Future use of Licence Exempt Radio Spectrum

A report for the UK Spectrum Policy Forum

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uk spectrum policy forum

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Introduction

This report presents the findings of a study that has been commissioned for the UK Spectrum Policy Forum to assess the current and future use of frequency bands which may be used by licence exempt wireless applications in the UK and Europe (hereafter referred to as "licence exempt frequency bands"). Its main purpose was to identify any actions that may need to be taken to maintain the economic value of licence exempt bands and to ensure equitable co-existence between new and existing licence exempt technologies and applications.

What area Licence Exempt Frequency Bands and why are they so important?

Licence exempt frequency bands are those that can be used by certain applications without the need for prior authorisation or an individual right of use. This does not mean that they are not subject to regulation – use must still comply with pre-defined technical rules to minimise the risk of interference. Most licence exempt bands are harmonised throughout Europe and are shared with other services or applications, such as radars or industrial, scientific and medical (ISM) equipment. Wi-Fi and Bluetooth are probably the most familiar examples of mass-market licence exempt wireless applications, but the bands support many other consumer devices, such as cordless phones, doorbells, car key fobs, central heating controllers, baby monitors and intruder alarms. Looking to the future, licence exempt bands are likely to be a key enabler of wireless machine to machine (M2M) communication applications.

Key benefits of licence exempt bands include:

- For end-users:
  - Greater convenience and flexibility by avoiding the need for lengthy runs of cable in home and work environments
  - Ability to connect mobile devices to a fixed broadband network, reducing dependence on the mobile network and potentially saving costs both for the service provider and the end-user
  - Enhanced convenience, safety and security, e.g. through installation of low cost wireless alarm systems or ability to unlock vehicles remotely rather than fumbling with keys
- For equipment vendors and operators:
  - Facilitating market entry – there is no need to acquire a licence to deploy a service
  - Enabling niche applications or services to be addressed quickly and cheaply using existing technology and spectrum – this has been particularly effective in serving new machine to machine (M2M) applications in areas such as health, transport and home automation.
  - Providing certainty about spectrum access – there is no need to compete or pay for spectrum access (though the collective nature of spectrum use means quality of service cannot be guaranteed)
  - The ability to extend the reach of fixed communication networks, by providing wireless local area connectivity in homes, businesses and at public traffic hotspots.

The two most notable drawbacks are the inability to guarantee quality of service and the more limited geographic range that is typically available (reflecting the lower power limits that apply to these bands). Licence exempt wireless applications cannot claim protection from interference arising from other users or radio services. They operate in shared frequency bands and must not themselves cause harmful interference to other radio services.

From a regulator's perspective, licence exempt bands can be more problematic than licensed bands in terms of refarming spectrum, since it is difficult to prevent the continued deployment of legacy equipment in the bands or to monitor effectively their utilisation. There is also generally no control over numbers and / or location of devices, which can make sharing difficult and limits the amount of spectrum that can be used in this way.

The market for licence exempt devices is very diverse, including wireless access (Wi-Fi), radio frequency identification (RFID), medical devices, audio / video links, alarm systems and a wide range of M2M applications. The economic and social benefits of licence exempt spectrum are substantial and growing but not straightforward to quantify. A number of studies have attempted to place a value on certain types of licence exempt use. One such study[1] estimated the economic value of Wi-Fi access to consumers in Europe in 2013 to be approximately €15 Billion, rising to €23 billion by 2023. The potential value of M2M applications served by Wi-Fi by was projected as €55 billion, though it was acknowledged there is considerable uncertainty about this this figure given the relative immaturity of the market. Another report[2] estimated that the consumer and producer surplus of Wi-Fi offloading of mobile data traffic in the UK would have an NPV of £31 billion over the decade to 2023. Significant social benefits arise from applications such as medical devices and wireless alarm systems.

Current Status of Licence Exempt Frequency Bands in the UK, Europe and Beyond

In Europe, regulation of licence exempt bands is primarily dealt with at an international level by European institutions. Most bands are fully harmonised, whereby free circulation of devices that comply with the relevant standards is effectively mandated throughout the EU. However some bands are subject to "soft" harmonisation, where the frequency limits and technical characteristics are harmonised but adoption of the band is left to national administrations to decide.

Most fully harmonised licence exempt bands are defined in a 2013 EC Decision (2013/752/EU) on Harmonisation of the Radio Spectrum for use by Short-Range Devices (SRDs). ECC Recommendation 70-03, relating to the use of SRDs also includes bands that are subject to soft harmonisation**.** A separate EC Decision, 2007/90/EC covers the harmonised use of radio spectrum at 5 GHz for wireless access systems.

The 2014 Radio Equipment Directive (2014/53/EU) introduces more stringent requirements for receiver performance in radio equipment, which is particularly relevant to licence exempt devices as some of these have in the past been affected by interference from new services introduced in adjacent bands due to inadequate receiver selectivity. Interference can sometimes limit the effectiveness of licence exempt devices, especially where these have inadequate receiver performance or lack interference mitigation mechanisms. An example is the 433 MHz band where many low cost devices such as car key fobs suffered interference when TETRA was introduced in the adjacent band. Analogue video links operating in the 2.4 GHz band can block Wi-Fi signals and the recent introduction of cellular services in the former UHF TV band below 862 MHz has led to compatibility problems with short range devices in the 863 – 870 MHz range.

[1] "Valuing the use of spectrum in the EU, an independent assessment for GSMA", David Lewin, Phillipa Marks and Stefano Nicoletti, Plum Consulting, April 2013",

[2] "Impact of radio spectrum on the UK economy and factors influencing future spectrum demand - Final Report for DBIS and DCMS", Michael Kende, Philip Bates, Janette Stewart, Mike Vroobel, November 2012

A full list of the main frequency bands identified for licence exempt wireless devices and related technical standards can be found in the main report. These frequency bands account for approximately 12% of spectrum, both above and below 6 GHz, but it should be noted that this spectrum is generally shared with other services that licence exempt use is only permitted if it does not cause interference to these other services. It should also be noted that other parts of the spectrum may be used on a shared basis by certain niche licence exempt technologies, such as level probing radars that generally operate in shielded environments, but are not included in this figure. It is interesting to compare the European licence exempt frequency bands with those in other regions, particularly North America which historically has had substantially more bandwidth available below 1 GHz (notably the 902-928 MHz band which is largely used by cellular networks in Europe). A recent European initiative to identify spectrum in the 870 - 876 MHz and 915 - 921 MHz bands could go some way towards levelling the balance between the US and Europe in terms of licence exempt spectrum availability if full harmonisation of these bands can be achieved.

Managing Interference and Co-existence in Licence Exempt Frequency Bands

A number of interference mitigation techniques have been developed over the years to facilitate co-existence between different applications and potentially high volumes of devices in licence exempt bands. These range from simple radiated power limits to complex digital signal processing algorithms designed to detect and avoid collisions between data transmission from different devices (sometimes referred to as “politeness protocols”).

Examples of wireless technologies that operate in licence exempt bands and incorporate such mitigation techniques include Wi-Fi, Bluetooth, and ZigBee. More recent initiatives that address wider area M2M applications in licence exempt bands include SIGFOX, Weightless and WiSUNs, which use licence exempt wide area mesh technology based on the IEEE802.15.4g standard. There is also a plan to introduce a variant of the cellular LTE standard (LTE licence assisted access) in the 5 GHz band alongside existing Wi-Fi deployment. These M2M and LTE initiatives form the basis of the two technology co-existence case studies that are presented in the report.

Several regulatory initiatives have been underway internationally to improve the utility of existing licence exempt frequency bands and identify additional bands to cater for future demand growth. These include the identification of new spectrum in the 870-876 MHz and 915-921 MHz bands for M2M and RFID applications and expansion of the 5 GHz wireless access band to increase capacity for longer term demand growth. In both cases compatibility with incumbent services presents a challenge that will require a concerted effort by industry and regulators to overcome.

Conclusions and Recommendations

In conclusion, our review has highlighted the many benefits that arise from licence exempt bands, despite a relatively small proportion of radio spectrum being available for such use and the shared nature of most of the bands. Much of the benefit is derived from the free circulation of licence exempt devices, throughout Europe and in many cases other parts of the world. This is particularly evident for technologies like Wi-Fi and Bluetooth, which enable a single low cost chipset to provide connectivity anywhere in the world, and RFID devices that are increasingly used to track goods in global freight operations.

The two main areas of demand growth likely to impact on licence exempt frequency bands in the future are broadband wireless access systems (WAS) and machine to machine (M2M) communications. In both cases, additional spectrum has been identified that should be sufficient to cater for projected long term demand, but cannot be made fully available until compatibility with existing incumbent services has been satisfactorily addressed. The existence of a large amount of spectrum in the 60 GHz range also presents opportunities for very high speed data links, but regional variations in the availability of spectrum may hinder the take up of this band at a global level.

One of the principal drawbacks of licence exempt bands is the inability to guarantee quality of service, a problem sometimes compounded by inadequate specification of receiver parameters and a lack of suitable interference mitigation mechanisms. Whilst much has been done to improve this situation, particularly with regard to the latter, we believe there is scope for further tightening of the technical requirements for some licence exempt devices to ensure the value of the licence exempt bands is not compromised in the future by interference or technical incompatibility.

Our principal recommendations can be summarised as follows:

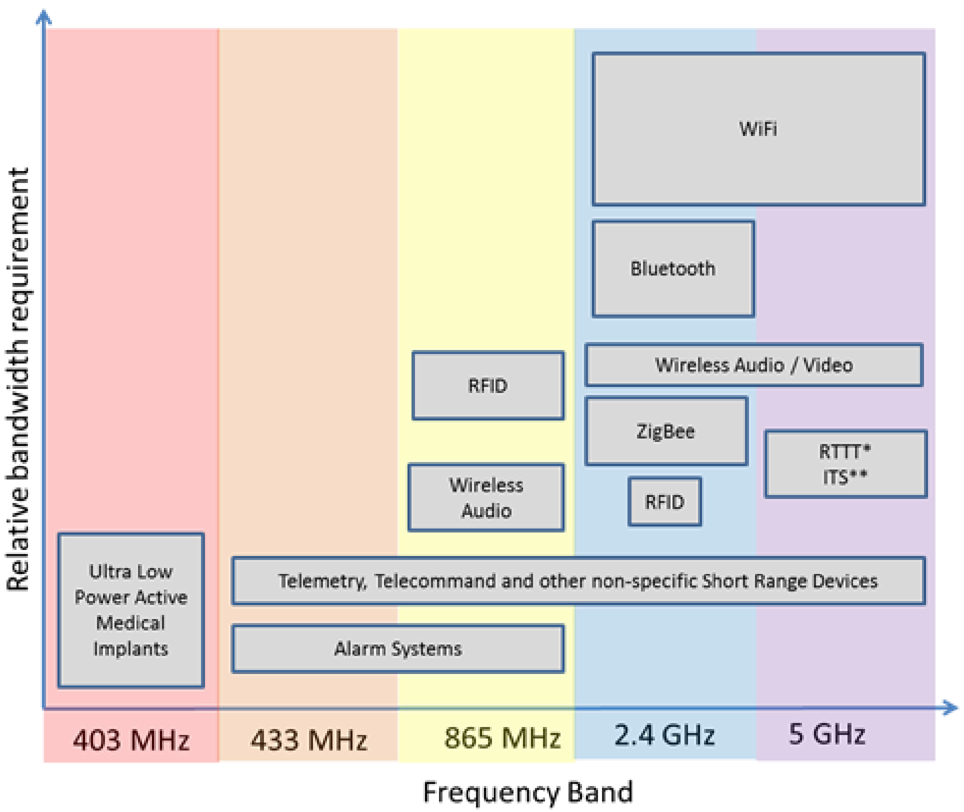
i. Promote further international harmonisation of licence exempt bands, in particular the recently identified 870 – 876 MHz and 915 – 921 MHz band that are likely to be critical for supporting future M2M demand growth in Europe.
ii. Maximise spectrum availability for wireless access systems, in particular we encourage European administrations to work alongside counterparts in other regions (such as the US and Asia Pacific) with a view to reaching workable co-existence solutions for expansion of the 5 GHz band in time for the 2019 World Radio Conference (WRC-19).
iii. Improving spectrum efficiency and technology co-existence in existing licence exempt bands, notably by applying more stringent receiver performance requirements that reflect the quality of service requirements of specific applications and seeking to phase out legacy technologies that do not incorporate suitable interference mitigation mechanisms. In the longer term, automated on-line registration of Internet-connected devices could be considered to facilitate market surveillance and simplify the process of removing legacy equipment, which can sometimes hinder the introduction of new technologies or applications in licence exempt bands.

1 Introduction

This report presents the findings of a study that has been commissioned by techUK on behalf of the UK Spectrum Policy Forum to assess the current and future use of frequency bands which may be used by licence exempt wireless applications in the UK and Europe (hereafter referred to as "licence exempt frequency bands"). The main purpose of the study was to identify any actions that may need to be taken by national administrations to maintain the economic value of licence exempt bands and to ensure equitable co-existence between new and existing licence exempt technologies and applications.

Licence exempt frequency bands play a major role in the daily lives of consumers, businesses and public organisations, supporting a wide range of applications, from very short range, narrow band devices like radio frequency identification (RFID) tags, to city or region-wide networks supporting broadband data or machine to machine (M2M) connectivity. The scope of this study covers all of the principal UK frequency bands above 100 MHz identified explicitly for deployment of licence exempt radio equipment, including recently identified bands that are considered candidates for future European harmonisation but excluding operation of licence exempt equipment operating in licensed frequency bands (such as mobile phones, broadcast receivers, white space devices or ultra-wideband equipment). Of particular interest are those bands associated with broadband data transmission and M2M communications, which are expected to exhibit particularly high demand growth and value in the future.

Figure 1-1: Example of wireless applications that use licence-exempt frequency bands



*Road Transport and Traffic Telematics **Intelligent Transport Systems

The technologies deployed in licence exempt bands are evolving continuously, with an increasing emphasis on facilitating co-existence both between different licence exempt applications and with other radio services that may sometimes share the same spectrum. One of the key issues for this study is the extent to which such evolution is likely to support the growing demand for licence exempt services and the ability for new and legacy technologies to co-exist on an equitable basis.

The remainder of this document is structured as follows:

- **Chapter 2** describes the key attributes of licence exempt frequency bands, in terms of their benefits and drawbacks, from both an economic and technical perspective
- **Chapter 3** highlights the current status of licence exempt frequency bands and technologies in Europe and how these are likely to evolve in the future
- **Chapter 4** reviews approaches to managing interference, congestion and co-existence in licence exempt bands
- **Chapter 5** presents two case studies highlighting co-existence issues, relating to (a) the planned introduction of LTE “licenced assisted access” (LAA) alongside Wi-Fi in the 5 GHz band and (b) the deployment of wide area licence exempt technologies for M2M communications alongside short range devices in sub-1 GHz frequency bands.
- **Chapter 6** presents our overall conclusions and recommendations.

2 What are licence exempt frequency bands and why are they so important?

2.1 Introduction

In simple terms, licence exempt frequency bands are those that can be used by certain devices without the need for prior authorisation or an individual right of use. The term “collective use” is also sometimes used to describe such use. The lack of an individual authorisation does not mean that these bands are not subject to regulation – access to licence exempt bands requires compliance with pre-defined technical rules that are intended to minimise the risk of interference between licence exempt devices or to other users of the radio spectrum. Most licence exempt bands available in the UK have been harmonised throughout Europe and the relevant regulatory and technical parameters are defined in European Union Decisions that have been transcribed into national law. These parameters are addressed in detail in chapter 3 of this report. Many of the bands are shared with other services or applications, such as radars or industrial, scientific and medical (ISM) equipment.

In this chapter we highlight the important contribution that licence exempt frequency bands make to the UK economy and the benefits created for both consumers and industry. We also explain some of the drawbacks associated with licence exemption and why such bands are largely complementary to, rather than substitutes for, licensed radio spectrum.

Licence exempt frequency bands play an increasingly important role in all of our lives. Almost all residential and many business broadband connections use Wi-Fi, which is probably the most familiar example of a mass-market licence exempt wireless application. Bluetooth is now ubiquitous in mobile phones and many other devices. Wireless technology is also widely used in many other consumer devices, such as cordless phones, doorbells, car key fobs, central heating controllers, baby monitors and intruder alarms, all of which rely on access to licence exempt frequency bands. Looking to the future, licence exempt bands are likely to be a key enabler of wireless machine to machine (M2M) communication applications.

2.2 Benefits and Drawbacks of Licence Exemption

2.2.1 Key Benefits of Licence Exempt Bands

The principal benefit of licence exempt frequency bands is that so long as devices conform to specified regulatory rules and technical specifications they may operate on an unrestricted basis without any need for prior authorisation. They are therefore ideal for wireless devices that are not directly connected to a network and hence entirely under the control of the end user. In recent years there has also been growing use of licence exempt Wi-Fi technology to connect devices to broadband networks in homes, at workplaces and at data traffic “hotspots” in public locations.

Key benefits from an end user’s perspective include:

- Greater convenience and flexibility by avoiding the need for lengthy runs of cable in home and work environments

- Ability to connect mobile devices to a fixed broadband network, reducing dependence on the mobile network and potentially saving costs both for the service provider and the end-user
- Enhanced convenience, safety and security, e.g. through installation of low cost wireless alarm systems or ability to unlock vehicles remotely rather than fumbling with keys

Licence exempt bands also provide significant benefits for equipment vendors and service providers, for example in terms of:

- Facilitating market entry – there is no need to acquire a licence to deploy a service
- Enabling niche applications or services to be addressed quickly and cheaply using existing technology and spectrum – this has been particularly effective in serving new machine to machine (M2M) applications in areas such as health, transport and home automation.
- Providing certainty about spectrum access – there is no need to compete or pay for spectrum access (though the collective nature of spectrum use means quality of service cannot be guaranteed)
- Security of tenure – in general licence exemption is not subject to an expiry date (though there are some exceptions, e.g. automotive radars at 24 GHz)
- Reduced congestion in licensed bands (e.g. through traffic offload from cellular networks to Wi-Fi).
- The ability to extend the reach of fixed communication networks, by providing wireless local area connectivity in homes, businesses and at public traffic hotspots.

2.2.2 What are the drawbacks of licence exemption?

Whilst they undoubtedly provide significant benefits, licence exempt bands are not a panacea and do have numerous disadvantages compared to licensed frequency bands. The two most notable are the inability to guarantee quality of service and the more limited geographic range that is typically available (reflecting the lower power limits that apply to these bands). Licence exempt bands are effectively open to any user or application that complies with the relevant technical standards and in general there are no limits on the number of such users at a particular location. As a band becomes more heavily used, contention between users may start to arise and although many licence exempt technologies are designed to operate in contended environments it is inevitable that service quality can degrade as the number of users increases.

It is particularly important to note that as the spectrum used by licence exempt wireless applications is available to anyone using compliant equipment, licence exemption does not provide users with any form of protection from interference arising from other users or radio services. Licence exempt devices operate in shared frequency bands and must not themselves cause harmful interference to other radio services.

Most licence exempt bands have strict limits on radiated power, to reduce the likelihood of interference and contention between users. However this can also have the effect of limiting the transmission range, particularly in cluttered environments. This can be overcome by deploying very high density networks but this only tends to be cost effective in high traffic locations such as city centres. Another option is to use licence exempt spectrum in conjunction with licensed spectrum and a number of initiatives are underway to provide seamless handover between the two (this is addressed in more detail in section 5.2). For narrow band applications (such as many M2M requirements) specialist techniques have been developed that enable delivery of relatively small volumes of data over large distances using similar low power technology to existing short range devices (SRDs). These "low power wide area" (LPWA) technologies are described in more detail in section 5.3.

From a regulator's perspective, licence exempt bands can be more problematic than licensed bands in terms of refarming spectrum, since it is difficult to prevent the continued deployment of legacy equipment in the bands. This can hinder the effectiveness of new technology standards intended to facilitate co-existence, as these may be adversely affected by the presence of older technologies which do not have effective interference mitigation capabilities. An example of the latter are the analogue video sender devices still widely deployed at 2.4 GHz, which can cause considerable disruption to Wi-Fi systems in this band.

It is also more difficult to monitor effectively the utilisation of licence exempt bands, partly because reliable market data about the penetration of licence exempt devices often does not exist and partly because the low power, sporadic operation and short range of most licence exempt applications makes physical monitoring of radio emissions challenging.

Finally, a key challenge in licence exempt bands is that there is generally no control over numbers and / or location of devices. This can be a barrier to sharing as it makes it difficult to enforce exclusion zones around sensitive sites or to control aggregate interference. As a consequence, some bands that might have been made available to licence exempt devices cannot be and there have been cases of interference from licence exempt devices to other users that cannot be readily dealt with. One way around this problem is the use of a "light licensing" or registration approach, such as has been adopted by Ofcom for fixed wireless access systems in the 5.8 GHz band and proposed for higher power mesh networks in the recently adopted 870-876 MHz band.

Since many licence exempt wireless devices connect to the Internet, in the future is it possible that some form of simple on-line registration could be used to enable devices to operate for a limited period or subject to periodic renewal. In the longer term this could provide a potential solution to the legacy equipment / refarming issues referred to above.

2.2.3 Defining the market for licence exempt radio devices

The market for devices operating in licence exempt band can be split into a number of key segments, reflecting the application areas defined in Figure 1-1. Some of the key market segments are described below

- **Wireless Access (Wi-Fi):** The UK has one of the highest densities of Wi-Fi networks in the world. A 2012 survey by Strategy Analytics found that 73.3% of UK households has a home Wi-Fi network, a proportion second only to South Korea. The UK also leads Europe in the deployment of public Wi-Fi hotspots, with several extensive networks operated by networks such as BT, Virgin Media, O2, Arqiva and BskyB (The Cloud). The volume of traffic carried over Wi-Fi networks continues to grow significantly – for example according to Cisco's Visual Networking Index (VNI) forecasts consumer fixed Internet traffic (most of which is connected via Wi-Fi) will grow 3-fold from 2013 to 2018, a compound annual growth rate of 22%.

- **RFID:** RFID technology is widely used in sectors such as transport, manufacturing and supply chain tracking and is rapidly expanding. A recent report from IDTechEx[3] predicted that a total of 6.9 billion tags would be sold worldwide in 2014, up 19% on the previous year, with the majority of the growth in passive UHF RFID labels. A 2009 report prepared for the European Commission[4] projected that the global RFID market would be worth €15-20 billion by 2018, with 20% of this in Europe. The report suggested the economic impact of RFID could be as much as an order of magnitude higher, largely comprising cost reduction, productivity growth and supporting the introduction of new products and services.
- **Medical Devices:** A recent report by US market analysts Markets and Markets[5] projected that the global market for wireless portable medical devices, many of which operate in licence exempt bands would grow from $7.5 billion in 2014 to over USD17 billion by 2020, representing an annual compound growth of 12.2%.
- **Wireless AV:** Commonly referred to as video senders these devices are widely deployed in homes to send TV signals from one room to another. There is no reliable data on the market size but many thousands of low cost devices can be found for sale on sites such as eBay and Amazon. Around half of these devices currently on sale operate in the 5.8 GHz band, the remainder in 2.4 GHz – the latter can adversely affect Wi-Fi systems which also operate in this band (see section 3.5.3). Premium Wi-Fi based products such as Sonos and Apple TV are gaining popularity, offering enhanced performance and improved co-existence with other Wi-Fi systems, but these are considerably more expensive.
- **Alarm Systems:** Many fire, intruder and personal alarm systems use wireless technology that operates in licence exempt bands. A 2012 CEPT report provided some estimates of the projected market for wireless alarms in Europe. The report estimated that more than 94 million wireless smoke alarm devices would be installed during the 5 year period to 2017, with an estimated value of over €5 billion. The current installed base of wireless intruder alarms in Europe was estimated at 80-100 million devices, growing by approximately 2 million per year. The UK was estimated to account for approximately 600,000 new installations per year. No specific data was available for the number of social alarms, but this was highlighted as a significant growth area, reflecting an increasing elderly population and an increasing desire for assisted independent living in preference to institutional care.
- **Machine to Machine (M2M):** M2M applications are widely acknowledged as one of the major growth areas over the coming decade. The term covers a wide range of individual market sectors and applications, many of which can be served by wireless technologies operating in licence exempt bands. For example, a 2013 report prepared for Ofcom by Aegis Systems and Machina Research[6] identified 149 distinct M2M applications across 12 market sectors. The report estimated that there would be over 350 million individual M2M connections in the UK by 2022, with the three largest sectors, intelligent buildings, utilities and automotive, accounting for over 80% of the total market volume. Of these, it was estimated that 15% were likely to be served exclusively by short range technologies (likely to operate in licence exempt bands), a further 59% could be served by either short range or wide area technologies (such as cellular) and the

[33] RFID Forecasts, Players and Opportunities 2014-2024", IDTechEx, July 2014

[4] "RFID Prospects for Europe, JRC Technical and Scientific Reports

[5] "Wireless Portable Medical Device Market by Technology, Component, Application and Geography – Global Forecast to 2020", marketsandmarkets.com, December 2014

[6] "M2M application characteristics and their implications for spectrum, Final Report", May 2013

remaining 26% would require a wide are wireless technology. However even many of these could be served using licence exempt bands using new M2M-optimised technologies that we describe elsewhere in this report (section 5.3)

2.3 Economic and Social Value of Licence Exempt Bands

The economic and social benefits of licence exempt spectrum are undoubtedly substantial and almost certainly growing but are not straightforward to quantify. This is partly because licence exemption means reliable records of numbers of users or devices do not generally exist (as they would, for instance, in the case of mobile phones) and partly because the benefits are often indirect or long-term. For example, it is difficult to quantify the efficiency benefits of devices such as car immobilisers or door openers and the benefits derived from wireless medical implants, such as glucose monitors for diabetics, may not become apparent for many years (in the form of extended longevity or improved long term health). On the other hand, the benefits of technologies such as Wi-Fi, which can provide a direct substitute for licensed network connectivity are easier to gauge, e.g. in terms of cost savings to end-users (by incurring lower mobile phone charges) or to networks (by requiring less infrastructure and/or spectrum due to traffic offload).

A number of studies over the last decade have attempted to place a value on certain types of licence exempt use. For example, a report prepared by Plum for the GSM Association in 2013[7] observed that nearly 3 billion devices globally were Wi-Fi capable, of which 900 million were in Europe. The report identified three distinct ways in which Wi-Fi use generates economic value, namely:

i. Enhancing the value of fixed broadband by allowing multiple devices to connect seamlessly from any location within a home or office.
ii. Lightening the load on mobile networks through data traffic offload, without which more traffic might otherwise be carried over mobile networks at an additional cost to the economy, and
iii. Providing a low cost solution for M2M communications for many applications.

All three of these were expected to grow over the next decade. Based on earlier willingness to pay research by Perspective Associates in the US in 2009 and updated by Thanki in 2012[8], along with consideration of what percentage of households might disconnect their fixed broadband if WLAN access were not available, Plum estimated the economic value of Wi-Fi access in Europe in 2013 to be approximately €15 Billion. Based on the assumptions that the percentage of households with fixed broadband would grow to 95% and that the value per household would grow by a further 30% in real terms to reflect the increased number of digital devices in the home, the projected value for 2023 was expected to grow to €23 billion.

The corresponding value for the avoided cost of carrying Wi-Fi traffic over the mobile networks was estimated at €5 billion in 2013, rising to €13 Billion by 2023 (reflecting the growth in mobile data traffic). The potential value of M2M applications served by Wi-Fi by was projected as €55 billion, though it was acknowledged there is considerable uncertainty about this this figure given the relative immaturity of the M2M market. It should also be noted that many M2M applications are inherently narrow band and hence may be better served by other licence exempt technologies (this is addressed further in section 5.3).

[7] "Valuing the use of spectrum in the EU, an independent assessment for GSMA", David Lewin, Phillipa Marks and Stefano Nicoletti, Plum Consulting, April 2013",

[8] "The economic significance of licence exempt spectrum to the future of the Internet", Richard Thanki, June 2012

In a 2012 report[9], Analysys Mason described the economic benefits and contribution to the UK economy generated by Wi-Fi and other licence-exempt uses of spectrum. The report estimated that the consumer and producer surplus of Wi-Fi offloading of mobile data traffic amounted to approximately £1.8 billion in 2011 and would have an NPV of £31 billion over the next ten years. Consumer surplus was estimated to account for 90% of this, resulting from savings on mobile data charges, whilst the remainder would go to network operators in terms of cost savings from not having to carry as much data. M2M applications were also identified as another key contributor to economic value but were not quantified.

2.4 Estimating future demand for licence exempt spectrum

A number of attempts have been made to estimate the likely future demand for licence exempt spectrum, particularly in relation to broadband data transmission and M2M communications which are seen as the likely fastest growing areas of the market.

A 2013 study undertaken by WIK-Consult and Aegis Systems for the European Commission[10] analysed the potential demand for spectrum to support Wi-Fi in high traffic locations and concluded that the peak traffic demand was likely to be in densely populated urban centres with a mix of residential Wi-Fi networks and public Wi-Fi hotspots. The estimated spectrum demand was in the range was up to 320 MHz to support residential Wi-Fi and between 160 and 320 MHz to support public Wi-Fi hotspots. The latter depends largely on whether in-band Wi-Fi links are used to interconnect individual Wi-Fi access points.

In the worst case scenario total demand could be as high as 640 MHz which exceeds the currently available spectrum – the report subsequently recommended the extension of the 5 GHz band to provide greater capacity, especially for the wider channels required to support the highest data speeds. Work is now underway in international fora such as CEPT and the ITU to identify options to expand Wi-Fi capacity in this band whilst protecting incumbent satellite and radar services – this is addressed further in section 3.6.2.

A 2014 study by Aegis Systems and M2M analysts Machina Research for Ofcom[11] concluded that it was likely that the growing demand for M2M communication could be met by existing licence exempt bands, providing the recently identified additional European bands 870-876 MHz and 915-921MHz are taken into account. Accommodating the projected growth in M2M applications, particularly those requiring wide area coverage and/or the ability to penetrate deep into buildings or other enclosed area, is likely to require full access to these new bands. Whilst that bands are already fully available in the UK, they are currently reserved for other services in most other European countries. This lack of harmonisation could hinder the development of low cost devices to serve the M2M market in Europe and is discussed further in section 3.6.1.

[9] "Impact of radio spectrum on the UK economy and factors influencing future spectrum demand - Final Report for DBIS and DCMS", Michael Kende, Philip Bates, Janette Stewart, Mike Vroobel, November 2012

[10] "Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum", 2013

[11] "M2M application characteristics and their implications for spectrum", May 2014

3 Current Status of Licence Exempt Spectrum and Technologies in the UK, Europe and beyond

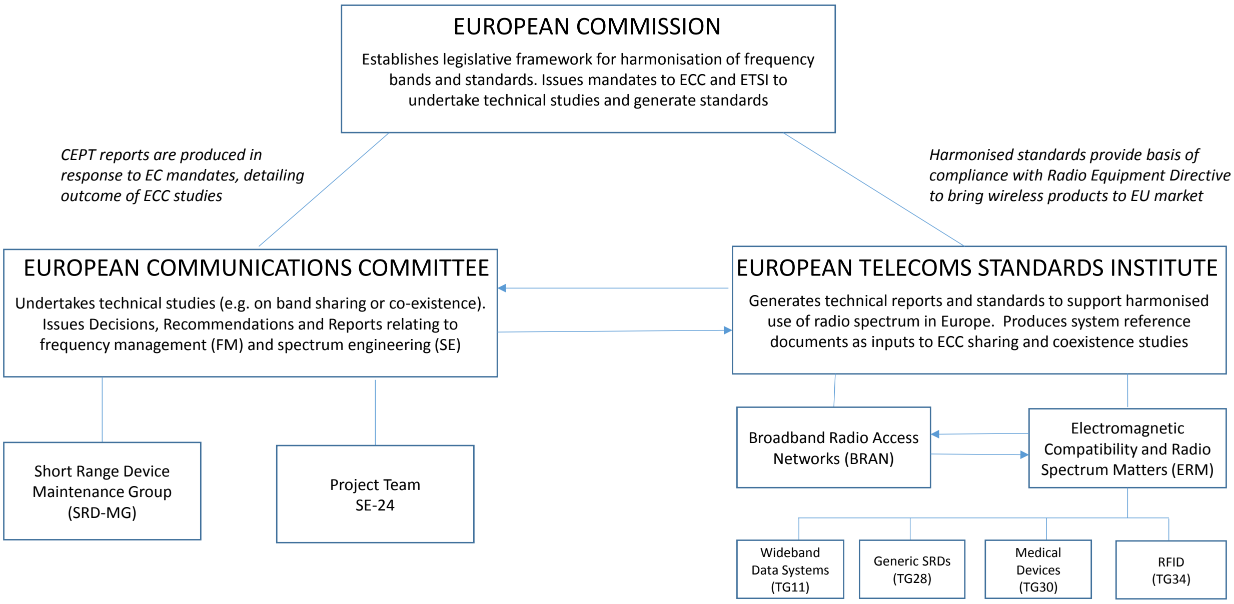
3.1 Introduction

In this section we outline the regulatory framework for licence exempt frequency bands in the UK and Europe, explain which frequency bands are currently available for various licence exempt applications and describe the main technologies that are deployed. We also describe recent regulatory initiatives to identify additional spectrum for licence exempt use, notably for SRD and M2M applications below 1 GHz and for wireless access at 5 GHz.

3.2 Regulatory and Standards Framework

In Europe, regulation of licence exempt bands is primarily dealt with at an international level and involves close co-operation between the European Commission (EC), European Communications Committee (ECC) and European Telecommunications Standards Institute (ETSI). The relationship between these three bodies is summarised in Figure 3-1 below. National regulatory authorities such as Ofcom in the UK are responsible for taking forward the decisions and recommendations emanating from the EC and ECC. In some cases (notably where a particular application or frequency band is covered by an EC Decision or Directive) this adoption is mandatory; in other cases (such as ECC Recommendations) it is left to individual administrations to decide whether to adopt the measure.

Figure 3-1: European spectrum regulation organisational arrangement



The European Commission (EC) largely determines spectrum policy within the EU, under the guidance of the Radio Spectrum Policy Group, which comprises senior representatives of the Member States and official representatives of the EC. When new harmonisation opportunities are identified, a mandate may be passed to the ECC (which is part of CEPT) to undertake the necessary technical studies, which are subsequently reported in the form of CEPT reports. In parallel, ETSI produces "System Reference documents" (SRDocs) to provide technical data in support of any new system, service or application that might result from the harmonisation measure.

The principal licence exempt frequency bands available in the UK are harmonised at a European level, but the extent of harmonisation varies between bands. Most bands are fully harmonised, whereby free circulation of devices that comply with the relevant standards is effectively mandated throughout the EU. However some bands are subject to "soft" harmonisation, where the frequency limits and technical characteristics are harmonised but adoption of the band is left to national administrations to decide.

Most fully harmonised licence exempt bands are defined in **EC Implementing Decision 2013/752/EU of 11 December 2013 on Harmonisation of the Radio Spectrum for use by Short-Range Devices (SRDs)**. This document, which amends an earlier Decision 2006/771/EC, defines 81 individual licence exempt frequency bands and 11 specific categories of SRD. The categories are based on either the deployment of similar spectrum access mechanisms or common usage scenarios that determine the expected usage density. This approach is intended to facilitate sharing of spectrum by grouping together applications with similar spectrum attributes in specific frequency bands.

ECC Recommendation 70-03, relating to the use of SRDs also covers fully harmonised bands but also includes bands that are subject to soft harmonisation**.** This document was originally released in 1997 and has been updated many times since; the latest version is dated February 2014. This document is intended to be used as a reference document by individual administrations, but unlike the EC Decision does not oblige them to comply with individual allocations. The Recommendation uses a slightly different set of application categories in defining how bands are used.

Responsibility for maintaining the technical aspects of both of these documents is vested in CEPT's Short Range Device Maintenance Group (SRD-MG), which reports to the ECC and is open to both national regulatory authorities and industry representatives (so long as the latter are members of ETSI). Part of the Group's remit is to inform and invite comments from appropriate sectors of the European SRD industry on issues of interest to those sectors. There is also a permanent mandate from the EC to the SRD-MG to review and update the technical annex of the 2013 Decision on an annual basis. More detailed technical analysis is handled by the ECC's spectrum engineering project team 24 (SE-24), which also has a specific remit on SRDs.

One significant exception that is not covered by the 2013 EC Decision or Recommendation 70-03 is the 5 GHz Wi-Fi band. This is covered by a separate EC Decision 2007/90/EC, which is also an amendment of the earlier Decision 2005/513/EC on "the harmonised use of radio spectrum in the 5 GHz frequency band for the implementation of Wireless Access Systems including Radio Local Area Networks (WAS/RLANs)". This Decision mandates specific technical provisions to ensure the protection of other incumbent services in the 5 GHz band, which we address further in sections 4.2 and 5.2. The DECT cordless telephone band is also covered by a specific Directive, 91/287/EEC

The typical process by which new requests for licence exempt spectrum or technical standards are made would be as follows (the example relates to generic short range devices):

- ETSI (TG28) develops a System Reference Document (SRDoc) describing the application(s) and associated spectrum requirement
- ECC PT SE24 carries out compatibility / interference studies

- ECC SRD/MG updates Recommendation 70-03 (allowing individual countries to release spectrum) and makes recommendations to the EC/RSC for changes to harmonised spectrum
- ETSI writes associated Harmonised Standards

Another important piece of EU legislation that impacts on licence exempt bands is the 2014 Radio Equipment Directive (2014/53/EU), which lays down minimum essential requirements for all radio equipment deployed in the EU. This new Directive replaces the 1999 Radio and Telecommunications Terminals Directive and among other things introduces more stringent requirements for receiver performance. This is particularly relevant to licence exempt radio devices, some of which have in the past have been affected by interference from new services introduced in adjacent bands due to inadequate receiver selectivity. We address this further in section 3.6.3.

The 2014 Directive includes a specific provision (Article 3.2) that *"Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference".* Fulfilling this and other essential requirements is in most cases based on compliance with harmonised technical standards maintained by ETSI, which works closely with the CEPT to develop the most appropriate technical conditions in each frequency band. The new Directive comes into force in June 2016 and all new equipment brought to market after that time will need to be compliant. A twelve month grace period will apply for existing equipment.

In the next section we highlight the main European licence exempt bands and associated applications (as defined in the 2013 Decision and ECC Recommendation 70-03) and relevant technical standards.

3.3 Principal European Licence Exempt Bands

The following table summarises the main European frequency bands identified for use by licence exempt wireless devices in the frequency range 100 MHz to 100 GHz. More detailed information can be found in the annex to the 2013 EC Decision and the annexes to ECC Recommendation 70-03.

Table 3-1: Principal European Licence Exempt Frequency Bands

Band	Frequency Limits (MHz)	Applications	Relevant Standards
169 MHz	169.4 – 169.475	Metering Devices	EN 300 220
403 MHz	401 - 406	Active Medical Implants	EN 302 537
433 MHz	433.05 – 434.79	Non-specific SRDs	EN 300 220
446 MHz	446 – 446.2	PMR 446	
868 MHz	863 – 870 MHz	Non-specific SRDs	EN 300 220
	863 – 865 MHz	Wireless microphones and assistive listening devices	EN 301 357
	865 – 868 MHz	RFID	EN 302 208
870 MHz	870 – 876 MHz*	Tracking, Tracing and Data Acquisition (TTDA)	EN 303 204
		Transport and Traffic Telematics; Non-specific SRDs	EN 300 220

Band	Frequency Limits (MHz)	Applications	Relevant Standards
915 MHz	915 – 921 MHz*	RFID	EN 302 208
		Non-specific SRDs	EN 300 220
		Assistive listening devices	EN 300 422
1880 MHz	1880 - 1900	DECT	EN 300 175
2.4 GHz	2400 – 2483.5 MHz	Wideband data transmission (e.g. Wi-Fi)	EN 300 328
		Movement detection; Non-specific SRDs	EN 300 440
	2446 – 2454 MHz	RFID	EN 300 440
5 GHz	5150 – 5350 MHz 5470 – 5725 MHz	Wireless Access Systems (e.g. Wi-Fi)	EN 301 893
5.8 GHz	5725 – 5875 MHz	Non-specific SRDs	EN 300 440
	5795 – 5805 MHz	Transport and Traffic Telematics (TTT)	EN 300 674
24 GHz	24 – 24.25 GHz	Non-specific SRDs	EN 302 858
		Movement Detection	
60 GHz	57 – 64 GHz	Non-specific SRDs	
	57 – 66 GHz	Wideband data transmission (e.g. Wi-Gig)	EN 302 567

* Note that the 870 - 876 MHz and 915 – 921 MHz bands are not yet fully harmonised and availability varies from country to country. The bands are fully available in the UK.

The relevant technical standards are summarised below and can be individually downloaded from the ETSI web site:

Table 3-2: Harmonised European Standards for licence exempt wireless devices

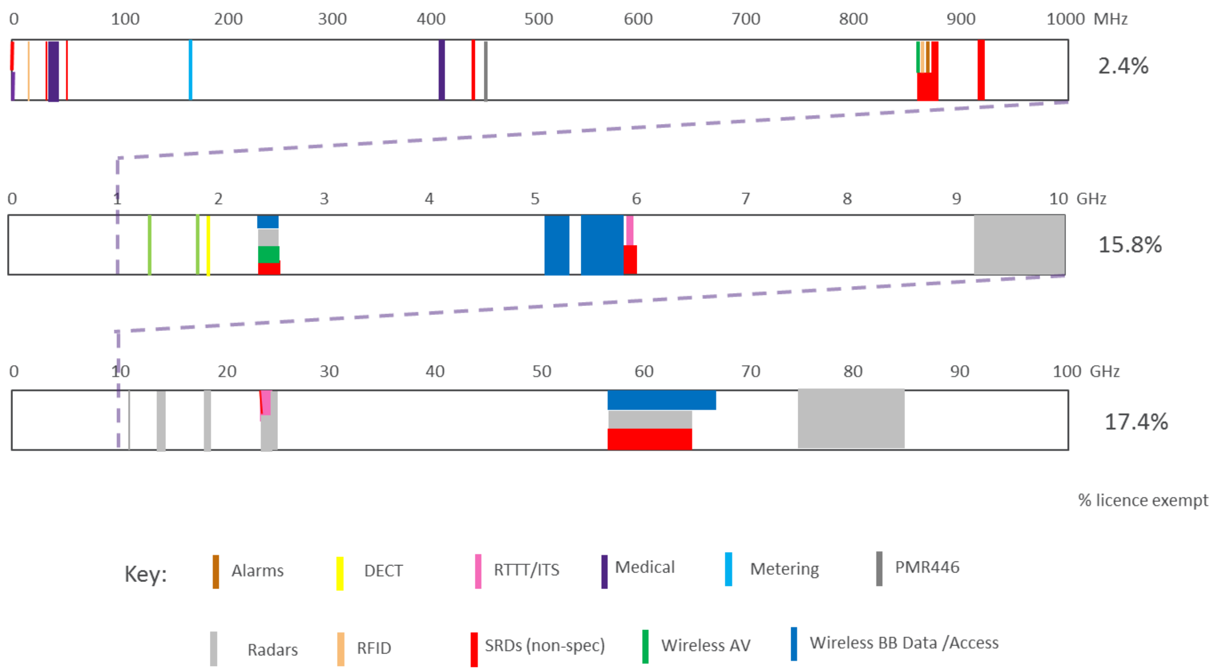
Standard	Scope
EN 300 175	Digital Enhanced Cordless Telecommunications (DECT)
EN 300 220	SRDs in the 25 – 1,000 MHz frequency range with power levels ranging up to 500 mW
EN 300 328	Wideband data transmission equipment in the 2.4 GHz ISM band using wide band modulation techniques
EN 300 422	Wireless microphones in the 25 MHz - 3 GHz frequency range
EN 300 440	SRDs in the 1 - 40 GHz frequency range
EN 300 674	Dedicated Short Range Communication (DSRC) transmission equipment (500 / 250 kbps) in the 5.8 GHz ISM band
EN 301 357	Cordless audio devices in the range 25 - 2 000 MHz

Standard	Scope
EN 301 893	5 GHz high performance radio local area networks
EN 302 858	Short range radar equipment operating in the 24.05 – 24.25 GHz frequency range for automotive applications
EN 303 204	Network Based SRDs in the 870 - 876 MHz frequency range with power levels up to 500 mW
EN 302 208	RFID equipment in the band 865 - 868 MHz with power levels up to 2 W
EN 302 537	Ultra Low Power Medical Data Service systems in the frequency range 401 - 402 and 405 - 406 MHz

The diagram below illustrates the relatively small proportion of radio spectrum that is available on a licence exempt basis, especially in the lower frequency range below 1 GHz. Note that some bands are designated for multiple licence-exempt applications, which can make co-existence particularly challenging. 2.4 GHz, for example, is not only heavily used by Wi-Fi, but also by video devices, movement detectors and a wide range of non-specific SRDs such as wireless computer peripherals. This is in addition to the widespread use of microwave ovens and other industrial, scientific and medical (ISM) applications which historically were the principal users of the band.

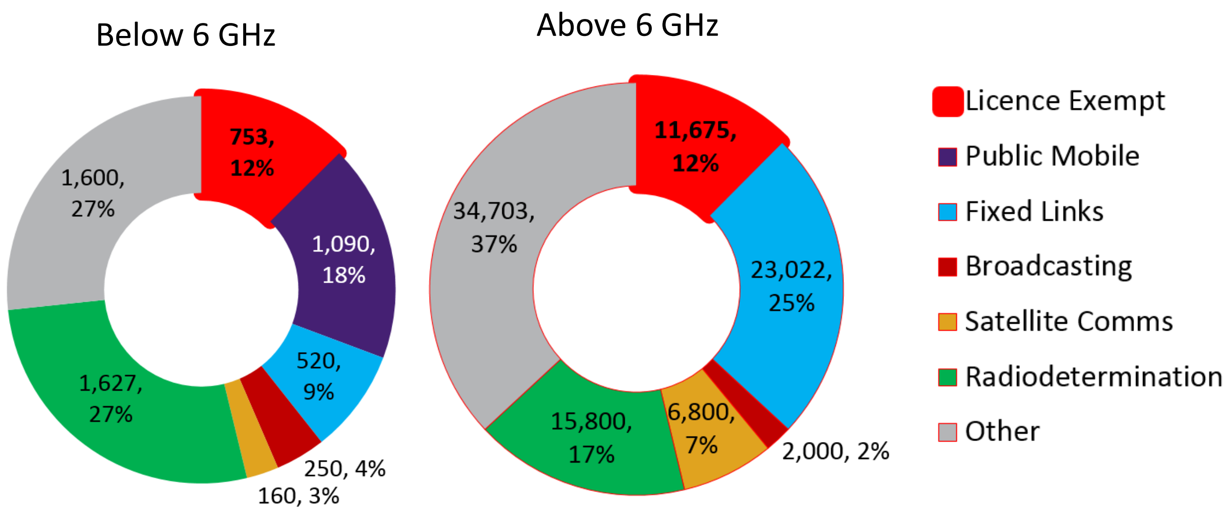
Note also that licence exempt bands are often shared with other services which must be protected from harmful interference arising from SRD use. For example the 5 GHz band is shared with a variety of radar and satellite systems which can constrain its use in some instances (this is considered further in section 3.5.5). It should also be noted that other parts of the spectrum may be used on a shared basis by certain niche licence exempt technologies, such as level probing radars that generally operate in shielded environments.

Figure 3-2: Principal European Licence Exempt Frequency Bands



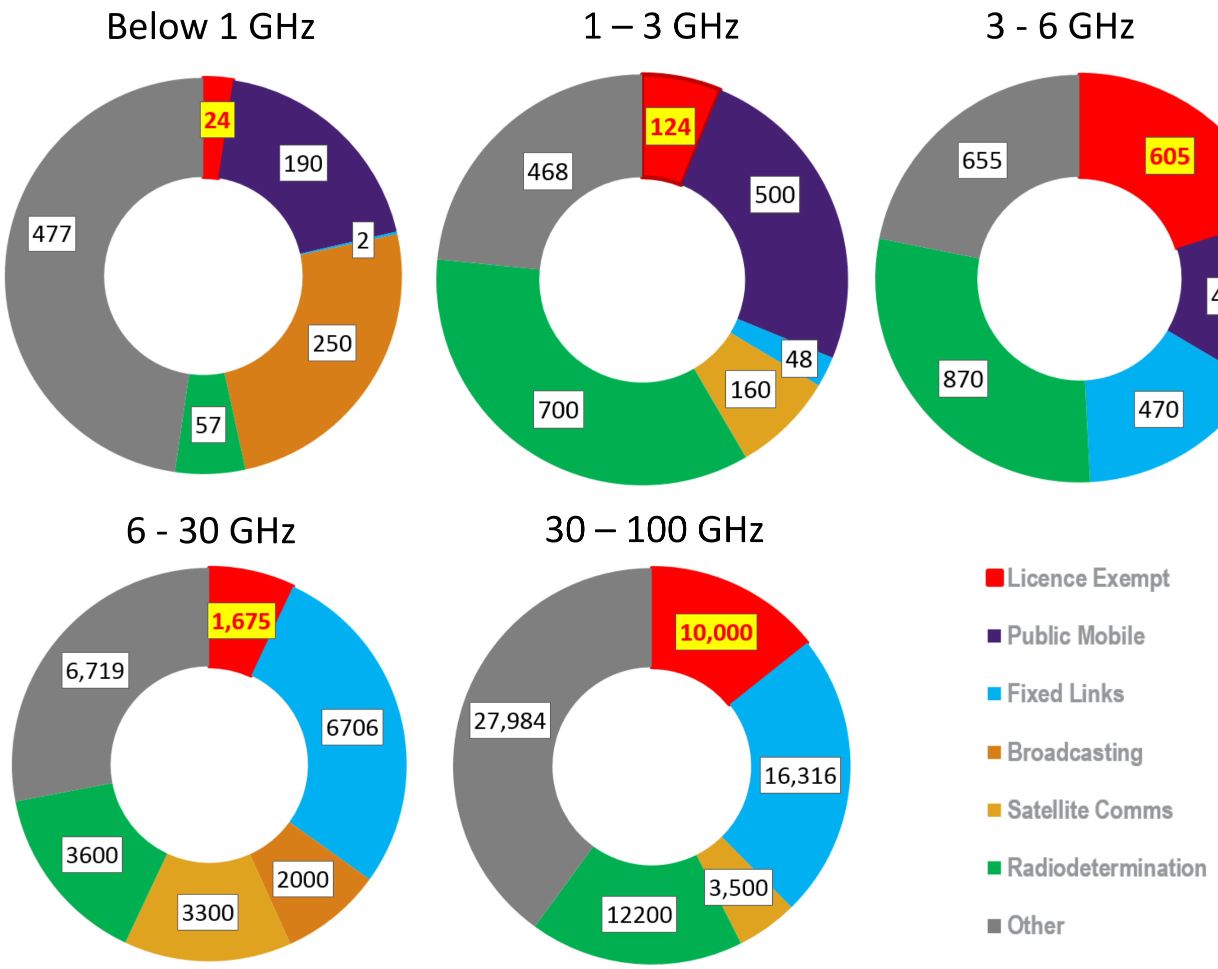
It is also helpful to compare the proportion of radio spectrum allocated for licence exempt use with that for licensed uses such as mobile, broadcast and fixed services. Licence exempt bands account for approximately 12% of spectrum, both above and below 6 GHz, as shown below.

Figure 3-3: Proportion of Licence Exempt spectrum above and below 6 GHz



Licence exempt bandwidth tends to be concentrated towards the upper end of these ranges, however, as shown in the more detailed analysis below. Of particular note are the allocations between 5 and 6 GHz and around 60 GHz which account for the lion's share of licence exempt radio spectrum but are largely restricted to wireless access services and local area networks.

Figure 3-4: Proportion of spectrum allocated to licensed and licence exempt use in various frequency ranges



Note – fixed link spectrum includes shared satellite bands. Broadcasting includes direct to home satellite

The applications catered for by licence exempt wireless technology are extremely diverse and their characteristics differ markedly in terms of their potential impact on spectrum demand. In particular, there are significant differences in the transmission ranges, data bandwidths, data volumes and required quality of service (QoS).

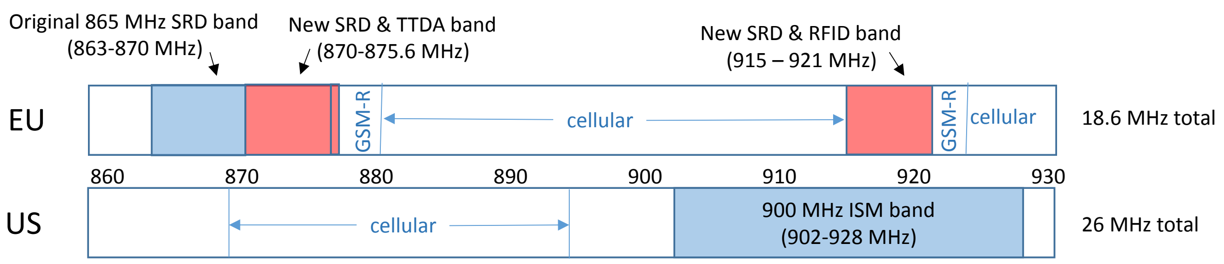
For example, Wi-Fi often involves the transmission of sizeable volumes of data at very high bit rates, whereas many M2M applications involve only occasional short bursts of data (potentially a kilobyte or less), but in some cases may have critical quality of service requirements (e.g. fire alarms, medical sensors or smart utility networks). Historically, licence exempt wireless applications have mostly been short range (100 metres or less) but recently there has been growing interest in the use of “low power wide area” technologies for M2M applications, some of which may operate in licence exempt bands.

3.4 Comparison with other regions

It is interesting to compare the European licence exempt frequency bands with those in other regions, particularly North America which historically has had substantially more bandwidth available below 1 GHz. The decision by the FCC in the 1980s to allow licence exempt use of the 902-928 MHz band prompted widespread take-up of the band for a range of applications including video links that in Europe were required to operate in higher frequency bands such as 2.4 GHz. Broadband data links based on spread spectrum technology have also been popular in this band, particularly in rural areas where relatively long distance transmission can be achieved.

The recent European initiative to identify spectrum in the 870 - 876 MHz and 915 - 921 MHz bands (which we discuss further in section 3.6.1) could go some way towards levelling the balance between the US and Europe in terms of licence exempt spectrum availability if full harmonisation of these bands can be achieved. This could create new opportunities for innovation, e.g. in the area of low power wide area networks for applications such as smart grids of metering. The figure below compares the licence exempt bands in the 860 - 930 MHz range in Europe and the US – although the European bands have less bandwidth in total and are more fragmented, arguably they may be of more value due to the absence of legacy equipment without interference mitigation mechanisms. It should also be borne in mind that the smaller licence exempt allocation in Europe below 1 GHz results in a correspondingly higher bandwidth allocation for licensed cellular services in this range.

Figure 3-5: Comparison of EU and US licence exempt bands in the 860-930 MHz range



The availability of frequency bands globally and regionally for SRD deployment is also defined in a 2013 ITU Report[12] and is summarised below. Note the relative paucity of globally harmonised bands.

Global Bands (above 30 MHz):

- 40.66-40.7 MHz
- 2400 - 2484.5 MHz (extended to 2500 MHz in some countries)
- 5725 - 5875 MHz
- 24 – 24.25 GHz
- 61 – 61.5 GHz
- 122 – 123 GHz

[12] Report ITU-R SM.2153-4, "Technical and operating parameters and spectrum use for short range radiocommunication devices, July 2013

- 244 – 246 GHz

Regional Bands:

- 312 - 315 MHz: available throughout ITU Region 2 (Americas) and in some Region 1 (EMEA) and Region 3 (Asia Pacific) countries, though not currently in Europe. Used for similar applications to the European 433 MHz band.
- 433.05 - 434.79 MHz: Available throughout Region 1 and in some Region 2 and Region 3 countries.
- 862-875 MHz: parts of the band are available in all of Region 1 and in some Region 3 countries. Not available in Region 2
- 875 – 960 MHz: although this entire band is identified for unlicensed SRD use in Region 2, in practice use is largely limited to the 902 – 928 MHz ISM band in North America and the Caribbean. Parts of this band are also available in some Region 1 and Region 3 countries, notably the 915 – 921 MHz band recently proposed as a harmonised European band for RFID and other non-specific SRDs.

3.5 Examples of interference and congestion in licence exempt bands

In the following sections we highlight historic and current examples of interference and congestion and how these have been dealt with or could be dealt with in the future.

3.5.1 433 MHz

The 433 MHz band was for many years the principal licence exempt band for short range devices (418 MHz was also used in the UK but was phased out to make way for the introduction of digital PMR services in this band). The band is widely used by a variety of applications at radiated powers of up to 10mW ERP and up to 10% duty cycle. The band is also shared with radio amateurs, including repeater stations, many of which operate in the 433 - 433.375 MHz range which overlaps with the SRD band.

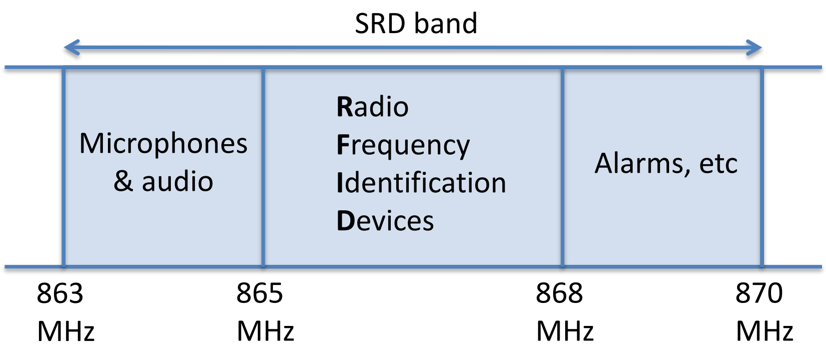
Many of the low cost consumer devices that operate in this band use the centre frequency (433.92 MHz) and employ very basic receiver technologies with limited selectivity and blocking performance. Hence the presence of other in-band signals (whether SRDs or amateur) or high powered out-of-band signals can severely affect performance. The rollout of a national TETRA network at 430 MHz in the 1990s (no longer operational) and signals from the Fylingdales early warning radar caused particular problems in this band, with as many as 12,000 interference cases a year being reported, typically resulting in drivers being locked out of their cars or alarm systems being falsely activated.

The band continues to be popular for less critical applications such as remote weather stations but many of the applications that traditionally used this band have now migrated to 868 MHz, where more stringent technical requirements apply and the sharing environment is more benign (although the presence of high power signals in adjacent bands can still be problematic for some applications, as we discuss below)

3.5.2 863-870 MHz

This band is currently the principal allocation for narrow band licence exempt applications in Europe. The band is segmented into three main sub-bands, the lowest being identified for wireless audio, the middle for RFID and the highest for alarm systems and non-specific SRDs as illustrated below (although the whole band may be used by non-specific SRDs using frequency hopping or spread spectrum technology). Interference concerns in this band largely relate to the impact of LTE user terminals operating immediately below 862 MHz and appear to be most significant for wireless audio equipment (due to their 100% duty cycle and having the smallest frequency separation) and wireless alarms (due to their safety critical nature and relatively large operating range).

Figure 3-6: 863 – 870 MHz band plan (source: Plum)



In 2011 and 2012 the UK regulator Ofcom commissioned research into the effect of LTE in the 800 MHz[13,14] band on SRDs. The studies concluded that for wireless audio equipment the operational range could be reduced under extreme conditions, but that in practice this was unlikely to cause operational problems unless a much extended range is needed and the interfering LTE device is operating very close by. Tests by the Association of Professional Wireless Production Technology (APWPT), a European industry body representing users of professional wireless audio equipment, found that LTE user equipment caused audible interference to wireless headphones but only at a distance of about 70 cm or less[15].

In the case of wireless alarms, measurements indicated that an LTE user terminal operating at the maximum power and throughput would require a separation of 26 metres to protect a social alarm receiver operating at its detection threshold, reducing by about half where a 20 dB link margin exists. Further tests based on a real world social alarm system suggested that although interference could arise where an LTE user terminal is used within 2 metres of the alarm system receiver, this would be largely eliminated if the LTE out of band emissions were 10 dB below the regulatory requirement (which is considered a typical margin for production equipment). It is worth noting that, unlike the situation at 433 MHz, the interference arising in this band is a result of out of band emissions from the interferer rather than inadequate SRD receiver selectivity. Hence there is limited scope for the SRDs themselves to take further mitigation measures.

[13] "Potential for LTE interference to Wireless Audio", Ofcom research document, May 2012

[14] Investigation on the receiver characteristics of SRD equipment in the 863 – 870 MHz band, report for Ofcom by ERA Technology and Aegis Systems, October 2011

[15] "LTE interference to wireless headphones", Dr. Harald B. Karcher, July 2013

A more recent investigation by CEPT[16] identified receiver blocking as a potential problem where LTE terminals are deployed in the same premises as SRDs, particularly for those with the lowest category receiver performance (category 3). A problem also existed with category 2 receivers but this was significant only towards the lower end of the band (corresponding to wireless audio links). The investigation concluded that removal of SRD receiver category 3 option in this band would reduce the risk of interference caused by blocking. Whilst there was still a significant risk of interference from out of band LTE emissions, based on the current ETSI standard, in practice the emissions were found to be typically 15 – 20 dB below the specified limits which largely removed the problem.

There would therefore appear to be a good case for tightening both the SRD standard (to remove the lowest receiver performance category and the LTE standard (to reflect actual out-of-band emissions) to support future co-existence between the two. We understand such an approach is being pursued by ETSI's Task Group 28 as part of its work on updating the generic SRD standard EN 300 220. SRD receiver performance is discussed further in section 3.6.3.

3.5.3 2.4 GHz

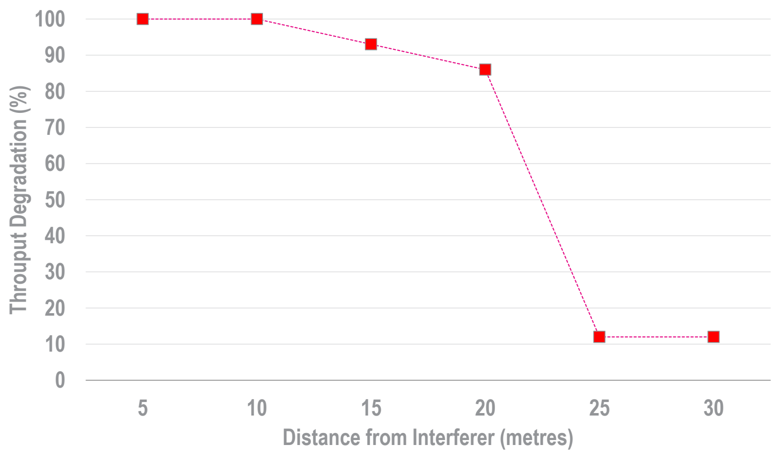
The 2.4 GHz band was until recently the only band used by Wi-Fi routers and devices and even today, with more widespread use of the 5 GHz band, there is still a high dependency on this band, not least because of the longer range available and the lack of 5 GHz functionality in many user devices. Whilst this can lead to serious congestion at certain times and locations (notably around public traffic hotspots such as airports and railway stations), the CSMA/CA protocol is generally effective at enabling a reasonable quality of service, especially in the residential environments where there tend to be relatively few overlapping users.

In practice a bigger problem is the presence of other, less "polite" technologies in the band, in particular the large number of analogue video senders which use FM technology with 100% duty cycle and can cause significant interference to nearby Wi-Fi systems. For example, tests conducted in Canada in 2010[17] with an analogue video camera (using similar technology to video links deployed in the UK) suggested co-channel Wi-Fi transmissions could be completely blocked at a distance of up to 10 metres, with some degradation of throughput apparent as far as 30 metres away,

[16] ECC Report 207, "Adjacent band co-existence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz", January 2014

[17] Ambient interference effects in Wi-Fi networks", Mahanti, Carlsson, Williamson and Arlitt, Dept. of Computer Science, University of Calgary, 9th International IFIP TC 6 Networking Conference, Chennai, India, May 11-15, 2010

Figure 3-7: Effect of nearby analogue video camera on co-channel Wi-Fi throughput



Source: Mahanti et al, University of Calgary

A 2012 report prepared by Mass Consultants for Ofcom[18] concluded that interference from analogue transmitters such as video senders, baby alarms and wireless security cameras was the most significant cause of performance degradation to Wi-Fi networks in the 2.4 GHz band. The report recommended the introduction of a certification scheme for “Wi-Fi friendly” products that incorporate interference mitigation mechanisms to facilitate co-existence.

3.5.4 DECT

In most of the world, digital cordless telephones based on the DECT standard operate in the 1880 – 1900 MHz band, however as this band is used for cellular in the Americas a variant of the standard known as DECT 6.0 has been introduced in that region, which operates in the 1920 – 1930 MHz band. This has led to cases of interference arising in the UK where illegally imported US DECT base stations have caused interference in to cellular networks and is a good example of where lack of international harmonisation of licence exempt bands can lead to interference problems.

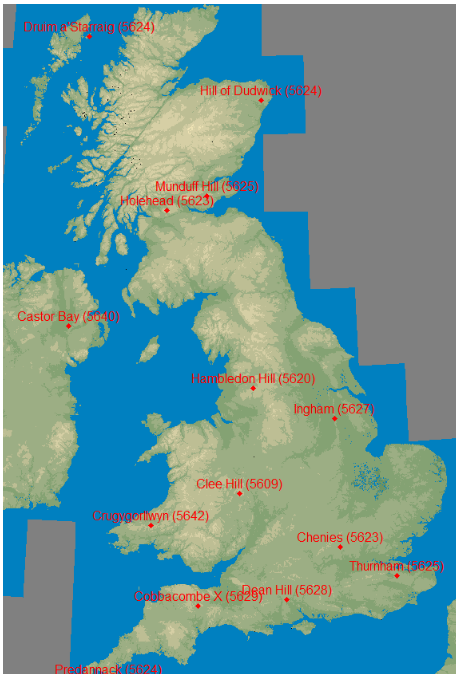
3.5.5 5 GHz

The interference environment in the 5 GHz band is more favourable compared to 2.4 GHz, reflecting the much larger number of channels available and the mandating of interference mitigation protocols in the band. However, the need to protect other incumbent band users, notably radar and satellite services may constrain the use of the band by Wi-Fi, particularly in outdoor locations.

As described in section 4.2.5, 5 GHz wireless access systems operating at frequencies above 5250 MHz must deploy Dynamic Frequency Selection (DFS) to protect incumbent radar systems. In the UK, the effect of the DFS requirement appears to be largely limited to the frequency range 5600 – 5650 MHz, which is used by a number of high power weather radars around the country (see map below).

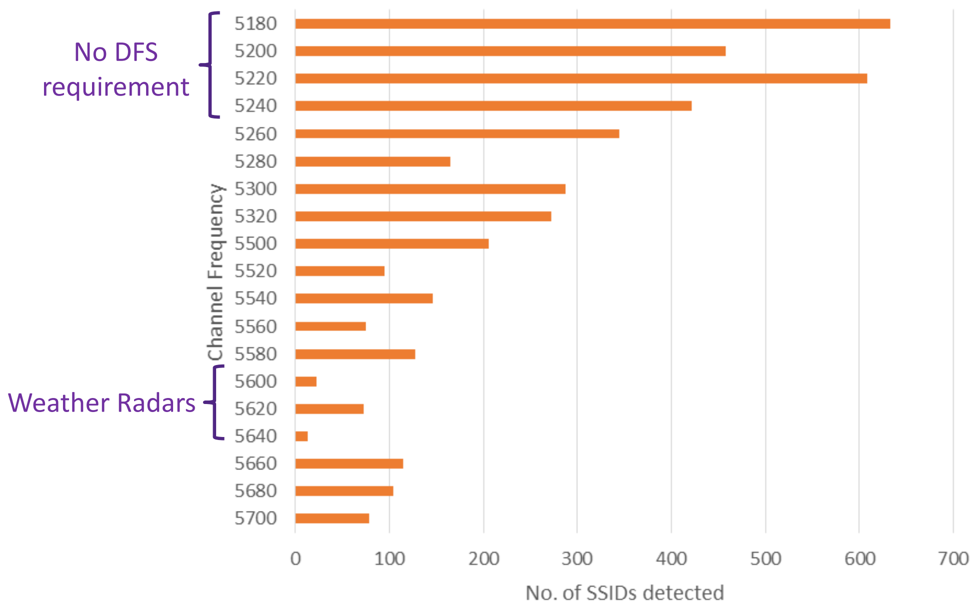
[18] “Estimating the Utilisation of Key Licence-Exempt Spectrum Bands”, Final Report for Ofcom, April 2009

Figure 3-8: Locations and frequencies of 5 GHz weather radars in UK (source: Eumetsat)



An indication of the utilisation of 5 GHz channels in a busy urban location is presented in the figure below, which shows the number of private and public (hotspot) access points detected on each 5 GHz channel during a half hour walk around the Westminster and Covent Garden area. It is interesting to note that public hotspots (many of which are outdoors at these locations) appear to use predominantly the higher channels whereas private access points tend to use the lower channels (particularly those below 5250 MHz that are not subject to the DFS requirement.

Figure 3-9: 5 GHz channel utilisation in central London



Concerns have however been raised by both the radar and Wi-Fi communities about the effectiveness of the current DFS mechanism in practice.

Reported interference to radar systems from wireless access systems in the 5 GHz band has been widespread but appear to be entirely due to illegal or non-compliant WAS deployments. For example a survey carried out by CEPT identified more than 200 cases across Europe in 2012[19]. All of these related to outdoor fixed WAS installations operating co-channel with the radar. The report observed that all the reported cases related to either deliberate illegal use (e.g. the DFS functionality being disabled by the user) or use of non-compliant equipment (where the DFS was not functioning as it should). No shortcomings in the DFS mechanism specified in the latest version of EN 301 893 were identified and none of the interference cases were related to failure of the DFS mechanism to detect a radar. The report noted that although EN 301 893 prohibits direct user access to any of the DFS settings, there are indirect ways that this can be done, including potential disablement of DFS functionality and that this may require a further enhancement of the applicable standard.

Work recently undertaken by BSkyB[20] questioned the effectiveness of the DFS and TPC mechanisms at 5 GHz and suggested that this potentially could make the 5 GHz spectrum less useful than 2.4 GHz for licence exempt use. The concerns were based on tests carried out on an outdoor stadium deployment with multiple access points operating within the radar frequency range, which revealed marked inconsistencies in the triggering of individual access points by radar signals, with different access points being triggered at different times. It was argued that in such an environment, if the DFS mechanism worked as it should, the DFS would trigger simultaneously on all access points whenever a radar pulse is present.

3.6 Current regulatory initiatives relating to licence exempt bands

A number of initiatives have been underway in Europe, driven by a combination of industry representatives, national administrations and the European Commission, to improve the utility of existing licence exempt frequency bands and identify additional bands to cater for anticipated future demand growth, particularly in areas such as M2M communication and RFID. In the following sections we review the most significant of these initiatives.

3.6.1 Identification of additional spectrum below 1 GHz

As we observed in section 3.4, ITU Region 2 (the Americas) has historically had access to a significantly larger bandwidth of licence exempt spectrum in the sub-1 GHz range than Europe. In particular, the availability of the 902-928 MHz ISM band has led to the development of a wide range of innovative applications covering both short range and wide area applications. Whilst the European 863-870 MHz band has provided some similar opportunities, the limited bandwidth available and massive growth in demand for applications such as RFID and more recently M2M communications has led to industry pressure to find additional spectrum to support future growth.

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[19] ECC Report 192, "The Current Status of DFS (Dynamic Frequency Selection) In the 5 GHz frequency range", February 2014

[20] "Defining the need for Wi-Fi spectrum – which bands and how much?", Sami Susiaho, BskyB, March 2015

In 2008 ETSI produced a system reference document (SRDoc)[21] that identified a need for additional spectrum to support anticipated market growth in a number of market sectors, including RFID, Home and Building automation and a wide variety of other M2M applications. The document identified two specific frequency bands, 870-876 MHz and 915-921 MHz, which had been allocated for business radio use for many years but had remained largely unused throughout much of Europe. Four other ETSI SRDocs relating to smart meters and smart grids (TR 102 886), metropolitan mesh machine networks (TR 103 055), alarm systems (TR 103 056) and assistive listening devices (TR 102 791) also identified a need for additional spectrum in this range.

In response to these SRDocs, ECC initiated studies to determine how best to accommodate these requirements. The outcome of the studies are described in ECC Report 200[22]. On the basis of the ECC studies the two bands have now been formally included in the Annex of CEPT Recommendation 70-03, using the layered approach illustrated below. Under this approach, higher power systems such as utility or M2M mesh networks are accommodated in the lower band below 875.8 MHz to provide a guard band for the adjacent GSM-R band, whilst the guard band may only be used by low power (25 mW), low duty cycle (≤1%) applications such as alarm systems. This also has the advantage of protecting such systems from interference that might arise from higher power licence exempt transmissions.

Higher powered RFID devices are accommodated on four specific frequencies in the 915-921 MHz band, with low power non-specific SRDs being allowed anywhere in the band subject to duty cycle limits which are lower in the two 200 kHz guard bands. The adoption of this band for RFID would effectively create a global band for this application, since it lies within the American 902-928 MHz band which is also widely used for RFID. This would be particularly beneficial for international freight transport and logistics operations, where RFID is widely used to track movement of goods.

[21] "ETSI TR 102 649-2, "System Reference Document for RFID and SRD equipment, Part 2: Additional spectrum requirements", April 2008

[22] ECC Report 200, "Co-existence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz, September 2013

Figure 3-10: Configuration of new 870-876 MHz SRD band (source: ECC)

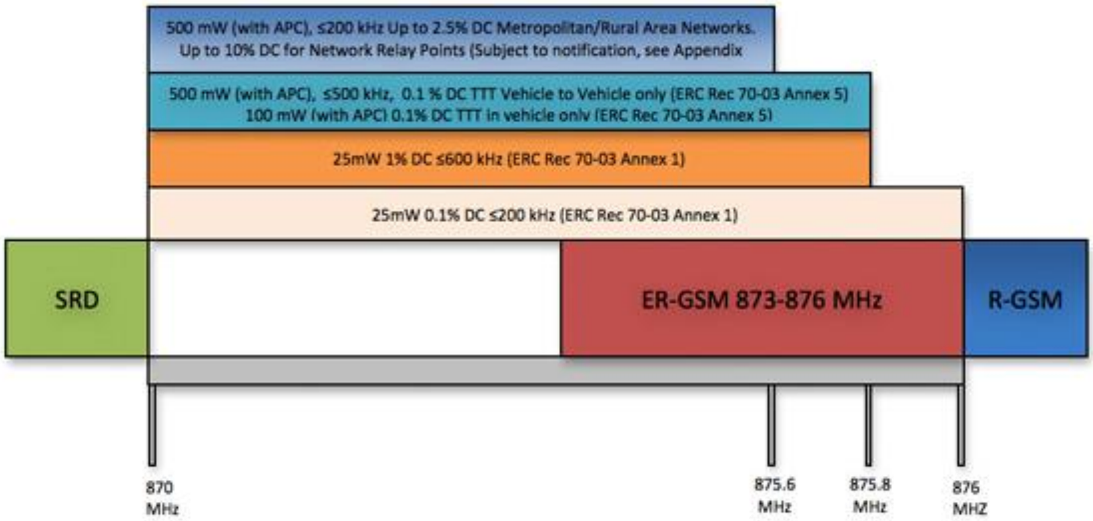
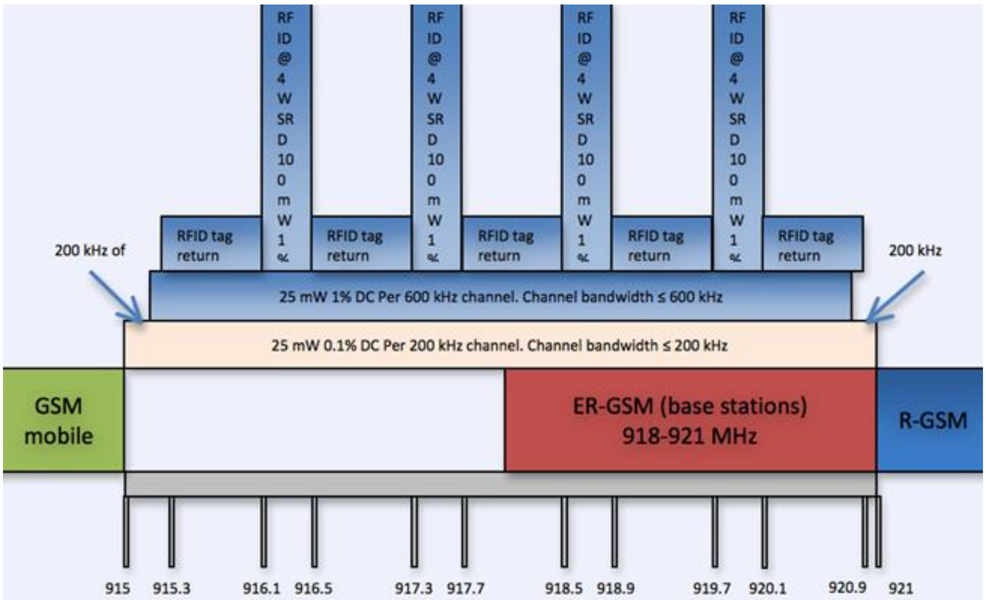


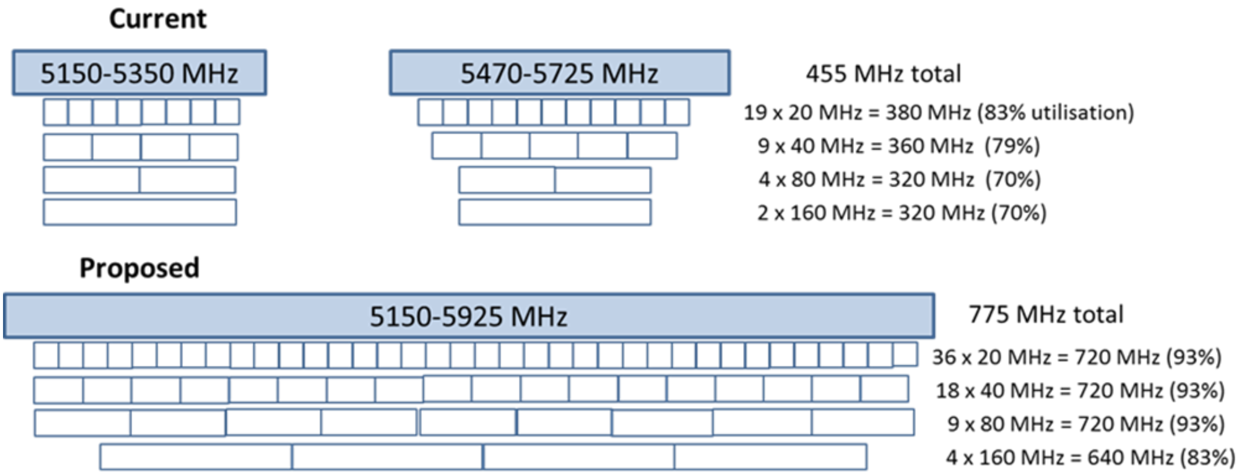
Figure 3-11: Configuration of new 915–921 MHz SRD band (source: ECC)



3.6.2 Finding additional spectrum for Wireless Access Services (WAS)

Whilst 2.4 GHz will remain important, there is no doubt that the additional capacity provided by 5 GHz will drive an increasingly large share of traffic into this band. In particular, only 5 GHz can support the latest high speed Wi-Fi implementations based on the 802.11ac standard, which caters for channel widths of up to 160 MHz. The current fragmentation of the 5 GHz band makes deployment of such wide channels particularly challenging and significantly limits the proportion of the band that can be utilised. The figure below compares the proportion of usable spectrum under various channel configurations with the currently available spectrum and if the entire 5150-5925 MHz range were to be made available:

Figure 3-12: Proportion of usable spectrum at 5 GHz (source: Plum)



European activities on 5 GHz expansion

CEPT was recently mandated by the EC to study and identify harmonised compatibility and sharing conditions for Wireless Access Systems in the bands 5350-5470 MHz and 5725-5925 MHz ('WAS/RLAN extension bands'). The mandate comprised two specific tasks, namely:

i) Identification of compatibility and sharing scenarios for WAS to operate on a shared basis in an uninterrupted band from 5150-5925 MHz whilst providing appropriate protection for existing and proposed future services in these bands, including:

   a. the planned introduction of GMES (Global Monitoring for Environment and Security) in the band 5350-5450 MHz

   b. the use of safety-related Intelligent Transport Services (ITS) applications in the frequency band 5875-5905 MHz

   c. current civil and/or military radio systems within the 5350-5470 MHz, 5725-5925 MHz and adjacent bands

ii) Development of compatibility and sharing conditions for WAS to operate on the basis of a general authorisation (i.e. on a licence exempt basis).

The outcome of the work was presented in a recent CEPT Report[23], which noted that there were still a number of open issues related to further studies that are still ongoing, particularly on possible mitigation techniques. In consequence there was unlikely to be any change decided at WRC-15 regarding any new mobile allocations for WAS in the 5-6 GHz range. In particular, various technical studies in CEPT and ITU-R have raised concerns about the feasibility of WAS usage in the 5350-5470 MHz band unless additional sharing / interference mitigation techniques can be identified to provide

[23] CEPT Report 57 to the European Commission in response to the Mandate to study and identify harmonised compatibility and sharing conditions for WAS in the bands 5350-5470 MHz and 5725-5925 MHz ('WAS/RLAN extension bands') for the provision of wireless broadband services, March 2015

the necessary protection to active earth exploration satellite services (EESS). Existing approaches such as DFS or an EIRP mask have been found to be insufficient. Reduction in the radiated power of WAS (e.g. to 25 mW) has been suggested (though this would significantly curtail the utility of the band for WAS applications) and the use of geo-location databases to facilitate sharing on a time and location basis has also been proposed but is considered to require further analysis.

In addition, compatibility with radars would be required in this band, including new types that are not reflected by the current DFS requirement. Similar mitigation techniques to those suggested for EESS protection have been proposed along with refinement of the DFS mechanism to cover the new radar types. Additional studies on mitigation techniques started in CEPT in April 2015. In parallel with this work, in December 2014 ETSI BRAN agreed to develop ETSI Technical Reports covering coexistence with EESS , ITS, road tolling and radars in the 5 GHz band. This work is being carried out in co-operation with CEPT.

5725 – 5875 MHz is a global ISM band and is widely used around the world by a variety of licence exempt short range devices. In the UK, a light licensing regime also exists to permit the operation of higher powered broadband fixed wireless services at radiated powers of up to 4 watts, subject to registration of each station with Ofcom. CEPT Project Team SE24 is currently undertaking compatibility studies on RLANs in the band 5725 - 5925 MHz, with a view to producing a new ECC report on the subject in 2016. Compatibility with fixed satellite services is a key issue but concerns also exist about earth exploration satellites, radars and direct air to ground communications (DA2GC). Other applications/services that have been studied in this band include Road Tolling and Broadband Fixed Wireless Access, where initial results indicate the need for significant separation distances.

Investigations are also currently underway in CEPT regarding the possible introduction of “Wireless Industrial Applications” (WIA) in the band. These would include applications such as monitoring, mobile worker communication, wireless sensors and actuators at moving parts. The proposed applications would generally be for indoor deployment at radiated powers of 400 mW. For co-existence between WIA and WAS, CEPT Report 57 concluded that it is expected that compatibility can be achieved through a coordination procedure within factory premises where WIA are expected to be deployed.

Activities elsewhere in the world

Investigations into the potential expansion of the 5 GHz band have also been underway elsewhere in the world. For example in the US, 2012 legislation required the NTIA and FCC to undertake evaluation of options to increase spectrum authorized for unlicensed device operations in the 5350-5470 MHz and 5850-5925 MHz bands. In 2013 the FCC issued a Notice of Proposed Rulemaking to modify existing rules and make available this additional spectrum. A 2014 report addressed interference and enforcement issues and recommended industry collaboration to develop innovative interference mitigation measures. The report also noted similar problems with interference to weather radars in the 5600-5650 MHz band due to DFS non-compliance as reported in Europe (see section 3.5.5).

In the 5350 – 5470 MHz band, existing mechanisms such as DFS, power limits and limitation to indoor use were considered insufficient and future work should therefore focus on new techniques such as use of dedicated networks of detectors or geographic databases. Airborne radars in the band are a particular problem as these would require a detection threshold at ground level well below the noise floor, hence the use of a dedicated network of rooftop mounted dedicated radar signal detectors has been suggested[24]. It is thought that a time / location database for EESS services may work domestically but would be challenging to implement internationally.

The US is proposing to continue work within an international collaborative environment with a view to addressing this band as an agenda item at the 2019 World Radio Conference (WRC-19). Meanwhile, in Europe, ETSI BRAN is understood to be working on mitigation techniques to allow Wireless Access Systems to share with Earth Exploration Satellite Service, Radiolocation and Road Tolling / Intelligent Transport Systems.

3.6.3 Improving receiver performance in licence exempt bands

In section 3.5.1 above we noted some of the historic problems that have arisen in the past due to the limitations of licence exempt device receivers. In addition to leading to interference and service quality degradation, inadequate receiver performance may also hinder the introduction of new applications or technologies by making existing equipment excessively prone to interference. Whilst it could be argued that licence exempt devices are not strictly entitled to interference protection, in practice the disruption of more critical applications such as alarm systems in particular would not be acceptable and widespread interference to services like Wi-Fi could lead to a significant consumer and industry backlash. Receiver parameters are particularly important where interference mitigation based on LBT is deployed, since this requires a receiver response that controls the associated transmitter.

This problem has been recognised by regulators for many years. For example, in 2008 the ECC produced a report on the impact of receiver performance on spectrum management[25]. The study identified several cases where it would have been possible to make a significant difference to an outcome in spectrum management if the application of receiver parameters, had been different. The report recommended that, where necessary for spectrum management purposes, ETSI should introduce specific receiver parameter values in relevant harmonized standards. A survey of NRAs conducted for the 2008 ECC report identified the main area where receiver deficiencies affected performance of licence exempt devices was short range devices in the 433 MHz band, as highlighted in section 3.5.1 above.

Under the current regulatory regime for bringing radio equipment to the market, many licence exempt standards have limited or non-existent requirements pertaining to receiver performance. According to the R&TTE Directive, receiver equipment should be allowed to operate “without unacceptable degradation of its intended use”, but “should also have an adequate level of immunity to other radio services”. Where no specific receiver parameters are defined in the harmonised standards it is left to the supplier to interpret what constitutes an adequate level of immunity, which for low cost equipment where the user may have little or no awareness of the interference environment may be far from adequate in practice.

The new Radio Equipment Directive includes a clearer requirement that radio receivers achieve a minimum level of performance so as to contribute to an efficient use of radio spectrum. For example, Recital 10 of the new Directive states that a receiver should have *“a level of performance that allows it to operate as intended and protects it against the risk of harmful interference, in particular from shared*

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[24] See Annex 8 to ITU-R Document 5A/636-E (November 2014), “Possible additional mitigation techniques to facilitate sharing between RLAN systems and incumbent services”

[25] ECC Report 127, October 2008

or adjacent channels, and, in so doing, supports improvements in the efficient use of shared or adjacent channels".

ETSI is currently considering how best to modify the receiver requirements in harmonised technical standards to support the above objective. One complicating factor is that many SRD standards are not application specific and cover a wide range of applications which may have very different quality of service requirements and interference tolerance. Hence a single receiver performance limit that does not take account of specific application requirements is unlikely be appropriate, by placing too onerous a requirement on low criticality devices like wireless weather stations but providing insufficient protection for more critical applications such as alarms or industrial telemetry systems.

The UK regulator Ofcom has proposed that SRD standards should in future reflect the needs of different applications by defining separate application specific sub-parts to the standards where applications require different levels of receiver performance to meet the expected service quality. This would replace the existing approach, whereby vendors may choose one of three non-application specific receiver performance categories, potentially leading to inadequate protection for some more critical applications where new services are introduced in adjacent bands, as illustrated in section 3.5.2.

It is unclear how this work will progress in ETSI at the time of writing, although an agreed position must be reached in time to meet the implementation deadline for the new Directive of June 2016.

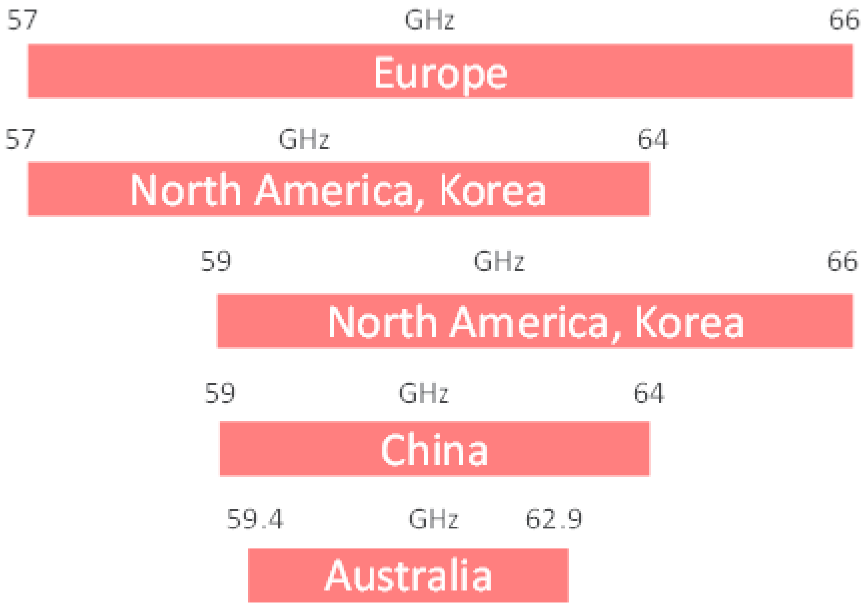
3.6.4 Promoting the use of the 60 GHz band

The 60 GHz band is particularly attractive for very short range, high data rate applications, having a total of 8 GHz of contiguous spectrum available in all EU Member States. The existing IEEE 802.11ad standard, sometimes referred to as Wi-Gig, effectively caters for Wi-Fi type deployments in this band and has recently been formally adopted by the Wi-Fi Alliance, with suggested applications including cable replacement for displays, wireless docking between devices like laptops and tablet, instant data synchronisation and backup and simultaneous streaming of multiple, ultra-high definition and 4K videos. The standard is intended to deliver multi-gigabit speeds (up to 4.6 Gbps in single antenna mode) with very low latency. Device chipsets are already available but no routers are yet on the market.

Work on a "next generation" 60 GHz standard (802.11ay) was recently initiated within IEEE, aiming at data rates in excess of 30 Gbps. Potential applications include line of sight wireless backhaul and high speed content downloads over very short ranges, similar to today's contactless smart card technology but enabling a full length movie to be downloaded in under a second.

Whilst the band is harmonised in Europe, this is not yet the case globally, as the diagram below illustrates:

Figure 3-13: International 60 GHz allocations for wireless access services



Interestingly the European allocation is the largest internationally and there would seem to be a good case to seek further international alignment of this band (ideally reflecting the European situation) to maximise the potential benefit from future technology developments. We note that in August 2014, SRD/MG identified the need to review the 60 GHz regulatory approaches under general authorisations in Europe, including the entry in Annex 3 of ERC/REC 70-03 for wideband data systems and ECC Decision (09)01 on 63-64 GHz Intelligent Transport Systems.

4 Managing Interference and Co-existence in Licence Exempt Frequency Bands

4.1 Introduction

In licensed frequency bands, interference is largely avoided by either limiting access to a single licensee or by regulatory co-ordination of frequency use between multiple licensees. The licensing process provides awareness of the location and type of transmissions on specific frequencies. In licence exempt bands devices can typically be operated at any time and any place without any restriction on who may use the spectrum, creating a significant risk of interference or congestion if many users are present at the same time and location.

To mitigate this risk, a number of techniques have been developed over the years to facilitate co-existence between different applications and potentially high volumes of devices in licence exempt bands. Interference mitigation techniques are often embodied in the harmonised European standards or the 2013 EC Decision referenced in section 3.2 and range from simple radiated power limits to complex digital signal processing algorithms designed to detect and avoid collisions between data transmission from different devices. The latter are sometimes referred to as "politeness protocols". Legacy devices that do not employ such protocols can cause problems where they co-exist in frequency bands that are used by newer technologies. A good example of this is interference from analogue video links into Wi-Fi systems at 2.4 GHz.

In the following sections we review the various approaches to interference mitigation used in licence exempt frequency bands, provide examples of specific technologies that are deployed in the bands and present examples of interference issues that have arisen in licence exempt bands.

4.2 Interference mitigation techniques

4.2.1 Introduction

In Europe, mitigation techniques for individual licence exempt bands or applications are generally stipulated in relevant EC Decisions, ETSI standards or ECC Recommendation 70-03, as discussed in the previous chapter. In the following sections we review the various approaches to interference mitigation techniques and provide examples of how these are applied in practice.

4.2.2 Power Limits

The most basic interference mitigation technique is to limit the transmission power of devices operating in licence exempt bands so that the potential for interference is limited to a relatively small area. All licence exempt bands are subject to radiated power limits which are generally significantly lower than those applied to licensed bands. As a general rule, the specified power limits are lower where no additional mitigation techniques are specified – for example in the 2.4 GHz band Wi-Fi systems may operate at radiated power levels up to 100 mW, whereas short range devices without additional mitigation techniques are limited to only 25 mW.

The table below summarises the power limits applicable in the main European licence exempt frequency bands and whether any further mitigation techniques are required, according to ECC Recommendation 70-03.

Table 4-1: Transmission power limits in main licence exempt bands

Band	Application(s)	Power Limit	Other mitigation requirements
433.05 – 434.79 MHz	Non-specific SRDs	10 mW	Duty cycle limits or max channel width of 25 kHz apply
863 – 870 MHz	Non-specific SRDs	25 mW	Duty cycle limits or LBT / AFA apply
863 – 865 MHz	Wireless microphones and assistive listening devices	10 mW	No other mitigation requirements
865 – 865.6 MHz	RFID	100 mW	200 kHz max bandwidth. No other mitigation requirements
865.6 – 867.6 MHz	RFID	2 W	200 kHz max bandwidth. No other mitigation requirements
867.7 – 868 MHz	RFID	500 mW	200 kHz max bandwidth. No other mitigation requirements
869.4 – 869.65 MHz	Non-specific SRDs	500 mW	Duty cycle limits or LBT / AFA apply
870 – 875.6 MHz	Tracking, Tracing and Data Acquisition	500 mW	Duty cycle limits and APC required. Wide area networks may require licence
870 – 875.8 MHz	Transport and Traffic Telematics	500 mW	Duty cycle limits and APC required. Highest power limited to vehicle to vehicle communication (100 mW otherwise)
870 – 876 MHz	Non-specific SRDs	25 mW	Duty cycle limits apply
915 – 921 MHz	RFID	4 W	May operate only when RFID tags present. 400 kHz max bandwidth. Detect and Avoid may be required above 918 MHz.
	Non-specific SRDs	25 mW	Duty cycle limits apply. 100 mW permitted on certain channels
	Assistive listening devices	10 mW	Specific sub-bands only. Duty cycle limit applies
1880 - 1900	DECT		
2400 – 2483.5 MHz	Wideband data transmission (e.g. Wi-Fi)	100 mW	Spectrum sharing mechanism (e.g. LBT or DAA) required. 10 mW/MHz max PSD
	Movement detection	25 mW	No other mitigation requirements
	Non-specific SRDs	10 mW	No other mitigation requirements

Band	Application(s)	Power Limit	Other mitigation requirements
2446 – 2454 MHz	RFID	500 mW	No other mitigation requirements
		4 W	Duty cycle limit applies. FHSS must be used. Indoor use only
5150 – 5250 MHz	Wireless Access Systems (e.g. Wi-Fi)	200 mW	Indoor use only. 10 mW/MHz max PSD. No other mitigation requirements
5250 – 5350 MHz	Wireless Access Systems (e.g. Wi-Fi)	200 mW	Mitigation techniques at least as effective as those in EN 301 893 required. Indoor use only. 10 mW/MHz max PSD
5470 – 5725 MHz	Wireless Access Systems (e.g. Wi-Fi)	1W	Mitigation techniques at least as effective as those in EN 301 893 required. 50 mW/MHz max PSD
5725 – 5875 MHz	Non-specific SRDs	25 mW	No other mitigation requirements
5795 – 5805 MHz	Transport and Traffic Telematics	2 W	Higher powers (up to 8W) may require licence. No other mitigation requirements
24 – 24.25 GHz	Non-specific SRDs	100 mW	No other mitigation requirements
57 – 64 GHz	Non-specific SRDs	100 mW	Max.10 mW input to antenna; PSD 10 mW/MHz max. No other mitigation requirements
57 – 66 GHz	Wideband data transmission (e.g. Wi-Gig)	10 W	Spectrum sharing mechanism (e.g. LBT or DAA) required. 20 mW/MHz max PSD, No fixed outdoor use

Power limits alone can be effective in certain situations, e.g. where devices are used in enclosed or shielded locations such as is the case for some RFID readers. However, with the exception of analogue audio and video equipment it is usual for additional mitigation techniques to be required.

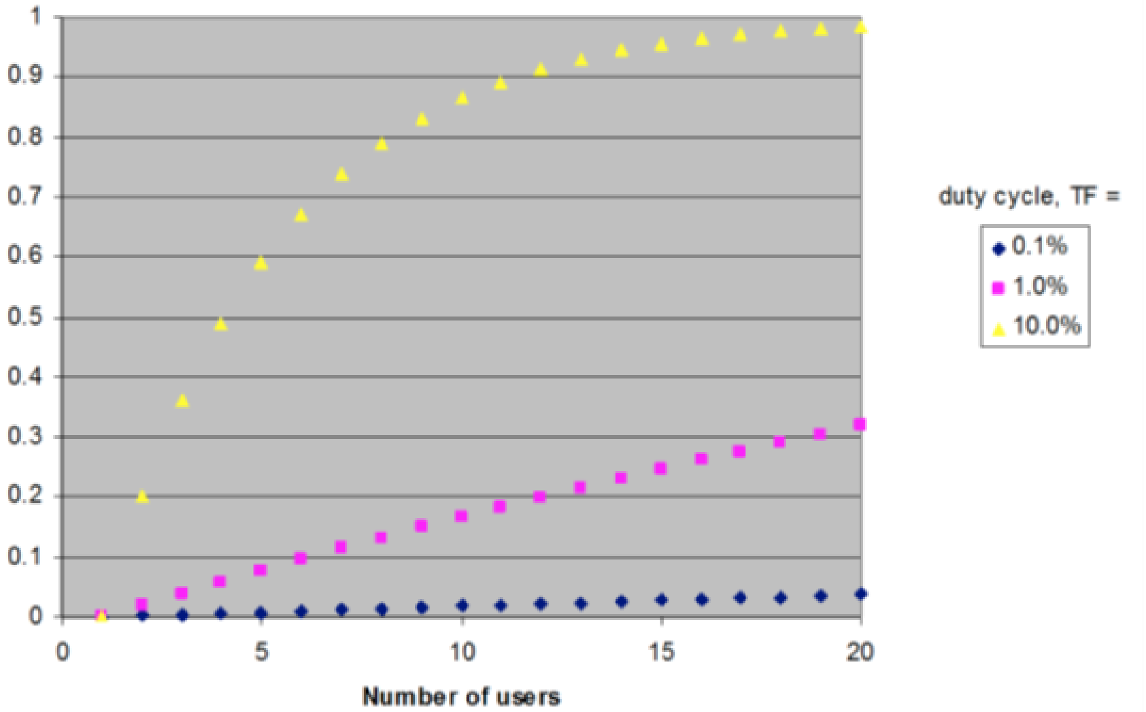
In addition to absolute power limits, in some cases transmitter power control is also required to ensure that devices do not transmit unnecessarily high EIRP. An example is in the 5 GHz band, where the harmonised ETSI standard (EN 301 893) requires wireless access devices to have a transmit power control range at least 6 dB below the maximum mean EIRP. In the absence of power control, the maximum EIRP is reduced by 3 dB.

4.2.3 Duty Cycle Limits

One of the most commonly used interference mitigation techniques for licence exempt SRDs is to limit the duty cycle when the device is transmitting. The technique is mainly applied to narrow band applications that operate only occasionally, such as alarms or car immobilisers, and where systems are used to poll or interrogate, such as RFID tag readers. Typical limits range between 0.1% and 10%, depending on the application.

Limiting duty cycle in this way can be very effective since the probability of multiple devices transmitting simultaneously at the same location is relatively small. However, where there is a high density of devices operating on a continuous basis, duty cycle limits alone may still result in a significant probability of interference. For example an analysis by CEPT[26] identified the probability of a collision between transmissions from co-located devices as a function of duty cycle and the number of devices to be as follows:

Figure 4-1: Probability of collision as a function of duty cycle and number of transmitting devices (Source: ECC Report 181)



It can be seen that in high density environments even a duty cycle of 1% could result in significant interference, hence for systems transmitting larger quantities of data it is preferable to apply other techniques to reduce further the likelihood of interference. These generally include some form of "listen before talk" capability, which we discuss in the next section

4.2.4 Listen Before Talk (LBT)

LBT involves the transmitting device checking whether the frequency channel is already in use prior to initiating its own transmission. This reduces the probability of interference arising, but does not eliminate it since another nearby device could initiate transmission immediately after the check has been carried out. Nevertheless LBT can allow effective operation in high density environments, particularly if deployed alongside some form of frequency agility (see next section). The principal drawback of LBT is the need for a receiver to detect the presence of other users, which makes it less attractive where low cost or power consumption are priorities.

[26] See ECC Report 181, "Improving Spectrum Efficiency in the SRD Bands, September 2012

4.2.5 Frequency Agility

Frequency agility is a generic term that describes the ability for a device to switch automatically to another frequency if it finds its existing frequency is in use. Various approaches to frequency agility have been adopted in licence exempt bands, including:

- Frequency Hopping
- Adaptive Frequency Agility (AFA)
- Dynamic Frequency Selection (DFS)

The first three are described briefly below. CSMA and CA are generally deployed together and are a key feature of the IEEE 802.11 Wi-Fi standards. The technique is described in detail in section 4.2.6 below. 0.

iv. **Frequency Hopping** was used in the earliest implementation of Wi-Fi and is still used by Bluetooth in the 2.4 GHz band. However as the technique relies on having a relatively large number of frequency channels to accommodate multiple orthogonal hopping sequences, it is less suitable for high bandwidth applications. Hence the technique has been superseded by direct sequence spread spectrum (DSSS) and orthogonal frequency division multiplexing (OFDM) in Wi-Fi systems.

v. A specific variant known as Adaptive Frequency Hopping (AFH) is used by Bluetooth devices (IEEE 802.15) to improve co-existence with 802.11 networks. AFH allows Bluetooth to adapt to the environment by identifying channels used by 802.11 devices and excluding them from the list of available channels for hopping. There are different methods for identifying channels occupied by 802.11 networks, for example measuring received signal strength or packet error rate.

vi. **Adaptive Frequency Agility** is typically deployed alongside LBT and enables a device to switch automatically to another clear channel if interference is detected. The technique is widely deployed in the 868 MHz band, with some devices capable of operating over the entire 863 – 870 MHz range and having up to 30 channels available.

vii. **Dynamic Frequency Selection (DFS)** is a specific technique that is mandated for wireless access systems operating in the 5 GHz bands (5250-5350 and 5470-5725 MHz). DFS requires each access point to scan continuously for the presence of radar signals within the band. If a signal is detected on a particular radio channel, that channel is flagged as unavailable and the Wi-Fi system must switch to another channel. Once a radar signal has been detected the affected channel cannot be used for at least 30 minutes. The key objective is to protect radars from interference by moving away from the channels they occupy. Key DFS parameters defined in standards include threshold, channel availability check, channel move time and non-occupancy time. There is also a requirement to select channels randomly across the frequency range so that the usage loading is evenly spread across the band.

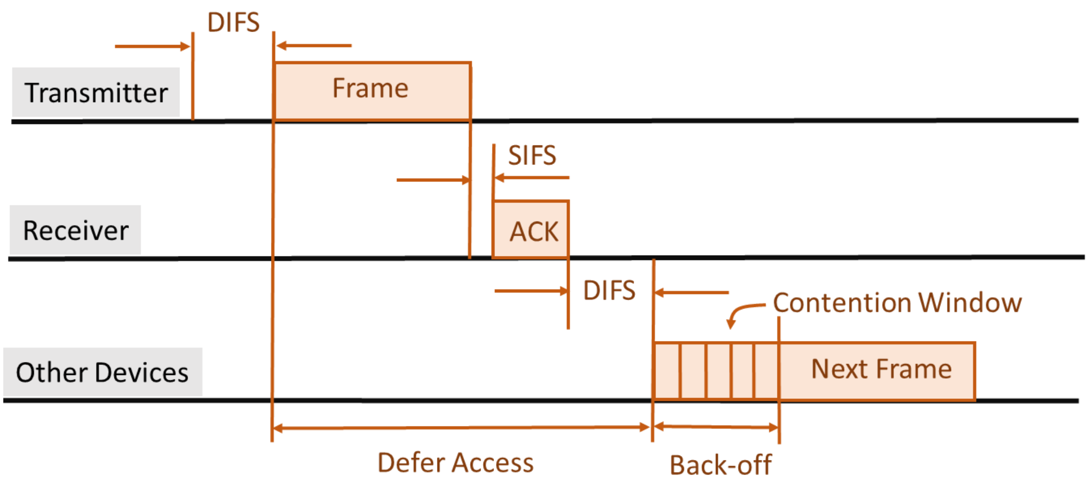
4.2.6 Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

CSMA/CA is a more advanced form of LBT that is used by contemporary 802.11 (Wi-Fi) networks. Prior to transmitting, a Wi-Fi device must first check whether any other transmissions are present on the same frequency channel. If the detected energy level is below a certain pre-defined threshold for a specified period of time (referred to as the *distributed coordination function interframe space* or DIFS), the device is allowed to transmit. If the frequency channel is busy the device waits until it has become free (the DIFS duration) and then chooses a random *back-off counter* which determines the amount of additional time the device needs to wait before it is can transmit.

This idle period after the DIFS duration is known as the *contention window*. During this period the device decreases its back-off counter until it is zero and then the transmission can take place. The receiver sends an acknowledgement packet after a short interframe space (SIFS) duration if no collision has occurred and the data is successfully received. In case of a collision, no acknowledgement is received and the transmitter attempts to re-transmit the data.

The contention window is initially assigned a minimum size and at each failed attempt to transmit the contention window size is doubled in a process referred to as *exponential back-off*, until a maximum value is reached. It then remains at this value even if further transmission attempts fail due to collisions. A packet is eventually discarded if it cannot be transmitted successfully after the threshold for maximum number of re-transmissions is exceeded[27]. The process is illustrated in the figure below.

Figure 4-2: Illustration of CSMA/CA process (source: Plum)

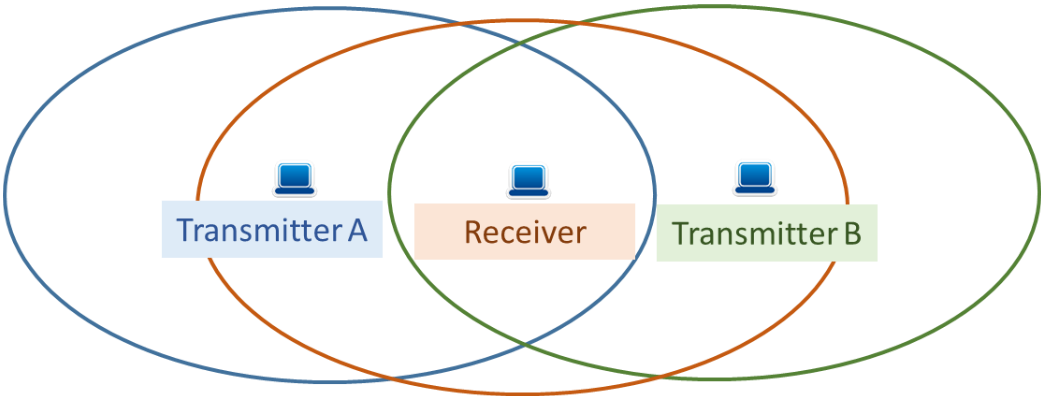


Devices attempting to access a channel may sometimes not detect each other. For example, in the following figure, transmitter A is outside the coverage of transmitter B and vice versa. When both transmitters attempt to send data to the receiver collisions may occur as transmitters are not aware of each other. This is often referred to as a *hidden node* problem[28].

[27] Effect of Contention Window on the Performance of IEEE 802.11 WLANs, Yunli Chen and D. P. Agrawal, Centre for Distributed and Mobile Computing, University of Cincinnati

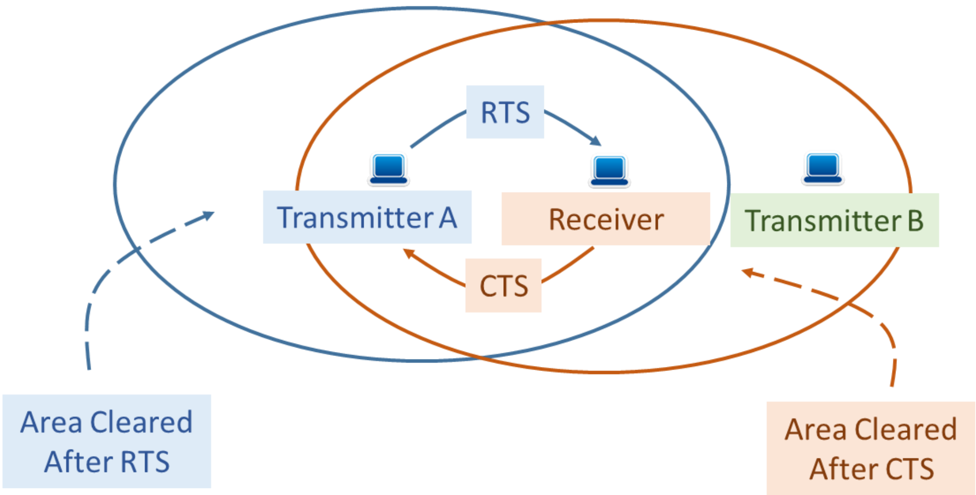
[28] IEEE 802.11 Tutorial, Mustafa Ergen, University of California Berkeley

Figure 4-3: Hidden Node Problem



In order to reduce the probability of collisions caused by devices not detecting each other and trying to access the channel simultaneously, a *virtual carrier sense* scheme involving a handshake to reserve the channel is used. This method relies on the use of short control packages: Request to Send (RTS) and Clear to Send (CTS). The transmitter first sends an RTS message (which includes the source, destination and duration of following data transmission) and the receiver replies with a CTS. The actual data and acknowledgement exchange can then take place. Neighbouring devices that receive either the RTS or CTS set their Network Allocation Vector (NAV) to reserve the channel for the impending data and acknowledgement transmission.

Figure 4-4: Virtual Carrier Sense Method (source: Plum)



CSMA / CA has proved a very effective mechanism for co-existence between multiple Wi-Fi devices even in highly contended environments, but relies on all devices having the same protocol. The presence of a similar politeness protocol is an essential pre-requisite for deployment of non-Wi-Fi technologies in the 5 GHz band and the practical implementation of this is a key issue for the planned future deployment of LTE cellular technology in the band, which we address further in chapter 5.

4.3 Specific Technologies deployed in Licence Exempt Bands

A wide range of specific technologies have been developed for use in licence exempt bands, some of which are very mature whilst others are still under development. Some of the more common technologies are described briefly below.

4.3.1 Wi-Fi

Wi-Fi (Wireless Fidelity) is a wireless broadband data technology based on the IEEE 802.11 series of standards, whose main use is providing wireless broadband connectivity to fixed or mobile user devices. The 802.11 series of standards, developed over the last 25 years by the US-based IEEE standards body. As described in the previous section, CSMA/CA interference mitigation is a key feature of the 802.11 standards and is intended to facilitate equitable spectrum access between multiple Wi-Fi systems even in highly contended environments.

The earliest version of 802.11 used frequency hopping spread spectrum (FHSS) technology in the 2.4 GHz band and was limited to a data rate of 2 Mbps. This was quickly superseded by the enhancements 802.11a and 802.11b, which used wider bandwidth technologies to increase the peak data rate to 54 Mbps and 11 Mbps respectively. These higher rates were achieved by using orthogonal frequency division multiplexing (OFDM) technology in the case of 802.11a and direct sequence spread spectrum (DSSS) in the case of 802.11b. 802.11a was specified to operate in the 5 GHz frequency band, where considerably more bandwidth is available.

In 2003, a further variant – 802.11g - was introduced which extended the 54 Mbps capability to the 2.4 GHz band whilst retaining backwards compatibility with legacy 802.11b devices. Most recent devices use the more recent 802.11n variant which may be either single (2.4 GHz) or dual band and incorporates additional enhancements such as multiple input multiple output (MIMO) antennas and the use of wider (40 MHz) channels, extending the theoretical over-the-air bit rate to as high as 450 Mbps per channel. Further enhancements are embodied in the recently released 802.11ac standard, notably the ability use even wider channels (80 or 160 MHz[29]), higher level modulation (256QAM) and up to eight MIMO streams to extend the theoretical over-the-air bit rate to well over 1 Gbps.

The two most recent enhancements to the 802.11 standards extend the capability to lower and higher frequency bands. 802.11ah is primarily aimed at M2M and other relatively low bit rate applications but may also be used to extend the coverage of broadband Wi-Fi connections by using sub-1 GHz spectrum. The new standard provides bandwidth options of 1, 2, 4, 8, and 16 MHz.

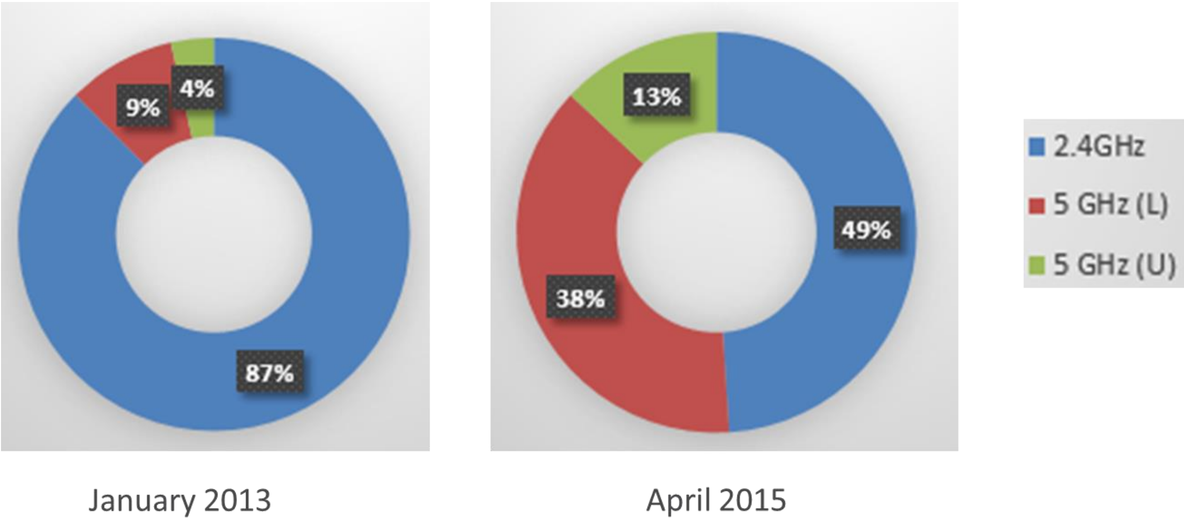
802.11ad, also referred to as Wi-Gig, operates in the 60 GHz millimetre wave band and is intended for very high speed, short range applications. The standard is expected to deliver speeds of up to 7 Gbps over ranges of up to 10 metres (in practice this is likely to be within a single room as most building materials have very high attenuation at these frequencies). The new standard has recently been brought within the ambit of the Wi-Fi Alliance (the global industry body which plays a leading role in overseeing certification and interoperability of Wi-Fi products

The prevalence of traffic offload onto Wi-Fi and (until recently) limited availability of dual band devices and routers has led to intensive use of the 2.4 GHz Wi-Fi band, particularly at urban traffic hot spots. The majority of new domestic and enterprise routers now support the 5 GHz band, as do an increasing proportion of public Wi-Fi networks, but there are still many user devices that do not support this band.

[29] Current implementations are limited to 80 MHz

The figure below compares the proportion of Wi-Fi signals detected in each band during random surveys in central London, in February 2013 and April 2015. The increase in 5 GHz take-up during this period is self-evident.

Figure 4-5: Proportion of detected Wi-Fi signals in each frequency band in Central London (source: Plum)



As described in section 4.2.6, the Wi-Fi standards mandate the use of CSMA/CA to facilitate co-existence between multiple systems. As the standards have evolved, further enhancements have been introduced to enable more effective co-operation between co-located systems, resulting in further enhancements to spectrum efficiency. These include[30]:

- Multiple Input Multiple Output (MIMO) antenna configurations
- Beamforming techniques to provide better targeted coverage, improved signal quality (and hence throughput) and reduced contention between nearby access points. Vendors claim an overall throughput improvement of as much as 70% is feasible, although it is unclear what assumptions underpin this estimate.
- Dynamic channel management protocols have also been adopted in a number of large scale outdoor Wi-Fi deployments to enhance performance and capacity, particularly in the congested 2.4 GHz band, with claimed capacity improvements of 25 – 50 %

4.3.2 Radio Frequency Identification (RFID) Devices

RFID devices are widely used in sectors such as transport, manufacturing and supply chain tracking and their use is rapidly expanding, with the main growth segment being passive UHF RFID labels[31]. RFID devices vary significantly in size, from large industrial units to individual item tags Transmitter power and range varies accordingly. RFID devices operate over four principal frequency ranges, namely:

[30] Further details can be found in the 2013 Aegis / Quotient report for Ofcom "Study on the use of Wi-Fi for Metropolitan Area applications".

[31] Source: "RFID Forecasts, Players and Opportunities 2014-2024", IDTechEx, July 2014

- **Low Frequency (LF)**: typically 125-134 kHz. Very short range (a few cm) and low transfer rate, often used for animal tagging, car immobilisers (a tag is embedded in the key-fob) and personnel tags.
- **HF**: 13.56 MHz, range up to 1.5 metres, medium to high transfer rates. Extensively used for smart labels, electronic payment cards and in Near Field Communication (NFC) devices.
- **UHF**: 865-868 MHz, range up to several metres, high reading speed – can read hundreds of tag ID's at the same time. This is the highest growing RFID standard currently
- **Microwave**: uses the 2.4 GHz and 5 GHz ISM bands, mainly for active tags for real-time locating systems (RTLS) or road toll collection.

Note that the LF and HF bands are used only by passive tags, whereas the UHF and microwave bands support both active and passive. The longer range of the UHF and microwave devices make these more prone to interference or spectrum congestion, particularly as the bands used are also shared with other short range applications. In the 2.4 GHz, use is constrained to the centre part of the band (2446-2554 MHz) but the permitted power level of up to 4 watts is substantially higher than for other licence exempt applications in the band. To protect other 2.4 GHz applications such as Wi-Fi, a duty cycle limit of 15% or less applies to higher power systems (above 500 mW).

4.3.3 Bluetooth

Bluetooth is one of the most ubiquitous short range device (SRD) technologies, being a standard feature of virtually all recent mobile phones, tablet and laptop computers, where it is widely used for wireless data and audio connectivity. The standard has evolved considerably since its introduction in the 1990s and the latest version (v.4.0) incorporates a low power mode that significantly reduces power consumption by reducing the amount of time the radio is switched on, making it particularly suitable for embedded M2M devices where long battery life is important. Bluetooth applications now include wireless sensors, industrial automation, sports, fitness, medical and healthcare devices.

Bluetooth operates in the 2.4 GHz ISM band and the latest implementations use specific interference mitigation techniques to improve co-existence with Wi-Fi systems operating in the same band. These include time division multiplexing Bluetooth and Wi-Fi signals where the two are deployed in the same device (e.g. smartphone) or adaptive frequency hopping (AFH), where the Bluetooth radio scans the band for interference and adapts its frequency hopping patterns accordingly (see section 4.2.5). Nevertheless, the intensive use at some locations in the 2.4 GHz band (where all Wi-Fi channels are heavily used) can be a problem for more critical applications.

4.3.4 Wireless Alarms

Wireless alarm systems mostly operate in the 868-870 MHz frequency range (although some legacy systems use 433 MHz). There are three principal types, namely fire, intruder and social alarms, the majority of which are now based on the harmonised ETSI standard EN 300 220 and currently operate in specific sub-bands, one of which is specifically identified for social alarms. A recent ETSI technical report[32] identified a need for additional spectrum to support alarm systems, based on projected growth in the numbers of alarm systems and the traffic generated. The report also referred to recent

[32] ETSI TR 103 056, "Technical characteristics for SRD equipment for social alarm and alarm applications", 2012

European Commission (EC) guidance favouring a move away from reserving sub-bands for specific applications. Instead, it was proposed that spectrum should be identified on the basis of specific technical characteristics and operational characteristics, notably very low duty cycles and low latency requirements. This approach is reflected in the 2013 EC Decision on SRDs.

4.3.5 ZigBee

The ZigBee standard is based in the IEEE 802.15.4 Wireless Personal Area Network (WPAN) standard and uses direct sequence spread spectrum (DSSS) with CSMA/CA channel access and a very low duty-cycle (<0.1%). ZigBee addresses the needs for low-cost, low-power wireless sensor and control networks across a range of market sectors. The standard is maintained by the ZigBee Alliance which currently has over 400 members and has defined a number of sector specific variants including building automation, health care, home automation, smart energy and retail services. There are currently over 600 certified ZigBee products.

In Europe ZigBee may operate in either the 2.4 GHz or 868.3 MHz bands (in the US the 900 MHz ISM band is used). 2.4 GHz provides more channels (16 compared to only one in the lower band) and a higher data rate (up to 250 kbps) but is more range constrained and more likely to suffer interference from other devices such as video links. In the 868 MHz band range is improved but the data rate is constrained to 20 kbps and only a single channel is available. Most European ZigBee equipment operates at 2.4 GHz, however 868 MHz is used for some very narrow band, low duty cycle applications, such as street light control.

4.3.6 WiMAX

The IEEE 802.16h (WiMAX) standard includes discussions on coexistence mechanisms for uncoordinated and coordinated deployment scenarios involving licensed and unlicensed networks. The most relevant section of the standard is 'uncoordinated co-existence with non-specific spectrum users' which mainly addresses the deployment of WiMAX networks in the bands where licence exempt devices operate.

The proposed co-existence mechanism is Dynamic Channel Selection (DCS). The DCS is used to find a least interfered channel at the system start-up, monitor the level of interference on the selected channel, undertake interference monitoring on other channels, construct available channels list and, if the existing channel suffers from an increased interference level, either use a more robust modulation scheme or switch to an alternative channel.

The timing and threshold parameters associated with the above procedures are not specified in the standard and left for each regulatory administration to decide.

If a degree of coordination is a possibility between different networks occupying a given channel the following mechanisms can be applied to improve co-existence conditions.

- Synchronisation at MAC frame level to separate base station and user terminal transmissions and enable synchronised operation,
- Dynamic and adaptive channel selection to find an optimum channel to use,
- Use coexistence frame, coordinated scheduling and fairness approach to allow access to a given channel by more than one network.

The implementation of these methods require an awareness of spectrum use in deployment environment and cooperation among networks involved. The standard therefore defines a coexistence control channel used for inter network coordination by means of synchronised time slots.

4.3.7 Wireless Smart Utility Networks (WiSUN)

Wi-SUNs use licence exempt wide area mesh technology based on the IEEE802.15.4g standard, which was approved in 2012, and operate at typical bit rates in the range 40 – 1000 kbps. The standard includes mechanisms that enable coexistence with other systems in the same band including IEEE 802.11, 802.15 and 802.16 systems. WiSUNs have established themselves in many countries as the pre-eminent bearer for connecting smart meters and utility network devices such as transformers, capacitor banks and circuit reclosers (sometimes referred to as smart grids).

Having a technology that is able to operate at higher powers than conventional SRDs (up to 500mW) and in a mesh topology allows a diverse set of applications to be deployed including high capacity smart meter operations (e.g. firmware upgrades and on-demand meter reads). The technology has latterly been adapted to provide similar advantages to smart streetlights and thereby start to offer a variety of 'smart city' M2M applications such as camera traffic flow monitors, environmental sensors and temperature sensors. Although the core of the network nodes are powered, latter iterations of the technology allow deployment of battery powered devices that can be suitable for more general M2M applications. The technology is supported by Cisco, Toshiba, Analog Devices and Silver Spring Networks.

Wi-SUN technology has been successfully deployed in markets such as the US where the 902-928 MHz band is available, but in Europe has been limited to the 868 MHz SRD band. The recent identification of additional spectrum in the 870 – 876 MHz band for higher power licence exempt systems is seen as potentially attractive for future European deployments.

4.3.8 LTE

The latest LTE standards include provision for deployment in licence exempt bands, most likely in conjunction with a network operator's existing (licensed) spectrum holding. The initiative is variously referred to as either LTE-Unlicensed (LTE-U) or LTE Licenced Assisted Access.

LTE-LAA is the latest proposed addition to the Long Term Evolution (LTE) standards, developed and maintained by the 3rd Generation Partnership Project (3GPP). The initiative, which is expected to be incorporated into Release 13 of the LTE standards is described 3GPP Technical Report 36.889[33], currently available in draft form from the 3GPP website (www.3gpp.org). The report is due to be finalised by June 2015 and at the time of writing there is considerable debate about how best to ensure equitable access to spectrum where LTE and Wi-Fi systems co-exist. The initiative and the potential implications are discussed in detail in chapter 5.

[33] 3GPP TR 36.889, "Study on Licensed-Assisted Access to Unlicensed Spectrum version", version 0 3.1, February 2015

4.3.9 Wireless Audio and Video links

Licence exempt bands have for many years been extensively used to connect audio and video devices, mostly in residential environments. Both Wi-Fi and Bluetooth can be used for this purpose (the latter is limited to audio links) but there is also wide deployment of low cost equipment using analogue FM technology. Video links typically use frequency modulation (FM) in a 20 MHz wide channel and operate in either the 2.4 GHz or 5.8 GHz band. Devices must conform to the ETSI standard EN 300 440, which limits the radiated power to 10 mW, however the 100% duty cycle and absence of any other mitigation protocols can sometimes lead to significant interference to co-located Wi-Fi systems (see section 3.5.3).

4.3.10 DECT

The Digital Enhanced Cordless Telephone (DECT) standard is now well established as the premier cordless phone technology both in Europe and much of the rest of the world. In Europe the technology is currently limited to an exclusive allocation at 1880 – 1900 MHz, sandwiched between the GSM1800 and 2GHz UMTS bands. CEPT has recently proposed to extend the current band to 1920 MHz, doubling the number of channels and facilitating the introduction of wider bandwidth DECT systems. As DECT is already recognised as IMT-2000 technology and is already deployed in the higher band in other parts of the world, it is expected that take-up in Europe would be relatively quick and compatibility studies are currently underway to investigate co-existence with existing in-band and adjacent band UMTS services.

4.3.11 Ultra-Narrow Band Wide Area Licence Exempt Technologies

Ultra-Narrow Band (UNB) wireless technologies have recently come to prominence in the M2M space, two notable examples being SIGFOX and Weightless. Both aim to provide very low cost connectivity and long battery life (ten years or more) for low throughput devices that only need to send and receive occasional messages. They are particularly attractive for the many applications that require the connection of widely scattered devices which is currently only viable using conventional high power wide area technologies such as GSM or LTE.

The introduction of wide area networks into bands historically limited to use by short range devices is considered further in section 5.3

5 Technology Co-Existence Case Studies

5.1 Introduction

In this chapter we examine two specific cases of technology co-existence in licence exempt bands, namely the proposed introduction of LTE technology into the 5 GHz band alongside existing Wi-Fi systems and the deployment of wide area M2M data networks alongside conventional SRDs in the 863 – 876 MHz bands.

5.2 Case Study 1: Wi-Fi and LTE-LAA in the 5 GHz band

5.2.1 Introduction

The use of licence exempt frequency bands to carry data traffic that would otherwise be carried on mobile networks using licensed spectrum is now well established and is commonly referred to as traffic offload. Currently, this offload traffic is carried over Wi-Fi connections with varying degrees of control by mobile network operators. Most offload traffic is carried over private Wi-Fi connections in home or workplaces, where connection typically requires a one-time registration by the user but is subsequently automatic and controlled by connection management software in the user equipment. However a sizeable amount of traffic is also carried over public Wi-Fi networks (commonly referred to as hotspots or metropolitan area networks depending on their scale), some of which are operated by mobile networks but with many operated by fixed networks or other third party providers.

Options exist within both the Wi-Fi and cellular standards to facilitate interworking between cellular and Wi-Fi networks, including, for example:

- **MAC authentication:** provides automatic authentication of pre-registered devices based on their unique MAC address and is commonly used by larger public Wi-Fi networks. Typically, the user is required to download an app to their device and to carry out a one-time registration to register the device MAC address on the network. Thereafter, the device will automatically connect to any of that network's access points when they are detected and data will be carried over this connection rather than the mobile network.
- **Passpoint™**: takes automatic authentication a stage further by adding features such as SIM-based authentication for Wi-Fi networks, which is particularly useful for implementing roaming agreements between mobile network operators and Wi-Fi service providers. For example, AT&T cellular subscribers from the US can now automatically roam on The Cloud network in the UK.
- **Access Network Discovery and Selection Function (ANDSF)**, part of the 3GPP LTE standards, which provides mobile operators with the ability to determine which access network a device will preferentially attach to (this could either be the mobile network or one or more preferred Wi-Fi networks).
- **LTE / WiFi Link Aggregation:** a recent initiative which involves splitting the LTE data signal at the Packet Data Convergence Protocol (PDCP) layer using a central anchor point in the mobile core network into two data streams, one of which is carried over the licensed LTE carrier and the other over Wi-Fi. The two streams are then recombined in the user equipment.

All of the above involve carrying some or all of the data over a Wi-Fi connection and retain all LTE transmissions in existing licensed spectrum. This has the advantage that no hardware modifications are required but means that the mobile operator has limited control over the quality of the Wi-Fi connection and the handover process between the cellular and Wi-Fi networks.

The mobile industry has therefore been pursuing the option of deploying LTE technology directly in licence exempt bands to provide more direct control of the user experience. Two approaches have been put forward, namely LTE-Unlicensed (LTE-U), which essentially deploys existing LTE technology in licence exempt bands and LTE Licence Assisted Access (LTE-LAA), which involves modifying the LTE standards to incorporate similar interference mitigation techniques to existing Wi-Fi technology. Only the latter can be deployed in Europe, since interference mitigation is mandated by the 2007 EC Decision on wireless access systems.

Adding the interference mitigation functionality (DFS to protect incumbent radar systems and LBT to facilitate equitable co-existence with other wireless access systems) requires substantive modification to the LTE air interface and is the subject of intensive study within the 3GPP standards body. The proposal to implement LTE-LAA in the 5 GHz band has raised concerns from some in the Wi-Fi community about potential adverse impacts on existing and future Wi-Fi use of the band and much of the discussion within 3GPP has focused on addressing these concerns. The timescale for agreeing a mutually acceptable approach is tight, since it is hoped to include the feature in the next release of the LTE standards (Release 13), due in 2016. In Europe, it is also necessary to update the ETSI standard for 5 GHz wireless access networks (EN 301 893) to bring it into line with the new Radio Equipment Directive, which comes into force in June 2016 and it is hoped to incorporate any necessary changes to accommodate LTE-LAA in the update.

In the following section we review the ongoing progress in the standards bodies regarding LTE-LAA and how the concerns that have been raised by the Wi-Fi community are being addressed. However we first explain the reasoning behind the proposed extension of LTE into licence exempt bands.

5.2.2 What is LTE-LAA and why is it needed?

LTE-LAA is a form of carrier aggregation, which is already defined in the LTE standards and enables multiple individual RF carrier frequencies, either in the same or different frequency bands, to be combined to provide an accordingly higher overall bit rate. LTE-LAA combines a supplementary carrier frequency in a licence exempt band alongside a main carrier which must operate in a conventionally licensed LTE band.

As noted above, mobile operators already use licence exempt bands extensively for data offload using Wi-Fi technology, however the cellular community have argued that deploying LTE technology directly in the licence exempt band can provide an improved performance compared to Wi-Fi[34]. It is also argued that combining the use of licensed and licence exempt spectrum using a single radio technology enables tighter integration of network infrastructure, network management and security capabilities. Claimed advantages for LTE-LAA include the following.

- More robust protection of control channels;

[34] A number of references in public domain (e.g. Qualcomm, Huawei and Nokia reports on LTE-LAA or LTE-U) are suggesting an increased average user throughput for an LTE compared to Wi-Fi and fewer node requirements to provide comparable capacity and coverage. The reported efficiencies may however decrease when LTE air interface is tailored to comply with licence exempt band operation.

- Improved link adaptation where rapid changes in channel conditions are handled using mobile device channel quality indicator reports;
- The ability to combine the received energy of an initial transmission with the subsequent transmissions at the receiver using hybrid automatic repeat request process;
- The use of sophisticated scheduling algorithms to allow coordinated multiple access to the spectrum;
- Improved coverage with techniques including enhanced inter-cell interference coordination and coordinated multipoint transmissions.

Concerns have however been expressed by some in the Wi-Fi community that deploying LTE alongside Wi-Fi could adversely impact on existing Wi-Fi systems or make access to the band more difficult for Wi-Fi devices[35]. The deliberations that have been underway in the 3GPP and ETSI standards bodies, which we discuss below, are largely focussed on addressing these concerns and identifying a satisfactory technical solution that will be acceptable to both the cellular and Wi-Fi industries. The technical background to this work is presented in more detail in Annex 2. It should also be noted that much of the concern raised so far relates to the “pre-standard” implementation of LTE-U alongside Wi-Fi (see box below) and is therefore limited to the North American market.

LTE-U vs LTE-LAA

Before elaborating on the LTE / Wi-Fi co-existence issues it is important to differentiate between the two variants of LTE that are currently being proposed for deployment in the 5 GHz bands, namely LTE-LAA and LTE-Unlicensed (LTE-U). LTE LAA, which is currently under study in the 3GPP, is intended to replicate as closely as possible the co-existence protocols embodied in the existing Wi-Fi standards and more specifically is intended to comply with the harmonised European Standard for wireless access systems in the 5 GHz band (EN 301 893). This includes the specific provision to include dynamic frequency selection (DFS) to protect incumbent radar systems as well as an appropriate listen before talk (LBT) mechanism to facilitate co-existence between wireless access systems. LTE-LAA will therefore require adoption of new technical standards before it can be deployed.

LTE-U is an initiative that has been promoted primarily by Ericsson, Qualcomm and the US based network operators T-Mobile and Verizon, to enable existing LTE technology to operate in licence exempt bands (albeit with some modification to facilitate co-existence with Wi-Fi). The operators are hoping to deploy the technology by the end of 2015. LTE-U is sometimes referred to as “pre-standard” LTE-LAA, since it provides an interim approach to licence exempt LTE deployment pending the completion of the full LTE-LAA standard that is currently under study in 3GPP.

LTE-U is essentially based on existing LTE Release 12 standards but applies duty cycling of the LTE transmission to facilitate sharing with Wi-Fi systems. Because it does not include DFS functionality, LTE-U can only operate in the parts of the 5 GHz band where DFS is not required. In the US, this limits it to the 5150-5250 MHz and 5725-5825 MHz bands (UNII-1 and UNII-3). In Europe, LTE-U cannot be deployed at all because it does not incorporate the LBT capability required by EN 301 893. Whilst there remain some concerns about the 3GPP activities relating to “full” LTE-LAA (which we elaborate on in the next section), it should be noted that the Wi-Fi Alliance’s concerns referred to above primarily relate to the pre-standard LTE-U technology.

[35] See for example the Wi-Fi Alliance statement on LAA at www.wi-fi.org/news-events/newsroom/wi-fi-alliance-statement-on-license-assisted-access-laa#sthash.sc9uGS2b.dpuf

5.2.3 LTE-LAA Standards Development Process

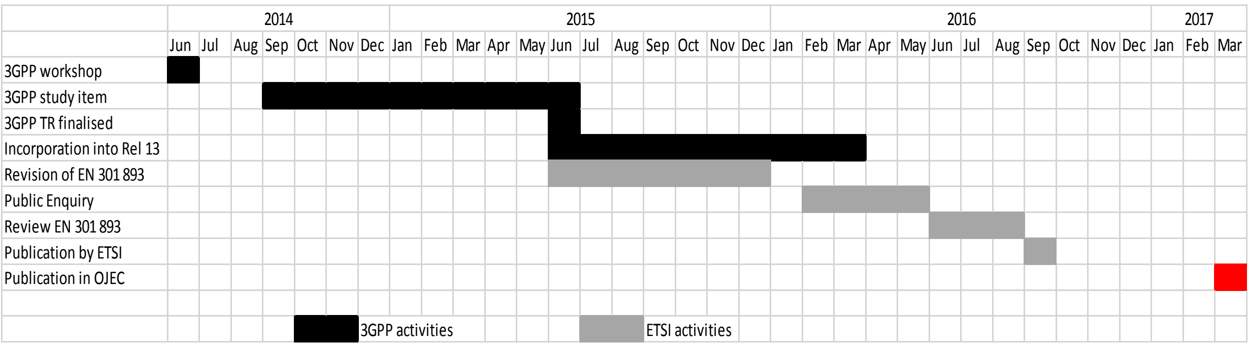
Work towards developing a standard for LTE-LAA has been led by the 3rd Generation Partnership Project (3GPP), which is the international body responsible for maintaining all of the technical standards relating to cellular networks in Europe and most other parts of the world. The work was initiated at a workshop held by 3GPP in June 2014[36]. In the workshop, the key 3GPP objectives for LTE-LAA were established as:

- deriving a global solution for all regions,
- enabling operation in licence exempt spectrum to opportunistically increase data rates
- targeting the 5 GHz bands and
- investigating optimum co-existence conditions between LTE-LAA and Wi-Fi devices.

A study item to examine the LTE enhancements needed to operate in unlicensed spectrum and to ensure co-existence with Wi-Fi was approved in September 2014[37] and is being progressed within 3GPP's Technical Group on Radio Access Networks (TG-RAN). The study item was due to complete in June 2015 and the outcome of the work will provide an input for the LTE Release 13 suite of standards, scheduled to be complete by March 2016. Commercial solutions are expected in the following 12 – 18 months[38]. The outcome of the study item is described in 3GPP technical report TR 36.889[39], which is currently in draft form and expected to be finalised by June 2015.

In parallel with the 3GPP activities, ETSI's Broadband Radio Access Networks (BRAN) is working to update the harmonised standard EN 301 893 to incorporate changes necessary to bring the standard into line with the new Radio Equipment Directive. It is intended that the update should also incorporate any changes necessary to reflect the planned implantation of LTE-LAA in the 5 GHz band. The earliest implementation of LTE-LAA in Europe will depend on when the updated ETSI standard is published as a harmonised standard in the official journal of the European Union, which is currently anticipated by March 2017

Figure 5-1: Planned timeline for LTE-LAA standards development



[36] 3GPP Workshop on LTE Unlicensed, Sophia Antipolis, June 13, 2014

[37] 3GPP TD RP-141664: "Study on Licensed-Assisted Access Using LTE", 3GPP TSG RAN #65

[38] The Prospect of LTE and Wi-Fi Sharing Unlicensed Spectrum, Signals Research Group on behalf of Qualcomm, February 2015

[39] 3GPP TR 36.889 V0.3.1; Technical Specification Group Radio Access Network; Study on Licensed-Assisted Access to Unlicensed Spectrum, February 2015

5.2.4 Summary of 3GPP progress on LTE-LAA

At the time of writing, the 3GPP had just concluded work on the study item on LTE-LAA, including publication of the final draft of TR36.899. Although this document is subject to final approval by the 3GPP TG-RAN plenary, no substantive changes are anticipated and it is expected that work will shortly commence on incorporating LAA functionality into the next release of the LTE standards (Release 13) in 2016. Note however that the 3GPP's proposals have still to be considered and accepted by ETSI before LTE-LAA could be deployed in Europe.

The TR addresses evaluation methodology and possible scenarios for LTE deployments, focusing on LTE Carrier Aggregation configurations. It also identifies and defines design targets for coexistence with other unlicensed spectrum deployments, including fairness with respect to Wi-Fi and other LAA services. The document identifies and captures coexistence evaluations of physical layer options and enhancements to LTE to meet the requirements and targets for licence exempt band deployments. Specifically, it contains an assessment of the feasibility of base station and terminal operation of 5GHz band (based on regulatory limits) in conjunction with relevant licensed frequency bands.

The report recommends that the channel access framework should be based on a category 4 LBT scheme including random back off and variable contention windows at least for the downlink data transmissions. The key parameters of the LBT scheme such as contention windows and defer periods should be configurable within limits to enable fair coexistence with other technologies operating in unlicensed spectrum.

It should be noted that the report is a 'living' document, i.e. it is permanently updated and presented to TSG-RAN meetings.

A wide range of stakeholders from across the cellular and Wi-Fi communities participated in the work and there has been an exchange of liaison statements between 3GPP and IEEE to agree on simulation assumptions to identify optimum LTE-LAA and Wi-Fi co-existence requirements. The Wi-Fi Alliance has been involved in the TG-RAN meetings. Much of the discussion focussed on the channel access framework to ensure equitable coexistence between LTE-LAA and Wi-Fi systems in the 5 GHz band. Further details of these deliberations, which may be further addressed in ETSI's subsequent review of the 3GPP decision, are presented in Annex 2.

5.2.5 Role of ETSI in approving European LTE-LAA Deployment

Whilst agreement appears to have been reached in 3GPP on a common technical approach to meeting the European LBT requirement for LTE-LAA deployment, this will still be subject to subsequent approval within ETSI and incorporation into an updated version of the 5 GHz WAS standard (EN 301 893). Maintenance of this standard is under the control of ETSI's Broadband Radio Access Networks project (BRAN), which is already tasked with updating the standard to bring into line with the requirements of the new Radio Equipment Directive. The deadline for updating the standard is currently December 2015 and at the time of writing it was hoped to reach agreement on the LBT requirement by end of July with a view to a stable draft of the revised standard by end of October.

The specific objective with regard to LBT is to replace the current two alternative options for load base equipment (LBE) with a single solution that provides equal spectrum access to different technologies. The conclusions of the 3GPP were due to be considered at the BRAN meeting on 23rd – 26th June 2015, assuming this is approved at the 3GPP TG-RAN meeting that takes place the previous week.

5.3 Co-existence case study 2: Wide area M2M networks and SRDs

5.3.1 Introduction

In the last few years there has been growing interest in the deployment of narrow band data transmission technologies over extended distances in licence exempt frequency bands to cater for the growing demand form M2M communications. There are currently two main areas of interest, namely the deployment of "ultra-narrow band" technologies in the established 868 MHz SRD band and deployment of wider bandwidth mesh networks for applications such as utility smart grids[40] in the recently identified new spectrum above 870 MHz. Two technologies in particular are currently being promoted at 868 MHz and are described in section 5.3.2 below. The potential for deployment of higher bandwidth wide area systems in the 870 -876 MHz band is considered in section 5.3.3.

5.3.2 Ultra-Narrow Band technologies at 868 MHz

There are two principal technologies being promoted in this band currently, namely SIGFOX and Weightless, which we describe in the sections below.

5.3.2.1. SIGFOX

SIGFOX is an M2M architecture developed by a French start-up company of the same name, which uses ultra-narrow band technology to achieve transmission ranges of several km whilst operating within the power constraints of the licence exempt 868 MHz band (the technology conforms to the harmonised standard (EN 300 220). Transmit power is 14 dBm (25 mW) and typical receiver sensitivity for user devices is -124 dBm. The company claims a maximum path loss of approximately 160 dB can be tolerated, which compares favourably with cellular phone networks. It is claimed that this enables 26% geographic coverage in France from an initial 57 base stations, falling to 12% if a 22 dB margin is applied. By the end of 2013 the network had been extended to 770 base stations, providing 83% coverage at the higher link budget and 55% at the lower.

Because a very low duty cycle is involved, a 20 year battery life is claimed, based on a 2.5 Ah battery and three short data transactions per day.

The company claims that up to 8 million devices per base station can be accommodated based on 3 transmissions per day, with only 8% loading of the spectrum. The networks deploy high performance base station with 120 dB dynamic range but low cost terminal devices, with any frequency instabilities being compensated for in the base station.

The standard is targeted at applications with particularly low data throughput requirements, defined by the company in the following terms:

[40] Smart Grids are increasingly used in electricity distribution networks and use digital communications technology to detect and react to local changes in usage.

- Up to 140 messages per object per day
- Payload size for each message is 12 bytes
- Wireless throughput up to 100 bits per second

The company claims that a SIGFOX base station can provide potentially greater coverage than a typical cellular base station and is planning to build a network covering all of France with 1,000 transmission sites, in partnership with the broadcaster TDF. The company claims also to have partners in the Netherland, Russia and Spain and to have local projects underway in Antwerp, Copenhagen, Dublin, Milan, Munich, Prague and Stockholm.

SIGFOX devices are subject to the same mandatory requirements in terms of duty cycle limits or use of listen-before-talk and adaptive frequency agility (LBT-AFA) as other devices in the band and outdoor base stations are unlikely to be in close proximity to other types of short range device. More critical applications like alarm systems have their own exclusive sub-bands and the short range nature of many other applications (e.g. remote key fobs) means a generous link margin is usually available. We do not therefore consider deployment of SIGFOX like technology in the 868 MHz band is likely to have any significant effect on the use of this band by other licence exempt applications. Whether other SRDs in the band would affect the performance of a SIGFOX base station is however more questionable, given the receiver sensitivity required to provide wide area connectivity in a cluttered or indoor environment.

5.3.2.2. Weightless

Weightless is an open standard that has been developed by the Weightless special interest group (SIG) specifically for M2M applications. It is intended to extend the cost advantages of existing short range M2M technologies like Bluetooth and ZigBee to a wide area environment by using frequency hopping spread spectrum technology to enhance range at the expense of data rate. Communication is between devices and base stations on a similar basis to cellular networks. The standard is claimed to have been designed to operate in the harshest mobile spectrum environments, giving the flexibility to be deployed in licence exempt spectrum, licensed spectrum or a mix of the two. The standard appears to be geared mainly towards less critical applications - one of the quoted design rules for M2M communication standards quoted on the Weightless web site, which states that M2M communication is "more tolerant of delay - most machine communication is relatively unaffected by a few seconds of delay whereas people quickly find this frustrating".

The initial focus was on the TV white space frequencies but in 2014 a new variant of the standard was launched that operates in the 868 MHz band. Like SIGFOX, the Weightless-N standard uses ultra-narrow band (UNB) technology and claims to achieve a range of several kilometres even in urban environments. Very low power consumption provides for exceptionally long battery life measured in years from small conventional cells and leading edge innovation in design minimises both terminal hardware and network costs.

Weightless-N uses differential binary phase shift keying (DBPSK) digital modulation to transmit within narrow frequency bands using a frequency hopping algorithm for interference mitigation and enhanced security. Multiple networks, typically operated by different companies, are enabled and can be co-located. Each base station queries a central database to determine which network the terminal is registered to in order to decode and route data accordingly.

5.3.3 Wide Area Mesh Networks

The bands 870-876 and 915-921 MHz were historically allocated to defence systems and digital trunked radio in Europe but in many countries have seen little or no use. The growing demand for SRD applications such as RFID and emerging M2M applications such as home and business automation prompted CEPT and ETSI to investigate scope for identifying additional spectrum to cater for longer term demand growth. The above bands have been identified in a number of ETSI Technical Reports (section 3.6.1 refers), which proposed that higher power RFID systems should be accommodated in the upper band and SRDs in the lower band.

One area of particular interest is the use of wide area wireless mesh technology to support smart grid networks in the utility sector. Smart grids provide a range of functionality including[41]:

- coexistence of centralised and decentralised power generation
- detection and resolution of emerging network issues
- response to local and system wide inputs
- rapid communication between peer devices and with centralised and distributed controllers;
- deployment of advanced diagnostics, feedback and control
- coordination of attached loads and distributed resources.

ETSI identified a need for wide area licence exempt mesh networks using higher power levels and duty cycles than most conventional SRDs and proposed that these could be successfully deployed in the 870 – 876 MHz band using interference mitigation techniques such as CSMA/CA.

Such networks also have wider potential to serve the growing M2M market and this has been separately considered within ETSI[42]. M2M devices are often low cost, battery powered and transmit only small amounts of data. Conventional cellular modules are consequently too expensive and consume too much power for such applications. Hence new wireless techniques have been developed for M2M devices operating under SRD rules to provide suitable low cost, low power connectivity. The ultra-narrow band technologies described in the previous section can cater for some applications, but others such as remote meter reading which require deep in-building penetration and have high cumulative bit rates require alternative solutions combining higher powers, duty cycles and bandwidths but retaining the low cost and power consumption. Metropolitan Mesh Machine Networks (M3Ns) comprising interconnected endpoints (sensors and actuators), routers and gateways can provide such a solution.

Following completion of compatibility studies by CEPT, an ETSI standard has been produced for network based SRDs operating in this band, at powers up to 500 mW and with duty cycles of up to 2.5 % for licence exempt operation. Higher duty cycles (up to 10%) are permitted but may be subject to a national licensing regime. In the UK, Ofcom has introduced a light licensing scheme to permit higher duty cycle systems in the lower half of the band (870 – 873 MHz)[43].

[41] Source: ETSI TR 102 886 on smart metering

[42] TR 103 055, on Metropolitan Mesh Machine Networks (M3N) and Smart Metering (SM) applications

[43] Statement on authorising high duty cycle Network Relay Points in 870 to 873 MHz, December 2014.

6 Conclusions and Recommendations

6.1 Introduction

In this chapter we summarise our key findings and develop specific recommendations for consideration by regulators and the licence exempt wireless device industry. Overall, our review of licence exempt frequency bands, applications and technologies has highlighted the many economic benefits that arise from these bands, despite a relatively small proportion of available radio spectrum being allocated for such use and the shared nature of most of the bands. Much of the benefit is derived from the free circulation of devices that operate in licence exempt bands, throughout Europe and in many cases other parts of the world. This is particularly evident for technologies like Wi-Fi and Bluetooth, which enable a single low cost chipset to provide connectivity anywhere in the world, and RFID devices that are increasingly used to track goods in global freight operations.

The two main areas of demand growth that are likely to impact on licence exempt frequency bands in the future are broadband wireless access systems (WAS) and machine to machine (M2M) communications. In both cases, additional spectrum has been identified that should be sufficient to cater for projected long term demand, but cannot be made fully available until compatibility with existing incumbent services has been satisfactorily addressed. The existence of a large amount of spectrum in the 60 GHz range presents opportunities for very high speed data links, either for short range applications such as cable replacement for providing interconnection of access points in metropolitan area networks. However there remain significant technical challenges in using these frequencies and regional variations in the availability of spectrum may hinder the take up of this band at a global level.

One of the principal drawbacks of licence exempt bands is the inability to guarantee quality of service, a problem that has been compounded in the past by inadequate specification of receiver parameters and a lack of suitable interference mitigation mechanisms. Whilst much has been done to improve this situation, particularly with regard to the latter, there is undoubtedly scope for further tightening of the technical requirements for some licence exempt devices if the full value of the available spectrum is not to be compromised by interference or technical incompatibility.

Our recommendations therefore fall into three main areas which we consider further in the following sections, namely:

i. Promoting further international harmonisation of licence exempt bands,
ii. Maximising spectrum availability for wireless access systems, and
iii. Improving spectrum efficiency and technology co-existence in existing licence exempt bands

6.2 Promoting further international harmonisation

As we noted in section 2.5, a recent study for Ofcom concluded that existing licence exempt bands should be sufficient to cater for projected demand for M2M wireless communication, however this was based on the assumption that the newly identified bands at 870-876 and 915-921 MHz would be fully available. Whilst this is now the case in the UK, this is not reflected in most other European countries. Only four countries (Slovenia, Spain, Sweden and the UK) have so far implemented the relevant

Annexes of ECC Recommendation 70-03. Elsewhere the band is either already used by military systems or reserved for other applications such as extension of the adjacent GSM-R band.

Given the likely demand for both short range and wide area M2M applications over the next decade, their potentially huge economic and social impact and noting that the traffic profiles and power consumption limitations of such applications are often better suited to lower power, narrower band technologies rather than broadband cellular networks, we suggest that priority be given to expediting the harmonisation of suitable spectrum to accommodate this growth. The 870-876 MHz band provides an opportunity to build on the success of the existing 863-870 MHz SRD band and to bring licence exempt spectrum availability more into line with North America, where the availability of the 902-928 MHz ISM band has done much to facilitate the development of innovative new wireless applications such as wide area M2M networks.

We would encourage national administrations to work towards the migration of military systems from these bands and as an interim measure to consider making at least part of the band available on a light licensing basis, such as that recently introduced in the UK. Cognitive technology (such as has been successfully demonstrated in the UHF TV band "white spaces" could also play a role in supporting co-existence between incumbent services in this band.

6.3 Maximising spectrum availability for wireless access systems

Licence exempt frequency bands play a vital role in facilitating access to broadband connections on both fixed and mobile networks. For many devices, there is no alternative to a Wi-Fi connection and the emergence of two de-facto worldwide frequency bands and globally harmonised technology standards makes it likely that Wi-Fi will remain the predominant broadband access platform for many years to come. It is therefore vital to ensure that the necessary spectrum resources are both available and of sufficient quality to support the continuing massive growth in data traffic. Numerous studies have been undertaken in the band that have demonstrated the benefit that would accrue from expanding the 5 GHz band and removing the current fragmentation, as we highlighted in section 3.6.2.

Whilst recognising the importance of protecting existing incumbent services, including airborne radars and earth exploration satellite services that are particularly relevant in Europe, there is a real danger that failure to address the current fragmentation of the 5 GHz Wi-Fi band could hinder the long term development of wireless access services in Europe.

A number of potential co-existence and interference mitigation options appear to have potential, including:

- Use of geographic and time database to prevent transmission at times or locations where satellites or radars may affected
- Restriction to indoor use
- Deployment of dedicated networks of signal detectors to facilitate detection of radars or transient satellite systems

We therefore recommend that European administrations work alongside counterparts in other regions (such as the US and Asia Pacific) with a view to reaching workable co-existence solutions in time for the 2019 World Radio Conference (WRC-19).

We also highlighted in section 3.6.4 the current regional inconsistencies in the availability of spectrum for wireless access systems around 60 GHz and again would encourage dialogue between European regulators and their counterparts in other ITU regions to work towards global harmonisation of this spectrum, ideally based on the current European allocation (57- 66 GHz) so that vendors can benefit from a single global market.

6.4 Improving spectrum efficiency and technology co-existence

In section 3.6.3 we highlighted the importance of adequate receiver performance in ensuring effective use of licence exempt bands, both in terms of the performance of existing equipment and the flexibility to introduce new applications, services or technologies in the future. Of particular concern is the susceptibility of some short range devices to blocking in the presence of nearby transmitters operating in adjacent frequency bands. This is perhaps best illustrated by the problems encountered by some short range devices in the 863 – 870 MHz band in the presence of nearby LTE mobile terminals operating in the adjacent 832 – 862 MHz band.

The 2014 Radio Equipment Directive introduces a more explicit requirement for all receiver devices (including licence exempt devices) to have receiver performance that takes account of broader spectrum efficiency objectives and work is underway within ETSI to update relevant technical standards to reflect this. The current SRD standards define three categories of receiver performance with significant differences in blocking levels and selectivity only specified in the most stringent category. The categories are not mandated for specific applications and it is left to vendors to decide which category to comply with. This makes it difficult for regulators to ensure adequate protection of more critical applications such as alarm systems since there is no control over which receiver category has been adopted by individual suppliers.

We note that Ofcom has proposed that in future applications where a more stringent receiver performance is appropriate should have this reflected in the relevant standard so that such applications would be less susceptible to interference from adjacent band systems in the future. This would ultimately lead to improved spectrum efficiency and we would encourage the SRD industry and other European regulators to support this initiative.

We would also encourage regulators to provide guidance to industry and consumers on the importance of receiver performance in radio devices and for the industry to adopt a suitable marking scheme to differentiate those products that conform to any new, more stringent technical requirements resulting from implementation of the Radio Equipment Directive.

Another factor that limits efficient use of some licence exempt band is the continued presence of technologies that lack effective interference mitigation mechanisms. This is a particular concern in the 2.4 GHz band, given the extensive reliance on this band for Wi-Fi. The ongoing issues at 5 GHz relating to co-existence with radars and other services that we discussed in section 3.8.4, the more limited transmission range achievable in this band and the ubiquity of 2.4 GHz devices mean that this band is likely to remain a vital enabler of Wi-Fi deployment for the foreseeable future. As we discussed in section 3.5.3, the widespread deployment of legacy video transmission equipment in this band has the potential to block Wi-Fi signals on the same frequency.

In the future we would expect the ubiquity and low cost of Wi-Fi technology, which is itself well suited to carrying video content, to largely obviate the need for these devices. We would therefore recommend that consideration be given to amending the relevant harmonised standard (EN 300 344) to remove the provision for video transmitters that do not incorporate CSMA/CA or similar LBT based protocols. This would have the further benefit of providing enhanced security for applications such as wireless CCTV or baby monitors, many of which also use analogue video technology currently. We believe also a case for phasing such equipment out in the 5.8 GHz band, which could in future be adopted as a Wi-Fi extension band, however we would suggest that 2.4 GHz is a more immediate priority given the extent or reliance on this band for Wi-Fi and extent of interference already apparent.

Finally, as an increasing proportion of licence exempt wireless devices can now connect to the Internet, this provides an opportunity for such devices to be periodically subject to an automated on-line registration process which would permit operation for a specified time period (e.g. one year), after which the device would cease to operate without repeating this process. This could provide a means of monitoring the number of devices in the market and simplify the process of removing legacy equipment over the longer term, which can sometimes hinder the introduction of new technologies or applications in licence exempt bands. Such an approach may be worth considering in the context of the growing number of M2M or “Internet of Things” applications likely to be served in licence exempt bands, though the benefit would have to be balanced against any cost considerations.

Annex 1: Glossary

3GPP	Third Generation Partnership Project
AFA	Adaptive Frequency Agility
AIFS	Arbitration Inter-Frame Spacing
ANDSF	Access Network Discovery and Selection Function
BRAN	Broadband Radio Access Networks
CEPT	Conference of European Post and Telecommunications Administrations
CTS	Clear to Send
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
DECT	Digital Enhanced Cordless Telephone
DCS	Dynamic Channel Selection
DFS	Dynamic Frequency Selection
DIFS	Distributed coordination function Interframe Space
DSSS	Direct Sequence Spread Spectrum
EC	European Commission
ECCA	Extended Clear Channel Assessment
EESS	Earth Exploration Satellite Services
EIRP	Effective Isotropic Radiated Power
EMEA	Europe Middle East and Africa
ETSI	European Telecommunications Standards Institute
EU	European Union
ECC	European Communications Committee
FBE	Frame Based Equipment
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum

ICCS	Initial Clear Channel Assessment
IMT	International Mobile Telecommunications
ITS	Intelligent Transport Services
ITU	International Telecommunications Union
LAA	Licensed Assisted Access
LBE	Load Based Equipment
LBT	Listen Before Talk
LTE	Long Term Evolution (4G cellular technology)
M2M	Machine to Machine
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
NRA	National Regulatory Authority
OFDM	Orthogonal Frequency Division Multiplex
PDCP	Packet Data Convergence Protocol
PMR	Private Mobile Radio
QAM	Quadrature Amplitude Modulation
RFID	RF Identification
RLAN	Radio Local Area Network
RTS	Request to Send
SDL	Supplementary Downlink
SRD	Short Range Device
SRD-MG	SRD Maintenance Group
TETRA	Terrestrial Trunked Radio
TPC	Transmitter Power Control
TDD	Time Division Duplex

TDM	Time Division Multiplex
TG-RAN	Technical Group – Radio Access Networks
TTDA	Tracking, Telemetry and Data Acquisition
TTT	Transport and Traffic Telematics
UNII	Unlicensed National Information Infrastructure
WAS	Wireless Access System
WIA	Wireless Industrial Applications
WPAN	Wireless Personal Area Network

Annex 2: Technical Background to LTE-LAA

A2.1 Review of LTE-LAA Technical Aspects

The key deployment scenario anticipated for LTE-LAA is a small cell using a secondary carrier operating in TDD (bidirectional) or supplementary downlink (SDL) mode to support best effort traffic not requiring a high quality of service. The LTE-LAA small cell area will also be covered by a licensed LTE network providing the primary carrier. In deployment scenarios where the primary and secondary carriers originate from the same location, the LTE carrier aggregation feature can be used to support the primary carrier (responsible for time critical traffic including most signalling and control information) and secondary carrier (taking advantage of available licence exempt spectrum opportunistically to deliver best effort traffic). In deployment scenarios where the primary and secondary carriers originate from different locations (e.g. primary carrier from an outdoor macro cell and a secondary carrier from an indoor pico cell), a link aggregation based on LTE Release 12 feature 'dual connectivity' can be facilitated at receiving devices. Similarly the link aggregation can be facilitated to aggregate LTE-LAA and Wi-Fi data.

When selecting an appropriate band combination for primary and secondary carrier intermodulation interference needs to be considered. While the 5 GHz band is mostly isolated from current IMT bands intermodulation may occur between 5470 – 5725 MHz and 1.8 GHz band[44].

In all potential deployment scenarios, the challenge is to ensure that the LTE-LAA impact on incumbent Wi-Fi systems is not greater than the impact that another Wi-Fi system carrying similar traffic would have. Wi-Fi uses a contention based protocol to share available channels where the addition of a new Wi-Fi system results in a proportional decrease in the data rate of existing Wi-Fi systems. LTE in its current form is designed for deployment in exclusive licensed spectrum with network data transmissions and management and control signalling operating continuously. This would give Wi-Fi systems little chance to access a channel in the presence of a co-channel LTE signal, giving an unfair advantage to the LTE system. For example, a research paper from Nokia reported that Wi-Fi performance can degrade by 70% in a sparse deployment scenario and 90% in a dense deployment scenario due to co-channel LTE interference[45]. To overcome this imbalance, the LTE-LAA MAC layer needs to be modified to co-exist more equitably with Wi-Fi systems in the same frequency space. How best to achieve the co-existence without substantially degrading the data throughput efficiency of LTE-LAA is a challenge that is currently being addressed in the 3GPP, whose work in this area is described in the next section.

It has been suggested that a number of existing LTE Release 10/11/12 MAC and PHY layer features could be used to improve LTE-LAA and Wi-Fi co-existence in the 5 GHz band[46]. These features include channel selection (performed during initial set-up and periodically afterwards by means of energy detection and/or technology specific measurements to identify the optimum channels for use by LTE-LAA networks) and carrier sensing adaptive transmission (which is an adaptive duty cycling where LTE-LAA networks use the channel depending on the activity of other technologies in a TDM fashion by performing carrier sensing over long intervals lasting 10 – 200 msec). The use of a licence

[44] U-LTE: Unlicensed Spectrum Utilization of LTE, Huawei, 2014.

[45] Performance Evaluation of LTE and Wi-Fi Co-existence in Unlicensed Bands, A. Cavalcante et al., IEEE Vehicular Technology, Spring 2013

[46] Qualcomm Research LTE in Unlicensed Spectrum: Harmonious Coexistence with Wi-Fi, June 2014

exempt band to accommodate an opportunistic SDL carrier can also facilitate sharing with Wi-Fi as the SDL carrier is turned on and off depending on the volume of the traffic on the licensed carrier.

These existing features are being used to support LTE-U deployments in the regions such as the US, South Korea and China, however in Europe there are additional mandatory co-existence requirement that must be met (as defined in EN 301 893). Some of the areas where LTE standards need to be modified to satisfy ETSI requirements are summarised below:

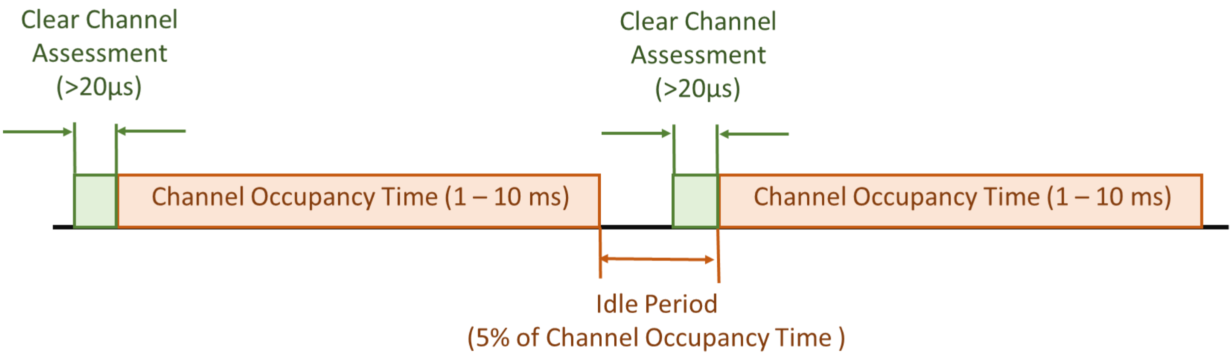
- ***Channel Access Mechanism***: A clear channel assessment must be performed to ensure that the channel is unoccupied. Current LTE implementations do not typically perform carrier sensing to access a channel. The network schedules periodic transmissions of resource blocks supporting multiple user terminals with dedicated traffic channels. The traffic is scheduled in 10 msec frames and the frames are divided between uplink and downlink into 1 msec sub-frames in TDD mode. The central control means that LTE's spectrum resource management can be more 'aggressive' compared to 'polite' usage procedures employed by Wi-Fi.
- There are a number of LBT implementation options that have been under consideration within 3GPP to modify the LTE standard and achieve a single solution applicable to LTE-LAA deployments[47]. These options are based on an adoption of one of the following implementations.
  - LBT implementation without random back-off. This is based on ETSI Frame Based Equipment channel access mechanism described in EN 301 893,
  - LBT implementation with random back-off using a variable size contention window. This is based on Option A for ETSI Load Based Equipment channel access mechanism described in EN 301 893,
  - LBT implementation with random back-off using a fixed size contention window. This is based on Option B for ETSI Load Based Equipment channel access mechanism described in EN 301 893.

  In the Frame Based Equipment channel access mechanism, if a device or access point wants to transmit it has to observe the energy level in a target channel for a duration equal to the clear channel assessment (CCA) period, which is at least 20 µsec. If the energy level in the channel is below the threshold[48] then the transmission can take place for a duration equal to the channel occupancy time which is between 1 – 10 msec. It is also required that at least 5% of channel occupancy time is an idle period. If the channel is busy transmissions are not allowed during the next fixed frame period which is equal to the channel occupancy time.

[47] Information Document on Work Item REN/BRAN-0060015 on the Revision of EN 301893, ETSI BRAN(15)000047r1, April 2015

[48] For an EIRP of 23 dBm, the threshold level is -73 dBm/MHz at the receiver input for 0 dBi receive antenna. If EIRP is below 23 dBm the threshold level is increased by an amount equal to (23 – EIRP) dB.

Figure 6-1: Frame Based Equipment (FBE) Channel Access Mechanism



By comparison, LTE carriers can be activated and deactivated based on the reported state of the channel in control and management data but the response time is of the order of 100 msec which is much higher than the time limits of Frame Based Equipment channel access mechanism. LTE also transmits continuously during transmissions therefore the 5% idle period requirement is violated.

In Option A for Load Based Equipment channel access mechanism, if the channel is found occupied after the clear channel assessment period the device is required to perform extended clear channel assessment (ECCA). The ECCA check uses q ECCA slots[49]. The initial value for q is 16 and this is doubled in each attempt because the previous ECCA check failed to find N unoccupied ECCA slots (where N is selected randomly between 1 and q at each attempt). The upper limit for q is 1024 and once this limit is reached q may be reset to 16. If N unoccupied ECCA slots are found during an ECCA check the device can start transmitting and q is set to 16. The maximum channel occupancy time is 10 msec and after that the device is required to perform a new ECCA check.

In Option B for Load Based Equipment channel access mechanism, the duration of ECCA check is equal to N x clear channel assessment observation period (which is at least 20 µsec and declared by the manufacturer). The value of N is randomly selected between 1 and q each time an ECCA check is performed. The value of q is fixed and selected by the manufacturer in the range 4 – 32. The maximum channel occupancy time is ([13/32] x q) msec.

It is argued that LBT will play a significant role in establishing a fair share mechanism between LTE-LAA and Wi-Fi. Therefore, intense discussions are underway to find an optimum solution. Our understanding is that one of the key discussion points is whether LTE-LAA networks should be obliged to implement LBT with an exponential back-off mechanism (where the contention window size is doubled at each attempt to access the channel after previous attempt fails) which is currently used in Wi-Fi.

In addition to the exponential back-off, Wi-Fi networks implement virtual carrier sense method using RTS/CTS to minimise the impact of hidden nodes. A similar process may also have to be incorporated into LTE-LAA networks. Furthermore, a degree of communication between LTE-LAA and Wi-Fi devices needs to be established to identify hidden nodes and avoid collisions.

[49]An ECCA slot is either an unoccupied idle slot of 18 µsec or a busy slot which is the total time channel is found occupied between two unoccupied idle slots.

One of the proposals put forward by LTE-LAA proponents is to avoid implementing preamble detection which is part of IEEE 802.11 channel access mechanism in order to minimise implementation costs. It is argued that the performance loss due to lack of the preamble detection can be compensated by lowering the energy detection threshold. However, the counter argument is that the low energy detection threshold may result in false triggers and reduce the efficiency of the channel access mechanism.

It is important to note that excessive clear channel assessment times, long back off periods and short data transmission times can all decrease the data rate efficiency if LTE-LAA networks were to adopt Wi-Fi-like co-existence procedures. Furthermore, while the centralised scheduling aims to eliminate the collisions among LTE users it might lead to situations where scheduled transmissions cannot take place due to lack of access to the channel at scheduled time because of the contention caused by Wi-Fi devices.

An alternative approach is to allow LTE-LAA to transmit only certain percentage of time (i.e. duty cycling). This approach can preserve efficiencies of LTE due to the scheduled nature of its air interface. However, this will mean that LTE-LAA will be still in control of the unlicensed spectrum. The extend of the LTE-LAA duty cycle, whether it should be adaptive taking account of Wi-Fi in the area and how to enforce it and by whom are outstanding questions. The duty cycling approach is pursued by potential 5 GHz licence-exempt implementations in the US, South Korea and China markets where there is no LBT requirement.

- ***Occupied Channel Bandwidth***: At least 80% of the declared nominal channel bandwidth must be occupied. LTE however uses a very modest portion of the OFDM carriers deployed in declared nominal channel bandwidth. These carriers need to be spread over 80% of the bandwidth to satisfy the ETSI requirement.
- ***Re-transmission Requests***: LTE uses 4 msec window between message transmission and receipt of acknowledgement. In licence exempt operation, there is no guarantee for channel access at a certain time therefore acknowledgements may not be sent in required time interval. LTE standards need to be modified to introduce flexibility for packet transmissions and acknowledgements.
- ***Emission Limits***: Unlicensed LTE networks need to meet in-band and out-of-band emission limits defined in certain part of the band in different regions.
- ***Beacon Signals***: Wi-Fi uses beacon signals to communicate information about the network. For example, an access point can identify itself by broadcasting MAC layer beacons. Furthermore, RTS / CTS control packages are employed to reserve the channel for transmissions. LTE standards do not include beacon signals.

To sum up, in order to ensure a fair sharing of spectrum, proposed techniques for LTE-U and LTE-LAA include ***dynamic channel selection*** where the aim is to avoid channels Wi-Fi devices operate, ***adaptive duty cycling*** where LTE-LAA transmission duty cycle is adjusted dynamically to accommodate Wi-Fi and ***listen-before-talk*** (LBT) implementation to comply with existing regulations in certain countries[50]. The dynamic channel selection and adaptive duty cycling approaches are pursued in the US and China (i.e. LTE-U) while the listen-before-talk approach is pursued within 3GPP and ETSI to comply with European standards (LTE-LAA). The work on the LBT approach for LTE-

[50] Making Best Use of Unlicensed Spectrum for 1000x, Qualcomm Presentation, February 2015

LAA has now been completed in 3GPP and will now be passed to ETSI for consideration, which it is hoped may lead to agreeing on a single global solution before LTE Release 13 in March 2016.

A2.2. Summary of 3GPP considerations on LTE-LAA

In the process of developing 3GPP TR36.899 there were a number of outstanding issues to be resolved regarding co-existence between LTE-LAA and Wi-Fi in the 5 GHz bands. Of particular concern were the mechanism to implement the LBT functionality required to comply with EN 301 893 and to minimise the impact on existing WiFi networks. There were also concerns that hidden node effects may not have been fully taken account of in the simulations and that the simulations may not take sufficient account of the impact of LTE-LAA in dense deployment scenarios such as large public events.

Various options for implementation of LTE-LAA are described in the technical report TR 36.889 which at the time of writing was in final draft form and due to finalised at the TG-RAN plenary meeting in June 2015. Considering the existing 5 GHz deployment requirements, as defined in EN 301 893, the minimum required functionalities for LTE-LAA were identified in the 3GPP TR as follows:

- ***LBT***: A clear channel assessment based on energy detection or carrier sensing should be applied before attempting to use the channel.
- ***Discontinuous Transmission***: Transmissions on a given channel should be discontinuous and the maximum transmission duration of a transmission burst should be limited.
- ***DFS***: This is required to avoid interference into radars.
- ***Carrier Selection***: The ability to select optimum channels is desirable mainly to prevent interference into other users.
- ***TPC***: The transmitter should be capable of reducing its EIRP by 3 dB or 6 dB compared to the maximum allowed level.
- ***Radio Resource Management (RRM) Measurements***: The measurement capability is required to improve link performance. To implement RRM measurements, the systems needs to identify cells for mobility, implement frequency/time estimation for demodulation, achieve coarse synchronisation and obtain channel state information.
- ***Bandwidth***: At least 20 MHz bandwidth is required for the 5 GHz operation.

Potential LTE-LAA deployment scenarios under consideration are mainly based on the use of small licence exempt cell clusters for indoor or outdoor coverage within areas served using licensed bands, which may use either conventional macro cells or small femto or pico cells. The aim is to provide additional capacity and this is achieved using carrier aggregation over licensed and unlicensed bands.

A number of performance metrics have been suggested to first assess the impact of one Wi-Fi system deployment on another. The same process should then be applied by replacing one Wi-Fi system with an LTE-LAA system. This can then demonstrate the relative impact of LTE-LAA on Wi-Fi. Proposed performance metrics include user perceived throughput, latency, average buffer occupancy and ratio of mean served and offered cell throughputs.

It is interesting to note that the simulations carried out to date to assess the impact of LTE-LAA deployment on existing show considerable variation, both in the base assumptions and the impact.

Most but not all of the simulations indicate an improvement in the throughput for Wi-Fi when a neighbouring Wi-Fi system is replaced with LTE-LAA. The bit rate over the LTE-LAA is also generally higher than the original Wi-Fi system, indicating an overall improvement in spectrum efficiency. However the impact is very dependent on assumptions regarding the LBT parameters, in particular whether a fixed or variable back off is applied (category 3 or 4) and the energy detection threshold applied.

With regard to the LBT requirement, four options have been considered by 3GPP, namely:

- Category 1: No LBT
- Category 2: LBT without random back-off. This corresponds to the FBE mechanism defined in EN 301 893 and described in section 0.
- Category 3: LBT with random back-off with fixed size of contention window. This corresponds to the LBE mechanism, option B defined in EN 301 893 and described in section 0.
- Category 4: LBT with random back-off with variable size of contention window. This corresponds to the LBE mechanism, option A defined in EN 301 893 and described in section 0.

At the April meeting of TG-RAN a way forward on the LBT implementation was proposed jointly by Huawei, Ericsson, Cable Labs, Cisco, HiSilicon, Ruckus Wireless, and Vodafone. The proposal is for LAA to adopt a Category 4 LBT scheme for downlink transmission based on the existing EN 301 893 option B but with the following modifications that ensure fairness with Wi-Fi:

i. The size of the LAA contention window should be variable using either exponential back off or a semi-static back off of between X and Y ECCA slots, where the values of X and Y are configurable parameters. The mechanism for adapting the size of the contention window requires further study.
ii. A minimum Extended Clear Channel Assessment (ECCA) slot size smaller than 20 µs should be considered.
iii. The initial Clear Channel Assessment (ICCA) value should be configurable so as to be comparable to the defer periods of Wi-Fi (e.g., DIFS or AIFS). The conditions under which the ICCA is used requires further study.
iv. When ECCA countdown is interrupted, a defer period should be applied after the channel becomes idle, which can be configured to be comparable to defer periods of Wi-Fi (e.g. DIFS or AIFS). An option to set the defer period to zero should also be investigated.

A further proposal by Intel to include adaptability of the energy detection threshold was also agreed at the meeting. The aim is to agree a single, mutually acceptable approach to meeting the LBT requirement that can be sent to ETSI BRAN for discussion and adoption into the updated version of EN 301 893.

These proposals appeared to go some way to addressing the concerns raised by some in the Wi-Fi community, although there remain some concerns about hidden nodes and the impact that failure by an LTE-LAA system to detect these could adversely effect on Wi-Fi performance. There are also ongoing concerns that the simulations undertaken so far have yielded varying results and may not adequately reflect the effect on performance in high traffic density locations.

The work so far has largely focussed on downlink only operation in the 5 GHz band, with LTE uplink signals being carried entirely in the licensed band. This reflects the downlink bias of most cellular data traffic and has the advantage that the LBT capability would only be required at base stations. Longer term deployment of LTE uplinks in the band would require user terminals with LBT capability.

Concern has also been expressed that simulations have taken full account of the potential impact of LTE on 802.11ac Wi-Fi deployments operating in 80 MHz RF channels, which could be forced to drop back to 40 MHz with a resultant loss of throughput (though a similar effect would also be encountered in the presence of another Wi-Fi network) and that most simulations relate to relatively low LTE loading levels that are not representative of high traffic locations like public entertainment venues. This could yield overly optimistic results in terms of the LTE-LAA throughput achieved.

It seems that the most important requirement for the Wi-Fi community is to have exponential back off incorporated into LTE-LAA design, as without this feature it is felt that equal access to the spectrum cannot be guaranteed. The ability to detect hidden nodes is also a concern. Wi-Fi networks try to minimise the impact of hidden nodes by implementing RTS/CTS. A similar procedure may have to be implemented in LTE-LAA. This appears to have been adequately addressed in the final version of the report.

A2.3 Wi-Fi community position on LTE-LAA

The Wi-Fi Alliance and IEEE have been involved in the 3GPP's deliberations on the LTE-LAA standard, alongside a number of major industry players in the Wi-Fi sector including Broadcom, Cisco and Cable Labs. Whilst the 3GPP position as expressed in the final draft of technical report TR 36.889 infers that an acceptable compromise has been achieved in terms of co-existence with Wi-Fi, there remain some concerns on the part of the Wi-Fi community. These have been expressed in some of the responses to the recent FCC notice[51].

Although many of the earlier concerns about LTE related to "pre-standard" LTE-U deployments in the US, Google's FCC submission argued that many of the coexistence challenges presented by LTE-U apply equally to LTE-LAA. The response noted that whilst fair co-existence with Wi-Fi might be possible with LAA if it implements LBT effectively, this would require close collaboration with all stakeholders, especially the IEEE 802.11 and the Wi-Fi Alliance,

Broadcom's response called for closer collaboration between 3GPP, IEEE, and the Wi-Fi Alliance to ensure that critical technical characteristics are carefully considered. A particular concern was that the standards-setting process should evaluate coexistence with Wi-Fi as it is currently deployed in the market, including provision for the widest channel widths (up to 160 MHz) and the latest MIMO and beamforming techniques.

[51] Source: Fierce Wireless Tech, "Google, Broadcom, Wi-Fi Alliance push for more collaboration between LTE-U/LAA and Wi-Fi",
15th June 2015