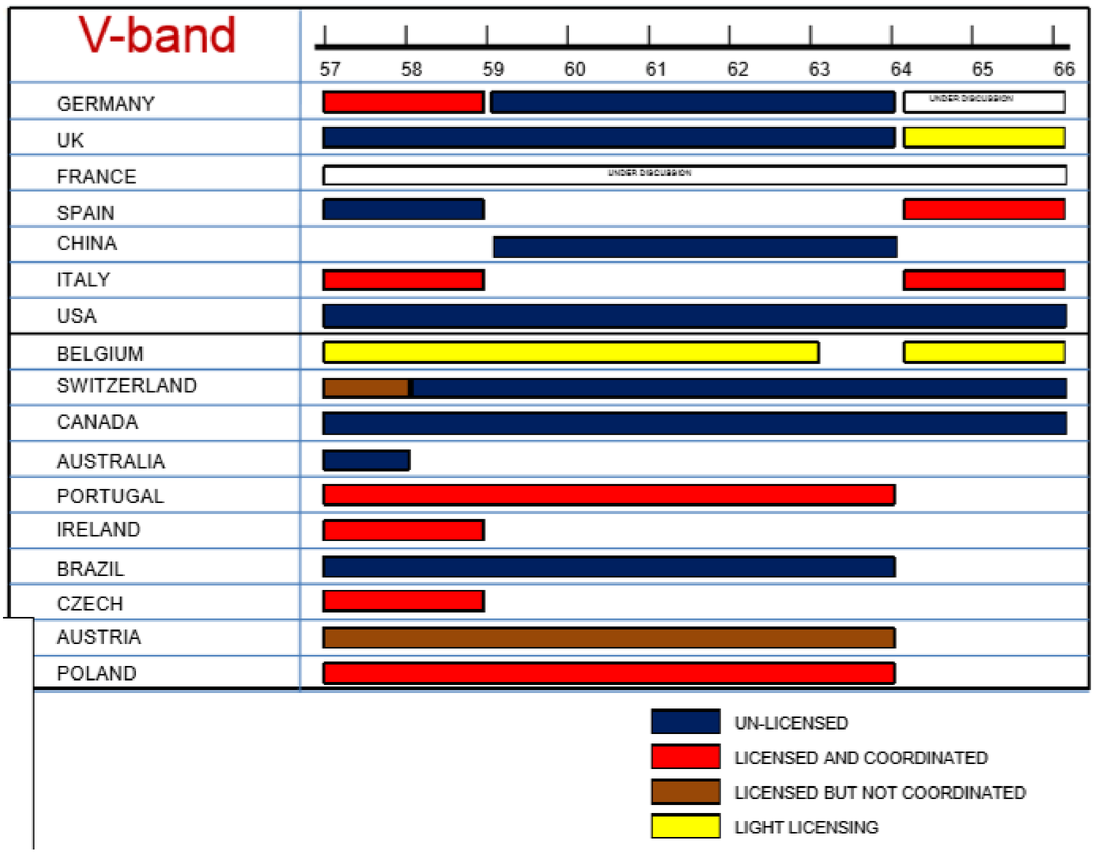

Figure 56: Different regulatory and licensing regimes for V-Band spectrum in selected markets. Source: ETSI [111]

Traditional per-link P2P assignment methods will often be unsuited to small cell backhaul in high frequency bands and so the other options outlined in Figure 3 will more commonly come into play. The EU Radio Spectrum Policy Group (RSPG) sets out the four options in its report 'Spectrum Issues in Wireless Backhaul' [112], noting that they fall within the Fixed Service regulatory framework for most CEPT countries [113]. Light licensing, block assignment and licence-exempt spectrum all have certain pros and cons compared to conventional per-link allocation with central coordination, the report indicates.

For instance, light licensing of fixed P2P links is similar to per-link licensing in terms of spectrum usage, but there is a higher risk of errors because coordination is carried out by the operator; there are larger numbers of players involved; and some of them may be "inadequately prepared technically".

Block assignment is most common for PMP fixed networks and since the operator can usually use any terrestrial wireless method in its block, this is often "considered the best compromise between efficient spectrum usage and flexibility for the user". Licence exempt spectrum, of course, is a trade-off between flexibility and low cost versus interference risk, though the latter is far lower in high capacity, underused unlicensed bands such as 60 GHz (57 GHz to 64 GHz).

A fifth emerging option is Licensed Shared Access (LSA), under which a limited number of licensees all share a frequency band. Most commonly, this is introduced as way to enable new entrants to enter a band alongside an incumbent without risk to the latter's service quality. The RSPG recommends that national regulators should "actively promote discussions and define the possibilities for LSA".

Other issues in the high frequency bands concern competing uses, between access, backhaul and IoT systems, for instance. Spectrum above 6 GHz may be on the agenda for the 2019 World Radio Conference, but until then, Ofcom and others have flagged up the competing demands on this spectrum as a risk.

Evolution of fixed wireless access:

Although over 80% of the UK's fixed wireless connections are for mobile backhaul, the fixed wireless access business is also evolving, because of the drivers outlined in 3.4. An important development is the use of LTE as a fixed technology. This signals the decline, over time, of proprietary platforms and of WiMAX, in favour of the huge ecosystems of LTE, in licensed spectrum (and possibly 5 GHz in future), and Wi-Fi, for lower cost deployments in unlicensed spectrum. Both these standards have expanded their original remit into a wide variety of applications, many of them fixed rather than mobile/portable.

For instance, the organisations behind both are developing variants for low power wide area (LPWA) networking, commonly used in fixed wireless smart city applications such as smart metering, and currently dominated by a bunch of specialist protocols running in the 868 MHz band (e.g. Sigfox, whose technology is being deployed in the UK by Arqiva; LoRa; Weightless). The 3GPP is working on low power implementations of LTE to try to take over this market, most of which will be part of Release 13, although vendors like Huawei already have pre-standard equipment. Likewise, the IEEE is working on Wi-Fi variants for the 868 MHz ISM band (900 MHz in the US), targeting the same business.

Fixed wireless operators deploying LTE and/or Wi-Fi variations can therefore target new applications such as smart cities and low latency M2M applications.

Along with smart cities and M2M, another expanding use of fixed wireless networks is for low latency data transfer, especially in the financial services sector. When financial services data is being carried between major trading exchanges, 'faster than fibre' performance is required. Ofcom says this is an application which has recently seen strong growth on the back of ultra-fast dedicated fixed wireless links. Electromagnetic waves in air are about 33% faster than optical waves in fibre optic cables, which meets the stringent low-latency requirements of these commercially critical data transfers [114].

LTE is becoming an important technology for delivering fixed home and business broadband wirelessly. This is not just a solution for rural areas, but for users who want rapid installation and affordability. For instance, UK Broadband sees students and business start-ups in cities as key target customers, not just remote communities.

UK Broadband is the largest FWA provider in the UK and has a portfolio of spectrum including a total of 124 MHz across the unpaired 3.5/3.6 GHz band (Bands 42 and 43), in which it is rolling out TDD-LTE. It has deployed fixed wireless networks in London, Reading and Swindon under the Relish brand.
The company claims that TDD-LTE can match fibre in many scenarios. Speeds of 30-50 Mbps can comfortably be achieved today. Next generation 3GPP advances such as massive MIMO and carrier aggregation provide a roadmap for peak rates of 440Mbps and up to 1000 Mbps by 2020.

The 3.5 GHz band has been in limited use until recently, although it has been widely allocated round the world for fixed wireless, often with very low spectrum costs. Some of the operators which initially deployed proprietary or WiMAX systems in this band are now converting to TDD-LTE, which is acquiring a broad ecosystem thanks to major deployments in China, the US, Australia, Japan and India. Most of these are in 2.3 GHz and 2.5/2.6 GHz but as capacity requirements rise, interest in 3.5 GHz is also increasing. Japan has recently issued licences to three operators in the 3.5 GHz band for LTE deployments.
Though usually a licensed band, in the US the FCC is proposing a multi-tiered scheme with differing levels of licence commitment and priority access. A portion of the band would be open to lightly licensed or unlicensed sharing, potentially by Wi-Fi and/or LTE. Some see potential for this to be a globally standardised band for small cell roaming.

The limited resources of many small FWA operators mean they are unlikely to get licensed spectrum, but they are concerned by the quality issues associated with licence-exempt. Emerging approaches, including various types of spectrum sharing, may provide a better balance between cost and QoS for the smaller players which typify FWA provision in the UK.

An important emerging development for these providers is wholesale provision, which is essential, under EU rules, to gain public subsidies for NGA deployment, and can significantly improve the commercial model too. In addition, relaxation of planning regulations is needed for small cells and Wi-Fi to succeed, according to INCA. That will help address spectrum shortages, by allowing more flexible usage of the spectrum available. Mandated access to dark fibre, as being considered by Ofcom, could represent a significant breakthrough for smaller providers and they also need more affordable access to mobile masts and backhaul.

12.7 Long-term technology and spectrum needs and options

The emergence of 5G, around 2020, will be the biggest development shaping fixed wireless spectrum and technology trends in the next decade. It will place new demands on wireless backhaul systems and is likely to be used, to an even greater extent than 4G, for fixed broadband and M2M applications as well as mobile. This means that the technology roadmaps for fixed and mobile networks, as well as their regulatory conditions, will increasingly be unified.

Whatever the precise technology underpinning 5G, the overall requirements are becoming clearer. As well as multi-gigabit data rates it will also need to support the needs of the Internet of Things (sub-5ms latency, very low power, high reliability, deep coverage) and other use cases. There will also be a need to support multi-operator and virtualised environments, which could increase the required bandwidth. All these key criteria point to ever-denser networks with a requirement for more continuous bandwidth than is found in current microwave bands.

Looking out to 2020 and beyond, then, the biggest change in the fixed wireless spectrum landscape is likely to be rising use of millimetre wave spectrum, including bands above 90 GHz. This will help to address the wireless data capacity demands, for access and backhaul, which can be assumed will continue to rise throughout the period as new devices and applications – such as advanced virtual reality – emerge.

As seen in 3.6, the millimeter wave bands are especially suited to dense small cell architectures, and in the 5G phase cells are expected to become even smaller. No 5G standards are yet in the works, but many of the R&D projects are focused on achieving an increase in capacity, coupled with a dramatic reduction in latency and power consumption, by using huge numbers of tiny, bare-bones cells linked to virtualised platforms in the cloud. Most of the many architectures which are being mooted involve a variety of topologies with multiple layers of cells and a mixture of fronthaul, midhaul and backhaul links.

In these scenarios, millimetre wave bands are expected to play a major role, though some players have warned against over-emphasis on high frequencies in the early stages of 5G, when microwave is still expected to be the workhorse for fixed wireless. The ITU will not have 5G spectrum bands on its WRC agenda until 2019. In their submissions for that discussion, Ofcom is focusing on bands above 6 GHz which already have a mobile allocation, though fixed wireless would also be an application; while the FCC has focused on a selection of bands above 24 GHz. There are likely to be two key phases of 5G standardisation, the first focused below 6 GHz, around 2020, and the second some years later and looking above 6 GHz for significantly higher data rates and area capacity density.

However, it is highly likely that millimetre wave frequencies will be playing a greater role by 2019, and that this will expand further in 5G. In a forecast created for the GSMA by ABI Research (see Figure 57), millimetre wave is expected to account for almost 30% of small cell backhaul usage in Europe by 2019, up from less than 4% in 2013. Europe and North America are the regions where these high frequencies will take the greatest role in small cell backhaul – the global figure for 2019 will be just short of 25%. However, microwave will still be the biggest player, accounting for almost 36% of small cell backhaul usage in Europe in 2019 (down from 56.7%), and 37.5% globally.

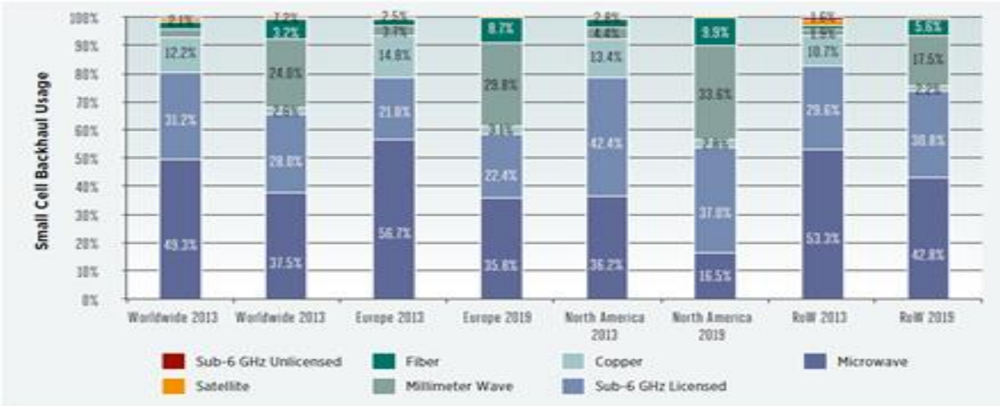

Figure 57: LTE small cell backhaul usage worldwide by technology, 2013 and 2019. Source: ABI for GSMA [115]

As well as new spectrum, fixed wireless capacity will also be increased with techniques to use existing allocations more efficiently, for access or transport. These include [116]:

- Higher order modulation to increase capacity. In the future there will be support for up to 4096 QAM (12 bits per symbol), though this is close to the theoretical and practical limits. To offset the downsides, notably increased sensitivity to rain, there will also be increased use of adaptive modulation and ATPC (Automatic Transmit Power Control).
- Systems which can adapt to different bandwidths on the fly.
- Polarisation multiplexing.
- Massive MIMO.
- Massive carrier aggregation.
- Full duplex radios supporting a self-backhauled small cell (e.g. Kumu Networks)
- Asymmetrical point-to-point links
- Multilayer header compression
- Radio link bonding
- Increased use of software defined networking and self-optimisation in fixed wireless
- Wider channel bandwidths (112 MHz bandwidths are allowed by many regulators below 40 GHz, and the 60 GHz to 80 GHz bands can support far higher bandwidths).

Some of these capabilities are still in the labs, while others are in the early stages of real world development. UK Broadband expects to be using massive MIMO, massive CA and channels of at least 80 MHz by 2020 to deliver gigabit-plus speeds. Networks of this calibre are set to open up new applications for fixed wireless, both in its own right, and to enable new approaches to mobile wireless.

New approaches to spectrum and licensing will support this. Future fixed link licensing must be considered in the context of the services it supports, as from a mobile perspective it can no longer be considered in isolation.

The requirements are summed up by the EC's RSPG report, which says: "In conclusion it can be stated that the backhaul requirements determined for mobile networks can be fulfilled in the mid-term by backhaul networks which use the current CEPT harmonised Fixed Service frequency bands and apply the currently available spectrum efficient techniques. In the long term, according to evolution of market demand, new frequency bands might need to be designated for Fixed Service applications and channel plans that could support the use of wideband systems in the current CEPT harmonised Fixed Service frequency bands might need to be introduced. Furthermore different kinds of licensing approaches might need to be considered and the feasibility of sharing between mobile and fixed service networks in the same frequency band might need to be assessed." [117]

A.13. Amateur radio

13.1 Scope of the sector

Amateur radio (AR) covers a wide range of applications, all of which use designated frequency bands for strictly non-commercial activities.

The word 'amateur' can be misleading, as it may imply 'non-professional' rather than just 'non-commercial'. In fact, many practitioners are as experienced and well trained as professional radio users (and may, separately, be engaged in the profession), and have to pass certain tests to take part in AR. An 'amateur' was defined in 1927 by the ITU as "a duly authorised person interested in radioelectric practice with a purely personal aim and without pecuniary interest" [118].

Non-commercial radio applications range from the purely recreational, and social interaction, to wireless experimentation (which may eventually feed into wider R&D programmes), and emergency communications.

The services which underpin these activities – the amateur service and the amateur satellite service – are defined by the ITU's International Telecommunications Regulations (ITU RR Articles 1.56, 1.57 and 25), while national regulators set local technical and operational rules, and issue licences and call signs to stations. Different frequency allocations, from 136 kHz to 248 GHz, support communications on a local, national and international basis, and even into space.

The UK's national AR society, the Radio Society of Great Britain (RSGB[12]) has over 21,000 members and is over a century old (founded 1913). It exists to represent the interests of AR to regulator Ofcom, and to international organisations; to provide support services to members, including a range of publications and an annual convention; and to extend awareness and education to the wider community, especially young people. It also manages the examinations which participants must pass (at Foundation, Intermediate and Full levels) in order to gain a user licence.

13.2 Contributions to social and economic value

The very nature of AR is to be non-commercial, but this does not mean the sector has no economic value, even if this is indirect or intangible. Indeed, it is increasingly important for this value to be recognised, given the high value attached to spectrum, including many of the frequencies used (for free) by AR. A calculation by ham blog Wireless Waffle, based on spectrum valuations for Ofcom, concluded that the UK amateur bands are worth around £64 million [119].

As well as driving the market for equipment, the AR community contributes to the UK's technology skills base, providing knowledge and education (at no cost). As stated above, AR practitioners are professional communicators, even if they are not engaged in commercial activities – they have to take examinations in order to gain their licences, and many have

[12] www.rsgb.org

extensive skills in areas such as RF design or antenna design. Some notable cases of where this practical expertise has been valuable stretch from the original Marconi company to the earliest University of Surrey satellites (that led to SSTL) and being able to support the Ofcom field team for the 2012 Olympics.

Many of these are skills which are in short supply in the UK, but AR enthusiasts help boost overall expertise by sharing their expertise and ideas with others, creating a valuable knowledge base into which commercial organisations can also tap. These ideas may be incorporated into commercial products, such as the FUNcube Dongle, invented by UK amateur Howard Long as a low cost receiver which is used by many AR enthusiasts, schools and other organisations.

In some cases, the challenges associated with narrow spectrum allocations mean that AR developers may have more advanced knowledge than their peers in the commercial sector. For instance, duplexing filters have to be built for narrower splits and higher performance than would be required in commercial PMR (private mobile radio). The RSGB also gives the example of deep propagation expertise, underpinned by amateur beacons, an area where it claims that, of necessity, there is a greater pool of knowledge in the amateur sector than in industry.

Some AR enthusiasts contribute to the international body of knowledge at the highest level. For instance, Joe Taylor, a US-based AR user, has a Nobel Prize for Physics and is developing weak signal digital techniques at Princeton University.

By sharing knowledge with young people, informally and through RSGB educational programmes, the AR sector can help to enthuse students and teach practical skills that are often missing from the mainstream curriculum. This can, in turn, increase the level of enthusiasm for science and technology subjects in general, and radio-related topics in particular, and so contribute to increasing the UK skills base in radio engineering, system engineering and embedded software.

A significant social contribution comes from the fact that AR is also a public service, supporting emergency communications efforts at home and abroad, with significant social impact.

The RSGB set up a national voluntary communications service, Raynet, run by AR volunteers, in 1953, in the wake of a major North Sea flood in which licensed amateurs were the only people able to talk to ships in distress. This can provide communications capabilities for emergency services and stranded citizens when other networks have failed or are under intense pressure. After the Lockerbie air disaster in Scotland, the local Raynet group was on 24-hour duty for 10 days.

AR enthusiasts also support disaster relief efforts round the world. For example, in the April 2015 Nepal earthquake, an Israeli amateur used a remote station in Iceland to provide emergency communications.

As people become ever-more dependent on 24/7 communications, emergency fallback plans are extending from actual disaster response towards providing constant contingency plans and peace of mind to citizens. This is especially seen in the USA, where AR is a significant element in the Federal Emergency Management Agency’s blueprint (and the head of FEMA is a licensed amateur).

The ITU Handbook on Emergency Communications states: "In situations where a professional and helpful attitude is maintained, served agencies point with pride to Amateur Radio volunteer efforts and accomplishments. Although the name says "Amateurs," its real reference is to the fact that they are not paid for their efforts" [120].

13.3 Current and recent past status

There are about 3.5m regular AR users in the world, with about 400,000 AR radio stations active in ITU Region 1 (Europe, Middle East and Africa) [121].

In the UK, there are about 70,000 licences, according to the RSGB (held by about 60,000 individuals, as some have multiple licences). UK usage has been increasing over the past decade, with about 8,000 new licences issued in 2011-2014.

Internationally, growth has varied considerably between different regions. There has been a strong increase in usage in China and India, and the US base has also been expanding, but other countries, notably Japan, have seen a decline. In the last 24 months the number of new Radio Amateur licences issued in China is greater than the number of existing licences that have been renewed (a requirement introduced about 24 months ago).

In the UK, the continuing rise in licensee numbers is combined with a widening variety of applications. Traditional continuous wave (CW) communications are still in use, but so are many other services including amateur digital TV, digital voice and data, EME (earth-moon-earth) links and many others.

This has led to a great proliferation of the infrastructure which the RSGB has to manage. The body coordinates almost 1,000 items; each assigned a licence and call sign by Ofcom.

The tally includes 265 simplex gateways; 480 duplex voice/TV repeaters to boost coverage; 100 propagation beacons, mainly in microwave bands; and many hundreds of datalinks. Many radios are also geared to report positioning and weather while the networks have to be linked for global routing too.

Each beacon, repeater and gateway has 3-4 closedown operators as well as the actual keeper registered with Ofcom, entailing considerable administration effort which is front-ended by the RSGB-ETCC organisation.

In addition to the above, in each county many RAYNET emergency groups have their own mobile or fast-deployment repeaters.

13.4 Sector trends

The most significant trend which has shaped AR technology and usage in recent years has been the convergence of radio networks and the internet/data. Indeed, AR has been a trailblazer in this respect: support for TCP/IP over amateur packet radio networks preceded the public Internet.

AR services have evolved to accommodate data alongside voice and messaging, and to support IP. Data services run alongside traditional continuous wave (CW) operations like Morse code, and there has been strong recent growth in digital voice systems like D-Star and DMR modes. The latter often exploit innovative network linking options between UK and international base station sites. Another trend is the introduction of position and weather reporting capabilities into radios, which can enable new applications.

Many see these expanding uses as essential to the relevance and survival of AR – though it will also create new pressures on spectrum.

For instance, John Regnault, the RSGB's VHF Manager, said in an October 2014 presentation[122] that the number of young people joining the community was in decline – a trend which could be reversed by shifting the focus from traditional voice, to their devices of choice, such as tablets. "Imagine what apps could sit over simple tablet (USB) to tablet radio communications!" he said, expressing a challenge for the whole sector [123].

Such pressures have helped to drive change in the underlying technology, particularly the emergence of increasingly software-defined radios, with some of that work being contributed from the AR sector itself. SDR is now almost the norm, says the RSGB, on both the transmitter and receiver ends, and SDR technology is constantly evolving. For instance, newer radios include embedded high performance ADCs (analogue-to-digital converters) to reduce interference.

Amateurs are contributing to the development of SDR by inputting to open source efforts such as the DttSP SDR library[124], or the DREAM project which is experimenting with new modulation methods such as QPSK, GMSK and COFDM[125].

Some other important projects for amateur SDR include the GNU Radio[126], which enables wideband operation with a sampling bandwidth up to 1,000 times that of a PC sound card; and the High Performance SDR project.[127]

Another important technology trend is the work on software that allows weak signals to be recovered from below the noise. The ability to use weak signal modes can allow AR users to reach considerable distances (more than 2,000 km at 1.3 GHz, for instance), and to achieve EME (earth-moon-earth) links with relatively modest power. It is becoming possible to make a two-way contact via the moon using a 100W transceiver at VHF plus an 8-element yagi antenna design. These improving capabilities also enable new applications such as low bandwidth digital TV.

As well as radio improvements, there are important developments on the satellite side of the service. Over the past 40 years, over 40 amateur satellites have been launched, but the pace is accelerating with the introduction of low cost microsats or cubesats. In addition to purely amateur satellites, the amateur service coordinates many dozens from the educational/research sectors.

Most cubesats, especially those run by universities, have their frequencies coordinated by the IARU (International Amateur Radio Union) on behalf of the ITU.

About 100 of these 10cm cube devices have been launched or will be imminently. These miniature satellites could transform the economies of scale of this sector. For instance, one launcher can carry over 30 cubesats, and China has recently put 10 small amateur satellites into orbit in a single launch.

Most of the satellites used for AR are in low earth orbit (LEO) but there are two projects, due to complete within the next two years, which will launch the first geosynchronous orbit

(GEO) satellites for AR use. These have greater longevity than their LEO counterparts and are permanently in view of ground stations.

Despite technology enhancements, there are still factors which threaten the quality of experience and may negatively affect usage trends. One is the difficulty of ensuring that electrical appliance equipment is of good quality. There are many EMC regulations but monitoring them is difficult and standards are less stringent for equipment working above 30 MHz.

Since AR often has to deal with weak signal activity, it is particularly vulnerable to interference, and the sources of that are proliferating. Some of the newer interference sources include plasma TVs, LED lights, land-based wind generators, and VDSL equipment, especially when that is self-installed by the end user. The RSGB is also concerned about the possible impact of wireless power transfer in urban areas, if that takes off.

There have been many predictions that, in the age of Twitter and instant messaging, interest in AR would decline, but such prophecies have so far failed to come true. There is no clear correlation between AR usage and the rise in instant messaging (for instance, 2012 was an all-time high, in the US, for AR licences, even as almost 40 million new Twitter accounts were created in the country). This is probably explained by amateurs being quick to adapt and adopt new technologies.

As well as far greater scope for technical experimentation than over-the-top communications, AR provides a tight community and the opportunity to learn new skills - and has generally been a far more tolerant environment than social media, ever since Paul Segal formulated the Amateur's Code in 1928, which said practitioners must be "considerate, loyal, progressive, friendly, balanced and patriotic" [128].

However, AR groups round the world are aware that their community does face challenges from internet-based alternatives and needs to remain relevant and differentiated in order to attract users as well as innovation. The American Radio Relay League (ARRL), for instance, initiated a 'Second Century' campaign in 2014, setting out the vision for AR going forward, which included increased disaster response and educational contributions. It also noted that, although licence numbers had increased, there has been a decline in the number of equipment vendors in the sector, and a slowdown in the R&D aspect of AR activity, at least in the US [129].

It asked: "Does the amateur radio service base its future on the precepts created and tested over the last twenty years or do we look at new and novel ways of growing, sustaining, and protecting the hobby that we love?" In other words, in an age of rapidly changing technology and user behaviour, AR everywhere is at something of a crossroads.

13.5 Spectrum usage

Frequencies in common use for amateur radio around the world reach from 136 kHz to 248 GHz, based on existing ITU allocations. This range is likely to extend both upwards and downwards – operations at as low as 9 kHz and >275 GHz have been tested internationally, for instance. The UK AR allocations are available in full at [130].

Of the commonly used spectrum options, the HF bands are by far the most popular for AR. Both local and worldwide or distant (DX) connections are possible at every time of day if the right frequency (for the time, date and state of the sunspot cycle) is selected.

The HF frequencies are:

- 3.5-3.8 MHz
- 5 MHz
- 7-7.2 MHz
- 10.1-10.15 MHz
- 14-14.35 MHz
- 18.068-18.168 MHz
- 21-21.45 MHz
- 24.89-24.99 MHz
- 28-29.7 MHz

The lowest frequency band allocated to the AR service is in 135.7-137.8 kHz, which was opened up to amateurs at the 2007 World Radio Conference. However, it has severe limitations because of the small amount of spectrum (usage is restricted to modes of 200 Hz bandwidth of less) and the power limit of 1W ERP, which makes efficient antenna design critical. It is only suited to continuous wave and local connections.

Another low frequency band, 472-479 kHz was added at WRC-12, though this is only currently available to UK users with a Full Licence since an international band plan has not yet been agreed. However, as more countries gain access it is expected to come into more general use. It supports CW up to 475 kHz and data modes above that.

The main medium frequency band for AR is 1.81-2 MHz, which is supported by most HF equipment. It supports local contacts during the day and may also be used for DX at night. It supports CW modes up to 1.838 kHz, data to 1.843 kHz and SSB (single sideband) in the upper reach. The wider HF allocations such as 3.5, 7 and 14 MHz are particularly popular and support national and international contest activities.

There are also allocations for AR in the VHF/UHF range. These are:

- 50-52 MHz (the 50 MHz band)
- 70-70.5 MHz (the 70 MHz band)
- 144-146 MHz (the 144 MHz band)
- 430-440 MHz (the 432 MHz band)

A wide range of amateur equipment from gateways to satellites can run in these frequencies, increasing the use cases, and many of the new developments in digital AR communications are targeted at this area of spectrum. Such digital developments are enabling an expansion into the 71 MHz and 147 MHz frequencies from 2015, courtesy of UK-specific permissions from Ofcom

Growth in certain applications and technology does influence how the allocations are band-planned by the amateur community. For example the most recent IARU conference in Varna in 2014, confirmed a new segment at the bottom of 144 MHz which will now be shared with new narrowband amateur satellite downlinks, whilst a sharing regime between amateur satellites and digital tv was agreed for the 430 MHz band.

Finally, there are the microwave and millimetre wave bands for AR. These support higher antenna gains than the other bands, but with narrower beamwidths. This presents challenges in ensuring that antennas align, and makes random CQ calls impractical, but on the plus side, microwave can support many other modes, including narrowband, FM, EME, datalinks and satellite, and so can help enable new use cases.

Until recently, the microwave bands were:

- 1240-1325 MHz
- 2300-2450 MHz
- 3400-3475 MHz
- 5.7 GHz
- 10 GHz

These are all secondary amateur allocations. Spectrum in these bands has also been reduced due to Public Sector Spectrum Release (PSSR) with 2350-2390 and 3410-3475 MHz being recently removed from UK Amateurs in April 2015, requiring TV users in particular to migrate.

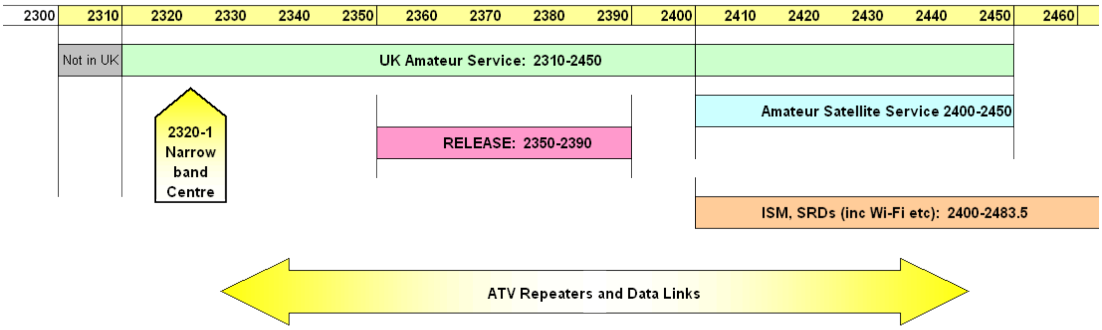

Figure 58: Amateur allocations & changes in the 2 300 – 2 450 MHz band. Source: RSGB

The bands below 3.5 GHz are home to repeaters, narrowband DX/EME, beacons, datalinks, satellites and ATV. In the UK the 5.7 GHz AR allocation is divided into several blocks, with the central one, at 5 760 MHz, housing narrowband, EME and beacons. Some 5 GHz 802.11-based equipment can be modified for use here. The amateur satellite service has two sub-bands in this range – 5 668 MHz for uplink and 5 840 MHz for downlink.

The 10 GHz band is the only microwave spectrum available to Foundation licensees (with a power limit of 1W). It houses narrowband, EME and beacons at 10 368 MHz. As in 5.7 GHz, the UK allocations for AR are not contiguous, following the reallocation of 10 125 - 10 225 GHz and > 10 475 GHz for commercial use.

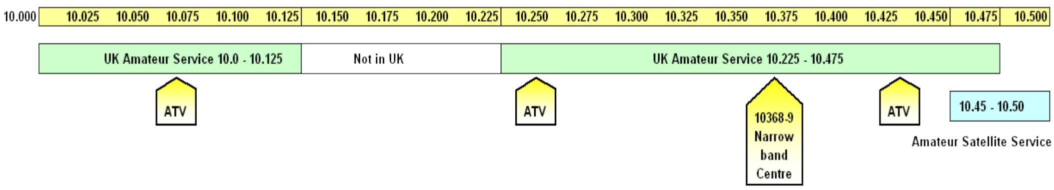

Figure 59: Amateur service allocations in the 10 GHz band. Source: RSGB

In the millimetre wave bands, there are allocations at:

- 24 GHz
- 47 GHz
- 76 GHz
- 122 GHz
- 134 GHz
- 248 GHz

There are primary allocations for AR in some of these bands and 24 GHz supports a significant beacon network and the most well equipped stations that can support EME. These high frequencies are well suited to highly portable equipment, and 134 GHz, a primary band, is preferred for new generation portables. By contrast, 122 GHz is a secondary allocation and suffers, like 60 GHz, from high oxygen attenuation; while 248 GHz suffers from a shortage of equipment. In the UK, no operation is currently permitted above 275 GHz, until the area of free space optics (FSO) is reached, which is beyond ITU radio regulations.

While each band has its own propagation qualities and appropriate applications, the main issue in most areas of the spectrum is interference, especially as many AR communications use weak signals. This makes spectrum with low noise levels, and preferably primary allocation status, a key goal.

In recent years, according to the RSGB, the HF and lower VHF bands have become less congested by other (non-AR) users, while the opposite pattern is seen higher up the spectrum. This is partly because there is a shift of usage towards the digital data applications which higher frequencies support.

At HF the RSGB has observed a decline in commercial MW/HF broadcasting, but a rise in interference from computers and wireline networks. Low band VHF has also been left largely vacant by the PMR industry. In contrast the amateur microwave bands (many of which are secondary) are facing increasing demands and spectrum loss to commercial wireless networks.

These factors make primary allocation a critical issue. Since AR is often working over long (often international) distances with weak signals, quality of service can be damaged when it does not have harmonised primary usage. While there are some primary allocations (see below), the RSGB believes these are insufficient. The chance of gaining new primary allocations, especially in the microwave and VHF areas, is often slim because these bands are desirable for commercial activities such as cellular. The spectrum requirement for primary is not that large in absolute terms and the RSGB prioritises ‘common narrowband segments’ for the weak signal narrowband, EME and satellite applications.

Frequency Range	Amateur %	Amateur-Satellite %	Amateur Primary %
0 - 87.5 MHz	6.4	3.1	77.0
87.5 - 1000 MHz	1.3	0.6	16.7
1000 - 6000 MHz	5.1	1.0	0.0
6000 - 15000 MHz	4.2	0.6	0.0
15000 - 86000 MHz	8.4	7.6	14.7

Figure 60: UK allocations to amateur radio and satellite as of 2015. Source: RSGB based on Ofcom data 2015 and 'Ofcom spectrum attribution metrics December 2013.

In the UK, according to Ofcom's Spectrum Attribution Metrics in December 2013 [131], an overall average of 3% of spectrum was allocated for amateurs, and 1% for amateur satellite. According to the IARU, on average, about 8% of spectrum is available to amateurs with up to 50% of that on a primary basis. In the UK, there is no primary allocation to amateur radio between 400 MHz and 24 GHz, which creates restrictions that can threaten confidence, investment and growth in AR. The problem is greatest for satellite transponders, EME and narrowband terrestrial equipment, which cannot retune as easily as short range wideband systems.

Table 16: Bands up to 24 GHz allocated to AR, indicating the primary allocations.

Band	Main users
50-52 MHz	Radio Amateurs 50 – 51 MHz Defence 51 – 52 MHz
70 – 70.5 MHz	Defence
144 – 146 MHz	Radio Amateurs
430 – 440 MHz	Defence Mobile (PMR) 431 – 432 MHz SRD/ISM 433 MHz
1240 – 1325 MHz	Defence, Aeronautical Radar, GNSS
2310 – 2450 MHz	Defence (incl. airborne telemetry) Fixed Links, PMSE, Low Power Devices, ISM Reallocated as part of Public Sector Spectrum Release
3400 – 3475 MHz	Defence, Wireless Cameras Reallocated as part of Public Sector Spectrum Release
5650 – 5850 MHz	Defence, Wireless Cameras, Low Power Devices
10000 – 10125 and 10225 – 10500 MHz	Defence, PMSE
24000 – 24250 MHz	ISM Radio Amateurs, 24000 – 24050 MHz Low Power Devices, 24050 – 24250 MHz

13.6 Expected changes to technology and spectrum

As noted above, Ofcom has extended the allocations for AR in the 144 MHz band. More broadly, there are positive and negative signs for near-term spectrum developments for AR.

On the plus side, there is greater willingness, in the UK and elsewhere, to consider temporary allocations of spectrum, not currently being used for other purposes, to encourage AR experimentation. In a March 2014 consultation question, for instance, Ofcom asked "*Do you agree with the proposal to make some spectrum not currently assigned to other applications available on a temporary basis for Amateur Radio use with these restrictions?*" Of 60 responses, all but one were favourable, often on the basis that such a policy would encourage innovation, both for AR itself and across the wider UK digital community, for instance harnessing the Raspberry Pi base.

However, in terms of permanent new allocations, there is increasing pressure on the desirable VHF and microwave bands, and the non-commercial basis of AR can make it hard to argue its case against major revenue generators like public mobile.

For instance, Ofcom's Public Sector Spectrum Review (PSSR) saw amateur services losing 40 MHz in the 2.3 GHz band and 65 MHz in 3.4 GHz, with the most serious impact falling on wideband datalink and TV applications. On the plus side, Ofcom did grant access to an unused segment in the 2.3 GHz band (2 300 - 2 302 MHz), which is allocated to some countries internationally.

Yet, like other services, AR will suffer from congestion caused by rising data usage and the introduction of new technologies. This is currently highest in the HF bands, though it is looming in other bands too – the RSGB sees the highest demand for new infrastructure in VHF/UHF spectrum, and rising use of microwave equipment like EME and beacons. While not congested, easier access to equipment is seeing increasing link distances in the 76 GHz and 134 GHz spectrum. Although the threat of congestion will be mitigated to some extent by continuing progress in highly efficient technologies, these advances are unlikely to offset the growing uptake of new applications.

Additional spectrum will be needed for several key reasons:

- Relieve voice congestion in certain areas. In particular, there is a rapid expansion of digital voice applications, which will require some new capacity even though this is being somewhat mitigated by multimode software radios and new codecs
- Allow room to experiment with new techniques
- Introduce or extend new services like digital amateur TV, which will especially affect lower bands.
- Introduce new bearer technologies
- Support new data modes and higher speed data networks. In particular, the UK currently has a low base in 5 GHz, but this is expected to see significant growth
- Enable higher bandwidth services to support new data applications, or to allow integration of voice, video and data
- Support the high level of interest and activity in small satellites in the UK, in order to preserve the country's lead in this area and encourage links with high orbit and International Space Station.

As outlined in section 13.3, these extensions of the applications and functionality of the service will be essential to maintain interest in AR, especially among younger people, and so preserve its role in communications, emergency relief and innovation.

As in other sectors, AR will be looking for ways to share spectrum more effectively in areas where it has little prospect of new or primary allocations. The RSGB argues that the AR community is already highly skilled in efficient band planning and in sharing, because of the constraints in which the spectrum managers have to work – very small slices of spectrum combined with a wide diversity of modes, usage and equipment. Band plans are reviewed nationally each year and internationally every 18-36 months, a discipline which feeds into effective sharing with other amateurs and with primary users.

Sharing mechanisms like LBT (listen before transmit), geo-awareness and DFS (dynamic frequency selection) are practiced, though usually with manual management rather than automation. Examples of successful UK sharing with third parties have included wireless industrial automation systems in 5 GHz and cars or helicopters in 77 GHz, and with highly sensitive primary users such as radiolocation and the Ministry of Defence. However, there are severe challenges in sharing with mobile broadband or ISM applications, says the RSGB.

13.7 Long-term technology and spectrum needs and options

As an amateur and enthusiast sector, the nature and usage of AR is shaped by its actual users to an even greater extent than in commercial services. With no commercial pressures, much of the usage is opportunistic and personal, and often experimental, so is hard to predict. The extent to which the AR demographic shifts to young people, for instance, will influence the way the service is used, and in turn, the demands on spectrum (though the RSGB is keen to point out that many young people are still attracted to Morse code).

However, some general patterns can be predicted. Over time there is sure to be increasing migration to newer digital modes, and further evolution of those to support new applications.

Key technology trends which are expected to impact on spectrum usage include:

- Further integration of software and radio and the development of highly flexible radios
- Further integration of wireless, networking and IP
- Accelerating growth in small satellites, boosting the whole amateur satellite segment and particularly the ISS applications
- Rise in remotely controlled and automated systems
- New options for bridging between digital modes/repeaters
- Increased use of apps to support additional uses and encourage non-technical users
- Rising interest in low-infrastructure solutions to connectivity, especially in remote or emergency situations (the internet that doesn't rely on the internet).

As in many areas of wireless communications, the AR community believes higher and higher frequencies will be important to open up new capacity and to support new applications that require very high bandwidth. Its members are already contributing to the body of knowledge in this area by developing services in millimetre wave frequencies, which are also likely to be a central focus of R&D for commercial 5G technologies.

Some of the spectrum changes which will be required to support these future trends will be discussed at the WRC-15 conference, while others may be placed on the agenda for its successor, the 5G-focused WRC-19.

The main WRC-15 agenda items of relevance to the AR and amateur satellite services are:

- AI-1.1: to consider additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for IMT. This could squeeze AR allocations in some areas.
- AI 1.4: to consider a possible new allocation to the amateur service on a secondary basis in 5.25-5.45 MHz.
- AI 9.1.8: Regulatory aspects for nanosatellites and picosatellites, a result of the rapid recent growth in small satellites, including those for amateur services.

Other discussions about new or revised allocations, for services such as fixed and mobile satellite or earth observation, may also impact on AR spectrum. However, the 2015 and 2019 decisions regarding mobile broadband and 5G are likely to be of most interest, because the quantities of spectrum involved are so large, and many are in key AR bands.

Although 5G is not yet defined, and will not be deployed commercially until 2020 or later, regulators like Ofcom are already considering possible spectrum allocations. In its recent update on bands above 6 GHz that might be suitable for 5G, Ofcom included the amateur satellite allocations at 10.465 GHz and 47 GHz on its list of candidates [132].

Such debates indicate the uncertainty that surrounds AR spectrum allocations for the medium and long term, at a time when the need for additional capacity, to support new applications and continued experimentation, seems sure to grow.

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