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Foreword

This report on “Developments in Spectrum Management for Communication Services” was prepared by the Working Party on Communication Infrastructure and Services Policy (WPCISP). It explores spectrum management objectives, developments in spectrum policy, and future considerations in spectrum management for communications services.

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EXECUTIVE SUMMARY

Radio spectrum is a limited national resource, in the form of invisible airwaves, which continues to fuel wireless communications and services, and as such, the economy and the digital transformation of our society. Its timely availability is key to foster a vast array of critical use cases and to enable wireless connectivity for mass consumer and business communications. Radio spectrum plays an important role in the variety of ways that we connect in the digital world. It makes us more productive, supports the automation of industries, and can reduce our environmental impact. Therefore, the availability and efficient use of spectrum can contribute to expanding overall economic and social welfare. For these reasons, it is increasingly a priority in OECD countries' policy agendas.

Efficient and effective spectrum management is critical to addressing the increased societal demands on this scarce resource. Multiple users of spectrum provide a wide range of services (e.g. space-based and terrestrial wireless communication services, including mobile, aeronautical, maritime, broadcasting, and satellite services, among many others). Among this variety of services, wireless communication services rely on spectrum to drive global broadband networks and to bridge connectivity divides. The role of spectrum policy in bridging these divides is high on the policy agenda as connectivity is a prerequisite for the digital transformation.

Overall, balancing the competing demands for spectrum use have been, and will continue to be, a key task and challenge for spectrum management in the future. This report discusses the effective stewardship of this vital, but scarce, national asset in the most efficient and expansive way possible, largely in the context of wireless communication services. The main takeaways of the report are the following.

The challenges are increasing and the stakes of spectrum management decisions are high

In a rapidly evolving technological landscape evermore dependent on spectrum, the stakes of spectrum management decisions are high and the challenges progressively complex. Emerging technologies are rapidly transforming entire economic sectors and linking previously separate markets. The art is in striking the right balance to achieve an efficient use of spectrum today and in the future for a variety of use cases. In this sense, agencies managing spectrum need to both anticipate and respond to new and emerging market realities as well as societal needs and sustainable development goals, while finding ways of adapting and navigating existing frameworks. Spectrum managers, therefore, are the protagonists of the digital transformation.

The challenges spectrum managers are facing are not necessarily new, but they are growing in intensity and complexity. There are increasingly diverse demands for access to spectrum to enable a wide breadth of wireless solutions for all parts of the economy, based on a broad array of different technologies. Tailoring licensing frameworks that meet the needs of these diverse uses and include new actors' demands to access spectrum (e.g. providers of private networks for industrial applications and local not-for profit community networks) will be pivotal to deliver on the potential of wireless connectivity. In addition, given that most of the useable spectrum has been assigned in the so-called "prime spectrum ranges", spectrum managers need to facilitate effective and efficient sharing models through licensing frameworks, and in some instances, may need to take more proactive measures such as to re-purpose spectrum.

The overarching goal: Increasing economic and social welfare through an efficient use of spectrum

Given the strategic nature of this vital but scarce resource and the myriad of its potential uses, spectrum management entails striking a delicate balance between different uses and users and between often competing desired policy outcomes. Therefore, entities in charge of spectrum management (i.e. spectrum managers and/or regulators) require a compass to navigate the different policy and technical considerations: a spectrum management vision or strategy.

While the policy context and objectives guiding spectrum management may be shared among countries, their implementation tends to be shaped by different historical contexts, and therefore, often differs across countries (i.e. no two countries' "spectrum journey" is quite the same). However, commonalities exist in spectrum management visions across OECD countries. They can be summarised as enabling services that increase economic and social welfare through a continued improvement in wireless communication services. This overarching aim can be broken down into several policy objectives, including putting spectrum bands to their most valuable or efficient use, and, in the context of mobile broadband services, fostering affordable access to communication services (by promoting competition, coverage and investment).

Spectrum policy has undergone dramatic changes in the past two decades

With the increasing demand for access to spectrum from multiple applications and services, spectrum management has shifted away from a "pure command and control" approach before the liberalisation of communication markets, to more market-based mechanisms for assignment and management. This can be seen in the increased use of competitive assignment methods (such as auctions) to promote allocative efficiency in the mobile market, as well as the inclusion of different policy objectives in assignment procedures. There has also been a more recent trend to use flexible authorisation (licensing) models to improve the efficient use of spectrum and allow for innovative services by packing users more densely and increasing the opportunities for sharing and coexistence through sophisticated technical analysis and modelling.

Experience across the OECD has shown that well-designed and transparent spectrum management frameworks, which include evolving approaches to allocation, advanced technical harmonisation approaches and licensing regimes, all contribute to foster long-term investment and innovation.

When the demand for spectrum exceeds the supply, as has been the case for mobile broadband applications, market assignment mechanisms, such as auctions, have become best practice in OECD countries. Well-designed auctions continue to be the gold standard in the OECD as they enable the licence to be assigned to the party that will make the most efficient use of it. However, auction design, which can embed different policy objectives, matters, and will determine its outcome.

Countries are looking to adopt flexible frameworks to promote spectrum sharing and secondary market access to spectrum

As the demands for spectrum increase, many countries are considering how to enable further access to spectrum on a shared basis with the aim to increase efficient use. While sharing is not a new concept and has been employed historically, new sharing frameworks are emerging that allow more dynamic and coordinated shared access to scarce spectrum. Since scarce spectrum is often assigned via individual licences, recent sharing models are making full use of the spectrum by allowing additional users to access it (e.g. through licensed shared access [LSA], tiered-based spectrum access systems [SAS], or light licensing models). However, while interest is growing, these sharing frameworks are still developing.

Secondary markets for spectrum trading and leasing provide an additional avenue to increase flexibility. Spectrum trading and leasing is allowed in most OECD countries. However, most countries report that it is seldom practiced by operators, particularly in bands where scarcity has been a particular issue, such as bands auctioned for mobile services. This may be due to frictions caused by high transaction costs, insufficient spectrum to meet demands, lack of a clear and enabling regulatory framework for these types of transactions, or hold-out issues by licensees, all of which contribute to illiquidity in the secondary market of spectrum. Addressing these frictions may encourage active secondary markets and enable more flexibility to manage spectrum use. Another component of a flexible spectrum management strategy is the availability of unlicensed, or licence-exempt spectrum, which supports a wide range of cost-effective short- range devices and applications, including Wireless Local Area Networks (WLANs, such as Wi-Fi).

Future considerations for spectrum management are being shaped by an evolving external context and emerging technologies

Looking ahead, the demands for spectrum will continue to grow and change; spectrum management must adapt to enable innovative use cases as they emerge. Many countries support wireless innovation by making spectrum available for temporary trials and developing regulatory sandboxes. Making such spectrum available is critical to allow innovation to proliferate, not only in relatively unchartered frequency ranges such as terahertz spectrum (above 100 GHz), but also for new or expanding use cases with promising benefits to society, such as unmanned aerial vehicles (UAVs), high-altitude platform stations (HAPS), and non-geostationary (NGSO) satellite constellations. Ensuring that the licensing framework is fit for purpose, placing spectrum in the market in an opportune way and adhering to the principle of technology neutrality for licences are key elements that enable the emergence of innovative use cases.

Finally, the growing relevance of the environmental sustainability of communication networks is shaping the future of spectrum management. OECD countries have begun to study the impact of communication networks on climate change, including with respect to spectrum management decisions. This includes understanding how communication networks affect and are affected by the environment, how technologies can help other sectors reduce their carbon footprint, and what actions can be taken to tackle the challenges presented by climate change. The complexity and importance of this issue requires a whole-of-government approach, where spectrum managers will need to coordinate with other government agencies.

Table of contents

Tables

Figures

Boxes

Developments in Spectrum Management for Communication Services

Introduction: The value of spectrum for society and its range of use

Radio spectrum enables space-based and terrestrial wireless communication services. It is a limited, valuable and essential national resource, in the form of invisible airwaves, which fuels today's economy and the digital transformation of our society. As such, it must be efficiently managed to achieve broader social and economic goals.

Spectrum is used for a wide variety of applications across all sectors of the economy that enable our globalised and digital world. It is used for applications that underpin a well-functioning supply chain and support international trade, such as logistics and aeronautical services (e.g. GPS, radars, and navigation systems). It is a critical asset for public services, including education, healthcare, digital government, law enforcement, emergency and public safety communications and military applications. Spectrum is also necessary for communication-based services, including content production and distribution, such as broadcasting and AM/FM radio services, which support cultural diversity and a functioning democracy. It is used to monitor our natural environment (for example through Earth Exploration Satellites and monitoring water levels),[1] and it is necessary to facilitate weather prediction and assess the effects of climate change. Moreover, the proliferation of the Internet of Things (IoT) also requires spectrum-enabled connectivity to support various applications that can help reduce our carbon footprint, ranging from smart electrical grids to connected forests, as well as others that enable the digital transformation of our industries.

Namely, spectrum is an essential input for the provision of communication-based services, such as mobile broadband connectivity. In a world where communication services and connectivity are more important than ever, reaping the benefits of the digital transformation requires policy makers to manage spectrum in the most efficient and expansive way possible for the benefit of all in society.

Looking into the future, communication operators, large tech companies and industrial players in other sectors will rely on the use of spectrum for a vast array of innovations. Many artificial intelligence (AI) systems as well as virtual and augmented reality applications will depend on spectrum-enabled connectivity. The use of non-geostationary orbit (NGSO) satellite constellations, which have an important potential to bridge rural connectivity divides, will continue to rely on spectrum (see the section on "Licensing for non-geostationary satellite services"). Drone applications, such as delivery solutions envisaged by Amazon (Amazon, 2022[1]), or applications to monitor agricultural fields, such as the start-up firm Chouette for vineyards in France (Chouette, 2022[2]), require spectrum to become a reality. Connected and automated vehicles, considered by some as the "ultimate mobile device", will rely on a range of connectivity solutions, including cellular and Wireless Local Area Networks (WLAN) also known as Radio Access Local Area Networks (RLANs), which again, will only be able to communicate with the environment and other vehicles via spectrum. Finally, Meta, formerly known as Facebook, has highlighted how their grand ambition of building the ultimate "metaverse" will require drastic improvements in mobile connectivity

(CNBC, 2022[3]; Mixed, 2022[4]). As such, today and in the future, how this scarce resource is managed will influence the practical implementation of innovations that are underway to transform our society.

Spectrum management involves planning, allocating, assigning, and monitoring how spectrum is used. While spectrum cannot be stored or transported (unlike other national resources), it can be shared, traded and leased to promote its efficient use. In a rapidly evolving technological landscape, the stakes of spectrum management decisions are high, as they involve potential opportunity costs if this essential, but often scarce resource is not used in the most efficient way. The challenges are increasing, as emerging technologies are rapidly transforming entire economic sectors, and linking previously separate markets.

Although the external context is in constant evolution, there are path dependencies on how this resource has been managed to date, which means spectrum managers rarely have a “clean slate” that allows them to design from “scratch” how this resource is used. While there are similarities across countries, each spectrum management journey is different. Therefore, spectrum managers need to be both responsive and reactive to new and emerging market realities, while finding ways of adapting and navigating existing frameworks and ensuring a certain level of harmonisation across countries.

Given this context, there are potentially important trade-offs to consider when managing spectrum, depending on different desired policy outcomes. Policy makers require a compass to navigate these different policy considerations: a spectrum management vision or strategy. Many policy makers across OECD countries have established spectrum strategy documents and have continued to update them regularly to take account of changes in technology and markets. Having a clear vision for spectrum management, which includes the main policy objectives to follow, is crucial to identify new ways to improve spectrum management. By doing so, policy makers may maximise the timely availability of spectrum and ensure that it is used in the most efficient way.

Due to the technical nature of the tasks involved, the role of spectrum managers cannot be overstated. At present and going forward, spectrum managers are the protagonists of the digital transformation of our societies.

This report discusses the overall vision for the effective stewardship of this vital, but often scarce, national asset largely in the context of wireless communication services. While the focus of this Working Party, and thus this report, is on the challenges and trends in managing spectrum for communication services, particularly mobile, it does so in the broader context of spectrum managers’ role to manage spectrum for the overall good of society. This role encompasses balancing demands from many different types of uses and users across all sectors of the economy. It should also be noted that while national security and cybersecurity are important aspects of spectrum management, they lie beyond the scope of the present report.

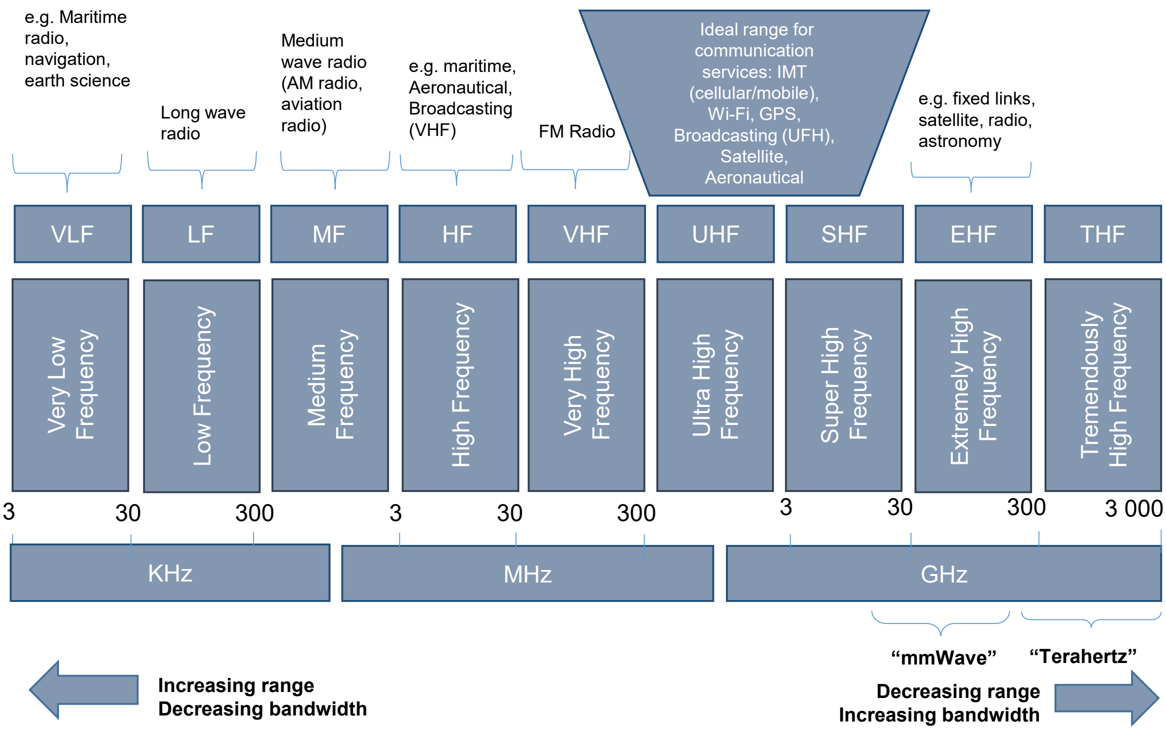
What is radio spectrum?

Radio spectrum, commonly referred to as “spectrum”, refers to the part of the electromagnetic spectrum frequencies spanning from the 3 hertz (Hz) to the 3 000 gigahertz (GHz) range, which the International Telecommunication Union (ITU) has divided into different bands (OECD/IDB, 2016[5]). Higher frequencies are more suitable for carrying large amounts of data but only over relatively short distances, whereas lower frequencies can travel long distances but may be less suitable for providing high-capacity services. Frequencies in the middle are suitable for providing sufficiently high-capacity services, such as mobile, over a reasonable distance. These middle-range frequencies –typically between 300 megahertz (MHz) to 6 GHz, are particularly suitable for the provision of wireless communication services (Figure 1).

Spectrum is a vital resource, and its scarcity relates to a given place, frequency, and time. In many countries, what is referred to as the “prime spectrum range” has already been allocated and assigned, and demand often exceeds supply. Given the strategic nature of spectrum, and with the continuous and rapidly evolving demand for wireless connectivity in all aspects of our economies and societies, clear policy objectives and strong technical understanding are needed to guide the timely and efficient management of this limited resource by national administrations and spectrum managers (or regulators).

As noted above, spectrum can be used for many types of different services and solutions. Within the category of spectrum-dependent communication services, a wide variety of wireless solutions enable the digital transformation. These range from cellular or mobile technologies, to satellite, to WLAN/RLAN (hereinafter referred as "WLANs"), where the most common type are "Wi-Fi" networks, (a WLAN/RLAN relying on 802.11 IEEE standards), to connectivity solutions for the Internet of Things (IoT) including short-range devices (UHF and SHF spectrum range in Figure 1). Unless stated otherwise, this report will focus on communication services delivered over radio spectrum, in particular for uses within the "prime spectrum range" (i.e. approximately between the 300 MHz and 6 GHz range) where the need to balance competing demands arises more often given "scarcity". Millimetre wave spectrum, (i.e. above 24GHz bands) is discussed in the context of trends in spectrum management and licensing.

Figure 1. Radio spectrum for wireless communication and its uses



Source: OECD elaboration based on Ofcom's spectrum map (http://static.ofcom.org.uk/static/spectrum/map.html) and ITU (2011), Telecommunications Regulation Handbook, www.itu.int/pub/D-PREF-TRH.1-2011.

The importance of efficient spectrum management

Many sectors of the economy already benefit from access to spectrum including for the expansion of affordable and reliable high quality broadband services, but many more could benefit in the future from more widely available access to spectrum. The remarkable growth of mobile broadband usage experienced in the last decade, along with the extensive deployment of 5G commercial networks, is just one example of the increase in overall spectrum demand globally and throughout the OECD area. Therefore, efficient spectrum management is required to meet overarching social and economic objectives.

Policy vision and objectives guiding spectrum management

Establishing a vision for spectrum management sets clear policy objectives to guide public entities in their spectrum management activities. Many OECD countries acknowledge the importance of this vision, as reflected in their spectrum strategies. These strategy documents are updated often to reflect the evolving technological and market landscape.

While the policy objectives guiding spectrum management are likely to be shared among countries (e.g. avoiding interference, promoting the efficient and effective use of spectrum, enabling innovation), their implementation (i.e. what countries deem to be the best way to achieve such objectives) is typically shaped by different historical contexts and as such, tends to vary across countries. The overarching spectrum management vision followed by countries can be summarised as *enabling services that increase economic and social welfare through a continued improvement in wireless services*. This overarching goal can be further broken down into several policy objectives guiding spectrum management, which include, among others:

- **Promoting the efficient use of spectrum:** Promoting the efficient use of spectrum is a key spectrum policy for OECD countries. This maximises the long-term economic and societal value of spectrum use. It includes awarding spectrum to the undertakings that will generate the highest value for society and to enable innovative services, covering the notions of static and dynamic allocative efficiency, respectively.[2] Promoting the efficient use of spectrum also encompasses allowing access to the widest possible number of users and avoiding spectrum underutilisation.
- **Avoiding harmful interference:** Spectrum needs to be considered in terms of space, time, and frequency. Interference should be managed in all three dimensions to ensure optimal use. Policy makers seek to increase transparency and establish long-term planning and coordination of spectrum to avoid harmful interference. Sharing frameworks should aim to manage harmful interference for all users sharing spectrum and instil confidence that sharing conditions will be upheld. Given the complexity in a shared environment, parameters to mitigate harmful interference may need to be defined on an ad-hoc basis, namely for each band and service provided over the band, being potentially complemented by some degree of receiver regulation/specification in terms of interference (OECD, 2014[6]).
- **Meeting the growing demand for wireless services:** Making additional spectrum available across a variety of bands, for both licensed and unlicensed users of wireless services, will be crucial to meet the increasing demands of the digital transformation. Namely, demand growth is met through re- allocating or re- purposing spectrum in the prime spectrum range, as well as introducing more flexibility in the spectrum management framework.
- **Increasing affordable access to communication services**: Spectrum managers have a role to ensure the availability, affordability, and reliability of communication services. This may be particularly relevant for mobile broadband markets if the spectrum manager is also responsible for the promotion of competition and consumer protection. Increasing affordable access can be further categorised into three main policy goals:
  - **Fostering competition**: Competitive markets foster innovation and investment in communication services, which is necessary to meet broader economic and social development policy objectives. How this resource is assigned has an important effect on the level of competition in communication markets and is thus an important consideration.
  - **Expanding coverage**: Spectrum is a crucial input to expand broadband coverage, in particular to unserved or underserved communities. As such, spectrum management has a role in the efforts to close connectivity gaps, for example, by imposing build-out requirements in licences or by allowing access to unused spectrum to expand connectivity in underserved areas. Increasingly, countries view an individual’s right to access communication services as similarly important as the right to electricity and fresh water, and as a prerequisite for the digital

transformation. There is also a trend in some countries to define access to connectivity as a constitutional right.

- **Promoting investment**: Legal certainty in licences, as well as licence duration and renewal process all have an impact on the incentives to invest. Sufficiently long licence periods provide legal certainty and promote investment. Licence conditions and renewal policies should be clearly defined and articulated when awarding the spectrum. For capital-intensive endeavours, such as in the case of mobile broadband networks, exclusive rights in licences have also played an important role in fostering investment.

- **Pursuing social and cultural objectives**: Spectrum for content production and distribution has an important role to play in promoting cultural diversity and media pluralism (e.g. spectrum for broadcasting and radio services) and fostering a well-functioning democracy by informing citizens. Spectrum is also a critical asset for public services, including education, healthcare, digital government, law enforcement, and emergency and public safety communications.
- **Driving wireless innovation:** The availability of spectrum in different spectrum bands open to different actors is necessary to drive innovation in new services, by different players such as industry, the public sector, not-for-profit organisations, and other stakeholders. Given that markets are defined by rapid technological changes, providing flexibility in the use of spectrum for different applications across different sectors and players is gaining in importance. Furthermore, spectrum management has a role in further developing features and applications of existing communication networks and related ecosystems.

Effective spectrum management entails a vast array of tasks. These tasks must rely on a set of overarching principles, which include observing technological and service neutrality to the extent possible, ensuring the highest degree of legal certainty (predictability) for market players and other stakeholders, providing transparent and clear conditions for spectrum use and making decisions based on evidence (such as cost- benefit analyses). In addition, spectrum managers need to be both proactive to anticipate changes in the market, but also reactive to circumstances that may arise. In carrying out these tasks, several OECD countries explicitly state technological neutrality in spectrum management as a guiding principle (e.g. Denmark, Hungary, Italy, Luxembourg, Mexico, Poland, and Slovak Republic), for others it is implicitly included in the authorisation legislation (e.g. United Kingdom).

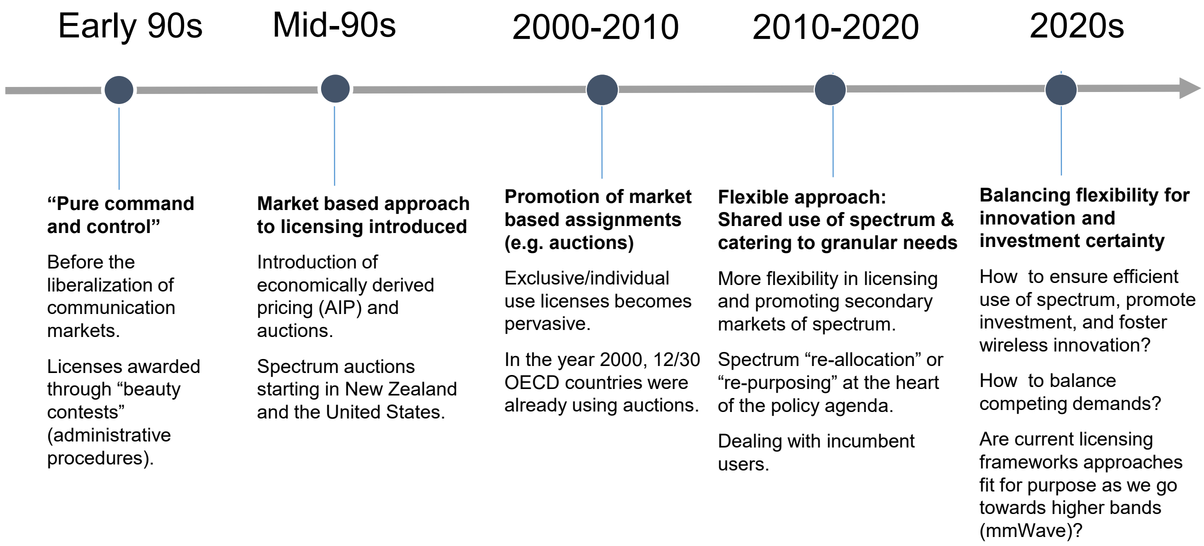
Regulatory tools that increase transparency may include public consultations, spectrum roadmaps and regulatory agendas, and public access to spectrum plans (ITU, 2020[7]). To facilitate spectrum sharing and manage interference, a useful regulatory tool is to make accurate and up-to-date information publicly available on where spectrum is being used and by which services, along with their protection requirements (RSPG, 2021[8]) (see section on Regulatory approaches to facilitate sharing of spectrum resources).

The spectrum strategy followed by countries and the respective policy objectives derived from such a vision can be achieved through a combination of spectrum management approaches. With the aim of maximising the most expansive and efficient use of spectrum, the approaches to spectrum management discussed in this report include measures targeted at increasing spectrum resources for wireless communication services, such as spectrum planning and allocation. They also include measures to place spectrum in the market and foster its efficient use, such as spectrum assignment[3] (licensing) and spectrum sharing models. These approaches, which are not mutually exclusive but rather interlinked, will be discussed through the lens of the policy objectives noted in this section.

Evolution of spectrum policy

Spectrum policy, and in particular licensing, has evolved in many OECD countries over the past two decades. One general trend has been to move away from a “pure command and control” approach to spectrum management, to more market-based mechanisms for assignment to promote allocative efficiency, as well as an increased use of flexible spectrum management frameworks to encourage spectrum's efficient use (Figure 2).

Figure 2. Evolution of spectrum management approaches: From "command and control" to market-based and flexible frameworks



Source: OECD elaboration.

The concept and nomenclature of *flexibility* in spectrum management can vary according to the national context. Examples include "flexible use licences" in the United States and "flexible authorisation (licensing) models" in the United Kingdom. "Flexible use licences" in the United States allow spectrum to be used for any service within the technical parameters set by the spectrum manager or regulator (i.e. as set forth in the national frequency allocation table). The Federal Communications Commission (FCC) in the United States has used this type of licence in several recent auctions,[4] including in the 2.5 GHz band auction that concluded in September 2022 (FCC, 2022[9]).[5] The 2.5 GHz band licences are "new flexible-use geographic overlay licenses" (FCC, 2022[10]), where 'overlay' means that "licensees obtain the rights to geographic area licenses 'overlaid' on top of the existing incumbent licenses" (FCC, 2019, p. 77[11]). In the United Kingdom, "flexible authorisation (licensing) models"[6] seek to provide flexible access to spectrum on a technology-neutral basis[7] that would enable the types of use to evolve where possible, without the need to request a technical licence variation from the spectrum manager, provided the licensees remain within the existing technical conditions (Ofcom, 2021[12]). In the case of the United Kingdom, depending on the context, flexibility can also refer to making spectrum available for innovation with flexible technical options for the use of spectrum in a licence or authorisation (i.e. conditions related to location and power levels while avoiding interference). It may also describe a situation where Ofcom retains an ability both to change licence terms as the market evolves (Ofcom, 2021[12]),[8] and to establish licensing frameworks that can adapt to changing spectrum demands (Ofcom, 2019[13]).[9]

The term "flexible spectrum management frameworks," for the purpose of this report, refers to approaches taken by countries to enhance flexibility in spectrum use (or to provide flexible access to spectrum) by means of promoting spectrum sharing and secondary market access to spectrum, and/or by means of increasing the ability to access spectrum in a flexible and opportune way via an agile licensing regime (e.g. light licensing models, flexible authorisation options when assigning spectrum rights, "flexible use licence", etc.). Agile licensing regimes may also include the use of spectrum use databases and transitory periods for licences (e.g. *trial* licences to foster innovation, “depreciating licences” implemented via “foothold auctions”, etc.).

From the 2020s on, spectrum managers have increasingly been balancing flexibility for innovation with investment certainty, considering demand for diverse wireless technologies, applications, services, and solutions. This includes tailoring licensing frameworks to these diverse uses, and enabling new actors (e.g. providers of private networks for industrial applications, local community networks, etc.) to deliver this wide variety of wireless services. In addition, as countries find that much of the spectrum in “prime spectrum ranges”[10] is already allocated, then finding options for future sharing or repurposing (re-allocating) spectrum have become the main challenges. Finally, one overarching challenge for policy makers and spectrum managers, which only keeps growing in importance, is to ensure an inclusive digital transformation (i.e. that no one is left behind).

In the pursuit of ensuring efficient use of spectrum and driving wireless innovation, at present and going forward within the next five to ten years, some new challenges for spectrum managers will arise. These challenges are driven by trends in the wider connectivity ecosystem. First, the societal context is continuously evolving, which includes environmental concerns and the resilience of communication networks. Second, technologies and network architectures are rapidly changing (e.g. private networks, satellite constellations, and the use of higher frequency bands). Third, there are new demands for spectrum from emerging applications, such as automated vehicles, drones, ultra-reliable services and smart cities and devices, among others. All these wider connectivity trends are shaping important trade-offs that spectrum managers face today and going forward, which include the following.

Balancing competing demands. Effective spectrum management must support access to spectrum for a broad range of organisations and individuals to enable a wide variety of uses. A key challenge for spectrum managers is how to balance competing demands across users. There is a myriad of services that rely on spectrum resources, which should be considered when managing radio spectrum (e.g. mobile broadband, WLANs, satellites, national security, GPS, radars, aviation, etc.). Thus, one main issue today is related to handling the demand of spectrum in a forward-looking way, striking the appropriate balance between enabling access to existing versus emerging services, and ensuring spectrum is used in the most efficient manner to obtain the maximum benefits for society.

Understanding diverse spectrum needs. Spectrum managers must work across different sectors to understand each sector’s specific requirements and how wireless connectivity may meet their needs. This understanding may therefore shape spectrum management decisions (e.g. taking a more granular approach to licensing through regional or local approaches). The goal is to ensure that different businesses and organisations can access the spectrum they need, where and when they need it.

Fostering wireless innovation while promoting investment certainty. Spectrum management should have innovation at the heart of its approach to support current and future demands for wireless spectrum across sectors, which may require adding flexibility in licensing approaches to be able to re-purpose spectrum if an innovative and valuable use case appears in the future. At the same time, licensing regimes should promote investment certainty, which in turn requires sufficiently long licence durations and clear renewal processes. However, there is a potential trade-off between the objectives of investment certainty and spectrum market liquidity and the re-allocation of spectrum to innovative new services. New theoretical assignment approaches are emerging claiming to mitigate such a trade-off, including the use of “foot-hold” auctions, although the efficacy of these is not yet proven. (Please refer to 1Annex B for further details, which introduces the concept of “foot-hold” auctions).

Adding flexibility to the licensing framework while managing harmful interference. The increased move toward flexible spectrum management frameworks, for example through “flexible use” licences or flexible authorisation models and through spectrum sharing, could greatly enhance the efficient use of spectrum for certain services. In addition, promoting secondary spectrum markets to support spectrum leasing, trading or deeper forms of radio access network (RAN) sharing (i.e. spectrum pooling) can further promote efficient spectrum use. However, as more spectrum users share spectrum, the more complex it becomes to manage harmful interference. Likewise, promoting efficient use through secondary markets and spectrum pooling may require modifications to existing regulatory frameworks.

Reaping the benefits of international and regional harmonisation while ensuring flexible spectrum frameworks. In principle, spectrum harmonisation is a desirable goal for all types of radio communication services. It increases economies of scale for manufacturing equipment and simplifies assignment procedures, which in turn favours investment certainty for equipment producers and service providers and enables low-cost wireless solutions for businesses and consumers. On the other hand, spectrum harmonisation may be at odds with other policy objectives pursued at the national level, such as favouring flexibility, by introducing rigidities in spectrum band plans. Moreover, historical differences and legacy uses may render full harmonisation challenging.

The importance of harmonisation at global, regional, and national levels

Spectrum harmonisation refers to the uniform allocation or identification of radio frequency bands across regions for a certain category of wireless use, such as mobile, satellite, radar, trains, broadcasting, space exploration, aviation, maritime, terrestrial wireless, etc., and their designation as primary or secondary allocations in a specific band. Harmonisation efforts are undertaken at an international, regional, and national level. The harmonisation of spectrum bands at the global and regional level has significant economic implications for policy makers and while the choices made by individual countries go beyond the scope of this report, the benefits and some of the challenges to harmonise spectrum across borders are presented in this section.

International harmonisation efforts are coordinated by the ITU, under the Radio Regulations,[11] which are revised at World Radio Conferences.[12] The ITU's Radiocommunication Sector unit (ITU-R) is in charge of ensuring rational, equitable, efficient and economical use of spectrum worldwide by extending international cooperation among all member countries. In particular, ITU-R facilitates efforts to eliminate harmful cross-border interference of radio stations located in different countries (OECD, 2019[14]). Regionally, harmonisation takes place in regional organisations, such as the Asia Pacific Telecommunity (APT),[13] the Inter-American Telecommunications Commission (CITEL),[14] and the European Conference of Postal and Telecommunications Administrations (CEPT).[15] Within the European Union, this coordination takes place through the policy advisory Radio Spectrum Policy Group (RSPG) and the legislative Radio Spectrum Committee. In the European Union, binding regional harmonisation decisions exist.

In simple terms, harmonisation plays an important role in spectrum management in two main ways. First, harmonisation facilitates coexistence and compatibility amongst services and influences the level of protection against harmful interference by developing the least restrictive technical conditions possible for a particular type of use. Secondly, it creates economies of scale.

Designating types of services as either primary or secondary allocations in a certain band in the ITU Radio Regulations influences the level of protection from interference[16] afforded to the service[17] when deployed, from services in other countries. Services given a primary allocation receive a higher level of protection from interference than secondary allocations. Therefore, the importance of "least restrictive conditions" is vital to maximise access by as many different types of services within a given band as possible. It is also feasible for more than one service to be identified as primary in a particular frequency band, giving all such services a "co-primary" allocation status. The ITU's efforts to mitigate harmful interference apply to cross-border areas between neighbouring countries. With respect to minimizing harmful interference, regional harmonisation may be more important, and often more feasible, than global harmonisation.

One of the main benefits of global harmonisation at present is that it provides certainty to the market on what services may be developed and offered in an allocated band, and what equipment could be manufactured, potentially creating economies of scale. Global harmonisation allows for the emergence of ecosystems conducive to the expansion of services, where the alternative could be fragmented national approaches to allocation. These benefits of harmonisation have proven to be particularly important in frequency bands where the propagation characteristics of the spectrum mean that the signals are likely to cross national borders, such as for harmonised uses in bands in lower frequencies (i.e. below 6 GHz). For example, in terrestrial mobile broadband, lower frequency spectrum bands may have a higher risk of cross-border interference due to their better propagation characteristics. This may be less of a concern with higher frequency bands (e.g. mmWave) where its propagation characteristics mean that signals travel shorter distances, negating the spectrum management benefits of wide scale harmonisation, except for equipment or service purposes. Overall, the higher the frequency band, the less likely signals are to travel further distances due to changes in propagation characteristics. Thus, the benefits of any specific harmonisation measures in higher bands may possibly be reduced beyond national, local co-ordination or co-ordination of areas close to national borders.

Many applications (terrestrial mobile broadband WLANs and other short-range device [SRD] applications) are often supported by global specifications and standards, led by international and often commercially driven standards bodies (e.g. ETSI, IEEE, ISO, 3GPP). The ability of these bodies to respond to industry requests and develop standards provides a way forward for the use of common, harmonised band plans and influences how the ecosystem develops for these band plans (OECD, 2014[6]). On the one hand, this creates important benefits (e.g. economies of scale and increased interoperability). On the other, some stakeholders have voiced concerns that the central role of standardisation bodies may increase barriers to entry for smaller industry players that may not have a seat in these bodies, or may stifle new innovations, which raises further questions regarding technology neutrality. That is, the benefits of harmonisation leading to economies of scale for manufacturers and to the roll-out of mass services occur only if those services are taken up in the majority of relevant administrations. Given that spectrum demand for services is not uniform across the world, or even across regions, when harmonisation only serves one market or is compromised by competing and non-interoperable technology, it may not always be conducive to the efficient use of spectrum.

Global harmonisation is a desirable goal where feasible, particularly for lower frequencies. For some types of use, it may be critical due to their global or mass market nature, or because of safety considerations (e.g. aeronautical and maritime services, satellites, global navigation satellite systems, WLAN, and SRD devices among others). However, global and regional harmonisation efforts may involve lengthy processes[18]and historical band assignments may, over time, be a roadblock to the development of either new and innovative technologies and/or services. This may render complete harmonisation rather challenging and regional differences may remain. When global harmonisation is not possible, regional harmonisation may be the next best option, and in some instances, harmonisation is only possible at the national level.

Although the demands may differ for different types of radio communication services, harmonisation brings several important benefits, including guaranteeing a certain level of protection from interference, providing long-term stability, enabling and maximising the potential to develop new applications and services that benefit from economies of scale, reducing cross-border complexity, and enhancing interoperability and international cooperation (e.g. roaming for consumer mobile and mass market short range device equipment such as routers for WLANs). Nevertheless, the benefits brought by harmonisation should also be balanced with other goals, such as favouring flexibility by promoting access to the widest possible range of applications and services, or giving due consideration to specific domestic circumstances (e.g. historical band allocations and incumbent uses that may have great significance). Innovation in wireless technologies may also be, to some extent, limited by a lack of flexibility in harmonised "band plans" and technical conditions (OECD, 2014[6]).

OECD countries are preparing for the World Radiocommunication Conference in 2023 (WRC-23),[19] where the allocation and identification of additional spectrum resources for several radio communication services, including mobile, satellite, Earth stations in motion, high altitude platforms among many other items, will be discussed. It should be noted that while the ITU establishes a regulatory framework for harmonisation, it does not pre-empt regional harmonisation or national allocations. Countries can establish the conditions for regional harmonisation and determine their national band plans. Nevertheless, decisions made at the WRC will play a defining role in spectrum allocation and impact the development of ecosystems for new technologies.

Spectrum allocation at the national level

Spectrum allocation refers to the process followed by national spectrum managers to "allocate" or designate a specific spectrum band for a certain category of wireless use or application (e.g. terrestrial wireless, satellite, broadcasting) (ITU-R, 2020[15]). At a national level, "allocated" use would normally mean that the internationally allocated use may provide a framework for the National Frequency Allocation Table. For example, OECD countries are currently considering the allocation plans for the 6 GHz band (Box 1).

Box 1. Case study: The allocation of the 6 GHz band

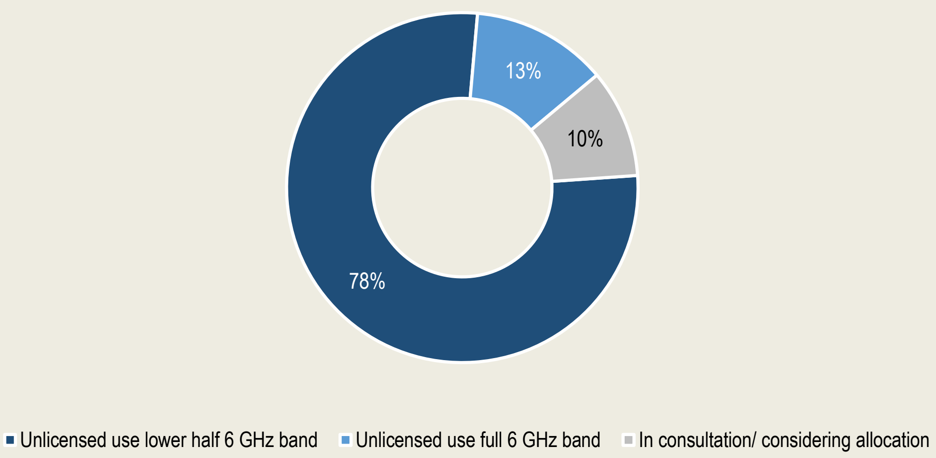
The 6 GHz band allocation debate centres on whether to allocate up to 1 200 megahertz (the full band from 5 925 - 7 125 MHz) to unlicensed use by WLAN applications, the lower half of the band for WLAN and the upper half of the band for mobile, or the whole band for mobile. The 6 GHz band, 6 425 – 7 025 for Region 1, which includes Europe and Africa, and 7 025 – 7 125 MHz globally, is under study for possible IMT identification at the next World Radiocommunication Conference in 2023 (WRC-23) under Agenda Item 1.2 (ITU, 2019[16]; ITU, 2019[17]). Further, studies are being conducted regarding possible sharing with indications of a potential opportunity for sharing between IMT (macro) and other services allocated to this band. However, as noted above, an IMT identification at WRC-23 ITU does not pre-empt regional harmonisation or national allocations and therefore leaves room for regional harmonisation efforts (e.g. at the European Union). Nevertheless, the policy debate regarding this band will undoubtedly consider the outcomes of WRC-23, namely whether countries in Region 1 trigger further harmonisation measures in the 6 425 – 7 025 MHz band for IMT.

In conjunction with the WRC-23 discussions, some OECD countries are already considering possible allocations in the 6 GHz band. In Canada, the government decided to allocate the full 6 GHz band (1 200 megahertz) for unlicensed use by radio local area network (RLAN) devices, noting current speed and capacity constraints as key drivers as well as its potential to support wireless ISPs (WISPs) to enhance rural connectivity at low cost (Government of Canada, 2021[18]). In 2020, the United Kingdom made the lower part of the 6 GHz band available for RLAN (Ofcom, 2020[19]), and the European Union adopted "Decision C(2021)4240" designating the use of the lower part of the band (5 945 - 6 425 MHz) on a "non- exclusive, non-interference and non-protected basis" to support wireless access systems including RLANs (European Commission, 2021[20]). The Decision takes a technology-neutral approach when defining the harmonised technical conditions to support RLAN applications.

Considerations regarding the possible allocation of the upper part of the 6 GHz band across Europe are ongoing at CEPT and will take into account WRC-23 outcomes on Agenda Item 1.2. The CEPT has initiated studies, which aim to be completed by mid-2024, assessing the possible use of WLANs in the 6425 – 7125 MHz band to operate and coexist with existing services, (CEPT, 2021[21]). OECD countries that are members of the European Union follow its decisions to harmonise spectrum use among European Union member countries. In Mexico, the IFT carried out two public consultations related to the possible classification of the 6 GHz band in 2020 and 2021 (IFT, 2020[22]; IFT, 2021[23]). Some of the key concerns expressed in the consultations were regarding the coexistence between services, as well as whether to reserve the upper portion of the band for mobile services. The IFT expects to decide on the possible allocation before the end of 2022 (IFT, 2022[24]).

At the time of writing, from a sample of 39 countries (comprised of 37 OECD countries, Brazil and Singapore), 78% of countries had split the allocation of the band between IMT and unlicensed use, by allocating the lower half of the band for unlicensed use. However, as noted above, decisions regarding the remaining bandwidth in the 6 GHz band (upper half), especially in countries in Region 1, will likely be influenced by the outcomes of WRC-23 discussions. Thirteen percent had allocated the full 6 GHz band to unlicensed use. The remaining countries (10%) are currently considering the band's allocation, with some countries consulting on the issue during 2022 (Figure 3).

Figure 3. Allocation of the 6 GHz band across OECD countries, Brazil, and Singapore



Note: The full 6 GHz band refers to 5 925 - 7 125 MHz (1200 MHz). The lower half of the 6 GHz band refers to 5 945 – 6 425 MHz (480 MHz) for members of the EU and to 5 925 – 6 425 MHz (500 MHz) for the United Kingdom. EU members are considered as allocating the lower half of the band for unlicensed use in line with "EU Decision 2021/1067", despite the current state of implementation of the Decision. This figure shows allocation at the time of writing. Please note that countries that have allocated the lower half of the 6 GHz band may still take a decision for the upper half of the band. The figure includes OECD Member countries, along with Brazil and Singapore.
Source: OECD based on questionnaire responses and desk research.

Sources : ITU (2019[16]), *Resolution 811 (WRC-19): Agenda for the 2023 world radiocommunication conference*, https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000D0041PDFE.pdf;ITU (2019[17]), *Resolution 245 (WRC-19)* https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000D0002PDFE.pdf; Government of Canada (2021[18]), *Decision on the Technical and Policy Framework for Licence-Exempt Use in the 6 GHz Band*, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11698.html; European Commission (2021[20]),*Commission Implementing Decision C(2021)4240*, https://ec.europa.eu/newsroom/dae/redirection/document/77409; IFT (2020[22]), *Consulta Pública de Integración del "Cuestionario sobre la banda de frecuencias 5925-7125 MHz"*, http://www.ift.org.mx/industria/consultas-publicas/ficha-de-consulta-publica?project_cp=16968; IFT (2021[23]), *Consulta Pública sobre el Anteproyecto de Acuerdo mediante el cual el Pleno del Instituto Federal de Telecomunicaciones clasifica la banda de frecuencias 5925-7125 MHz como espectro libre y emite las condiciones técnicas de operación de la banda*, http://www.ift.org.mx/industria/consultas-publicas/ficha-de-consulta-publica?project_cp=17436; IFT (2022[24]), *Programa Anual de Trabajo 2022*, http://www.ift.org.mx/sites/default/files/contenidogeneral/transparencia/pat2022.pdf..

Managing interference, and avoiding harmful interference, is one of the main goals of spectrum allocation, planning and authorisation. An important element to consider when new allocations are added, whether internationally or nationally, is protecting existing systems in adjacent bands. Current regulatory frameworks tend to focus on avoiding interference by limiting transmission and spectrum managers may enforce strict power/deployment restrictions on transmitters. A recent example of the importance of managing interference between different uses can be illustrated with the case of the aviation industry and communication operators in the United States (Box 2).

Box 2. Managing harmful interference: The case of the 3.7 GHz band in the United States

The end of 2021, and the beginning of 2022, were marked by a public debate between the aviation industry in the United States and communication operators concerning the already auctioned 3.7 GHz band (3.7 - 3.89 GHz or "C-band" spectrum in the United States). Verizon and AT&T were set to activate 5G services using this frequency range on 5 December 2021. The Federal Aviation Administration (FAA) and the aviation industry voiced concerns over this deployment based on a technical report that purported to show a small number of radio altimeters could be susceptible to out-of-band signals (which would be 400 megahertz away from the altimeter band initially and shrinking to 220 megahertz in 2023) from communication wireless operators in the 3.7 GHz band, and a further delay of 5G commercial launches was requested (Mobile World Live, 2022[25]). In late January 2022, after settling flight-safety issues with the FAA, Verizon and AT&T launched 5G services using this spectrum band.

In terms of frequency ranges, many European countries have allocated mobile frequencies in a lower range (i.e. 3.4 - 3.8 GHz), while in the United States and Canada, these services are planned up to the 3 980 MHz band, ultimately closer to the bands used by the aviation industry (i.e. 4.2 - 4.4 GHz).[20]

However, similar issues may also arise in other countries, and certain European countries are increasing awareness of measures to manage harmful interference in mid-band spectrum (FranceInfo, 2022[26]). For example, France has implemented precautionary measures to avoid harmful interference between aviation and mobile services at the end of 2020. In addition to the United States and France, similar approaches have been implemented in the Czech Republic and in Canada.

In Europe, the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) started to work in 2021 on assessing the compatibility between mobile-fixed communication networks (MFCN) operating in 3.4-3.8 GHz and radio altimeters (RA) operating in 4.2 - 4.4 GHz band (CEPT, 2021[27]). By bringing together all relevant stakeholders, including communication regulators, aviation regulators (i.e. Eurocontrol, EASA), as well as representatives of the mobile and aeronautical industry, CEPT intends to help clarify the 5G parameters to be taken into account in the upgrade of radio altimeter standards. At the moment of writing, CEPT had not found cases yet of interference across Europe from either 5G in the 3.8 GHz band or shared use between 3.8 - 4.2 GHz. The aviation industry is conducting a similar workstream (i.e. via the European Organisation for Civil Aviation Equipment [Eurocae] and the Radio Technical Commission for Aeronautics [RTCA]), which should also take into account 5G uses in the vicinity of the 4.2 - 4.4 GHz band, not only in the United States and Europe, but also in countries such as Japan and Korea. These guidelines will also be useful for establishing conditions for the coexistence of low and medium power networks with radio altimeters in Europe.

Concerning commercial aviation, some direct measures that may help mitigate potential harmful interference risks include establishing a certain minimum distance for mobile transmitters and/or a coordination zone around airports, limiting mobile transmitter heights and antenna elevation angles near airports, and upgrading transmitter and receiver equipment by the aviation industry.

When addressing the long-term social and economic benefits of allocating spectrum for a certain category of wireless use or application, policy makers should rely on quantitative and qualitative criteria, including cost-benefit analyses to undertake the relevant impact assessments. Such criteria could include: i) the compatibility with the existing regulatory framework, ii) the possibility to share spectrum with other applications/uses, existing or new, iii) the extent of social and economic benefits, iv) the timeframe for the availability of an equipment ecosystem, v) the potential economies of scale via harmonisation, and vi) the key risks associated with the use/application.

In many countries, a large fraction of the most usable spectrum, particularly in lower frequencies, has already been allocated, so spectrum allocation frequently necessitates spectrum repurposing or sharing. However, liberating and re-farming bands, which may occur in the process of repurposing (or reallocating) a band, presents several challenges. When repurposing spectrum, the spectrum manager often needs to address several questions, depending on the historical licensing regime in the country and the historic roll-out and uptake of different services. These include: 1) how the current incumbents in the band will be treated; 2) how to resolve potential interference issues between the new services and the incumbent services in the band or in adjacent bands; 3) what new rights will be assigned in the band to new licensees and incumbents; and 4) what mechanism will be used to assign these new rights.

In the process of "re-allocating" spectrum, the spectrum manager may also need to: i) restructure the geographic scope and bandwidth of licences; ii) provide an alternative band to which incumbents can be moved; iii) "repack" incumbent users (i.e. consolidating remaining incumbents into a smaller portion of the band); and/or iv) compensating them for giving up their rights (e.g. through an incentive auction).

Changing the use of a certain spectrum band is often a long and cumbersome process. This could be particularly challenging if the incumbent users provide military, public protection and disaster relief (PPDR) or other public use services. One example during the past decade is the digital dividend transition, which shifted spectrum use from broadcasting to mobile communications in the 700 MHz and 800 MHz, related to the switch-over from analogue to digital terrestrial television (DTT). As seen in many OECD countries, the process to migrate the spectrum to mobile use required a great deal of planning and time.

The use of market-based mechanisms may, under the right circumstances, help to create incentives to transfer spectrum resources from one use to another (e.g. as shown with the DTT transition in the United States with the use of "incentive auctions"[21]). These include, but are not limited to, establishing reverse auctions that pay incumbents for their spectrum rights, innovating on the structure of spectrum licences (e.g. theory of "foothold auctions"), introducing new licensing regimes with flexibility by design (e.g. area- wide apparatus licences in Australia or the local licence regime in the United Kingdom), adapting licensing frameworks for increased shared use of spectrum and increasing the efficient use of secondary markets (e.g. spectrum leasing and trading), as discussed in subsequent sections of this report.

Spectrum licensing or assignment

Given that spectrum is a public national resource, the right to transmit signals using spectrum is subject to an authorisation by national administrations, a process also known as licensing or authorisation.[22] Therefore, spectrum assignment refers to the process followed by national spectrum managers to make spectrum available in the market, and licence it to users. This could be to specific users through an individual licensing regime, or as a general authorisation regime, for example, where spectrum can be used in a "licence-exempt" regime, provided equipment or devices comply with a certain set of characteristics.

Spectrum licensing regimes in OECD countries continue to evolve and adapt to new technologies. In general, countries have accommodated market mechanisms into their regimes to promote a more efficient use of spectrum for communication services, in particular where spectrum scarcity may be an issue. Other assignment mechanisms have also been used, such as administrative selection processes, also known as "beauty contests". As such, spectrum licensing can be categorised into three main approaches, which are not mutually exclusive: individual licence, light licensing, and licence-exempt (also known as unlicensed) (Table 1).

Table 1. Regulatory options towards spectrum licensing and models to access spectrum resources

Licensing model	Individual licence	Light licence		Licence-exempt
Authorisation framework	Individual authorisation (Individual rights of use)	Individual authorisation (Individual rights of use)	General authorisation (No individual rights of use)	General authorisation (No individual rights of use)
Procedure to obtain licence	Traditional procedure for issuing licences.	Simplified procedure to obtain a licence (e.g. first-come-first-served basis).	Only registration required.	No registration required. Subject to complying with some regulations, i.e. on transmitter power limits, and the use of "listen before talk" feature often defined in the equipment standard.
Models to access spectrum resources by third parties; and/or approaches to shared use of spectrum	**Exclusive licensed access**: • Spectrum leasing, • Spectrum trading, • Spectrum pooling (i.e. extension of RAN sharing agreements). **Shared licensed access with incumbent users**: • Licensed shared access (LSA), • Tiered-based spectrum access system (SAS) (e.g. CBRS in the United States).	Several users, with limitations on the number of users (e.g. AWL in Australia). **Concurrent Shared Access**: A limited number of licensed operators in a given band with individual, but not exclusive rights of use (i.e. "club use" model).	No limitations in the number of users.	No limitations on the number of users (e.g. WLAN).

Source: OECD based on EEC (2009[28]) Report 132, https://docdb.cept.org/document/240, RSPG (2021[8]), https://rspg-spectrum.eu/wp-content/uploads/2021/02/RSPG21-016final_RSPG_Report_on_Spectrum_Sharing.pdf, and GSMA (2022[29]), Spectrum-Leasing-5G-Era.pdf (gsma.com).

For bands where there is competitive pressure and/or spectrum scarcity, individual licensed spectrum is normally assigned through a market mechanism (e.g. auctions). However, some countries use administrative procedures (i.e. beauty contests) or assign individual licensed spectrum through a hybrid approach, which includes elements of both administrative procedures and auctions. Individual spectrum licensing arrangements require rules of temporary property rights and protection from interference (OECD/IDB, 2016[5]). These usually reflect the technical harmonisation conditions agreed at the regional and/or international levels. This type of licensing regime is mainly used for spectrum in bands with foreseeable scarcity and where large network cost investments are required. As such, spectrum for mobile service is usually licensed through this regime. Spectrum awarded through individual licences tends to be for exclusive use. Nevertheless, individual licensing schemes can also incorporate mechanisms to allow for third parties to access spectrum resources. This can be done through secondary markets (i.e. leasing and trading of rights of use), by more deep forms of active Radio Access Network (RAN) sharing (i.e. spectrum pooling) in the case of mobile networks, or by shared use of spectrum. For example, Licensed Shared Access (LSA) and tiered-shared access are concepts that allow spectrum that has been licensed to an incumbent user to be used by more than one entity on a shared basis.

Licence-exempt access to spectrum, also known as "unlicensed", is an assignment mechanism, with no entry price attached nor licence required. Users must only comply with conditions of shared use, which are set by the authorities and define the technical requirements that equipment must meet to operate without a licence. In Australia, this type of licensing regime is referred to as "class licensed spectrum". Licence- exempt access permits the use of radio communication devices on shared frequencies through a general authorisation regime, where no registration is required, and without a limit on the number of users, subject to the adherence of conditions of use and technical standards. It is suitable for low-power, short-range devices and services that can self-contain or manage interference levels, such as Bluetooth, Wi-Fi and the IoT. This approach has proven its merits in many cost-effective applications, such as wide-range and short-range devices (SRDs) and access equipment for WLANs, such as Wi-Fi (OECD, 2014[6]). It can also lower barriers to entry faced by social-purpose operators (APC, 2019[30]).

Light licensing models are the middle ground between individual authorisations and general authorisations and provide a more flexible and simplified approach of issuing authorisations for spectrum use, involving a "low-cost" licensing alternative available upon request to any user on a "first come, first served" basis. These models can include simplified administrative procedures to obtain licences with a limited number of users in the case of individual authorisation regime, or unlimited number of users where only registration is required. Apparatus licences, such as Area Wide Apparatus Licences (AWL) in Australia that authorise the operation of an individual type of device to deliver an approved service at a defined geographical location, may be included within this category (Box 3). Light licensing approaches are generally used for wireless/fixed point-to-point links (e.g. backhaul), or in some cases, for mmWave antennas, given the limited low risks of harmful interference due to the propagation characteristics of such devices. Similarly, within the light licensing model, another type of approach allowing a limited number of users is concurrent shared access, whereby several licensed operators have individual but non-exclusive rights of use (i.e. "club use").

Box 3. Area-wide apparatus licensing in the 26 and 28 GHz bands in Australia: An example of a light licensing approach

Spectrum users in Australia have requested to the Australian Communications and Media Authority (ACMA) to provide more options and flexibility in its licensing products. Therefore, responding to these requests, ACMA introduced an innovative approach to licensing in 2020 that provides flexibility to cater to local uses through area-wide apparatus licences (AWL), meant to expand the regulator's (ACMA) licensing toolkit to meet the growing demand for local area wireless broadband (ACMA, 2020[31]). The licence type can support a wide variety of localised spectrum use cases including private 'campus-style' broadband networks to service industrial precincts, hospitals, mines, farms, and education centres.

Area-wide apparatus licences in Australia are an example of a light licensing approach, characterised by a relatively light administrative burden and an openness to a wide number of services and users. AWL is an area-based licence type that grants the authorisation to operate one or more radio communication devices in a certain area, depending on the availability of spectrum in the requested area. AWL is predicated on 'building block' geographic units that can be aggregated and are scalable. These can be used for a broad range of purposes, uses, services, applications, and technologies. AWL licensees, for example for mmWave spectrum, may share spectrum in certain areas with "class licences" (i.e. licence-exempt spectrum), as well as individual licences for mobile services.

The AWL licensing approach has been used to assign 26 and 28 GHz mmWave frequency bands in December 2020 for 5G mobile and fixed wireless access (FWA) broadband, and fixed satellite service (FSS) in urban, regional, and rural environments, where allowed (ACMA, 2020[32]). The granular nature of the AWL product means it can facilitate private networks, which is expected to be an ongoing trend in spectrum demand in Australia.

Source: ACMA (2020[31]), "Area-wide licensing: ACMA approach to introducing area-wide licences", https://www.acma.gov.au/publications/2020-02/guide/area-wide-licensing-acma-approach-introducing-area-wide-licences
ACMA (2020[32]),"Area-wide apparatus licensing in the 26 and 28 GHz bands", https://www.acma.gov.au/area-wide-apparatus-licensing-26-and-28-ghz-bands

Licence duration and renewal policies

Well-designed licensing regimes provide legal certainty and can foster long-term investment. A central issue for spectrum managers has been the choice of spectrum licence duration and renewal policies across a range of different types of wireless use. Transparency and predictability regarding licence duration and renewal are important for all spectrum users, but may be particularly relevant to foster investment in capital- intensive services (e.g. mobile networks). In the case of mobile networks, spectrum licences awarded for sufficiently long periods, or that at least provide licensees with sufficient certainty at the time of assignment that their licences will be renewed by a transparent renewal path (including methodologies to define renewal conditions) are important to promote network investments.

Long-term licences with a high probability of renewal, within reasonable conditions, provide higher incentives to invest in networks. Shorter licence durations without renewal, conversely, may allow the entry of new players and the emergence of new use cases. On the one hand, a longer licence duration with renewal expectancy may provide legal certainty, which in turn strengthens incentives to invest in networks and which also allows existing users of spectrum to innovate in their service offerings over time. On the other hand, shorter licence terms with no renewal expectancy allows a country to hold an assignment procedure after the initial licence period ends to transition the spectrum to other parties which may offer new use cases and applications. Therefore, given the nature of certain frequencies, a key issue for spectrum managers is determining the optimal licence duration that balances investment and innovation goals. There is also value in the underlying legislation supporting and enabling the authorisation regime to have sufficient flexibility built in by design, enabling spectrum managers to strike the right balance as the market evolves.

With the aim of providing sufficient incentives to invest in networks, most OECD member countries have spectrum licence duration periods ranging from 10 to 30 years, depending on the spectrum band, with most periods lasting around 20 years (Annex Table A 1). For OECD countries within the European Union, the European Electronic Communications Code (EECC) specifies that member states should provide regulatory certainty for at least 20 years (Art. 49) (European Commission, 2018[33]). Furthermore, spectrum licences should last at least 15 years with the possibility of an "adequate" 5-year extension (European Commission, 2018[33]). In Colombia, recent changes to the communication legal framework, which follows an OECD recommendation made in 2014 (OECD, 2014[34]), extends spectrum licence duration from 10 to 20 years, with the possibility of a renewal (ICT Modernisation Act, Law 1978 of 2019, art. 12).

While most OECD countries favour long spectrum licences with clear conditions for licence renewals, this does not mean that countries cannot revoke spectrum licences. The United Kingdom, for example, removed predefined licence duration terms to increase investment certainty surrounding spectrum licences (i.e. "indefinite licences), but the spectrum manager (Ofcom) can revoke any licence for spectrum management grounds, with a five-year notice. In other words, "indefinite licences" only mean that Ofcom has limited rights of revocation during an initial term of 20 years. After this term, with appropriate notice to the licensee, Ofcom can revoke the licence. Ofcom retained this right due to the risk of specific market failures, such as lack of competition, as part of a suite of regulatory levers that are designed to ensure spectrum's efficient use. Other levers include ensuring optimal allocative efficiency in the first instance and the application of opportunity cost licence fees after the expiry of the initial term (OECD, 2020[35]).

While most OECD countries seek to ensure regulatory certainty through long licence durations and high probabilities of renewal, after the initial period of the licence, many opt to undertake auctions when other parties show interest in making use of the spectrum. In fact, several OECD countries only renew the licence if there is no other party interested in the spectrum (Annex Table A 1). Often, conditions placed on spectrum licences are also key levers used by OECD spectrum managers to promote both mobile market competition and network coverage.

Some academics have proposed a theoretical approach to licensing that may better balance the competing objectives of strong investment incentives and facilitating innovative entry (Milgrom, Weyl and Zhang, 2017[36]; Weyl and Zhang, 2021[37]). In illiquid secondary spectrum markets, incumbent users may exert market power when setting the price of spectrum, or may have strategic considerations to hoard spectrum to block entry of future competitors (i.e. foreclosure). In such cases, parties interested in new use cases may prefer to compete for short-term licences in efficient auctions, rather than engage in secondary market transactions. Recent economic theory has started to develop potential further market-based solutions. Rather than providing incumbents with a renewal expectancy, or with no path for licence renewal, one alternative concept proposed by Milgrom, Weyl and Zhang (2017[36]) is to implement the theory of "depreciating licences" through the use of "foothold auctions" (See Annex B on "Depreciating licences and their potential application to spectrum rights"). Under this approach, there would be a limited licence term (e.g. three years), which would be followed by an auction in which incumbent licensees compete against other bidders interested in the spectrum. To protect investment incentives, the incumbent licensee would receive a share of the proceeds as compensation for relinquishing their spectrum "equity" if they were not the highest bidder (e.g. a payment of 70% of the final auction price for their spectrum).

Spectrum assignment procedures for mobile services

OECD countries are increasingly seeking to incorporate several policy objectives in licensing procedures (e.g. enhancing competition and providing incentives to expand coverage of mobile networks). As such, licence assignment is often accompanied by certain obligations to ensure the assignee will meet the goals of the regulator and or the spectrum manager. Coverage obligations in spectrum assignment procedures, along with a competitive communication market, have proven to be an effective tool in OECD countries to extend mobile broadband coverage in rural and remote areas. Spectrum assignment can also shape competitive dynamics in the communication sector. Many recent spectrum assignment procedures in OECD countries have included clauses to promote market competition (e.g. giving priority to new entrants, spectrum caps, or commitments to host mobile virtual network operators [MVNOs]).

Given that countries seek to promote the most efficient use of spectrum to increase overall welfare in their respective spectrum management strategies, fiscal revenue maximisation in spectrum assignment procedures is not a guiding policy principle in many OECD countries. In fact, in several regulatory frameworks across the OECD, revenue maximisation for spectrum management is not an object of sectoral legislation, while enhancing social welfare through expansive and efficient use of spectrum is explicitly stated in many spectrum strategies. That being said, appropriate spectrum pricing is a mechanism to promote efficient use, as it requires licence holders to pay a price that reflects the value of the spectrum. This maximizes welfare by putting the spectrum to its most effective use.

The choice in spectrum assignment procedure depends on the type of bands in question and the type of service or use anticipated. If spectrum supply exceeds demand in a band, then a low-cost assignment procedure, such as a first-come-first-served mechanism may enable spectrum to be put into use in a speedy manner. If licences subsequently increase in value, flexibility in these licences would allow for a trading mechanism for spectrum to be rechannelled into more efficient uses. In some cases, when spectrum supply exceeds demand in a given band, the spectrum manager may also wish to consider whether the band is allocated to its highest value use. If there is a strong indication that the spectrum band is not allocated to its highest value use, the spectrum manager may weigh the opportunity cost of holding off on assigning the band until an even higher value use emerges, given the difficulties associated with spectrum repurposing.

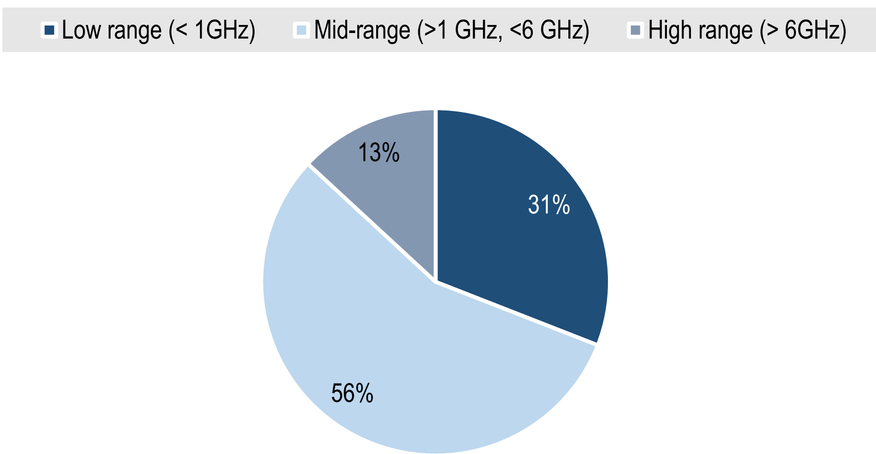
If spectrum demand exceeds supply in a band, then spectrum managers would likely choose between a comparative selection procedure and an auction (RSPG, 2016[38]). The use of market-based auction mechanisms for spectrum assignment is an effective way to help ensure that the resource is used in the most efficient manner. As such, spectrum auctions have been common practice in many OECD countries for the last two decades for bands where there is likely to be greater demand, for example for bands identified for mobile services. The first auctions for mobile use took place in the United States and New Zealand back in the early 1990s. By the year 2000, 12 out of the then 30 OECD countries had already introduced auctions to assign spectrum for mobile communications. By 2022, auctions were used in 36 out of 38 OECD countries.

One of the reasons OECD countries introduced auctions for assigning spectrum was to increase transparency in spectrum assignments. A second reason was to use this as a tool to discover the market value of the spectrum, given that, due to their knowledge and experience, industry players are better placed than government administrators to assess its value. A third reason was that alternative mechanisms for assigning spectrum, such as comparative selection or administrative procedures (also known as "beauty contests") or lotteries, often led to inefficient assignments and did not maximise social welfare (Milgrom, 2004[39]; Cramton, 1997[40]). With a well-designed auction, licences will go to the parties that value them the most, and thus will make the best use of the spectrum (Cramton, 2002[41]). Economic theory has made a strong case against using administrative selection, pointing out that if the good is initially assigned to the "wrong hands" in the primary market, there is generally no way to design a private bargaining process (i.e. a secondary market) without delays or failures (Milgrom, 2000[42]).[23]

Between 2016 and the end of 2021, 84 spectrum assignments in different frequency ranges were auctioned in the OECD and in Brazil for mobile communications, with many of these auctions being conducted for licences in multiple bands. The most common frequency range was mid-band spectrum (i.e. above 1 GHz and below 6 GHz) (Figure 4).

In terms of design, spectrum caps are widely used in auctions to encourage entry and address dominance. Since 2016, out of the 84 spectrum auctions conducted in OECD countries and Brazil, 62 (73.8%) included spectrum caps, while only 9 (10.7%) reserved blocks for entrants. With the aim of bridging connectivity divides, 41 (48.8%) auctions included coverage obligations, when considering all bands. Out of these 84 auctions considering all bands, 26 pertained to low frequency spectrum (i.e. below 1 GHz), which contains spectrum bands particularly suitable for extending coverage in rural areas. Coverage obligations were included in 73% of low-band spectrum auctions.

Figure 4. Share of spectrum assignments according to frequency ranges auctioned during the 2016-21 period in OECD countries and Brazil



Note: Total of 84 assignments through auctions considering different bands, with many bands being auctioned in a multiband setting.
Source: OECD elaboration.

Pursuing policy objectives through auctions

Spectrum assignment procedures include three key policy considerations in their design, which should be taken into consideration simultaneously: extending coverage, fostering investment, and promoting competition. These are overall policy objectives that spectrum managers pursue in assignment procedures.

Well-designed auctions allow players in the market to reveal their valuations for spectrum and assign the spectrum to the bidders with the highest valuations, and as such, generally ensure spectrum is used in the most efficient manner.

Spectrum auctions can have different formats. Some that are commonly used by spectrum managers or regulators include Combinatorial Clock Auction (CCA), Simultaneous Multiple-Round Ascending Auction (SMRA) and Sealed Bid Auctions (with first and second price rules). Each format has advantages and disadvantages, and as such, the choice of the specific format tends to depend on the combination of spectrum bands or blocks to be auctioned, the technology to be deployed and the services to be provided (RSPG, 2016[38]).

To achieve different policy objectives, a range of elements or tools in relation to spectrum auctions can be used. All of these influence the auction outcome. These elements include: establishing the reserve price, setting spectrum caps, determining the bandwidth and geographic scope of licence blocks, setting spectrum aside for a specific purpose, establishing coverage obligations and offering bidding credits, and the potential use of annual fees (in addition to the auction payment). [24] The different elements included in the auction or award process, will be internalised by bidders, and thus influence auction outcomes (i.e. the participants in the auction, spectrum pricing resulting from the auction as well as which bidders are assigned spectrum).

These elements of spectrum auctions can shape competition dynamics in various ways. For example, spectrum caps and reserving blocks for entrants may affect the spectrum holdings per operator, and hence influence the competitive dynamics in the mobile market. In addition, coverage obligations can play a vital role in expanding connectivity and bridging connectivity divides. The following non-exhaustive list includes a set of considerations for each of these elements that may influence the outcome of auctions.

- **Reserve prices**: If the reserve price set in an auction is too high, it could result in unsold spectrum blocks and less competition in the market. As such, reserve prices should be set at a level which allows for market players to reveal their valuations for the spectrum.
- **Spectrum caps:** Spectrum caps are common in OECD countries, where they are widely used as a tool to encourage entry and address situations of dominance. As noted by the RSPG, “spectrum caps are often set to limit the total amount of spectrum that an individual operator may hold, but they may additionally be used to limit the amount of spectrum that an operator may hold within a particular range” (RSPG, 2016[38]). On the one hand, larger players may have a strategic incentive to “hoard spectrum” to foreclose rivals and raise their costs. Therefore, spectrum caps serve to prevent incumbents from acquiring spectrum to foreclose or raise the costs of competitors. By balancing spectrum holdings, caps help ensure that enough competitors will have similar cost structures in the market. Caps may also help to rebalance access to spectrum (e.g. after a merger). On the other hand, tight spectrum caps may penalize the most efficient operators that have acquired a large customer base due to providing better service and that therefore may require more spectrum for efficiency reasons.
- **Coverage obligations**: Coverage obligations are common across the OECD and can contribute to a broader coverage of the population in rural and remote areas. When designing the auction, spectrum managers should ensure, however, that the extent of the coverage obligation is not an impediment for certain actors to bid in the auction and should consider the costs of these obligations when establishing the reserve price. Coverage obligations should further consider the spectrum band in

question as well as the geographical scope of the licence. As noted by the RSPG, "coverage obligations are best developed at the national level where they can be aligned with national policy and priorities" (RSPG, 2016[38]). Setting coverage obligations demands careful analysis due to challenges both in design and enforcement. Lax coverage obligations, for example, may waste the opportunities to ensure mobile broadband access in areas where there are fewer economic incentives to deploy network infrastructure. On the other hand, obligations that require extensive geographical coverage in too short a time may impose an excessive burden on operators (OECD, 2018[43]). For example, Brazil considered extending broadband coverage as the most important policy objective to consider in the 5G auction that concluded in November 2021 (as opposed to focusing only on revenue maximisation). The award process included coverage obligations (for the 700 MHz band) in federal highways and investment commitments to increase mobile broadband coverage and fibre backhaul in Brazilian municipalities (Anatel, 2022[44]).

- **Spectrum set asides (reserving blocks):** In this case, blocks are reserved to be auctioned for a specific class (or type) of bidders. This element of spectrum auction design is often used to facilitate the entry of new players into the market and spur competition. Some considerations when setting blocks aside include that spectrum may remain unused if there is no new entrant, or if "greenfield" deployments[25] take time. In addition, if there is insufficient competition for the set-aside blocks, spectrum may be assigned to firms that will not make the most efficient use of spectrum. This potential inefficiency should be balanced with the potentially enhanced competition gained with the entry of new players. Set asides may also reduce the amount of blocks available to all bidders, resulting in higher competition in these blocks, and hence prices paid for spectrum.[26] Another consideration in terms of ensuring efficient use of spectrum is preventing a situation where set-aside winners don't use the spectrum, but rather seek to sell the licence to an incumbent for a profit.
- **Bidding credits**: Bidding credits can be used in auctions to increase the participation of a designated subset of entities in the auction, for example small businesses or service providers in rural or tribal lands. Eligible entities receive bidding credits that offset the total amount of the winning bid, subject to certain limit or cap (Rosa, 2022[45]). For example, in the United States the FCC, will routinely offer bidding credits to small firms or providers in tribal lands, which lowers their final payments by a pre- established amount (FCC, 2022[46]).
- **Annual fees:** High annual fees, on top of auction payments, are not common practice in OECD countries. They may cause uncertainty in the amount that operators may ultimately pay for the licence over its duration (e.g. if these are set annually or changed over the course of the licence term by an agency in government with the objective of maximizing fiscal revenues). A rationale for auctioning spectrum licenses without annual licence fees is that by requiring bidders to pay the full price of the spectrum up front, the auction mechanism will promote the most efficient use of the spectrum band. This is reflected in the winning bidder's willingness to pay to acquire the licence. Thus, no additional fees are required as long as the licence has not expired. In the United Kingdom, for example, Ofcom only applies annual fees to mobile spectrum that was not initially auctioned, given that their primary way of determining the value of spectrum is through an auction procedure (Ofcom, 2015[47]; Ofcom, 2010[48]).[27] Moderate annual fees attached to spectrum licences after spectrum has been assigned through an auction, if employed at all, should ideally be set at relatively low levels. While some countries have annual spectrum fees related to recovering administrative costs of managing spectrum on a yearly basis (or some other form of annual regulatory fee), when an auction mechanism is in place, annual fees beyond such cost recovery are not usually employed. To the extent that a country places additional spectrum fees over and above the fees determined through a competitive bidding process, there is a risk of undermining policy objectives if they curb investment and innovation (Box 4).

Box 4. Effects of high annual fees on top of the upfront auction payments for spectrum

In most OECD countries, spectrum pricing is based on a one-time only, up-front payment levied upon winning bidders. While most countries use an initial auction to determine the total price of spectrum, over the lifetime of the licence, some countries may allow bidders to spread payments over a number of years, which may ease capital market constraints for some players. However, this practice differs to the case where a hybrid model is employed, which sets an up-front auction fee and a high administratively determined annual fee. In the former case, the auction mechanism sets the total fee, while in the latter, a significant share of the total cost of spectrum is administratively determined.

There seems to be two main potential drawbacks of using this form of hybrid model instead of an approach that relies entirely on an auction. First, when auction participants are completely certain of the levels of the annual fees during the lifetime of the licence (i.e. certainty of contractual terms set by the authority), they take into account the net present value of these fees when bidding in an auction, which has the effect of increasing the reserve price of the auction. That is, if the sum of annual fees plus the up-front reserve price set by the regulator in an auction is too high (i.e. substantially higher than the market value that would have been determined from a single auction), it may deter participation in the auction by players that may have introduced more competition, as bidders internalise these fees in their strategies. It may also cause spectrum blocks to go unsold. That being said, any system with a reserve price set too high may encounter a similar problem (OECD, 2017[49]).

Second, if auction participants are not certain of the level of annual fees that will apply during the lifetime of the licence, it may dissuade them from properly revealing their value for spectrum during the auction, leading to a misallocation of this scarce resource (i.e. spectrum being allocated to a player that will not make the most efficient use of it). This effect of dissuading participants from properly revealing their valuation due to uncertainty is known as the “ratchet effect”[28] (Laffont and Tirole, 1988[50]), and results from the mere fact that bidders believe there is a risk of lack of commitment from the seller, in this case, the government (OECD, 2017[49]).

Like many other OECD countries, Mexico uses auctions to determine the value of spectrum. However, as pointed out in the “OECD Telecommunication and Broadcasting Review of Mexico 2017”, setting high-annual fees for spectrum rights, together with an auction (i.e., up-front payment), sets Mexico apart from the much more common practice in OECD countries where an auction determines the full amount for payment. According to the regulator (IFT), the sum of annual fees over the lives of licences granted under this practice represented between 70% and 90% of the total cost of spectrum (IFT, 2020, p. 11[51]). While the Mexican Congress had not changed spectrum fees in real terms since 2003 until 2017,[29] this scenario already increased contractual risks, with the potential drawback of blocks remaining unsold in future auctions (OECD, 2017[49]).

In recent years, the Mexican Congress substantially increased these annual fees,[30] which led to consequences in the structure of the mobile market, as well as in spectrum auction outcomes. For example, at the end of 2019, Telefonica returned spectrum licenses to the communication regulator in Mexico (IFT) and finalised the transaction by 30 June 2022. The company reports that one reason for doing so was the high cost of detaining spectrum assets in Mexico, stemming from high annual fees (El Economista, 2020[52]). To be able to continue to provide mobile services in the country, the company signed a network sharing agreement with AT&T. In July 2022, Telefónica claimed that returning spectrum in Mexico led to savings of 90% of their financial debt due to spectrum costs and the operation of the radio access network (DPL News, 2022[53]). In addition, in October 2021, Mexico held an auction 800 MHz and 2.5 GHz spectrum bands, where out of the 41 blocks available, 38 blocks remained unsold (and only two companies submitted bids) (IFT, 2021[54]). The regulator, IFT, publicly voiced concerns on how the annual fees set by Congress deterred entry in the auction. These fees may also exacerbate competitive and financial asymmetries between operators.

Sources: OECD (2017[49]), *OECD Telecommunication and Broadcasting Review of Mexico 2017*, OECD Publishing, Paris, https://doi.org/10.1787/9789264278011-en; Laffont, Rey and Tirole (1988[50]), "The Dynamics of Incentive Contracts", Econometrica, vol. 56, no. 5, 1988, pp. 1153–75. JSTOR, https://doi.org/10.2307/1911362; IFT's press releases: (IFT, 2020, p. 11[51]); (IFT, 2021[54]), and preiodicals: (DPL News, 2022[53]); (El Economista, 2020[52]).

In recent years, some innovative designs have been used for spectrum auctions, such as combining forward and reverse auctions, which among other goals, can be used to ensure coverage obligations. The communication regulator of Austria (RTR), for example, used such an auction mechanism in the "5G- pioneer spectrum" multi-band auction (i.e. 700 MHz, 1.5 GHz 2.1 GHz bands) that was conducted on September 2020 to expand mobile broadband coverage. The design allowed RTR to address far reaching coverage targets, while avoiding risks linked to ambitious coverage obligations (e.g. potentially high deployment costs, barriers to build sites, unsold frequencies, etc.). Successful bidders of the ascending auction had the possibility to earn a price discount on the spectrum fee by accepting coverage obligations. The price discount and level of coverage was determined by a combinatorial reverse auction (i.e. the winning bids would be the lowest cost of deployment and/or highest level of coverage). The auction resulted in 85% of previously underserved municipalities receiving high-quality mobile broadband coverage (RTR, 2020[55]).

An example of an innovative spectrum auction design that sought to tackle the issue of re-purposing spectrum for new uses while preserving rights of licence holders was the "Broadcast Incentive Auction and Post-Auction Transition" in the United States in 2016-2017, known as the "incentive auction" in the 600 MHz band (FCC, 2017[56]). The auction was comprised of two separate but interdependent auctions: i) a reverse auction, determining the price at which broadcasters would voluntarily relinquish their spectrum usage rights; and ii) a forward auction, determining the price that communication operators were willing to pay for flexible use wireless licenses. What held both auctions together was the "repacking" process that involved reorganising and assigning channels to the remaining broadcast television stations in order to create contiguous blocks of cleared spectrum suitable for flexible use (OECD, 2014[6]; Symons and Milgrom, 2018[57]). The auction ended on 30 March 2017, which resulted in repurposing 84 megahertz of spectrum from television broadcasting to mobile broadband (i.e. 70 megahertz for licensed use and another 14 megahertz for wireless microphones and unlicensed use) (FCC, 2017[56]).

In the United Kingdom, while Ofcom had initially intended to impose coverage obligations on winners of the 700 MHz band auction, instead, mobile network operators (MNOs) in conjunction with the UK Government developed a Single Rural Network (SRN) solution. The SRN is an advanced form of network and spectrum sharing designed to ensure population and geographic coverage. Operators agreed to invest GBP 532 million to close connectivity gaps in areas where there is currently only coverage by one but not all operators (i.e. "grey areas"), with the aim of increasing competition in those areas. This private investment will be complemented by more than GBP 500 million of government funding to eliminate connectivity gaps in areas where there is currently no coverage from any operator, also known as "white areas" (UK Government, 2020[58]).

Licensing regimes, including general authorisations, intertwine with all other aspects of spectrum management as they are the main instrument of authorization and enforcement, by which policy makers put into effect all their different policy considerations and objectives. Spectrum managers and policy makers are often looking to see whether licensing frameworks may need to evolve to enable more flexible access approaches, such that diverse types of spectrum users can access relevant frequency bands when and where they need it.

Some questions for policy makers and spectrum managers that may arise are the following. How can spectrum managers and policy makers ensure the licensing framework achieves efficient use of spectrum, promotes investment, and fosters wireless innovation, all at the same time? How can they balance competing demands? Are current licensing frameworks approaches fit-for-purpose as they move to authorise higher bands for mobile services (e.g. mmWave)? This report does not seek to provide a generic answer to all these questions, given that licensing frameworks sit within the context of the legal regimes in different countries. However, this report does look at current developments and trends in spectrum management in the following sections to increase our understanding of the issues. This includes taking stock of lessons learned so far, as well as areas where countries are considering adapting their frameworks.

Trends in spectrum management

OECD countries are exploring innovative approaches to spectrum management in light of emerging technologies and the evolving market landscape. Examples include new forms of spectrum sharing, ways to handle spectrum repurposing, flexibility in licensing to cater to local and national needs, secondary markets of spectrum, as well as dynamic spectrum sharing. This section provides an overview of the main trends in spectrum management.

Trends in licensing

Developments in millimetre wave (mmWave) spectrum

While mmWave bands have been used in many countries to support services such as point-to-point fixed links, Earth Exploration Satellites and short-range devices, some mmWave bands have been made available to provide mobile services. One of the advantages of using mmWave spectrum for mobile networks is the amount of spectrum available in those ranges. In addition, another benefit is the increase of spectral efficiency (i.e. the net data rate that can be supported per unit of spectrum). However, the use of mmWave spectrum for mobile services, given its propagation features, requires network densification (i.e. placing smaller cells closer to connected devices, which necessitates much more mobile backhaul and a high number of small cells to be deployed) (OECD, 2019[14]). As such, network densification entails important investments to deploy communication networks, as well as access to power supplies to enable network functions. This does not necessarily mean that small cells will be deployed everywhere, but rather that more base stations will be required where 5G mmWave networks are deployed (e.g. local networks using the 26 GHz band) compared to a deployment solely relying on mid-band spectrum covering the same area.

Millimetre wave spectrum also faces technical challenges such as being susceptible to attenuation due to obstacles and having difficulties penetrating walls to reach indoors. These challenges are likely to necessitate the use of complementary connectivity solutions to resolve indoor network coverage, or the use of complementary spectrum bands. Complementary connectivity solutions, such as WLAN connectivity solutions (e.g. Wi-Fi) combined with 5G connectivity solutions, are already being used, especially in locations with a high-density of connected devices, such as airports and sport stadiums, as well as in residential settings where offload to WLAN networks is common. For example, in the United States, mobile operators that have deployed 5G networks using mmWave spectrum established partnerships with neutral hosts, such as Boingo,[31] which is specialised in connectivity solutions for indoors and dense public places making use of the Citizens Broadband Radio Service (CBRS) band, a portion of the 3.5 GHz band (OECD, 2022[59]).

While most 5G commercial network deployments have relied on mid-band and lower-band spectrum (i.e. below the 6 GHz band, e.g. using 700 MHz and 3.5 GHz frequency bands), a few 5G commercial deployments are making use of mmWave spectrum (e.g. Australia, Japan, the United States) (OECD, 2022[59]), sometimes for specific or local needs.[32] In Italy, for example, Fastweb launched a Fixed Wireless Access (FWA) service in December 2020 using mmWave spectrum, and at the end of February 2022, Fastweb, in partnership with Qualcomm, announced plans to commercialize 5G standalone (SA) services using mmWave spectrum (RCR Wireless, 2022[60]; Qualcomm, 2022[61]).

The benefits of the use of mmWave spectrum (high capacity and availability of spectrum) may help support a wide range of applications requiring low-latency and high-bandwidth services, such as mission-critical applications. Speeds are also likely to be faster if higher spectrum bands are used (e.g. mmWave) (OECD, 2022[59]). A study by Opensignal shows that smartphone users of commercially deployed mmWave 5G networks in the United States experienced average download speeds that were ten times faster than 5G networks using sub-6 GHz spectrum (Opensignal, 2021[62]).[33] Experienced 5G speeds by country,[34] however, may vary depending on consumer demand, network design, spectrum holdings by operators, as well as the type of spectrum used to deploy 5G networks and the speed of roll-out of commercial services.[35]

Some claim that there have been few commercial deployments of mobile networks using mmWave (beside trials) due to low demand. For example, this may be the case in Europe according to the 5G Observatory (European Commission, 2021[63]). However, a GSA report found that, as of December 2021, 192 operators in 48 countries were investing in 5G mmWave deployments (including trials, acquiring licences, and deploying networks), 140 operators in 24 countries held mmWave licences, and 28 operators in 16 countries were actively deploying 5G commercial networks using mmWave spectrum (GSA, 2022[64]). As such, it seems that the mmWave ecosystem is maturing, and that more deployments will be observed in the near future.

The main question facing spectrum managers is, what is the optimal licensing model for mmWave bands in their respective country? For example, is there merit in a national award for the 26 GHz band, or are regional or local licences a more suitable model? Several OECD countries are holding public consultations this year to study the market demand for mmWave spectrum and appropriate award schemes (e.g. France, Italy for the lower part of the 26 GHz band, Portugal, Spain), have published reports on the matter (e.g. Ireland), [36]or are consulting on the licensing approach, such as the United Kingdom, which covers the 26 GHz and 40 GHz bands (Ofcom, 2022[65]).

In countries that have licensed mmWave for mobile, five main licensing models can be observed: 1) nationwide exclusive licence (auction or comparative selection); 2) exclusive sub-national/regional licences; 3) a hybrid approach (nationwide licence combined with spectrum reserved for local private networks); 4) nationwide licences with a club use model ("use it or lease it" clause); 5) licences for local (private) networks or local licences in a first-come-first-served basis (Table 2). The detailed table of mmWave assignments is found in Annex Table C.1.

Other countries have explicitly stated their intentions to assign mmWave spectrum in the upcoming years: parts of the 26 GHz band in Austria (in 2023), the 26, 28 and 38 GHz bands in Canada (in 2024), the 26 GHz band in Colombia, the 26 and 28 GHz band in Costa Rica, the 26 GHz band in Estonia, the 24 GHz band in Israel (in 2022), the 26 GHz band in Latvia (in 2024), the 26 GHz band in Norway (in 2022), the 26 GHz band in Poland, the 26 GHz in Spain,[37] and the 26 GHz band in Sweden (in 2025-26). Sweden[38] and Estonia plan to take a hybrid approach, i.e. both national licences and spectrum reserved for local networks. Latvia intends to licence the 26 GHz band in 2024 and plans to reserve 850 MHz for private networks for industry use or non-communication service providers, where a public consultation will be planned for interested parties to express their views.

Table 2. Licensing models for mmWave spectrum

Licensing model for mmWave spectrum	Countries
1) National level exclusive licence (auction or comparative selection procedure)	Croatia (2021), Slovenia (2021), Greece (2020), Chile* (2021), Japan (2019), Korea (2018), Singapore (2020), Finland (2020)
2) Sub-national (regional) exclusive licences	Brazil** (2021), Canada (2019), United States (2019)
3) Hybrid approach: National level (traditional) licences + spectrum reserved for local (private) networks or local apparatus licence	Denmark (2021), Finland (2020), Australia (2021)
4) National level licences with concurrent shared access, "club use" model ("use it or lease it" clause)	Italy (2018, upper part of the 26 GHz band)
5) Local licences for (private) local networks or local licences first-come-first-served basis	Germany (2021), United Kingdom (lower part of 26 GHz, sharing framework for indoor use, first-come-first-served basis), Latvia (1 GHz in the 26 GHz band in first-come-first-served basis, while the rest may be assigned through an auction in the future).

Note: *Chile assigned spectrum to three national MNOs in March 2021, but the blocks in the 26 GHz band were regional. Depending on the regions, there are one, two, or three licensees per region (5G Observatory EU, 2021[66]). **Brazil assigned national and regional licences for the 26 GHz band in the auction concluded in November 2021.
Source: OECD elaboration based on country replies to the regulatory questionnaire.

A more granular approach to licensing to accommodate different needs

As economies and societies continue in their digital transformation, new and more granular spectrum needs arise. The number of players that require spectrum and the volume of spectrum they seek to use is increasing, as are the use cases across different sectors of the economy and society. Some of these spectrum needs may require more flexibility in terms of time, but also geographical location.

The geographical scope of licences: catering to national, regional, and local needs

With the aim of supporting a growing diversity of services and applications, some authorities are considering localised spectrum access for services that would suit specialised services in specific geographical areas such as airports, farms, or industrial plants. National licences or large sub-national (regional) licences, on the other hand, can support public communication services requiring wide coverage and serving a large end-user base.

A granular approach to licences is not new for certain types of radio communication services that have been assigned in regional and local levels given their nature or size of the country. The nature of some services is well suited to local licences, such as fixed point-to-point links for backhaul, spectrum for Programme-Making and Special Events (PMSE), which can use spectrum on a fractional occupancy basis based on time and location, as well as broadcasting, among others. However, in some countries, a granular or sub-national approach to mobile licences has been a relatively recent development. When assigning spectrum for bands where demand typically exceeds supply, such as spectrum below 6 GHz for mobile broadband, the main trend at present remains national (or large regional) licences. However, increasingly countries have implemented a combination of approaches, to cater to both national and regional/local needs, such that spectrum is effectively used where and when it is needed.

When a more granular approach to mobile licences is taken, policy makers may have several questions in mind. These include: What are the main challenges of a granular/local approach to licensing and how can these challenges be mitigated? What is the optimal geographical scope of a licence, for example a national licence versus a regional or local licence? Does the geographical scope of the licence depend on the type of frequency band in question?

One of the main challenges when following a more granular approach to licensing, (which also occurs in national licences), is how to ensure an efficient use of spectrum from both a technical and economic perspective (i.e. that spectrum is not being hoarded or unused) while also offering enough resources to satisfy local needs to promote innovation and investment by deploying local networks. With granular licensing, the main challenge to ensure efficient use is having a spectrum assignment mechanism that allows operators to efficiently aggregate licenses across geographic areas. To find a proper balance between entities' demands and spectrum available for local use, spectrum managers need to understand the actual demand for local licences and their intended use cases. Granular approaches may lead to spectrum fragmentation, which may in turn decrease the benefits from the economies of scale for licence holders or decrease their ability to benefit from potential geographic complementarities of licences. This is particularly true if the service in question requires large channel bandwidth or specific band plans, as is often the case for mobile services in higher frequency bands. Therefore, this understanding is important to ensure efficient spectrum planning and assignment, and hence, the efficient use of spectrum.

For a regional or local licensing approach, one of the main challenges is to ensure that the spectrum authorisation framework is appropriate for the typical use cases that are likely to be deployed using the spectrum. In some cases, the "typical" use cases can be vastly different from each other. For example, in the 3.8 to 4.2 GHz band, local licences can be used for a dedicated onsite private mobile network for a campus, factory, or for a rural FWA system offering broadband connections over a few kilometres' radius. When considering the assignment approach, finding the right balance will ensure that the spectrum is used efficiently. This is currently being examined at CEPT following a mandate from the European Union for low and medium power local networks in the 3.8 - 4.2 GHz bands (CEPT, 2021[67]), and it is already underway in the United Kingdom in its Shared Access Licence framework for the 3.8 – 4.2 GHz band (Ofcom, 2019[68]).

Another aspect in granular approaches to licences is setting the technical conditions for efficient geographical delimitation to protect users from harmful interference (i.e. interference coordination at geographic boundaries), which may be rendered more complex with a local approach compared to larger areas (i.e. regional or national). These conditions need to be carefully assessed to avoid inefficient use of spectrum or poor quality of service due to interference. This may be a balancing act between the needs of local licence holders for predictable conditions (i.e. the proper operation for the user in a service area) while accommodating the demands of neighbouring networks and protecting them at the border of these local assignments. Potential harmful interference is a lingering issue and could be mitigated by the use of a frequency planning platform. The performance of transmitting and receiving equipment also plays a role in the avoidance of harmful interference (see below). Radio synchronisation (compatibility) of neighbouring applications needs to be ensured as well.

Concerning the geographical scope between national versus regional licences, regional licences may be inherently linked to the relative geographical size of the country in question. In the early 2000s, there were examples of countries assigning regional licences for mobile services, but these were often granted on an exclusive regional basis, creating segmented mobile markets by horizontal players (MNOs). Since then, this trend of placing regional "monopoly" licences has been reversed so that MNOs could compete on equal footing on a national and regional level (and mitigate the use of roaming charges across regions of the same country). At present, for some smaller countries, there is a question of whether splitting the market into smaller segments may limit opportunities for profitable business cases (e.g. Lithuania, Costa Rica). However, in larger countries (e.g. Brazil, Canada, the United States), a regional approach combined with national licences, or regional licences that can be aggregated at a national level, may have the advantage of both supporting national MNOs while allowing possibilities for entrants in different regions. For example, in November 2021, Brazil held a successful multiband auction for mobile services destined to enhance 5G deployment (2.3 GHz, 3.5 GHz, 700 MHz and 26 GHz) that included both national and regional blocks to allow for national MNOs to gain spectrum, while allowing for regional entrants to participate in the auction (Ministério das Comunicações, 2021[69]). In the United States, licences are typically sub-national. However, licensees often have aggregated licenses to achieve national coverage, which avoids the need to decide how much of the band will be assigned in national licenses compared to how much in regional licenses. This approach also encourages competition in an auction by allowing regional players to compete against national players. Canada typically only uses regional licences. In 2019, for example, Canada auctioned flexible use (mobile/fixed) licences in 16 distinct regions. The country took a more granular approach in the 2021 3 500 MHz auction, as flexible use licences were available in 172 regional areas. In addition, Canada announced smaller service areas in 2021 that could allow licencing to over 654 distinct regions.

The geographical scope of a licence may also depend on the frequency band in question. Some countries note that there is an increasing trend towards more granular assignments, not only due to the growing demand for frequencies for local use, but also the identification of higher frequencies for mobile services (such as mmWave). The propagation features of mmWave spectrum, as well as the amount of spectrum available, may render this type of assignment easier in practice (i.e. fewer interference issues with neighbouring applications that may arise with local assignments and fewer competing demands). Overall, when local licences are being considered for mid-band spectrum, it is important to consider the total amount of spectrum available in that band when several types of users compete for the same spectrum, including, for example, MNOs and industrial players.

Spectrum managers across the OECD engaged in granular approaches are following different measures to ensure the efficient use of spectrum. For mobile licences, when spectrum has been assigned on a national basis and is not being used in every location, some regulators may deem it appropriate to enable access to this spectrum for new users, provided that avoidance of harmful interference can be guaranteed, and their licensing framework is flexible enough to enable this. In addition, spectrum managers may wish to introduce flexibility in the licence framework by allowing further use by local players (e.g. by shared access, discussed more thoroughly in the subsequent section). In the event that the local licence is not used in the most efficient way by local players, building flexibility into the licensing framework may allow them to revoke licences.

The following list summarises the countries that have taken regional and local approach to licence mobile spectrum within surveyed countries (the countries surveyed include 37 OECD countries, Brazil, and Singapore) (Table 3).

Table 3. Countries taking regional and local spectrum licensing approaches

Country	Local or regional licence	Band	Future Plans*
Australia	Local and regional: AWL licence	26 and 28 GHz bands	Plans for 3.5 GHz
Austria	Regional	3.5 GHz	26 GHz [local]
Brazil	Regional	700 MHz, 3.5 GHz, 2.3 GHz, 26 GHz	
Canada	Regional	3.5 GHz, 3.8 GHz and mmWave	White spaces to support rural connectivity. White space is not planned for the 3.5 GHz band but may be used in the future for other bands.
Chile	Regional	26 GHz	
Germany	Regional and/or local	3.7 – 3.8 GHz and 26 GHz	
Finland	Local networks	24.25 – 25.1 GHz	
Ireland	Regional	3.6 GHz	
Japan	Local (private) networks	2 575 – 2 595 MHz, 4.6-4.9 GHz and 28.2- 29.1 GHz	
Korea	Local (private) networks		28 GHz band
Mexico	Regional	850 MHz**	
Sweden	Local	Part of 3.7-3.8 GHz and 26 GHz bands	
United Kingdom	Local	1.8 GHz, 2.3 GHz, 3.8 – 4.2 GHz, and 24 – 26 GHz (first-come-first served)	
United States	Regional (and county level)	3.45 GHz, 2.5 GHz, 3.7 GHz, 3.5 GHz, and mmWave	

Note: *Spain, Latvia and Norway have expressed plans to consider local licences in the near future. **Mexico: The latest mobile spectrum auction in Mexico (IFT-10) included regional spectrum for the 850 MHz band. It was offered by Basic Service Areas (BSA), which is a geographic area made up of one or several municipalities or territorial demarcations within the country. Mexico is divided into 65 BSA, and 37 of them were included on IFT-10 auction.
Source: OECD based on questionnaire responses supplemented by national sources.

In the United Kingdom, Ofcom published its spectrum management strategy for the next decade in July 2021 (Ofcom, 2021[12]). Within this strategy, Ofcom proposes to support the growing diversity of wireless services and providers by considering further options for localised spectrum access when authorising new access to spectrum. In 2019, Ofcom introduced two new flexible licences that can address local needs: the *shared access licence* and the *local access licence*. The shared access licence is available in the 1 800 MHz, 2 300 MHz and 3.8 – 4.2 GHz band spectrum bands, as well as the 24 – 26 GHz bands. There are medium and lower power licences available under the shared access licence.[39] In addition, for spectrum that had already been licensed on a national basis, Ofcom introduced a local access licence that allows other uses to access spectrum licensed to a mobile network operator (MNO) in locations where a particular frequency is not being used (Ofcom, 2019[70]).[40] Ofcom also strives to build enough flexibility in the licence design that would allow the regulator to revoke a licence in a short time frame if spectrum is not being used during the prescribed period stated in the licence. CEPT is studying similar conditions to those implemented by the United Kingdom to develop harmonised technical conditions for low and medium power local networks in the 3.8 – 4.2 GHz band (CEPT, 2021[67]).

Germany took a combined approach to cater to both national and local needs. The German communication regulator Bundesnetzagentur (BNetzA) initially reserved the upper part of the 3.5 GHz band (3.7 – 3.8 GHz) band for local use (by industrial players), while the lower part (3.4 – 3.7 GHz) was auctioned in a national exclusive licence approach for MNOs. The 26 GHz band has also been assigned locally, as was open for both MNOs and industrial players. Germany amended its regulations in December 2021 to allow campus licence holders to also opt for operator agreements in the 3.7 – 3.8 GHz band (Bundesnetzagentur, 2021[71]). With this regulatory change, MNOs could also use the upper part of the 3.5 GHZ band in Germany but would need to enter into agreements with campus licence holders (Policy Tracker, 2022[72]). The changes aim to make it easier for MNOs and campus licence holders to coexist in the band (Policy Tracker, 2022[72]).

Australia introduced an innovative approach to licensing in 2020 that provides flexibility to cater to local uses through the area-wide apparatus licences (AWLs, see Box 3), meant to expand the regulator's (ACMA) licensing toolkit to meet the growing demand for local area wireless broadband. This licence type is capable of supporting a wide-variety of localised spectrum use cases; including private 'campus-style' broadband networks to service industrial precincts, hospitals, mines, farms, and education centres (ACMA, 2020[31]). In addition, the ACMA is currently finalising plans for spectrum assignments in the 3.4 – 4.2 GHz band to support further deployments of 5G networks, which includes both exclusive licences and AWL licences to support local access wireless broadband in rural, regional, and metropolitan areas. The outcome of the public consultation led to exclusive licences for wide area wireless broadband in 3 700 – 3 800 MHz in metropolitan and regional areas, and local area wireless broadband in 3 700 – 3 800 MHz in remote areas on a shared basis (coexistence) with other services in the band (ACMA, 2021[73]).

An additional licensing model to address connectivity needs in different geographical areas, for example in rural areas, is through not-for-profit or social purpose licences. Only three out of 38 OECD countries have a specific licence for social purposes or non-commercial networks that can be used for community networks: Australia, Mexico, and the United States. In Australia, non-commercial licences pertain to community radio and broadcasting (i.e. television). However, certain community broadcasting services will have access to licensing arrangements until 2024 and then can be provided using online platforms.[41] In Mexico, this type of licence can be used to provide a wider range of not-for-profit communication services, such as mobile broadband. To date, five licenses have been granted for the provision of communication services and 467 commercial, for-profit licences have been granted through Wireless Internet Service Providers (WISPs), which provide services mainly in rural areas. In the United States, the 2.5 GHz band was licensed spectrum to non-profit schools for educational purposes, and in 2020, the FCC established a "Tribe Priority Window" to allow for Tribes in rural areas to directly access unassigned 2.5 GHz spectrum to expand broadband in their lands (FCC, 2021[74]). In Canada, while there is no social purpose licence, broadcasting spectrum has been used to provide wireless cable TV-like services for small, isolated communities. Nevertheless, community-owned communication service networks are also arising in Canada. For example, Keewaytinook Mobile (KMobile) is community-owned mobile network to serve five indigenous communities in Northern Ontario that relied on a regional licence previously assigned to a telephone operator together with partnerships with GSM operators (Beaton et al., 2015[75]).

In other countries, the licensing framework may cater to local networks to address rural connectivity needs, including with low-cost licences to extend coverage in rural and remote areas. In Finland and Sweden, for example, local licences are granted for any purpose, including for community or smaller networks. In New Zealand, licences may be granted for rural or local use, but the trend has been relatively static given that the three national MNOs have significant national coverage and the number of WISPs that provide regional services has remained constant in the last three years. In Japan, licences intended for local 5G networks may be used by various entities, including municipal governments. In the United Kingdom, low-cost licenses suitable for use by community, rural, non-profit are available under the local shared access licences framework already noted above, and through two other low-cost licences: Fixed Wireless Access (FWA) connectivity solutions through WISPs in the 5.8 GHz band (Ofcom, 2022[76]), and connectivity solutions in the EHF bands (i.e. in the 30 – 300 GHz range) (Ofcom, 2022[77]).

Catering to use cases across all sectors of the economy

Developments of wireless networks, including cellular (5G) and WLANs (e.g. Wi-Fi), can help meet performance requirements of a variety of use cases stemming from the digital transformation across all sectors of the economy. For example, current trials and deployments for 5G focus on energy, transport and mobility, health care, agriculture, industry, public safety, environment, tourism, and culture (OECD, 2019[14]). This list is not exhaustive and could be extended to other areas.

Across the OECD area, 5G private networks have been emerging in several countries. Private networks are usually local, non-public communication networks, dedicated to the owner of the network. Private networks can be operated by the entities owning the networks or they can be operated by MNOs, even in scenarios where they are not the owners of the network. A major hurdle for the development of 5G private networks is providing access to appropriate and affordable spectrum. Local private networks can access spectrum resources either through direct local licences assigned to non-communication service providers (i.e. industrial firms, public entities, etc.), or via mobile operators offering such capabilities, which may leverage features such as network slicing to facilitate these dedicated networks. It could also be facilitated by tiered-shared access (e.g. the case of CBRS in the United States), which is discussed more in detail in the section below on “Approaches to share access with incumbent users”.

Depending on the use case and the business model, public mobile networks could deliver the network capacity and meet the performance requirements of some industrial applications, while other applications may be better met via private networks. A third option is that industrial applications could be delivered as “specialised” services over mobile networks (e.g. dedicated industrial networks). Developments in private networks could also increase demands for local spectrum access licenses.

By the end of June 2022, the Global mobile Supplier Association (GSA) identified 70 countries and territories with private network deployments based on LTE or 5G technologies, or where private network spectrum licences suitable for LTE or 5G had been assigned (GSA, 2022[78]).[42]

Communication regulators can follow diverse approaches to foster local wireless networks for industrial use cases.[43] First, many countries may be enabling the deployment of mobile networks, which can support connectivity solutions for private networks through dedicated offerings by mobile operators. With 5G standalone networks, network slicing may become an important feature for private networks. Secondly, some countries have started the process of opening up spectrum for local use in specific bands (e.g. France, Germany, Japan, Korea, the United Kingdom and the United States), which would enable the deployment of private networks.

Thirdly, countries may opt to attach wholesale access obligations, including leasing obligations, to mobile network operators (MNOs)’ licences so that mobile operators grant spectrum access to other players, such as industrial stakeholders and public institutions (e.g. Czech Republic, Denmark,[44] Italy, France, Norway, and Poland). Among the examples cited, Czech Republic, Denmark and Norway focused on leasing obligations. For example, in the Czech Republic, certain 20 MHz frequency blocks auctioned in the 3.4 – 3.6 GHz band carry requirements, which apply for the entire licence’s duration. Winning bidders of these blocks must lease the assigned spectrum to interested parties, for a limited geographic area[45], for the purpose of operating local private networks (CTU, 2020[79]). In Denmark, the 3 740 – 3 800 MHz block of spectrum auctioned in the 2021 multiband auction carries an obligation to lease the spectrum to requesting parties for the purpose of establishing private networks for the first 4 years of the licence’s duration (Danish Energy Agency, 2021[80]). Similarly, in Norway, the 3.6 GHz band (3.4 – 3.8 GHz) auction that concluded in September 2021 included within the rules an obligation for licensees to offer tailored solutions for private networks or, alternatively, the possibility for the private network to lease frequencies for a limited geographic area so that the private player can develop the private 5G local network itself (Nkom, 2021[81]).[46]

Finally, shared coordinated approaches of licensed bands, including industrial players, can be used for the proliferation of local networks (e.g. the CBRS band in the United States or Local Shared Access licences in the United Kingdom). The latter relates to new trends in spectrum sharing discussed in the subsection below.

Considering the first approach to foster local wireless networks for industrial use cases, there are recent examples of private networks receiving connectivity via mobile operators around the world. At present, MNOs are operating dedicated industrial networks for their clients without necessarily relying on 5G network slicing technology or leasing spectrum to third parties. In addition to dedicated industrial networks and spectrum leasing, 5G deployments, with the use of network slicing, are an additional way to enable private networks. A recent example of network slicing and Standalone (SA)-5G in the electricity sector is Vodafone UK's announcement in July 2021 of a partnership with UK Power Networks, the country's largest electricity network operator. Vodafone UK and UK Power Networks are trialling a "smart substation"[47] project called "Constellation" to manage the electricity grid in real time. These substations, that transform voltage in the electricity grid, will communicate with each other over a dedicated, highly secure slice of Vodafone's SA-5G network (Vodafone, 2021[82]).

Considering the second approach, a number of OECD countries, including Germany, France, Japan, and Korea have assigned local licences with dedicated spectrum for private networks, or have a general approach to local licences with shared access that could foster private networks (e.g. Australia, United Kingdom and the United States). As mentioned previously, Germany set aside 100 MHz of spectrum in the 3.7-3.8 GHz band specifically for industrial use for local campus licences. By September 2021, BNetzA had awarded 148 licences to applicants for deploying private 5G networks, almost double compared to the 74 licences it had awarded in September 2020 (Bundesnetzagentur, 2021[83]). One of the first applicants to the local campus licences in Germany was Lufthansa. In February 2020, Vodafone Germany and Lufthansa launched a private 5G network based on standalone technology in an 8 500 m² aircraft hangar in Hamburg, Germany (Telecoms.com, 2020[84]).

In France, the communication regulator Arcep has offered frequencies in the 2 600 MHz band to metropolitan businesses. Spectrum is granted through a portal opened in May 2019. For example, the airport operator, ADP Group and its subsidiary Hub One, have been granted a 10-year 4G and 5G licence (European 5G Observatory, 2020[85]). Hub One aims to manage and set up the network on behalf of Groupe ADP and Air France. Ericsson has been selected to deploy the private mobile network covering Paris-Charles de Gaulle, Paris-Orly and Paris-Le Bourget airports and enable Hub One to comply with the new security obligations of France's National Agency for Security of Information Systems (Ericsson, 2020[86]).

In Japan, The MIC has assigned frequencies for local 5G networks making use of mmWave spectrum that will allow various entities, such as local companies and local governments, to build and use 5G networks flexibly on a local basis within their buildings and premises.

In Korea, as part of the Digital New Deal, the key policy direction for the communication sector focuses on taking advantage of the early deployment of 5G networks in the country to foster industrial applications with high economic and social impact (Ministry of Science and ICT, 2021[87]). Korea plans to leverage 5G networks for industrial use cases and support the expansion of B2B 5G business models. By the beginning of 2022, the goal is to facilitate the deployment of dedicated private 5G networks. One milestone will be to assign new spectrum by early 2022. To promote 5G private networks, the Korean government launched the "5G convergent services promotion strategy" in September 2021 with an implementation roadmap (Ministry of Science and Technology, 2021[88]) (Box 5).

Box 5. Korea's 5G private networks policy

The Korean MSIT announced the "5G Private Network Policy Plan" in January 2021, which outlined the concept of private networks. It provided an overview of the respective trends in Korea and surveyed communication operators and other firms (e.g. industrial players) wishing to deploy private 5G networks. Based on the survey responses, the number of entities considered for the rollout and operation of 5G private networks has been expanded beyond communication operators to also include so-called "local 5G operators" (MSIT, 2021[89]). The plan is based on three pillars: i) diversifying the players in the ecosystem by fostering competitive 5G private networks, ii) assigning frequencies for 5G private networks, and iii) linking public projects with private ones to create demand for these networks.

The aim is to provide sufficient mmWave spectrum (i.e. 600 megahertz-wide channels in the 28 GHz band) to interested stakeholders wishing to deploy 5G private networks in Korea. In addition, the plan aims to secure additional frequencies for B2B business models through spectrum sharing below 6 GHz at the regional and local level. If a company wants to install its own network, it can access spectrum resources through a "special" frequency assignment procedure. If the company registers with a communication operator, the private network will have access to spectrum resources through the operator's licensed spectrum. The company does not need to negotiate a leasing agreement with the operator, but rather notify the regulator. In order to assign frequencies at a regional or local level, detailed allocation plans, price calculation, and interference improvement measures are being prepared.

In June 2021, the "5G Private Network Spectrum Frequency Assignment Plan" was announced. It presents detailed policy measures that were established after a public consultation to assign spectrum frequencies suitable for 5G private networks. The Korean government plans to assign spectrum to firms through a comparative selection process, whereby spectrum frequency costs will be calculated at a level that does not impose an excessive burden on companies (MSIT, 2021[89]).

In October 2021, MSIT published the "5G Private Network Guidelines", which provides relevant information on how to build and operate private 5G networks. Companies can use the Guidelines to independently assess whether they need to deploy private networks and, if so, plan the deployment of their specialised networks. Additionally, the Guidelines include information related to administrative procedures, such as spectrum assignment procedures and reporting obligations (KCC, 2021[90]).

With respect to setting spectrum aside for private networks, mobile industry stakeholders have pointed out potential disadvantages, such as the risk of underused spectrum, as private networks fulfil niche needs while public networks can offer services to a broad range of users on the same spectrum band. Furthermore, mobile operators note that if there is mobile coverage in the areas where industrial users require access to specific licensed bands, private networks can access spectrum resources through mobile operators with sharing and leasing agreements (GSMA, 2021[91]), in addition to commercial provisioning agreements. On the other hand, as noted by the RSPG in 2019, depending on the national context, there are some industrial players whose needs may not be adequately addressed by mobile operators due to various factors, including: overly specific service requirements that may not be economically feasible to meet via network slicing, lack of business interest in 5G coverage in their local area, and the fact that some industrial players may want to retain full control of their network for data security, cost, or other reasons (RSPG, 2019[92]).

Spectrum sharing and the role of secondary markets

Key policy objectives for spectrum sharing approaches

Many spectrum managers around the OECD are considering how to promote policy objectives such as ensuring the efficient use of spectrum and to enable simpler access to spectrum resources. Sharing frameworks offer a way to promote a more efficient use of spectrum by enabling other users to access it (e.g. in cases of spectrum underutilisation). Spectrum sharing is usually managed on three different axes: frequency, time, and location (geography). If an incumbent user is not using the spectrum in a certain area, or at a given time, or for a given portion of the frequency band, then spectrum could be more efficiently used if another user was allowed to access it. In a similar vein, spectrum trading and leasing through secondary spectrum markets can also promote the efficient use of spectrum by allowing other users to access underutilised spectrum. Enabling spectrum to be used more efficiently, through both sharing and secondary markets, also addresses the policy objectives of meeting the growing demand for wireless services by providing additional avenues for spectrum use, where possible. This is becoming more important, as spectrum managers are often limited by the amount of spectrum available to meet new demands or use cases, given that prime spectrum bands often have already been allocated and assigned.

Another overarching policy objective for policy makers when managing spectrum is to limit harmful interference. This objective is even more important under sharing schemes, as the risk of harmful interference is not only between bands allocated to different services or at national borders, but within a spectrum band that has been allocated to different users and at the sub-national geographic borders of those users. Indeed, this is one of the critical challenges outlined above facing spectrum managers: how to increase the efficiency of spectrum in the licensing framework while managing interference between different users.

Adding to this complexity, the radio equipment used for transmitting and receiving radio signals directly impacts sharing conditions. High performing radio equipment, capable of limiting emissions to minimise interference with other services on the one hand (i.e. transmit), and increasing immunity to interference on the other (i.e. receive), can greatly influence how well sharing frameworks work in practice. The role that transmitters and receivers play in efficient spectrum use is recognised at the international level; the ITU's Radio Regulations mention several provisions related to transmitter and receiver performance (ITU-R, 2020[15]).[48]

While in many cases regulation has focused on placing limits on transmitting equipment to minimise interference (e.g. through technical parameters such as power limits and antenna heights), receiver performance has come to the forefront in some OECD countries. Decreased receiver susceptibility to (or, conversely, increased immunity from) interference from unwanted emissions can greatly support increased sharing. Said another way, increased immunity could mean that a better performing receiver would be more likely to receive the intended signal, despite another signal interfering with it, compared to a lower performing receiver. Therefore, under the same circumstances, only the lower performing receiver would experience harmful interference to its signal.

In the United Kingdom, Ofcom's spectrum management strategy considers the role of receiver performance, in the context of its impact on spectrum sharing. It aims to support spectrum sharing by: i) encouraging greater resiliency to interference in wireless systems, ii) striking the right balance between protecting against interference and ability to transmit and iii) adopting a "more realistic" approach when assessing coexistence scenarios that avoids over-protecting services (Ofcom, 2021[12]). To promote wireless systems to be more resilient to interference, Ofcom further notes that it will generally refrain from acting on interference issues if they are due to "poor performance of receivers or wider systems" (Ofcom, 2021[12]).

In the United States, the FCC recently launched a Notice of Inquiry (NOI) examining “receiver interference immunity performance” and the FCC’s role on the topic, in the context of its spectrum management duties (FCC, 2022[93]). The NOI notes recent FCC proceedings, such as those in the 3.7 GHz band, where receiver performance has played a key role in the timing and introduction of new services in a band, based on how able the incumbent’s receivers were at filtering out-of-band signals (FCC, 2022[93]). This NOI diverges from the FCC’s historical emphasis on transmitting equipment, apart from a 2003 NOI that considered the topic and limited cases where the FCC has directly addressed receiver performance (FCC, 2022[93]). However, the 2022 NOI notes the multi-faceted nature of the topic; for instance, a receiver’s immunity from interference depends on several factors (e.g. its technical design, the characteristics of the signals it receives) and varies between services. In addition, better performing receivers may be more costly and choice of receiver (and its level of interference immunity) is often in the hands of customers, meaning the licensee has no control over receiver performance (FCC, 2022[93]). Nevertheless, the performance of both transmitters and receivers can significantly influence the feasibility of introducing new services in the same, or nearby frequencies bands. As transmitting and receiving equipment become more densely packed, both from a geographic and spectral perspective, the performance of both types of equipment become increasingly important to consider.

Furthermore, to enable sharing without causing harmful interference, accurate and up-to-date information on where spectrum is being used in a country (at a granular level), by which services, under what technical conditions, as well as their protection requirements, is needed. If this information is made publicly available, it could help to encourage new sharing requests (e.g. through private sharing agreements) or help spectrum users to better self-regulate and handle spectrum issues if they occur in sharing cases (RSPG, 2021[8]).

Regulatory approaches to facilitate sharing of spectrum resources

A key trend in spectrum management in recent years is the increasing examples of coordinated sharing of scarce spectrum, where much of the innovation regarding spectrum sharing is occurring. Sharing is not a new concept; national frequency allocation tables often allocate different services within the same band (e.g. primary and secondary users), and there is a long and established practice of sharing on a geographical, sub-national basis, and among certain services. There are several examples of sharing on a geographic basis (e.g. regional or local level), which allow different users of the same band in the same service to access spectrum in different geographic areas. Such licenses have been issued traditionally for fixed point-to-point links and Programme-Making and Special Events (PSME), with increasing examples for mobile service, as mentioned above (see “The geographical scope of licences: catering to national, regional, and local needs”). Sharing between certain services, for instance services with co-primary allocations in a band, has also been established through coexistence and sharing studies. One such example is sharing between the fixed service and fixed satellite service (FSS). For instance, CEPT Decision (00)07 addresses the shared use of the 17.7- 19.7 GHz band by fixed and receiving FSS earth stations, which both have a primary allocation in the ITU Radio Regulations (CEPT, 2016[94]). Another well-known example of sharing can be seen in unlicensed spectrum. For example, short-range devices (SRDs) operate on a non-interference and non-protection basis, meaning that they cannot interfere with or claim protection from existing services in a given band where they are allowed to operate.

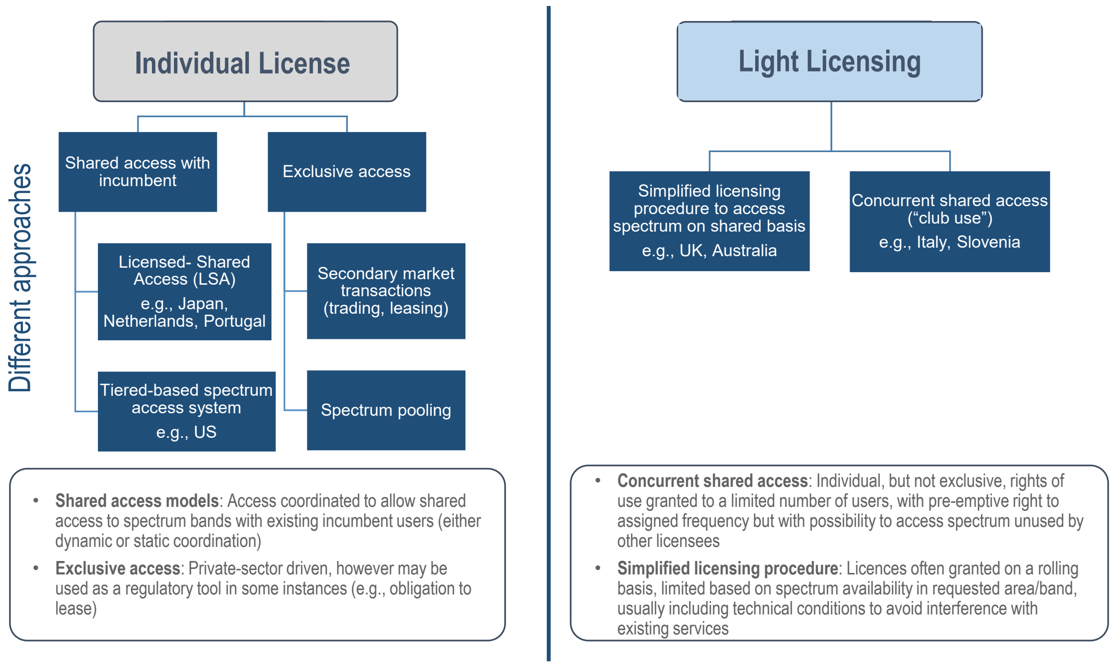
These established types of sharing are widely used to facilitate the efficient use of spectrum and will continue to play an important role in spectrum management. However, this report also considers newer forms and ways that spectrum is being shared. Overall, sharing approaches are emerging in a wider number of bands and in traditionally scarce spectrum, which are assigned via individual licences that often provide exclusive spectrum access to the licensee over a defined geographic area. The proliferation of the use of sharing approaches across more bands and more types of use is novel. In this context, a key aspect for spectrum managers considering such approaches is their effectiveness in promoting effective sharing (without harmful interference) and providing access to a wide array of users, for a large variety of services.

Spectrum sharing strategies should aim to be as multi-dimensional as possible, accounting for the diverse demands for spectrum and considering the broadest ranges of bands possible. Coordinated sharing approaches are a developing trend; slightly less than half of OECD countries do not currently have such regimes in place.

Furthermore, sharing can occur through a regulatory framework, or it could be an agreement between private entities, although regulatory approval may be required. Both cases fall within the scope of the report. However, "intra operator" spectrum sharing, such as dynamic spectrum sharing (DSS) in the context of an operator balancing spectrum between 4G and 5G traffic within its own network,[49] is outside the scope of this report because it relates to private spectrum management decisions, as opposed to regulatory action.

There are different types of models that can foster sharing both within services (intra-service), such as sharing between two or more MNOs in a band designated for mobile, and between services (inter-service), where two different services are sharing the same band (e.g. incumbent use and unlicensed services). As described in Table 1, sharing models can be applied to individual licence and light licensing models. Under individual licensing models, shared access approaches can be grouped into two categories: shared access with incumbent use (e.g. Licensed shared access [LSA] and tiered-based spectrum access systems [SAS]), and exclusive access models agreed in secondary market transactions (spectrum trading or leasing) or private agreements (spectrum pooling). Under a light licensing approach, there are two types of approaches. The first is characterised by frameworks that have simplified licensing procedures to allow third parties to access spectrum on a shared basis. The second describes a concurrent shared access approach ("club use"). These are described below (Figure 5). While there may be some overlap in the classification of sharing models and while nomenclature may vary between jurisdictions, this framework aims to provide a structure to consider the various sharing models emerging in OECD countries.

Figure 5. Different sharing approaches and examples by licensing model



Note: Diagram for illustrative purposes only. There may be overlap in classification of sharing frameworks.
Source: OECD elaboration based on (ECC, 2009[28]; GSMA, 2022[29]; RSPG, 2021[8])

Approaches to share access with incumbent users

The most restrictive type of licence is an individual licence, which grants a licensed user the right to transmit in its currently assigned frequencies and geographic space at all times, whether or not the licensee is operating (transmitting or receiving) in that frequency and geography, free from interference. In some instances, it may also denote exclusive access to those frequencies in defined areas. However, regulators are increasingly considering shared access models that allow third parties to access the spectrum resources covered under an individual licence, which may require a modification to licence terms.

Licensed shared access (LSA) is a sharing model whereby the existing user shares spectrum with one or more licensed users in a controlled manner (i.e. in accordance with sharing rules included in their individual rights of spectrum use) (OECD, 2014[6]; RSPG, 2021[8]). The initial concept, coined "Authorised Shared Access (ASA)", was originally proposed in 2011 by private sector actors (Qualcomm and Nokia Siemens Networks), and in 2012, CEPT considered "a refined regulatory approach of ASA" called Licensed Shared Access (OECD, 2014[6]). The European approach to LSA models is intended to be used for different services (e.g. inter-service, such as governmental incumbent use and commercial use for LSA) (CEPT, 2014[95]). LSA models aim to guarantee to a "certain level" access to spectrum and protection against harmful interference for *both* the existing user of the band (i.e. "incumbent") and the LSA licensee (CEPT, 2014[95]).[50] This allows both to offer a relatively stable and predictable quality of service, although LSA licensees must still protect the incumbent service from harmful interference. Only a limited number of LSA licensees are authorised under this model and each are granted an individual licence to use spectrum on a shared basis, under specified terms and conditions (CEPT, 2014[95]). The first use case for the LSA model was envisaged to facilitate mobile broadband services (e.g. mobile/fixed communication networks, MFCN) in the 2.3 - 2.4 GHz band with existing incumbent use. CEPT issued harmonised technical and regulatory conditions for the band to facilitate the introduction of LSA for interested administrations (CEPT, 2014[96]). On the standardisation side, ETSI developed an LSA system reference document for mobile broadband in the band (ETSI, 2013[97]). Given the work done in Europe to define and advance the LSA model from a regulatory and technical perspective, this term will be used in this report to describe similar examples seen in European countries and others.

Italy, the Netherlands and Portugal have conducted LSA trials in the 2.3 GHz band (Ministry of Economic Development, 2016[98]; Anacom, 2020[99]; Agentschap Telekom, 2018[100]). The Netherlands has implemented an LSA "booking system" to manage dynamic use of spectrum in the band for mobile video connections (electronic news gathering/outside broadcasting); however, it has not implemented an LSA model to facilitate sharing by mobile broadband services (Agentschap Telecom, n.d.[101]). Japan has assigned a 40 MHz block of spectrum in the 2.3 GHz band to KDDI Group, for use on a shared basis with incumbent users (broadcasting and governmental use) (MIC, 2021[102]; MIC, 2022[103]). The shared access will be dynamic and coordinated by a spectrum sharing management system, described in further detail below (MIC, 2021[102]).

Tiered-based spectrum access systems deviate from the two-tier model of LSA by defining additional tiers of users, whereby each tier has different access priorities to use the spectrum and protection from interference. This allows accommodating a variety of commercial uses on a shared basis with incumbent users of specific bands. Such is the case of the 3.5 GHz band in the United States, also known as Citizens Broadband Radio Service (CBRS), which defines three different tiers of users: incumbent access (existing federal and non-federal users); priority access licences (PAL); and general authorised access (GAA) (FCC, 2021[104]). Table 4 presents a summary of approaches that OECD countries have taken recently to promote sharing taking LSA and tiered-based approaches; more details can be found in Annex Table D.1.

Table 4. Examples of recent models to allow shared access with incumbent use around the OECD

Sharing model	Country	Band	Services sharing spectrum
Licensed Shared Access (LSA)	Italy	2.3 - 2.4 GHz band (trial)	Trial conducted to allow mobile sharing with incumbent use (Fixed, PMSE, federal users)
	Japan	2.3 GHz band	Mobile sharing spectrum with incumbent users (broadcasting and governmental use)
	The Netherlands	2.3 - 2.4 GHz band (trial)	Trial using LSA booking system for mobile video connections (intra-service sharing)
	Portugal	2.3 - 2.4 GHz band (trial)	Trial conducted to allow mobile sharing spectrum with incumbent use (PMSE)
Tiered-based spectrum access systems (SAS)	United States	3.5 GHz band	Sharing between incumbent users (federal users, FSS, grandfathered wireless broadband licensees), Priority Access Licensees (flexible use allowed under Fixed or Mobile allocation), General Authorised Access (licence-exempt users)

Note: Illustrative examples highlighting different approaches; some examples may contain aspects of different approaches. Approaches to unlicensed spectrum will be discussed in more detail below and therefore are not included here.
Source: OECD based on questionnaire responses supplemented by national sources. Italy: (Ministry of Economic Development, 2016[98]) Japan: (MIC, 2021[102]); (MIC, 2022[103]); (MIC, 2022[105]). Netherlands: (Agentschap Telekom, 2018[100]); (Agentschap Telecom, n.d.[101]). Portugal: (Anacom, 2020[99]). United States: (FCC, 2021[104]); (FCC, 2020[106]).

The United States' three-tiered sharing approach in the 3.5 GHz band provides an example of a deployed, widespread sharing approach and how effective the model is at providing access to a greater number of users. In the 3.5 GHz band auction, Priority Access licensees were granted a 10 MHz, 10-year renewable licence on a county (sub-national) level (FCC, 2021[104]). According to the results, the auction for priority access licences (PAL) "offered the greatest number of spectrum licences ever made available for bidding in a single auction", of which 20 625 out of a possible 22 631 licences were awarded to 228 licensees (FCC, 2020[107]). While the volume of licences must be attributed partly to the geographic scale of the United States, the auction results still point to a hearty appetite among industry players to bid for PAL spectrum. A range of actors won PAL licences, including traditional MNOs, power companies, electricity providers, cable companies, small businesses, regional or local Internet providers and universities (FCC, 2020[107]). Through the design of this auction, a wider range of actors were able to obtain spectrum, which can help to meet rural connectivity goals, by allowing non-traditional actors such as regional or local Internet providers, cooperatives, or community networks, to use the spectrum to provide broadband locally where coverage may be lacking. As one example, the Seattle Community Network is leveraging the general authorised access (GAA) tier of the CBRS band to build a 4G LTE network to connect underserved communities in Seattle (Jang, 2020[108]).

National carriers also bid for CBRS spectrum for their nationwide networks; for instance, Verizon has been leveraging the band through its 557 PAL licences in 157 counties to provide additional capacity in urban areas (Alleven, 2020[109]). This additional spectrum can also help MNOs to improve their speeds on their networks. According to analysis from Opensignal, Verizon's average 4G download speeds was 78.8% faster on connections using CBRS spectrum than on those without it, and Verizon users connected to the CBRS band in an increasing number of cities (Opensignal, 2021[110]). However, CBRS spectrum does have limitations. Because of the lower transmitter power limits required due to adjacent band interference issues, the speed improvements from CBRS spectrum rapidly drop as the distance from base stations increases, more so than other bands analysed (700 MHz, 850 MHz, 2.3 GHz, and 2.5 GHz bands) (Opensignal, 2021[110]).

Secondary market transactions and spectrum pooling: Examples in the mobile market

Other ways to share spectrum under individual licences include secondary market transactions and spectrum pooling. These are often agreements negotiated between private sector actors, driven by commercial interest. Secondary market transactions include trading or leasing of underutilised spectrum to third parties, improving its efficient use. Spectrum trading refers to the transfer of some or all available frequencies and geographical coverage under a spectrum licence to another party for the remaining duration of the licence term (GSMA, 2022[29]). The entity buying the spectrum rights would then be liable for upholding the licence's conditions. Note that spectrum trading refers to a market transaction limited to spectrum assets, as opposed to a merger or acquisition, which is the broader acquisition of the acquired company's assets that may include spectrum resources. Spectrum leasing is a more temporary tool of the secondary market and allows third parties to access some or all a licensee's spectrum under defined conditions of use that set out the time period, frequency and geographic areas of use to be followed by the leasing party. Different leasing approaches exist regarding responsibility for upholding the original terms and conditions of the spectrum licence, which may stay with the original licensee or with the licensing party (GSMA, 2022[29]).

Spectrum trading in the secondary market is a complementary tool to ensure efficient spectrum management, alongside spectrum sharing. This can allow licensees to optimise their mobile assets and offer spectrum access to actors willing to pay for it. Such markets could additionally offer an avenue to transfer spectrum to a higher value use and increase the liquidity of spectrum assets, especially for the case of long licence terms (e.g. mobile spectrum licences). Spectrum trading has also helped to increase national footprints, especially in the context of sub-national licence (e.g. France spectrum trading in the 3.5 GHz band allowed one MNO to achieve nationwide spectrum coverage (RSPG, 2016[38])). However, efficient spectrum assignment in the primary market (i.e. assignment to the player that will use it most efficiently) has implications for the secondary market as well. Inefficient assignment in the primary spectrum market will not always be corrected by the secondary market (Milgrom, 2000[42]; Hazlett, Munoz and Avanzini, 2011[111]).[51]

Since secondary markets could increase efficient use of mobile spectrum, given their traditionally longer licence terms, this section considers a few examples of secondary market transactions in the mobile market. While spectrum trading and leasing is allowed in most OECD countries (except for three countries), many regulators have reported that it is seldom practiced by operators. There are a few exceptions. Recently, for instance, Canada approved 28 spectrum licence trades and leases ("subordinations") in 2020 and 16 in 2021 (Government of Canada, 2022[112]). In the United Kingdom, there were several licence trades in different services over the past two years, including business radio, fixed links, maritime, satellite service, and six trades recorded in the system for spectrum access in the 3.4 GHz and 3.6-3.8 GHz bands between Telefonica UK and Vodafone (Ofcom, 2022[113]).[52] To note, the six trades between Telefonica UK and Vodafone was the required process to make one swap of spectrum (i.e. exchanging Telefonica's 40 MHz block in the 3.4 GHz band spectrum for Vodafone's 40 MHz block in the 3.6 GHz band). Spectrum trades and leases also occurred in Australia and Ireland in recent years (Dense Air, 2021[114]) (ComReg, 2021[115]; Dense Air, 2021[114]). In the United States, the FCC took steps to facilitate spectrum secondary markets as early as 2003 (FCC, 2019[116]). Existing secondary marketplaces in the United States cover several spectrum bands (Select Spectrum, 2022[117]), with some new developments to create an automated platform for Priority Access Licence (PAL) users to lease under-utilised spectrum in the 3.5 GHz (CBRS) band (Federated Wireless, 2021[118]). Nevertheless, these examples are the exception among OECD countries.

There are several possible explanations that may cause frictions in secondary market access to spectrum, and as such, may lead to illiquidity in secondary markets. High transaction costs may hinder secondary markets, such as regulatory red tape and long approval times, as some countries require regulatory approval for spectrum trades and/or leases. A lack of information on the available spectrum to lease can prove to be another barrier. Incumbent users may not have sufficient spectrum to meet current or perceived future demand (i.e. spectrum crunch due to congestion in networks) and given the uncertainty of future demand and the infrequent assignment of spectrum, they therefore may be unwilling to offer spectrum for trades or leases. Conversely, even if spectrum is made available, secondary markets may be thin as there may be few "buyers" or "sellers" to lease or trade a particular spectrum band in the given geographic area. Hold-out issues may also prove to be an important barrier to active secondary markets. Hold-out issues arise for two reasons. First, since incumbent users operate to maximise revenues, unlike regulators that uphold public welfare objectives in spectrum assignments, they will be naturally inclined to charge monopoly price mark-ups on spectrum in secondary markets. Second, they may have an incentive to hoard spectrum to reduce a vital asset of rivals to foreclose competition.

Easing these frictions may encourage active secondary markets and enable more flexibility to manage spectrum use. These considerations point to a possible regulatory role in secondary markets, which could include introducing platforms to exchange spectrum to reduce transaction costs, as seen in the United States, or employing innovative licensing mechanisms that solve the issue of illiquid secondary markets (see Annex B on "Depreciating licences and their potential application to spectrum rights"). Alternatively, spectrum managers may rely on complementary sharing frameworks in cases where spectrum trading or leasing may not be an effective approach, for instance due to the challenges noted above (e.g. the United Kingdom's local access licence).

Furthermore, some regulators are considering using spectrum leasing as a tool to promote different objectives (e.g. efficient use of spectrum, expanding coverage, driving wireless innovation) (see Table 5). For instance, in recent auctions of the 3.4 – 3.8 GHz bands in Czech Republic, Denmark, Italy and Norway, rules were introduced related to spectrum leasing. Czech Republic, Denmark and Norway focused on leasing obligation to provide access to private networks (see further details in the section, "Catering to use cases across all sectors of the economy"). Italy's "use it or lease it" clause has a different goal, aiming to close coverage gaps. In Italy's multiband auction, the 3.6 – 3.8 GHz band carried a "use-it-or-lease-it" policy for certain areas with less than 5 000 inhabitants included in "the free list" (Agcom, 2018[119]).[53] Eligible third parties can apply to lease unused spectrum in order to provide service to the "free list" municipality. Finally, Germany obligates licensees holding unused spectrum in the 3.4 - 3.7 GHz band in some areas to *negotiate,* not lease, with parties interested in leasing this spectrum (i.e. obligation to negotiate). The Bundesnetzagentur must approve the leasing arrangement (Bundesnetzagentur, 2018[120]).

In addition to secondary market transactions, another option to share spectrum is through private agreements to share spectrum, or "spectrum pooling". Spectrum pooling is an extension of radio access network (RAN) sharing whereby mobile network operators (MNOs) agree to share spectrum resources. Under spectrum pooling, the end users of the operators sharing spectrum tap into the composite shared spectrum resources when accessing the services of their respective MNO (RSPG, 2021[8]). In a so-called "Multi-Operator Core Network (MOCN)", spectrum pooling is generally used, as opposed to Multi-Operator RAN (MORAN), which does not include spectrum sharing (RSPG, 2021[8]). In contrast to secondary market transactions, under spectrum pooling, each MNO retains its rights of spectrum use over its own spectrum. Operators usually instigate spectrum pooling through private agreements, which define the terms of the spectrum use. Such agreements often require regulatory approval to ensure competition is not harmed, especially considering that sharing frequency resources lessens the ability of the participating operators to differentiate the quality of their services. For example, the French competition authority (*Autorité de la concurrence*) noted this issue when assessing network sharing approaches, as spectrum sharing, especially in densely populated areas, "eliminates partners' ability to differentiate", thereby impacting network infrastructure competition (Autorité de la concurrence, 2013[121]).

Nevertheless, where it is not found to detrimentally impact competition, pooling can be a value-enhancing form of spectrum sharing by allowing providers to pool scarce resources, potentially improving coverage and/or network availability. In recent multi-band mobile spectrum auctions, Austria and Slovenia established network sharing conditions that permit spectrum pooling to a certain degree (Table 5). In Slovenia, pooling is permitted where it does not limit competition, especially in "challenging areas" of the country and in cases where network densification needs are expected to be high (AKOS, 2021[122]). In Austria, the spectrum pooling framework outlined in auction guidelines for the 2020 multi-band spectrum auction allows operators to pool their 700 MHz and 2100 MHz spectrum for underserved municipalities, for newly deployed sites and for a low share of existing sites. The overall share of sites eligible for pooling is also subject to a limit. The pooling is subject to approval and must comply with competition law. These limits do not apply to operators holding low amounts of spectrum rights (i.e. less than 10% of nationwide spectrum rights in several IMT bands) (RTR, 2019[123]).

Table 5. Examples of spectrum leasing and spectrum pooling used to promote policy objectives

Country	Approach	Band	Description
Czech Republic	Obligation to lease	3.4-3.6 GHz (certain 20 MHz blocks)	Winning bidders of these blocks must lease the assigned spectrum to interested parties, for a limited geographic area, for the purpose of operating local private networks.
Denmark	Obligation to lease	3740-3800 MHz block	Winning bidders must lease spectrum to requesting parties for the purpose of establishing private networks.
Germany	Obligation to negotiate	3.4-3.7 MHz	Licensees holding unused spectrum in the band in some areas are obligated to negotiate with interested parties.
Italy	"Use-it-or-lease-it" policy	3.6 – 3.8 GHz	Eligible third parties can apply to lease unused spectrum in order to provide service to the "free list" municipality.
Norway	Obligation to offer leasing option	3.4 – 3.8 GHz	Licensees must offer tailored solutions for private networks *and* give the option for the private network to lease frequencies. The third party may decide which option to pursue.
Austria	Spectrum pooling	700 MHz and 2100 MHz	Pooling is allowed for underserved municipalities, for newly deployed sites and for a low share of existing sites. The overall share of sites eligible for pooling is also subject to a limit. The pooling is subject to approval and must comply with competition law. These limits do not apply to operators holding low amounts of spectrum rights (i.e. less than 10% of nationwide spectrum rights in several IMT bands).
Slovenia	Spectrum pooling	700 MHz, 1500 MHz, 2100 MHz, 2300 MHz, 3600 MHz	Spectrum pooling permitted in "challenging areas" of the country and for network densification.

Source: OECD elaboration based on questionnaire responses and national sources. Czech Republic: (CTU, 2020[79]); Denmark: (Danish Energy Agency, 2021[80]); Germany: (Bundesnetzagentur, 2018[120]); Italy: (Agcom, 2018[119]); Norway: (Nkom, 2021[81]); Austria: (RTR, 2019[123]). Slovenia: (AKOS, 2021[122]).

Light licensing approaches to shared access

Moving towards more flexible sharing models, two types of approaches are distinguished, which for the purposes of this report are grouped as "light licensing". The first is sharing frameworks that have simplified licensing procedures to access spectrum on a shared basis. The second is concurrent shared access, which grants non-exclusive rights to spectrum. While concurrent shared access could be classified differently, it is treated as an alternative type of light licensing model in this section, given the non-exclusivity of the licences granted under the model and the treatment of all users as a "class" (i.e. in a single tier).

In the first type of light licensing, sharing regimes are characterised by having simplified procedures to obtain a licence, which in the case of shared access, usually entails an application process to ensure the shared use will not cause harmful interference. A greater number of users, which may or may not be limited, can access spectrum resources compared to LSA and tiered sharing approaches. Some degree of coordination between users may be required. Licences issued under a light licensing sharing framework often grant users rights to use spectrum in a defined area and frequency band and include technical conditions to avoid interference. A light licensing regime could also require users to register or notify the national regulatory authority (e.g. for use of network or user equipment as a way to manage the number of users in a given area) (RSPG, 2021[8]).

Some OECD countries are considering simplified licensing procedures to allow sharing under light licensing regimes, including Australia, New Zealand, and the United Kingdom (Table 6). Australia's area-wide apparatus licence (AWL) in the 26 and 28 GHz bands is one example of the light licensing approach (see Box 3), which demonstrates a relatively light administrative burden and openness to a wide number of services and users, depending on availability of spectrum in the requested area (ACMA, 2020[32]). An earlier example is New Zealand's Managed Spectrum Park (MSP) licence, established in 2010, which allows the shared use of 40 MHz (plus a 5 MHz guard band) of spectrum from 2 575-2 620 MHz to encourage local and regional broadband communication services (RSM, 2015[124]). MSP licences are administered on a rolling basis and have low licence fees. Licensees are expected to coordinate with one another to avoid harmful interference (RSM, 2015[124]). The United Kingdom has two types of licences that fall under the light licensing regime, the *local access licence,* and the *shared access licence* (Ofcom, 2019[13]). The process to obtain both types of licences is by application on a rolling basis. Low licence fees apply. Ofcom will then issue individual licences, which include technical conditions to avoid interference. The *local access licence* allows other users to access spectrum that was licensed to an MNO but not in use in certain areas (Ofcom, 2019[125]). *Shared access licence* provides access to spectrum in four bands on a shared basis (Ofcom, 2019[13]).

Table 6. Examples of light licensing sharing approaches

Sharing model	Country	Band	Services sharing spectrum
Light licensing model – simplified procedure	Australia	26 and 28 GHz	Area-wide apparatus licensees (AWL) will share spectrum with class licensees (unlicensed in Australian framework) in the 24.7-25.1 GHz band and individual IMT licences in the 25.1-27 GHz band. AWL licences can be used for a range of services (incl. FWA, mobile wireless broadband, private networks, FSS and to support IoT).
Light licensing model – simplified procedure	New Zealand	2575 MHz - 2620 MHz	Managed Spectrum Park (MSP) licences are intended to support the provision of local or regional communication services. MSP licences (providing communication services) must coordinate among themselves to avoid interference.
Light licensing model – simplified procedure	United Kingdom	Mobile bands covered under United Kingdom's mobile trading regulations	*Local access licences* allow other users to access unused MNO spectrum and is envisaged to support other mobile use cases (e.g., private networks, mobile coverage (rural/indoor), fixed wireless access). However, the shared user does not have to employ the same technology as the incumbent licensee.
Light licensing model – simplified procedure	United Kingdom	1800 MHz, 2390-2400 MHz, 3.8-4.2 GHz, and 26 GHz; 116-122 GHz, 174.8-182 GHz and 185-190 GHz	*Shared access licences* allow other users to access spectrum in requested spectrum and areas, dependent on interference assessment with existing users (each band has different existing users, e.g., FSS, Fixed, Mobile, Telemetry, and PMSE, unlicensed). Intended to support mobile use cases (e.g., private networks, mobile coverage (rural/indoor), fixed wireless access).
Concurrent shared access ("club use")	Italy	26 GHz	Mobile services sharing between licensees.
Concurrent shared access ("club use")	Slovenia	26 GHz	Mobile services sharing between licensees.

Note: Illustrative examples highlighting different approaches; some examples may contain aspects of different approaches. Approaches to unlicensed spectrum will be discussed in more detail below and therefore are not included here.
In addition, the United States auction of the "flexible use geographic overlay licences" in the 2.5 GHz band began in July 2022 but has not been finalised and is therefore not yet included in this table.
Source: OECD based on questionnaire responses supplemented by national sources. Australia: (ACMA, 2020[32]); New Zealand: (RSM, n.d.[126]; RSM, 2015[124]); United Kingdom: (Ofcom, 2019[13]); Italy: (Agcom, 2018[119]); Slovenia: (AKOS, 2021[122]).

In addition, as mentioned above, CEPT was given a mandate in December 2021 to study possible harmonised technical conditions for shared use of the 3.8 - 4.2 GHz band to support wireless broadband systems providing local connectivity (low and medium power), protecting fixed and fixed satellite services in the band and supporting their long term development (CEPT, 2021[67]). Finally, the United States' auction of "flexible use geographic overlay licences" in the 2.5 GHz band, which began in July 2022 and is still ongoing, shares some similarities to some of the other light licensing approaches noted above (FCC, 2022[10]). While the spectrum is being auctioned, instead of being available on a rolling basis, the licences will be for unassigned spectrum in smaller local areas (i.e. on a county basis). The licences can operate anywhere in the geographic area under the condition they protect the licensed areas of incumbents (FCC, 2022[10]). However, the FCC notes that for a "substantial number" of licences, there may only be a small amount of unassigned spectrum and/or unassigned over a small area within a given county (FCC, 2022[10]).

In particular, the United Kingdom's shared access licence aims to support private networks, mobile coverage (rural or indoor coverage) and fixed wireless access use cases. Thus, this licence may help to promote rural connectivity by allowing new spectrum users such as small businesses, fixed wireless access service providers, cooperatives, or community networks to access shared spectrum and provide broadband locally where traditional coverage may be lacking. As of mid-June 2022, the uptake of the shared access licences stands at 4 473medium power licences that have been assigned to 34 licensees and 1 089 low power licences have been assigned to 56 licensees since becoming available at the end of2019 (Ofcom, 2022[113]). This is a promising rate of adoption and shows demand for such licences by diverse market actors. From the perspective of promoting rural connectivity, the local access licence regime has enabled a community network to provide local connectivity to the Chalke Valley, a rural area in the United Kingdom, leveraging unused 800 MHz spectrum in the area (ThinkSmall Cell, 2018[127]; Ch4lke Mobile, n.d.[128]).

The second type of light licensing approach is concurrent shared access, also known as "club use", as seen in Italy and Slovenia (Table 6). Concurrent shared access defines sharing among a single tier of user. Under this approach, the regulator selects a predefined number of licensees in a single tier (i.e. a "class" of users) that must coordinate among themselves to ensure coexistence in a specific band (RSPG, 2021[8]; GSMA, 2021[129]). The licensees have individual, but not exclusive, rights to use the band, meaning that a licensee has the first rights over the block of spectrum it was assigned, but can use all of the spectrum in the band where it is not being used by other licensees (RSPG, 2021[8]). In Italy's multi-band auction, the 26 GHz band is an example of a concurrent shared access model. In this case, each licensee was granted 200 megahertz and could use up to all awarded spectrum (1 gigahertz) when the spectrum was not in use by the other licensees (Agcom, 2018[119]). Each licensee has a "pre-emptive" right on its assigned 200- megahertz block and all licensees in the band (whose number is defined by regulator) must coordinate to ensure coexistence. Slovenia's multi-band auction contained a similar clause for the 26 GHz band (AKOS, 2021[122]).

Other countries are considering shared approaches in specific bands, including Canada (3.9 - 3.98 GHz band), Finland (1 427 – 1 518 MHz band) and Australia (3.4 – 4.0 GHz band). Further details can be found in Annex Table D.1.

Coordinating shared access: From static to dynamic approaches

Traditionally, spectrum sharing has been coordinated through static means, for instance defining fixed conditions of shared use based on geography, time, or frequency. This is still a straightforward approach used by regulators to minimise interference in sharing regimes. The increased use of automation, for instance in the approval process for sharing applications, is another area where some regulators are considering action. For example, Ofcom in its "Spectrum Strategy for the 2020s" noted the potential of automated spectrum management tools (Ofcom, 2021[12]). Another way to facilitate spectrum sharing may be through dynamic spectrum access (DSA),[54] which could be combined with automation techniques that allow users to access spectrum in a dynamic way for a defined period or in a defined area.

In addition, the shift towards the more dynamic management of spectrum access has been seen with the emergence of systems or databases that dynamically manage shared spectrum use, based on where spectrum is currently in use, and in which frequency bands. An early example of a dynamic database system can be seen in TV White Space systems, which facilitate access to unused spectrum by white space devices that operate on a licence-exempt basis (see further details below).

A more recent example of a dynamic approach can be seen in the automated frequency coordinators, called Spectrum Access Systems (SASs), that facilitate coordination between and among the three tiers of users in the CBRS band (3.5 GHz) in the United States (FCC, 2021[104]). The role of the SASs serves two purposes: to protect higher tiers from harmful interference from lower tiers[55] and to facilitate more efficient spectrum use among all users. Another critical piece in the CBRS approach is the Environmental Sensing Capability (ESC) systems, which are networks of sensors that detect signals from governmental users (incumbents) in the band and send that information to the SASs (FCC, 2021[104]). Priority Access Licences (PALs) and General Authorised Access (GAA) users must register their Citizens Broadband Radio Service Devices (CBSDs) (e.g. an access point) with an SAS (FCC, 2015[130]). SASs coordinate the three tiers by “assigning frequencies, establishing registration processes and registering users and storing information” and “direct[ing] commercial users to vacate occupied channels, if necessary” based on information received from ESC systems (FCC, 2015[130]). SAS may also decide to facilitate spectrum leasing of PAL licences under a “light-touch” procedure (FCC, 2021[104]). The FCC relies on third parties to operate the SASs and ESC systems for CBRS spectrum,[56] based on approval by the FCC.

The first phase of the CBRS approach protected federal incumbent radar users by defining exclusion zones, which prohibit PAL and GAA use. In the second phase, incumbent use is instead protected by ESC systems and SASs, who ensure that the other tiers aren’t using the spectrum in use by the incumbent (FCC, 2015[130]). As incumbent use can change over time, SASs may be better equipped to leverage available frequency than static exclusion zones, which are not available for use regardless of whether the spectrum is currently being used there or not.

A further dynamic approach is being implemented in Japan. The Ministry of Internal Affairs and Communications (MIC) has established a “dynamic spectrum sharing management system” to be used to manage shared access to the 2.3 GHz (2 330 - 2 370 MHz) band between incumbent users (broadcasting and governmental use) and mobile services (MIC, 2021[102]). Incumbent users input their spectrum use (e.g., frequency, location, day, time) into the sharing system and mobile operators then apply for shared use (MIC, 2021[102]). Depending on the request and availability, the system decides whether the mobile operator can access the spectrum. In May 2022, MIC has assigned KDDI Group a licence to use this 2.3 GHz band spectrum for five years (MIC, 2022[103]; MIC, 2022[131]).

However, these systems are complex and time-consuming to establish, and current coordinated shared access techniques are still in the developing stages. Nevertheless, the promising benefits of shared access have prompted research on forward-looking techniques. For example, building on the LSA sharing model, recently ETSI has defined “evolved LSA” (eLSA) technical specifications, primarily to cater to the expected demand from industrial actors wishing to establish local private networks (ETSI, 2020[132]). Leveraging the original LSA framework, eLSA aims to automate the licensing or leasing process for local private actors wishing to access LSA spectrum.

Under the original LSA framework, the number of LSA licensees would be somewhat limited in number and licensed through an application process, as defined by the national regulator/administration (RSPG, 2013[133]). To account for possible changes in incumbent spectrum use and protection requirements, the LSA framework established an information sharing mechanism[57] to adjust an LSA licensee’s spectrum usage in accordance with the incumbent’s adjusted use (CEPT, 2014[95]). Building on this original framework, eLSA sets out that interested parties would query the information sharing system to see if the requested spectrum is available for use in the requested area and for the desired period (ETSI, 2020[132]). The system would decide upon the request, considering the sharing terms and conditions determined by the regulator (or an incumbent, in the case of leasing)[58] and the availability of the requested spectrum (ETSI, 2020[132]). If successful, a licence or lease would be issued, and the new licensee could begin using the spectrum. After the eLSA system has been established, the automated licensing process may enable more vertical local private networks to access spectrum on a shared basis and reduce the administrative burden in terms of time and resources for the incumbents, the regulator, and the requesting parties. This would enable a greater number of possible licensees under this framework, although still depending on the availability of spectrum.

In addition, some of the innovative elements of 5G networks may enable spectrum sharing in the future, notably through network slicing. While it is not a model for spectrum sharing, per se, it may enable operators to better enact sharing of spectrum resources, both among MNOs and to support different service providers (e.g. local private networks). In cases where two or more MNOs agree to share spectrum under spectrum pooling agreements, for instance, network slicing can designate a slice to each MNO in the agreement (RSPG, 2021[8]). Network slicing is also envisaged as a possible way to provide dedicated services for local private networks, whereby the MNO handles the infrastructure, spectrum usage and coexistence management (ETSI, 2020[132]). Under this scenario, the local private actor is a consumer of the MNO, and no sharing agreement is needed. Slicing can also be used to provide slices to different services with varying service requirements.[59]

Another possible future tool that may enable sharing is the use of artificial intelligence (AI) systems to boost automated and dynamic approaches and promote more efficient sharing of spectrum. For instance, AI may assist regulators to provide faster decisions on possible sharing assignments or provide better sensing for use in spectrum sharing databases. The National Institute of Standards and Technology (NIST) in the United States conducted a study in 2019 using AI to detect incumbent radar signals and found that three of the AI methods developed outperformed traditional methods (NIST, 2019[134]). More accurate readings of incumbent use may lend more certainty to existing users that their signals will be protected in shared systems, which may help to lend credence to the approach and lessen fears concerning interference. Nevertheless, the use of AI systems in spectrum management is not likely to become widespread in the near future, with the United Kingdom noting the uncertainty in current use of the technology to manage spectrum (Ofcom, 2021[12]).

Challenges to spectrum sharing

Spectrum sharing can provide important benefits and uphold policy aims such as promoting efficient spectrum use and providing access to a wide group of diverse spectrum users. However, sharing can prove to be complicated for regulators for several reasons. Inherently, increasing shared access to spectrum both increases the risk of interference and the complexity in managing that interference. At the technical level, many parameters affect the likelihood of harmful interference, including which services are operating in the band and in neighbouring bands, the quality and performance of transmitting and receiving equipment and the technical parameters at which they are operating. This means sharing conditions may vary on a case-by-case basis, making it time-consuming and difficult to agree on appropriate sharing parameters. Moreover, the behaviour of one user in the band may affect the usage conditions of the other users sharing it. This lack of "trust" or confidence (i.e. the belief that other users will operate in a way that interferes with the service in question) could incentivise users to act in a way to protect themselves from interference.

Establishing a sharing regime may require balancing competing demands for spectrum (e.g. defence, SRDs and railways requiring access to 874 - 880 MHz/919 - 925 MHz in Europe).[60] Regulators may also face pressure from incumbent users, which may not be inclined to accept additional users for fear of interference and possible degradation of their service. Different technologies serving the same application could also compete for the same part of spectrum. When implementing technology neutrality in sharing conditions, for instance, it is up to the standardisation process to identify a balanced sharing framework between both. However, this can be a challenging task. For a recent example, in Europe, two competing technologies have emerged for short-range communications between vehicles and their surroundings, under Intelligent Transport Systems (ITS) in the 5.9 GHz band, ITS-G5 (a WLAN based standard) and LTE-V2X (mobile based). Recent work within ETSI aims to identify sharing conditions between the two technologies (ETSI, 2021[135]). The European Union passed a decision on the ITS in 2020 (Decision (EU) 2020/1426). However, due to the ongoing debate regarding the two competing technologies, Article 4 of Decision 2020/1426 stipulates that it must be reviewed in light of market and standards developments, or no later than 2023 (European Commission, 2020[136]). As shown in this example, such discussions over competing technologies extends the process to define regulatory frameworks, including those that may enhance spectrum sharing.

Sharing regimes are often technically complex, requiring time and resources to analyse potential risks, and to trial, develop and implement sharing mechanisms. For example, the three-tiered spectrum sharing system in the 3.5 GHz band in the United States took many years to implement. The FCC's initial notice of proposed rulemaking was announced in 2012, while the auction took place eight years later, in 2020 (FCC, 2012[137]; FCC, 2020[106]). Similarly, the European LSA framework was put forth in 2014, and there have been trials, but limited active deployments (CEPT, 2014[96]). In addition, due to the priority given to protect against harmful interference, conservative parameters may be applied during sharing and compatibility studies that address a "worst case" scenario, instead of using realistic parameters, addressing both transmission and reception. This may be compounded by a lack of trust between the different actors involved in compatibility studies and may result in general sharing conditions that are more conservative than what may be technically possible. The end result may decrease the attractiveness for services and applications to use the shared spectrum, due to a limited ability to provide a reliable quality of service (QoS) and could hamper change.

Moreover, the regulator may need to establish priority in terms of protection from harmful interference among competing cases, which may not always be a straightforward or swift process. In addition, from a technical coexistence perspective, sharing between providers of the same service (e.g. Fixed-Fixed sharing) or between certain services (e.g. Fixed-Mobile) is easier than between others (e.g. Mobile-Mobile). For example, mobile services are more dynamic in nature than some more static fixed services (e.g. point-to-point links). This makes sharing conditions inherently more complex to accommodate, for instance in cases where there are multiple competing mobile operators accessing the shared spectrum. Finally, given the developing nature of many sharing approaches and the challenges outlined above, it is important for spectrum managers to review the effectiveness of their shared frameworks to support evidence-based policy making. Spectrum managers should monitor the demand and take-up of sharing opportunities and, in case of low demand, re-assess frameworks to explore alternative ways to promote spectrum's efficient use.

Some of these challenges raise important questions for spectrum managers, to which this report merely alludes. For example, how can spectrum managers and international harmonisation efforts lead to overall improvements in radio equipment performance, for transmitters *and* receivers? How can trust between the parties involved in sharing and compatibility studies be strengthened? How to define realistic parameters and ensure that they are used in such studies systematically? These are technical, complex questions, and are unfortunately beyond the scope of this report. They are better suited to be further analysed by the relevant entities specialised on these topics (e.g. regional and international harmonisation bodies, standardisation bodies, etc.). Furthermore, for communication regulators and spectrum managers, addressing these issues may relate to industries possibly beyond their remit, and as such, may require regulatory cooperation and a multi-stakeholder approach.

The role of unlicensed spectrum

Allowing a wide range of users to access spectrum without the need for a licence (e.g. licence-exempt or unlicensed use) can support key policy objections. Namely, unlicensed spectrum can drive innovation by lowering the barriers to access spectrum and thereby promoting more and new users to experiment and innovate with new services. Unlicensed spectrum does not require registration or notification to the regulator, nor any entry price to be paid, and there are no limitations on the number of users. Users must only comply with technical conditions of shared use set by the authorities, usually in the form of exemption regulations which list the technical conditions (such as maximum power) with which the equipment must comply to operate without a licence. These technical conditions are usually determined with relevant standards bodies (e.g. ETSI), which detail the particular technical requirements. As the spectrum is available to anyone using compliant equipment, licence exemption does not provide users with any form of protection from other users. Users should be aware that there may be congestion at certain locations and the ability of equipment to withstand interference may depend on its design, quality, and robustness. Spectrum managers usually have no remit to regulate the quality of such devices, as long as they comply with the minimum international standards set by the Standards Organisations (such as ETSI).

Such licence-exempt regulatory regimes are well-established among OECD countries. For example, there has been a regulatory regime for Short Range Devices (SRDs) in the European Union since 2005 and at the European level since the 1997 (with subsequent revisions) (EU, 2006[138]; CEPT, 1997[139]). Bands designated for unlicensed use are shared by several applications, with the most important likely being SRDs.[61] SRDs are usually low power, mass market consumer devices such as alarms, radio frequency identification (RFID) applications, medical implants, and wireless access networks/radio local area networks (WLAN/RLAN),[62] better known as Wi-Fi. WLANs are an important enabler for enterprises as they allow employees working from the home and office to access fixed network connectivity.

These devices benefiting from unlicensed spectrum are subject to technical conditions (e.g. maximum transmit power, power density) and potentially restrictions of use (e.g. limited to indoor use), which are established to minimise interference with other users and services. For instance, power requirements in WLAN standards set low power limits for indoors use and very low power limits for outdoor use to help avoid interference. SRD devices may be equipped with techniques to further promote coexistence and mitigate interference, such as “listen before talk”, “detect and avoid” and “dynamic frequency selection”, where relevant or necessary given the type of application and its use, although it may not always be required (RSPG, 2021[8]). Canada and the United States are considering Automated Frequency Coordination (AFC) to manage unlicensed use with fixed links, which allows a higher power limit (standard power) for WLAN devices (see below). CEPT in Europe considered the possible need for similar database approaches in the lower range of the 6 GHz band in past reports (CEPT, 2020[140]), with a new CEPT work item on dynamic spectrum access coordination (CEPT, 2022[141]). According to this regulatory framework, manufacturers, designers, and users understand that short range devices will operate in a shared spectrum environment, which carries a risk for interference from other similar radio equipment. This is considered in the application, design, and manufacture of such devices. Therefore, users accessing unlicensed spectrum, which may include wireless providers, are not necessarily protected from interference.

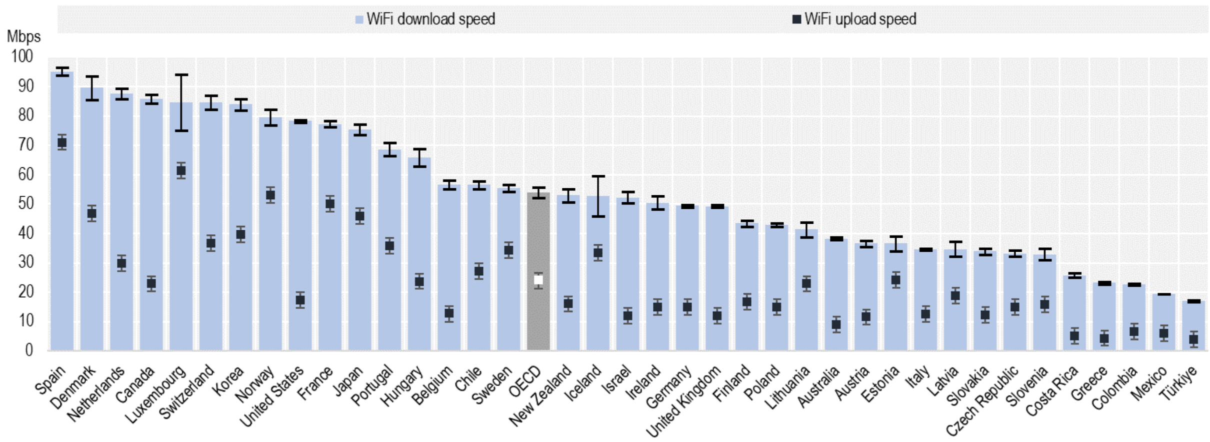
Adopting such measures has allowed for a diverse set of applications to leverage unlicensed spectrum, brought substantial consumer benefit, and encouraged innovation to flourish across a wide range of SRD applications, including IoT applications that may rely on SRDs (European Commission, 2019[142]). All OECD members have recognised the importance of unlicensed use and have duly attributed licence-exempt spectrum to allow a broader audience to access spectrum, especially for SRDs and WLAN/RLAN applications.[63]

The use of unlicensed spectrum by WLAN applications

WLAN is a particularly important use case that benefits from unlicensed spectrum to support connectivity, primarily indoors, for residential home networks as well as local area networks for enterprises. WLAN applications are a fixture of our daily lives (e.g. Wi-Fi), as they provide a cost-effective option to boost fixed signals to allow devices to connect wirelessly both at home and at work. WLAN's role to provide connectivity within the house or office also serves to offload data from mobile networks, with estimates that WLAN networks offload close to 60% of mobile data traffic and carry 51% of all IP traffic in 2022 (Cisco, 2019[143]).

Considering the large percentage of mobile data offloaded to WLAN networks, WLAN speeds therefore also contribute to users' quality of experience. Looking to a common type of WLAN technology, Wi-Fi, download and upload speeds experienced by smartphone users in OECD countries show a wide range, for download from close to 20 Mbps to nearly 100 Mbps and for upload around 4 Mbps to 70 Mbps (Figure 6). The top Wi-Fi download speeds experienced are led by Spain (95.2 Mbps), followed by Denmark (89.6 Mbps) and the Netherlands (87.7 Mbps), and the OECD average at 53.9 Mbps. Spain leads in Wi-Fi upload speeds with 71.1 Mbps, followed by Luxembourg (61.5 Mbps) and Norway (53 Mbps), and the OECD average of 24 Mbps.

Figure 6. Wi-Fi download and upload speeds experienced by smartphone users in OECD countries, 4Q 2021



Notes: The OECD average is for available countries only; upper and lower confidence intervals for Wi-Fi download speeds only. Data collected in the 90-day period starting 1 October 2021. Opensignal definition: "Wi-Fi speeds shows the average download speed experienced by Opensignal smartphone users calculated in Mbps (Megabits per second)." Experienced speeds can be influenced by several factors, such as distance from the router, the number of concurrent users, the performance and quality of Wi-Fi components of a terminal device, in this case a smartphone, and the age and quality of router equipment.
Opensignal, a mobile analytics company, is the global standard for measuring real- world mobile network experience. Using billions of measurements collected 24/7 from tens of millions of smartphones, Opensignal analyses real-world mobile network experience at the largest scale and frequency in the wireless industry: by operator and country, regionally and worldwide. Opensignal believes measuring how the network performs directly through users' eyes is key to building better wireless networks. Network operators, telecommunication regulators, equipment makers and analysts use Opensignal's mobile analytics insights to inform industry analysis and make key business decisions. For more information or any questions about the data, please visit the Opensignal website (http://www.opensignal.com/) or send an email to info@opensignal.com.
Source: Opensignal Limited © 2022.

Given WLAN's role to support end-to-end connectivity and offload mobile traffic, many regulators have designated unlicensed spectrum bands to support its use, historically in the 2.4 GHz band and the 5 GHz band. However, WLAN capacity and speeds under the current bands may become a bottleneck for households, especially as more people upgrade to faster fixed broadband connections. For instance, by June 2021, fibre subscriptions amounted to 32% of total fixed broadband subscriptions on average in the OECD area, although there is a wide range among OECD countries (OECD, 2022[144]). In addition, multiple users in one household may be using several WLAN-enabled devices simultaneously. This may be increasingly difficult for current capacity to handle under the currently allocated bands, due to congestion, and may lower end-user perceived speeds and quality of experience. To address existing constraints, Wi- Fi technologies are continuing to develop.

Building upon previous Wi-Fi generations, Wi-Fi 6[64] aims to improve performance particularly for large outdoor Wi-Fi deployments (e.g. outdoor hotspots), as well as increase throughput and spectral efficiency in dense deployments and reduce device power consumption (Oughton et al., 2021[145]). A new generation of Wi-Fi 6 devices is being introduced that can operate in the 6 GHz band (Wi- Fi 6E), in cases where parts of this band are allocated for these purposes. This new generation would have the possibility of wider channels than in existing bands, allowing them to offer greater speeds and performance While still at an early stage, looking ahead to Wi- Fi 7,[65] discussions have focused on further increasing performance to support use cases with more stringent service requirements in terms of throughput and latency (Oughton et al., 2021[145]). Wi-Fi 7 standard is expected to be published in May 2024 (IEEE, 2022[146]).

Dynamic approaches to manage unlicensed use

Similar to the trend seen above to coordinate shared access to spectrum more dynamically, there are also approaches to manage unlicensed use in a more dynamic way. Dynamic ways to coordinate the licence-exempt use of spectrum, which is shared by its nature, began several years ago. The first geolocation database-driven spectrum sharing system, known as Television White Space (TVWS), facilitated unlicensed access to unused channels in TV bands. The United States and the United Kingdom first considered TVWS as early as 2008 and 2007, respectively, with other OECD countries similarly conducting consultations and pilots (e.g. Germany, Slovak Republic, Canada, New Zealand) (Ofcom, 2015[147]; FCC, 2020[148]; OECD, 2014[6]).

While the rules for access by unlicensed devices under the coordination of a TVWS geolocation database system were finalized several years ago by the United States, Canada, and other countries, there has been increasing adoption of the technology in recent years. The Airband initiative in the United States, led by Microsoft, and more recently the designation of geolocation database system administrators in Canada, is resulting in broader commercial use of the technology, primarily to support rural connectivity (Microsoft, 2020[149]; Government of Canada, 2022[150]). Under Canada's framework, the white space database system coordinates spectrum access of white space devices by providing a list of available channels and the permitted power levels for each one to the devices (Government of Canada, 2021[151]). It also keeps track of the geolocation information it receives from the devices to dynamically manage spectrum (Government of Canada, 2021[151]). Similarly, in 2020, the United States revised its rules governing TV white spaces to encourage the use of white spaces devices to provide wireless broadband services in rural areas (FCC, 2020[148]).

Another dynamic approach to managing unlicensed use of spectrum can be seen in the United States, which established an automated frequency coordination (AFC) system to manage spectrum use by unlicensed, standard-power wireless access points in the 6 GHz band (FCC, 2020[152]). The 6 GHz band has existing incumbent use in the fixed, mobile, and fixed satellite services (FSS), with fixed services being the largest user group. The AFC would determine exclusion zones and permit unlicensed access to the bands only at certain frequencies and locations outside of these zones to protect fixed services in particular (e.g. point-to-point stations), as well as radio astronomy sites (FCC, 2020[152]).[66] The AFC system is based on licensing information from the FCC's Universal Licensing System; licensees must keep their licence records up to date to ensure the AFC is accurate (FCC, 2020[152]). Unlicensed standard-power devices must check the AFC system daily and cease operation if incumbent use is granted close to its location. The FCC relies on third parties to operate the AFCs[67] (6 GHz band), based on approval by the FCC. Canada will also adopt an AFC system to protect incumbent use and enable unlicensed standard-power devices (access points) to operate in the 6 GHz band, harmonising with the United States approach to the extent possible (Government of Canada, 2021[18]). In Europe, CEPT is also undertaking an initiative to introduce AFC in the lower 6 GHz band (5 945 - 6 425 GHz) to enable the use of 1 watt to 4-watt WLAN/RLAN equipment in this band.

Looking ahead: Future considerations in spectrum management

New horizons

Making spectrum available for innovative use cases

A myriad of current trends are emerging that call for new uses for spectrum: the need for ubiquitous connectivity for an inclusive digital transformation, emerging B2B cases, the proliferation of the IoT, advances on AI systems, and the automation of industry. Combined with the scarcity of available spectrum resources, efficient wireless systems and radio access technologies are needed that will drive innovation in spectrum use.

Many OECD countries note wireless innovation as a key goal in their spectrum strategies. For example, Ofcom has placed "supporting wireless innovation" as one of three main action areas of the United Kingdom's vision for the future use of spectrum during the next decade (Ofcom, 2021[12]). In Canada, the Policy and Licensing Framework for Spectrum in the 3.8 GHz band incorporates a policy objective of fostering investment and the evolution of wireless networks by enabling the development and adoption of 5G technologies (Government of Canada, 2021[153]).

Countries are taking measures to support wireless innovation by making spectrum available before its long-term use is known. This includes offering temporary licences for tests and trials that cover individual radio equipment as well as systems and networks, which may be labelled as experimental, developmental, or scientific licences. The majority of OECD countries are promoting and authorising the temporary use of radio spectrum for technical trials and scientific studies using various technologies and include: Australia, Canada, Brazil, Costa Rica, Colombia,[68] Czech Republic, Denmark, France, Germany, Greece, Ireland, Iceland, Israel, Japan, Lithuania, Latvia, Mexico,[69] Portugal, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Republic of Türkiye (hereafter "Türkiye"), the United Kingdom, and the United States.

Some countries also use regulatory "sandboxes" for spectrum to foster innovative use cases. These sandboxes include setting spectrum aside with the specific aim of enabling trials or innovative new users to access spectrum, including allowing commercial deployments (RSPG, 2019[154]). For example, in Australia, apart from offering scientific licences and assigning spectrum by administrative or competitive processes to foster innovation, ACMA has used exemption arrangements to support limited technology uses that would otherwise be banned because of its interference characteristics, such as counter drone technology (jammers). Where Radio Navigation Satellite Service (RNSS) (also known as GPS) jamming devices are subject to comprehensive bans, the ACMA amended the relevant regulations to provide that RNSS repeaters were not RNSS jamming devices. This change facilitates lawful importation, possession, operation and supply of RNSS repeaters and creates a pathway for the ACMA to authorise trials of the devices through scientific licensing. Another example is Greece, which has reserved 10 MHz in the 3.6 GHz band and 200 MHz in the 26 GHz band for pilot testing and research applications. In France, Arcep set up a "5G pilot" window in 2018 to assign frequencies to interested players so that they can test the full-scale deployment of 5G pilots (ports, hospitals, connected roads, etc.), including use cases and business models.[70]

Communication regulators have also facilitated testbeds to encourage the discovery of business models for connectivity solutions involving different stakeholders in different sectors. For example, several countries followed an approach of test licences for mmWave spectrum (Austria, Canada,[71] Latvia, France, and the United Kingdom). In Costa Rica, the MICITT is working with IDB and other interested parties to enable 5G testbeds in low, mid, and high spectrum bands. In January 2019, the French Government and Arcep jointly launched a call for projects for 5G test beds in the 26 GHz frequency band. The aim of this call was to encourage all interested parties to take advantage of the possibilities offered by this frequency band, and to identify new uses for 5G. More than a dozen projects responded to the call beyond the communication sector (e.g. logistics, mobility, smart city companies, and sporting events). The United Kingdom also established 5G test beds and trials in 2019.[72]

Apart from temporary licences, regulatory sandboxes and testbeds, countries have underscored that placing spectrum in the market in an opportune way and adhering to the principle of technology neutrality for licences are both key aspects enabling the emergence of innovative use cases.

Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs), commonly known as drones, can deliver many social and economic benefits. Beyond-line-of-sight drones may support a broad range of uses, such as delivering medical supplies to rural and remote areas, monitoring traffic systems and responding to emergency situations (Public Protection and Disaster Relief [PPDR]), to name a few. Improvements in logistics driven by such drones may, in turn, reduce the carbon footprint of deliveries.

As the demand for the use of UAVs grows, spectrum managers need to explore spectrum and authorisation options to support beyond-line-of-sight drone use. Spectrum for UAVs is required for two separate functions: 1) control by the UAV operator, and 2) monitoring of the location of the UAV by the relevant air regulator. There will be a need for regulatory cooperation with relevant national and international aviation authorities to ensure coordinated regulatory frameworks. For example, in Europe, the RSPG has issued the opinion that “the European Commission and Member States should support the development of drones within relevant harmonised electronic communication services bands” (RSPG, 2021[155]).

The mobile industry has pointed out that the benefits that drones can deliver for society are contingent on effective UAV authentication, monitoring, and connectivity (GSMA, 2022[156]). They call for easing regulatory barriers for the use of mobile networks for UAVs, and highlight that adopting a service- and technology-neutral framework is a way to foster the drone ecosystem (GSMA, 2022[156]). However, it is important to note that the use of “terrestrial” spectrum or mobile networks at altitude could increase the risk of adjacent band interference due to the characteristics of operating these vehicles above landscape and with obstructions. As such, 3GPP is currently working on these issues through the different releases of the 5G standard (since Release 15).[73] In Europe, CEPT also has initiatives on the use of UAVs in harmonised frequency bands and aims to publish technical conditions in 2022 (CEPT, 2021[157]; CEPT, 2020[158]).

High Altitude Platform Stations (HAPS)

Spectrum managers are also following recent developments in high-altitude platform station (HAPS) systems, as they show promise to potentially bridge connectivity divides in rural and remote areas (OECD, 2021[159]). HAPS stations operate in the earth’s stratosphere (i.e. the layer of the atmosphere starting at 20 km),[74] and can provide broader coverage compared to terrestrial systems but with a lower latency than satellite systems. They have existed since the late 90s but have recently become more viable due to technological advances in energy efficiency, among other factors. However, the economic viability of this technology also depends on spectrum availability and other existing underlying infrastructures (ITU, 2022[160]). Namely, developments in HAPS technologies may enable High Altitude IMT Base Stations (HIBS), bringing them a step closer of providing a future solution to bridge connectivity divides (RSPG, 2021[155]). This item will be studied at WRC-23 (i.e. Agenda Item 1.4).

Licensing for non-geostationary satellite services (NGSO)

Over the past few years, satellites in Non-Geostationary Satellite Orbit (NGSO) have emerged as an alternative method to provide broadband connectivity to end users, especially for rural and remote areas, as well as to support terrestrial networks by offering backhaul services. Satellite connectivity in the past has largely been provided using satellites in geostationary earth orbit (GEO), which are synchronised with the Earth's rotation (OECD, 2017[161]).

While GEO satellites have a large coverage area, they are typically larger and more expensive to build, and suffer from higher latency due to their high orbit above the Earth's surface. Newer approaches propose satellites in low earth (LEO) or medium earth orbit (MEO), which offer lower latency (due to their lower orbits) and smaller satellites that are cheaper to build and launch, depending on the size and complexity of the satellite (OECD, 2017[161]). However, their lower orbits require many more satellites to complete a worldwide constellation. Thus, one satellite hands over coverage of a certain area to another as it moves along its orbit, which introduces complexity to the system design compared to GSO systems. For the same reason, NGSO user terminals must be able to track satellites as they move through the sky, as opposed to GSO user terminals, which can be pointed to a fixed location. In general, satellite user equipment must be highly sensitive to be able to receive the comparatively dim signals from satellites, which must travel across great distances. This makes them at risk of interference, as their sensitivity threshold is lower than for other services whose transmitting signal is much closer by. This risk is influenced on the receiver's level of immunity from interference, as well as the technical parameters of the services operating in nearby bands (FCC, 2022[93]). Noting this concern and the unique characteristics of satellite receivers, the FCC included the topic of satellite receiver interference immunity in its recent inquiry into receiver equipment and their resilience to interference (FCC, 2022[93]).

Several companies have plans to or have already launched satellites to build LEO constellations to offer satellite connectivity, including SpaceX's Starlink, OneWeb, Boeing, Telesat and Amazon's Project Kuiper. While Starlink and OneWeb are deploying their constellations now, Project Kuiper plans to launch its first satellites by the end of 2022 (Amazon, 2021[162]). Starlink has 1 469 active Starlink satellites in orbit (as of January 2022), out of 4 408 planned satellites and OneWeb launched up to two-thirds of its planned LEO constellation (428 satellites launched) (Musk, 2022[163]; FCC, 2021[164]; OneWeb, 2022[165]). There are also many satellite constellations aiming to service the IoT market, mainly LEO, such as Swarm Technologies, Hiber, Kinéis and Globalstar. In addition, Earth observation satellites support several use cases in agriculture, as well as disaster preparedness and weather and climate monitoring. Data from such satellites is expected to play an even greater role as countries grapple with the impact of climate change.

The number of different satellites proposed raise several questions for regulators. Regulating satellites' use of spectrum to manage radio interference takes place on two axes: the international level, coordinated by the ITU, and the domestic level, managed within the country by the domestic regulatory authority. The current licensing process for these constellations is complex, across these two axes. At the international level, the role of the ITU to manage radio interference across borders is crucial. There are regulatory processes for the use of frequencies in space (e.g. satellite space stations) as well as international coordination to ensure frequencies can be used without harmful interference to other existing space operations (i.e. satellite frequency coordination process). The ITU manages the process of international coordination and notification and maintains the Master International Frequency Register to record the use of spectrum in space (ITU, 2022[166]). The domestic regulator oversees approving filings for proposed satellite systems (including use of frequencies) and submitting the requested frequencies to the ITU, which may require coordination with other countries to ensure two systems can coexist.

At the domestic level, national regulatory authorities are responsible for the authorisation of earth stations, which the satellite operator may have to apply for in multiple countries, depending on its operational plans and the requirements of its system. Domestic regulators are also in charge of the process to authorise the satellite operator as a communication provider in the country, as well as possible regulatory approval to allow the use of end user terminals (e.g. satellite dishes installed on a customer's premise). In Australia, entities can apply for the authorisation of earth stations under the area-wide apparatus licence (AWL) in the 26 and 28 GHz band (ACMA, 2020[32]). This streamlined process may ease some of the regulatory burden on satellite providers to provide service in the country, which may support rural connectivity in the country, a key aim of the country. In the United Kingdom, Ofcom authorises NGSO Earth stations through its satellite (non-geostationary Earth station) licence ("Earth station licence") and NGSO end user terminals through its satellite (Earth station network) licence ("end user terminal licence") (Ofcom, 2021[167]).

Some stakeholders note that the current system of satellite filings may be time and resource intensive for both satellite providers and domestic regulators, raising questions whether the current process may delay innovations of newer satellite constellations. Nevertheless, international coordination and management at the ITU is a necessary step, given the boundary-transcending nature of satellite constellations and the requirements to ensure coexistence between systems. Given the regulatory questions being raised by such constellations and their growing prevalence, there are several WRC-23 agenda items related to the topic. This includes Agenda Item 7, which considers possible changes related to "advance publication, coordination, notification and recording procedures for frequency assignments pertaining to satellite networks, in accordance with Resolution 86 (WRC-07), in order to facilitate the rational, efficient and economical use of radio frequencies and any associated orbits, including the geostationary-satellite orbit" (ITU, 2019[16]).

Another regulatory question is whether the number of proposed satellites is feasible, when considering dangers related to space debris. The National Aeronautics and Space Administration (NASA) of the United States reportedly raised concerns regarding Starlink's request for authorisation of an increased constellation of 30 000 satellites (and other large constellations being proposed) (Brodkin, 2022[168]). Namely, these systems may increase congestion in LEO orbit, bringing additional risk of debris-generating collisions and possibly impacting human spaceflight and science missions. The European Commission announced a "Space traffic management" approach, dealing in part with space debris management and collision avoidance (European Commission, 2022[169]). The complexity of mitigating interference between different systems is also increasing as the number of satellite constellations grows, both considering protection of existing GSO systems as well as with other NGSO systems.

At the national level, these questions have prompted regulatory discussions. In the United Kingdom, for example, Ofcom introduced changes to its NGSO licensing framework, including its application process to incorporate further checks regarding coexistence and competition, and to increase transparency by publishing applications and allowing a comment period. The changes also introduce new conditions to its existing Earth station and end user terminal licences and remove an existing licence exemption for end user terminals operating in the Ka band to bring all terminals under the same regulatory framework (Ofcom, 2021[167]). Several of the changes relate to coexistence and technical cooperation between NGSO systems, likely in response to the regulatory challenges arising from the challenges to avoid harmful interference between systems as their numbers increase. These changes feed into Ofcom's broader "Space Spectrum Strategy", which it is currently under consultation (Ofcom, 2022[170]). Namely, Ofcom proposes three priority areas for its actions in the near term in the space sector: satellite communications (including NGSO constellations), Earth observation and navigation, and access to space, in light of rising concerns over space debris and the increasing number of objects in space (Ofcom, 2022[170]).

Other governments are considering satellite's potential, especially NGSO constellations, to help meet domestic connectivity goals, given its ability to reach remote areas that are under- or unserved by terrestrial networks. For example, in Colombia in February 2022, the Ministry of Information and Communication Technologies (MinTIC) issued a new regulatory regime for the provision of satellite services, which modernises the management framework and lowers fees (MinTIC, 2022[171]). A key aim of the new framework is to encourage the development of satellite connectivity in the country, particularly for hard-to-reach areas (MinTIC, 2022[172]). In a recent report from March 2022, the Swedish Post and Telecom Authority (PTS) assessed satellite's potential to reach its 2025 broadband targets. The report noted that broadband via satellite "appears today to be the only realistic alternative" to reach the most remote areas and fully achieve its targets (PTS, 2022[173]). PTS will undertake further analysis in 2022 to determine whether potential measures are needed to promote satellite broadband in the country. The European Commission recently announced plans for an "EU space-based secure connectivity system" leveraging satellite connectivity (European Commission, 2022[169]).

Towards the use of Terahertz spectrum and the development of beyond 5G technologies

Research on beyond 5G technologies has already begun in a handful of countries (OECD, 2022[59]), who are examining and attempting to anticipate innovations in beyond 5G technologies. For example in Europe, the RSPG has stated that "European Commission and Member States should actively support 6G research and the development of future eco-systems in response to European policy objectives and, when needed, ensure that available EU harmonised spectrum is able to support the development of 6G and other technologies beyond 5G" (RSPG, 2021[155]).

The potential use of higher spectrum frequencies (above 100 GHz),[1] may enable wireless innovation, including beyond 5G technologies. There is a myriad of diverse use cases that are currently in the R&D phase (e.g. terahertz communication and sensing, immersive extended reality (XR), holograms, etc.) (OECD, 2022[59]). Some stakeholders note that the development of terahertz systems is being driven by the vision of providing a design for joint communication, localisation and sensing (Ofcom, 2021[174]; Bourdoux et al., 2020[175]). To foster experimentation for applications using terahertz bands, temporary licences may be helpful. For example, in the United States, the FCC opened a 10-year spectrum licence in the 95 gigahertz (GHz) to 3 THz range for companies to test and verify their potential new services for beyond 5G technologies (FCC, 2019[176]). In the future, the licensing framework for these very high bands may require a fresh approach to licensing with out-of-the-box thinking given the distinct nature of this type of spectrum (i.e. propagation features and potential use cases).

The environmental sustainability of communication networks

OECD countries consider it critical to analyse the environmental impact and sustainability of communication networks, as made evident in the OECD Council Recommendation Broadband Connectivity adopted in February 2021 [OECD/LEGAL/0322].[75] Working towards analysing and addressing the environmental sustainability of communication networks includes understanding how they affect the environment, and are affected by it, how technologies can help other sectors reduce their carbon footprint, and what actions can be taken to tackle the challenges presented by climate change.

There are two different facets to be considered concerning the issue of environmental sustainability and the interplay with spectrum management. The first relates to ensuring that communication networks are sustainable (i.e. their environmental footprint), which includes questions on how networks are rolled out (e.g. the energy efficiency of the technologies used to deploy networks; how many base stations are needed and their energy consumption; how much energy different network technologies consume to run efficiently and provide in- and outdoor connectivity, and whether the use of AI can enhance energy management of networks, etc.). This also includes positive impacts of connectivity enabling smart devices that may reduce the carbon footprint. The environmental sustainability of networks is a crucial question for policy makers. However, often spectrum managers lack a direct mandate to tackle unilaterally these issues and may require regulatory cooperation with other government agencies within a whole of government approach (as explored in the report "Communication Regulators of the Future" (OECD, forthcoming[177])).

The second facet relates to the role of spectrum in monitoring our natural environment (through Earth Exploration Satellites)[76] and thus the effects of climate change.

OECD countries have started to study the impact of communication networks for climate change, for example, Denmark, Ireland, and France, with the latter looking into spectrum management decisions. At the European Union level, both RSPG and BEREC are active. The RSPG, the administration led advisory group to the European Commission, published a report recommending positive actions at the European Union level (RSPG, 2021[178]). BEREC is currently undertaking a study on the environmental sustainability of communication networks (BEREC, 2022[179]).

Some regulators take into account environmental sustainability considerations for spectrum management by analysing the environmental impact of the use of different spectrum bands, the impact of deploying thousands of additional base stations, or the technology trends in the development of more energy efficient networks. Moreover, assigning spectrum in a technology-neutral and flexible way may allow for operators to use the most energy-efficient combinations of spectrum per type of use requirement and adopt new energy efficient technologies.

While many spectrum managers may not have an explicit mandate at present related to the environment (e.g. Australia, Colombia, Poland, Spain, United Kingdom), some regulators are coordinating these efforts as part of a whole-of-government approach (e.g. Canada, France, Ireland[77]). Other countries have already a specific mandate in this respect within their legislation. In Costa Rica, the sectoral legal framework establishes that both the Ministry (MICITT) and the communication regulator (SUTEL) need to ensure "the sustainable development of telecommunications in harmony with nature".[78] SUTEL establishes general sustainability obligations for operators through spectrum licences.

Some countries are analysing the environmental impact of making more spectrum available in different bands. For example, in Europe, the RSPG recommended that, "*The European Commission in cooperation with Member States should ensure that adequate spectrum is made available under harmonised conditions to support EU initiatives to combat climate change and improve energy saving*" (RSPG, 2021[155]). In addition, countries also may be considering the impact of different spectrum bands to lower CO_2 emissions. In France, the government asked the regulator (Arcep) to provide information by the end of 2021 on ways to take the environment into account in future frequency allocations in the 26 GHz range. Arcep held a collaborative workshop on this issue in November 2021 (Arcep, 2021[180]).

New technologies may help mitigate some environmental effects of communication networks. For example, the use of AI systems in networks, enabling massive MIMO sleeping mode, may optimise energy consumption of networks. In addition, when assessing the environmental impact of communication networks, the increased openness and virtualisation of networks could be considered. For example, within the scope of its national 5G strategy, the Portuguese government plans to develop initiatives to promote energy efficiency and environmental sustainability in the installation of 5G systems.

Infrastructure sharing may also be an important channel to increase the sustainability of communication of networks, and as such, wholesale-only infrastructure companies (e.g. Mexico's wholesale-only shared mobile network, Red Compartida) and tower companies may become increasingly relevant. Moreover, regulators may be adding environmental policy objectives to their assessments in the competitive reviews of RAN sharing agreements (e.g. Latvia), or may actively promote infrastructure sharing for its environmental benefits (e.g. Slovenia).

Fostering smart devices, such as the Internet of Things (IoT), may have a positive impact on the environment through smart grids, connected forests, or traffic management systems that reduce congestion. In 2019, the Irish communication regulator (ComReg) assigned its 400 MHz Band Spectrum Award for the use of Smart Grids. The award was complementary to the Irish Government's climate policies, with Smart Grids described as "an efficient utility network system typically using digital automation technology for monitoring, control, and analysis within the supply chain" and a key enabler for the reduction of greenhouse gas emissions (ComReg, 2019[181]). Germany awarded an exclusive licence in the 450 GHz band for a smart electrical grid private network in February 2022 to 450connect, a consortium of German regional and municipal energy and water utilities along with energy companies (Smart Energy, 2022[182]).

Several countries have expressed that one of the main human health and environmental considerations in spectrum management concerns standardization activities related to electric and magnetic fields (EMF) exposure limits (e.g. Israel, Lithuania, New Zealand and the United Kingdom).

Going forward, there is a need to explore in depth circular economy models for the digital transformation so that carbon footprint may be reduced or avoided (e.g. making devices and batteries more durable), with a particular emphasis on the whole lifecycle approach to assess the environmental impact of networks and devices.

Conclusion

Spectrum is a key asset for all wireless communications, from WLANs to radar, satellite to mobile and broadcasting. Its timely availability to bridge connectivity divides is essential. Therefore, ensuring the efficient use of spectrum for all users, when and where they need it, contributes to overall social and economic welfare.

Given the strategic nature of spectrum, clear policy objectives and a strong technical understanding are needed to guide the timely and efficient management of this often scarce resource by national administrations. Spectrum managers are simultaneously striving to ensure efficient use, avoid harmful interference, promote wireless innovation, foster investment, and balance competing demands for spectrum. With an ever-changing external context and a growing dependence on this vital, but limited resource, spectrum managers aim to strike the right balance between several policy objectives to ensure spectrum is used in the most effective and expansive way possible. As such, the report set the scene on the policy vision and principles guiding spectrum management for communication services. This includes a trend towards market-based spectrum assignment mechanisms and their inclusion into the spectrum management strategies followed by different countries, as well as some of the likely developments in spectrum assignments in the near future.

At present and going forward, spectrum managers are confronted with manifold challenges, which are becoming more intense and complex as markets and technologies evolve. Some of the key challenges for spectrum managers that become increasingly important going forward include: moving towards flexible spectrum management frameworks; balancing competing demands among a plethora of spectrum uses and users; re-purposing spectrum, given existing allocations and users in prime spectrum frequency bands; harnessing the benefits of harmonisation, where feasible, while balancing other objectives, such as enhancing flexibility; promoting spectrum sharing while managing interference, which requires a deeper analysis of receiver performance; and adapting licensing models to foster emerging technologies, among other issues. However, while the report alluded to many challenges, some are beyond the scope of this report (e.g. radio equipment performance, in particular receivers and realistic parameters for compatibility studies), which should be addressed by the relevant entities specialised on these topics (e.g. regional and international harmonisation bodies, standardisation bodies, etc.).

To better understand how OECD countries are facing these multi-faceted challenges, the report discussed developments in spectrum management. OECD countries are exploring innovative approaches to spectrum management in light of emerging technologies and the evolving market landscape. For example, countries are considering new forms of spectrum sharing to enable broader access to spectrum, granular approaches to licensing, developments in mmWave spectrum and the best approaches to assign it and the role of unlicensed spectrum. Finally, the report concluded with future considerations for spectrum management in light of technologies on the horizon (e.g. Terahertz applications, drones, HAPS, NGSOs) as well as the growing relevance of the environmental sustainability of communication networks.

As evidenced by the developments seen around OECD countries, there are many ways to approach spectrum management to meet policy objectives. Importantly, how one country may decide to do so may differ from another's, based on historical context and national prioritisation of policy objectives. With shifting demands and new technologies, spectrum management will be faced with evolving challenges in the coming years. However, learning from other OECD countries about how they may be tackling existing challenges and installing frameworks able to evolve and adapt to changing circumstances can provide a useful signpost for spectrum managers of the future.

Annex A. Spectrum licence duration and renewals

Annex Table A 1. Typical duration of current mobile spectrum licences in OECD countries

Country	Licence duration	Can licences be extended?	General policy for licence renewal	How does the regulator calculate extension or renewal fees*?
Australia	Up to 20 years	Yes (upon request)	The process for considering licence renewals can vary on factors such as whether it is an apparatus or spectrum licence, the licence duration and whether the licence includes a renewal statement.[1]	The structure of the renewal fees is the same as the fees for an initial issue of the licence and will depend on the licence type. For apparatus licences there is: • fees for service charges for the issue or renewal of the licence and • an apparatus licence tax where the tax is set to promote the efficient use of spectrum and contribute to the indirect costs of spectrum management. For spectrum licences there is: • fees for service charges for the issue or renewal of the licence, • spectrum access charges to reflect the value of the spectrum and the licence and • spectrum licence taxes so that licensees can contribute to the indirect costs of spectrum management.
Austria	20-25 years	No	New auction.	New licence fees determined by the auction.
Belgium	20 years	Yes (with 5-year periods)	Renewal or new auction.	Renewal fee based on initial fee or new licence fees determined by the auction.
Canada	10 and 20 years, determined through public consultation.	Licence terms for spectrum licences issued through a competitive process are not extended under normal circumstances. However, they can generally be renewed.	Spectrum licences issued through a competitive process are typically accorded a high expectation for renewal, unless the licensee has breached their licence conditions, a fundamental reallocation of spectrum to a new service is required, or an overriding policy need arises. ISED typically consults on renewal of these licences 2 years prior to their end of term.	New licence fees determined by the auction, or licence renewal fee for the case of renewals. For licences issued through a renewal process, a separate consultation determines the spectrum licence fee so they reflect market value.
Chile	30 years	No	There is no automatic renewal. There is no preferential right. New comparative selection procedure.	New comparative selection procedure.
Colombia	20 years	Yes[2] (for current licences)	The ICT Modernisation Law extends the spectrum licence period from 10 to 20 years.	The National Spectrum Agency (ANE) provides the calculation of the fees to the ICT Ministry, which checks the documentation and conditions before agreeing to the renewal.
Costa Rica	15 years	Yes, for additional 10 years	SUTEL (regulator) and MICITT (rector) check if the operator has fulfilled licence obligations through the first 15 years.	No fees.
Czech Republic	15 years (since 2012); 20 years (since 2020)	Yes (with legal requirements)	Procedure given by law. The regulator is obliged to renew the licence on request of the licence holder.	The regulator appoints an independent expert to determine the price of the renewal.

Country	Licence duration	Can licences be extended?	General policy for licence renewal	How does the regulator calculate extension or renewal fees*?
Denmark	15-23 years	No	New auction.	Auction revenue is determined by the auction outcome. Annual spectrum fees are regulated by the national budget.
Estonia	Unlimited duration with annual fees, which may be referred as an extension of the licence.	Unlimited licence duration with annual extension by fees.	Fees regulated by the Electronic Communications Act.	Fees regulated by the State Fees Act
Finland	15 years (approximately).	Yes	Renewal fee or new comparative selection procedure. (Act on Electronic Communication Services, Section 17 a and b).	Act on Electronic Communication Services lays down the rules of market-based frequency fees (Section 288).
France	12-20 years	No	Licence extension[3] or auction.	Arcep, the French regulator, usually conducts auctions. No specific renewal fee.
Germany	10-20 years, depending on the spectrum assignment (i.e. local or national).	Yes, licence extension is possible in general.	Auction or possibility of renewal, subject to conditions'.	New licence fees determined by the auction. For renewals: The fees are based on the economic value of the frequencies. Different factors are taken into account in the calculation, for example the duration of the allocation, the bandwidth used or the range of use.
Greece	15	Yes, additional 5 years	There is a premium of 50% if the renewal is requested in advance, and a revaluation if requested one year prior to expiration date.	
Hungary	15 years	Yes (for 5 years).	New regulation took into force in line with the EU regulation (EECC) in 2020. If the renewal is not forbidden it would be possible.	At time of the extension or the renewal the fee (among all conditions) can be defined on the basis of the offer of the NMHH based on regulation
Ireland	20 years	No	New auction.	New licence fees determined by both the auction and annual administrative spectrum fees.
Iceland	15 years (plans for 20 years in the next assignment procedure).	Yes	In general licences are renewed if: • There is no negative impact on competition. • No negative impact on efficient planning and use of the spectrum. • The licensed use is still in conformity with international and national frequency plans. • The licensed technology is not obsolete. • Demand for spectrum does not exceed supply. • The licensee has not breached the relevant conditions and regulation • Market share is >10%. • Licensee agrees to changes to licence conditions deemed necessary by ECOI.	The renewal fees are usually decided in a specific legislation. Usually the fee decided in the law is based on the initial licence fee taking account of inflation and licence duration.
Israel	15 years with annual fees.	Yes	Annual fees determined by the sector Law.	Each year spectrum fees are adjusted according to the consumer price index.
Italy	20 years	Yes	Extension and renewal of right of use of frequency are regulated according to the EECC and requests are examined case by case, subject to public consultation.	"Spectrum Market Transactions" or a "Market Comparable Approach" is adopted to determine annual spectrum fees for licence renewal. The value of spectrum that resulted from other assignment procedures or trades in secondary markets are used to assess value of spectrum. The value is scaled to the amount of bandwidth and the duration of the extension period. The benchmark is then revised upwards on the basis of the monetary revaluation rate, and with the application of a 30% increase, proportionate to

Country	Licence duration	Can licences be extended?	General policy for licence renewal	How does the regulator calculate extension or renewal fees*?
				the others similar cases.
Japan	5 years with possibility of renewal.	Yes	If the assessment by the Ministry of Internal Affairs and Communications (MIC) shows that the application conforms to Radio Regulatory Laws, the licence will be renewed. A licensee must submit an application before expiration in order to renew a licence and continue operations after a valid term.	Renewal fees determined by an Ordinance of the MIC, or by comparative selection in the case of a new assignment procedure.
Korea	1-5 years	Yes	Act 38 of the Enforcement Decree of the Radio Waves Act. The Ministry (MSIT) and operators discuss renewal.	Usually price determined by auction.
Latvia	10-18 years	Yes	Renewal if no breach of rights of use of spectrum is identified.	No renewal fees.
Lithuania	15 years	In theory yes, if no other applicants. Otherwise it is auctioned. In practice, spectrum is re-auctioned.	Rules on the frequency assignment and use.	According to the Tariff rates for services provided and works performed by RRT.
Luxembourg	15 years	Yes	At least once for a period of 5 years.	Annual fees on the basis of total amount for 15 years period during the auction.
Mexico	20 years, with the possibility of extension for periods up to those originally established (LFTR, 2014, Art. 75).	Yes[3] (if there is no public interest in the band, and if so, it will notify the licensee its determination and the termination of the concession will proceed at the end of its term.)	It will be necessary for the licensee to request renewal to the IFT within the year prior to the start of the last fifth part of the term of the licence. The IFT will review the following: • The licensee is up to date in the compliance with the obligations established in the Law and other applicable provisions, as well as in their concession title. • The IFT will decide within the year following the presentation of the request if there is a public interest in recovering the spectrum. • In the event that the IFT determines that there is no public interest in recovering the spectrum, it will grant the requested extension, as long as the licensee previously accepts the new conditions set by the Institute, among which the payment of a renewal fee will be included. (LFTR, 2014, Art.114).	Renewal fee determined by the regulator (IFT), considering national and international references of the market value of the frequency band, among others.
Netherlands	20 years	No	New auction.	New licence fees determined by auction.
Norway	20 years	No	New auction.	New licence fees determined by auction.
New Zealand	20 years, but temporary licenses are sometimes	No, however New Zealand reviews	New Zealand aims to review spectrum rights at 6 years before licence expires, and provide	Fees depend on the spectrum band in question.

Country	Licence duration	Can licences be extended?	General policy for licence renewal	How does the regulator calculate extension or renewal fees*?
	granted for shorter periods	spectrum rights 6 years before licence expiration.	notification at 5 years before expiration.	
Poland	15 years	No	There is a tool to grant renewal of the licences called reservation for a subsequent period (reservation is valid during the same period as previously). Renewals are in line with operators' requests.	Calculated based on the price per MHz applied in the latest previous award of a band, with an inflation adjustment.
Portugal	15 years (20 years for 5G).	Yes	Licence extension. (Electronic Communications Law article 33).	NA
Slovak Republic	15 years	Yes, according to the new Act on Electronic Communications in force from February 2022.	NA	Extension or renewal fees are calculated on base of spectrum value
Slovenia	15 years	Yes	New auction or licence extension fee.	New licence fees determined by auction, or in the case of extension, the licence holders will pay a certain amount for the efficient use of this scarce resource determined by AKOS.
Spain	20 years	Yes	One renewal of 20 years.	Fees are revised annually.
Sweden	20-25 years	No	New auction.	New licence fees determined by auction.
Switzerland	15 years	Yes	Renewal upon request and decision of the Federal Communication Commission ComCom or by new auction.	Renewal fees determined upon request of the Federal Communication Commission ComCom. New licence fees determined by auction.
Türkiye	25, 20, and 15 years for 2G, 3G and 4/5G, respectively.	Yes	No general policy.	According to the related legislation at the time of the extension or renewal of the licences.
United Kingdom	Indefinite licence[5] (i.e. 15 years in the initial term, after which Ofcom can revoke licence for spectrum management reasons with a five years' notice).	Yes	Automatic renewal or auction in case of licence being revoked.	In 2015, Ofcom calculated the renewal fee of the 900 MHz and 1.8 GHz bands by: i) analysing the sums paid in the 4G auction of February 2013; ii) comparing the amounts bid in foreign spectrum auctions; and iii) assessing the technical and commercial characteristics.
United States	Varies[6]	Licenses are subject to renewal expectancy, (if there is no mutually exclusive applications for initial licences)	Generally, absent failure to comply with FCC's rules or the terms of the licence, operators may expect their licence will be renewed. In the case of mutually exclusive applications, the Balanced Budget Act of 1997 requires the FCC to use auctions to resolve mutually exclusive applications for initial licences unless certain exemptions apply (e.g. exemptions for public safety radio services, digital TV licences to replace analogue licences, and non-commercial educational and public broadcast stations).	Auction or renewal fees. Renewal fees are calculated based on labor hours and administration costs. Such fees are regularly reassessed and published on the FCC's website.

Notes: *Renewal fees in this table are either licensing fees of re-auctioning the spectrum, or an administrative fee of renewing the licence. It does not pertain to annual fees to cover administrative costs of managing spectrum. ACMA = Australian Communications and Media Authority; AKOS= Agency for Communication Networks and Services (Slovenia); ECOI= Electronic Communications Office of Iceland; ISED= Innovation, Science and Economic Development Canada; EECC= European Electronic Communications Code; FCC = Federal Communications Commission (United States); IFT= Federal Telecommunications Institute (Mexico); LFTR= "Ley Federal de Telecomunicaciones y Radiodifusión" (Telecommunication and Broadcasting Law of Mexico).

1. Australia: Information about the ACMA's general approach to licensing and allocation can be found at: https://www.acma.gov.au/publications/2021-03/rules/our-approach-radcomms-licensing-and-allocation.
2. Colombia: After changes brought about the ICT Modernisation Law, current licences may continue for one additional term.
3. France: Exceptionally, the government agreed with MNO investment commitments to accelerate mobile coverage (i.e. 900 MHz, 1 800 MHz and 2 GHz bands) for a ten-year renewal period without an auction (i.e. "the new deal" of November 2018).
4. Mexico: Spectrum licences can be renewed for an additional period. The licensee has to manifest interest in renewal a year before the licence term. The IFT has a year to resolve whether there is public interest in recuperation of the frequency band, and if so, it will notify the licensee of the licence revocation. If there is no public interest, then the IFT may grant the renewal (art. 114 in Chapter VI of the LFTR).
5. United Kingdom: Indefinite licences mean that Ofcom has limited rights of revocation during an initial term of 15 years, after which Ofcom can revoke the licence for spectrum management reasons, provided they have given the licencee at least five years' notice. The right to revoke licences on spectrum management grounds was retained because of the risk of specific market failures. There are exceptions to the indefinite licence term. For instance, licences for programme making and special events (PMSE) and "Innovation & Trial Licences" all have end dates.
6. United States: Licences for service areas are granted by the Commission when it makes a band available for licensed use, and therefore vary depending the decision the Commission makes in the specific context of each band. In 1993, Congress passed the Omnibus Budget Reconciliation Act. This gave authority to the Federal Communications Commission (FCC) to use competitive bidding to choose from among two or more mutually exclusive applications for an initial licence.

Sources: OECD elaboration based on responses to regulatory questionnaire supplemented by national sources. Australia: Australian Government (1992[183]), "Radiocommunications Act of 1992", https://www.legislation.gov.au/Details/C2021C00462; ACMA (2021[184]), *Modernising the Management of Spectrum*, https://www.acma.gov.au/publications/2021-03/rules/our-approach-radcomms-licensing-and-allocation. Canada: Government of Canada (2019[185]), *Policy and Licensing Procedures for the Auction of Spectrum Licences in the 2 300 MHz and 3 500 MHz Bands*, www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08621.html. Chile: Subtel (2005[186]), *Manual de Trámites de Autorizaciones*, www.subtel.gob.cl/manual_autorizacion/manual/manual_autorizaciones.pdf. Colombia: OECD (2019[187]), *OECD Reviews of Digital Transformation: Going Digital in Colombia*, https://doi.org/10.1787/781185b1-en. European Union: Cullen International (2019[188]), *Licence Extension and Renewal Policy*, www.cullen-international.com/radiospectrum.html. Japan: MIC (2019[189]), *Process of Frequency Assignment*, www.tele.soumu.go.jp/e/adm/proc/type/again/index.htm. Korea: MSIT (2019[190]), *A Public Notice for the 5G Frequency Auction*, www.msit.go.kr. Mexico: Government of Mexico (2014[191]), *Ley Federal de Telecomunicaciones y Radiodifusión*, www.dof.gob.mx/nota_detalle.php?codigo=5352323&fecha=14/07/2014. United Kingdom: Ofcom (2017[192]), *The Award of 2.3 and 3.4 GHz Spectrum Bands*, www.ofcom.org.uk/__data/assets/pdf_file/0030/81579/info-memorandum.pdf. United States: FCC (2020[193]), *About Auctions*, www.fcc.gov/auctions/about-auctions; FCC (2017[194]), *Wireless Licence Renewal and Service Continuity Reform*, http://transition.fcc.gov/Daily_Releases/Daily_Business/2017/db0713/DOC-345790A1.pdf.

Annex B. Depreciating licences and their potential application to spectrum rights

A theoretical approach for a new form of licence, coined as “depreciating licences”, that may have an application for assigning spectrum rights has been proposed by economic theorists Paul Milgrom, Glen Weyl, and Anthony Lee Zhang . The authors propose a licensing mechanism to balance potential trade-offs that may arise when policy makers seek to harness both the benefits of innovation through new uses of spectrum while encouraging investment in current use of spectrum. Their main claim is that this type of licence may alleviate the tension between providing investment incentives and facilitating re-allocation of the spectrum to new uses and users. However, in practice, this theory has not been implemented and may face several caveats. The theory behind this application to spectrum is based on a working paper by Weyl and Zhang on “Depreciating Licences” (2021[37]). The application to spectrum markets is based on Milgrom, Weyl, and Zhang (2017[36]).

Depreciating licences and how can they be applied when assigning spectrum rights: Weyl and Zhang on “Depreciating Licences” (2021[37])

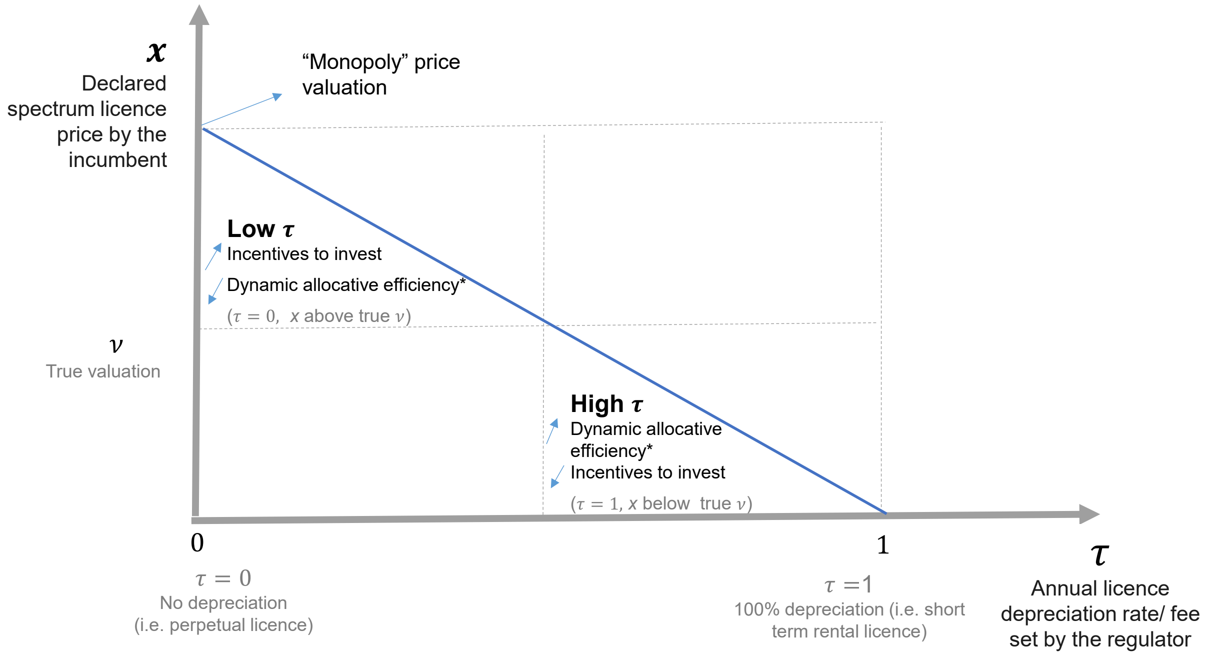
Depreciating licences are licences of unlimited duration, but that depreciate over time. The regulator sets a depreciation rate (τ), for example 10%, instead of setting a licence term. Every year the licensee must declare a price at which she is willing to sell the spectrum (x) and then pay a licence fee according to that declared price ($\tau * x$). This type of licence can be seen as a form of “contestable” spectrum property rights (Figure A.B.1).

This rule creates a trade-off for the incumbent licensee. If a licensee claims a high value because she wants to keep the spectrum, then she must pay a high licence fee every year. If instead, she declares a low value for the spectrum rights, then she pays a reduced licence fee, but must sell at that price if there is an entrant interested in the spectrum rights. The balance of these two effects disciplines the price declared by the licensee.

A 100% depreciation rate ($\tau = 1$) set by the regulator is equivalent to a short-term rental licence, whereby the regulator repossesses the entire licence each period, and incumbents compete on equal ground with other buyers to buy the licence. In this case, allocative efficiency may be reached, but there is no incentive to engage in long term investments. On the other extreme case, a 0% depreciation rate ($\tau = 0$) is effectively equivalent to a perpetual licence, investment is efficient, but allocative efficiency is reduced. In other words, the higher the regulator sets the depreciation rate, the more efficient is the assignment of the licence, as it enables the potential entry of innovative use cases (i.e. dynamic allocative efficiency). On the other hand, high depreciation rates reduce incentives to invest. By contrast, a low depreciation rate increases incentives to invest but reduces allocative efficiency (Figure A.B.1). Such a mechanism requires a platform – a depreciating licence exchange-, to work in practice.

Figure A.B.1. Depreciating licences in a "nutshell"

As the depreciation rate set by the regulator increases, innovation may be fostered, while incentives to invest decrease due to lower certainty brought by shorter licence periods



Note: Illustrative example to explain the trade-offs (i.e. actual figure and curvature depends on Weyl and Zhang's model parameters). *Dynamic allocative efficiency in this context refers to innovation brought by entry, i.e. new innovative uses/users for spectrum. That is, the ownership of the rights of spectrum change in the event there is a more efficient use for spectrum arising in the next period.
Source: OECD elaboration based on Milgrom, Weyl and Zhang (2017) and Weyl and Zhang (2021).

Foothold auctions, a potential alternative to depreciating licences: Milgrom, Weyl, and Zhang (2017[36])

In the absence of a depreciating licence exchange platform, the outcome of depreciating licences can be approximated by a "foothold" auction. Instead of reassigning licences through a platform, the regulator commits to hold auctions on at designated intervals (e.g. every three years), where the current incumbent licensee would be given a "foothold" of refundable bidding voucher.

The size of this bidding voucher is determined by the stakes the licensee has after depreciation $(1 - \tau)$. Therefore, to mimic a yearly depreciation rate of 10%, in a three year-year setting, the incumbent licensee holds an equity of 70% of the value of the licence, amounting to a foothold (auction credit) relative to other bidders. If the incumbent licensee wins the auction, she only pays 30% of the auction price (the rest being covered by bidding credits), but if she loses, she is paid by the regulator 70% of the final auction price as compensation for relinquishing her remaining stake in the licence.

This type of implementation is more in line with current licencing regimes. However, auctions at present can take up to 18-24 months to be implemented given public consultations on their design, and this may be a factor to consider when choosing the interval for conducting "foothold" auctions.

Annex C. Licensing approaches for mmWave

Annex Table C.1. Licensing approaches for mmWave spectrum in OECD countries

Country	Band(s) allocated	Date assigned	What was the assignment procedure? (A. Auction, B. Comparative Selection, C. Administrative selection, D. other)	Details
Australia	25.1-27.5 GHz	Apr-21	A	National licence
	24.7–25.1 GHz, 27.5–30 GHz and 25.1-27.5 GHz	Dec-20	C	Local: Area Wide Licence (AWL), apparatus licence
Brazil	26GHz	Nov-21	A	National and regional licences
Chile	26 GHz	Feb-21	B	National licence
Croatia	26 GHz	Sep-21	A	National licence
Denmark	26 GHz	Aug-21	D	Hybrid approach: National level (traditional) licences + spectrum reserved for local (private) networks
Germany	26GHz	Jan-21	D	Local licences for private networks
Finland	26GHz	Jun-20	A	Hybrid approach: National level (traditional) licences + spectrum reserved for local (private) networks
Greece	26 GHz	Dec-20	A	National licence
Singapore	26.3-29.5 GHz	Nov-20	B	Tender for a national network
Slovenia	26GHz	Jun-21	A	National licence
Korea	28 GHz	Jun-18	A	National licence
	28GHz	Nov-21	A	National licence
Japan	27GHz - 28.2GHz	Apr-19	B	National licence
	29.1GHz - 29.5GHz	Apr-19	B	National licence
	28.2GHz - 28.3GHz	Dec-19	D	Local licences for private networks
	28.3GHz - 29.1GHz	Dec-20	D	Local licences for private networks
Italy	26.5-27.5 GHz	Oct-18	A	National auction with club use model (use it or lease it clause)
Latvia	26 GHz		D	1 GHz in the 26 GHz band is available in first-come-first-serve basis, while the rest may be assigned through an auction in the future.
United Kingdom	24-26 GHz		D	Lower part of the 26 GHz band is part of sharing framework for indoor use. First-come-first-serve licences.
	57-71 GHz	Nov-18	D	Licence-exempt basis.
	116GHz- 122GHz	Oct-20	D	First-come-first-serve basis
United States	28 GHz	Jan-19	A	Auctioned for flexible use fixed and mobile services for 10-year terms.
	24GHz	May-19	A	Auctioned for flexible use fixed and mobile services for 10-year terms.
	Upper 37 GHz, 39 GHz and 47 GHz	Mar-20	A	Auctioned for flexible use fixed and mobile services for 10-year terms.

Source: OECD elaboration based on responses to regulatory questionnaire.

Annex D. Spectrum sharing in OECD countries

Annex Table D.1. Recent examples of spectrum sharing, spectrum leasing and spectrum pooling in OECD countries

Country	Sharing model	Band	Description
Australia	Light licensing model	26 and 28 GHz (inter-service sharing)	Area-wide apparatus licences (AWL) grant the operation of one or more radio communication devices in an area. For the initial allocation of spectrum, all licence applications were considered in an application window to assess whether there were any applications competing for an overlapping area in the same frequency range. Applications are now considered on a first in time basis according to the availability in the requested frequency band and geographic area. AWL licensees will share spectrum with class licensees (unlicensed in Australian framework) in the 24.7-25.1 GHz band and individual IMT licences in the 25.1-27 GHz band. AWL sharing with class licences will be nationwide, with restrictions to manage interference; AWL sharing with IMT licensees will be outside specified areas. AWL licensees must coordinate with existing services and follow operating conditions at the geographic boundary of the licence. A range of services is supported and in some cases reserved, incl. FWA, mobile wireless broadband, private networks, FSS and IoT.
Australia	Light licensing model (under consultation)	3.4-4.0 GHz (inter-service sharing)	The ACMA consulted on a proposed framework to allow area-wide apparatus licences (AWLs) in the 3.4-4.0 GHz band in remote areas of the country to support local area wireless broadband use cases (e.g., wireless Internet Service Providers (WISPs), fixed wireless access providers and local private networks). The consultation sets out the technical framework to allow coexistence with other services operating in and adjacent to the proposed band. ACMA expects that the assignment process will not begin before Q4 2022.
Austria	Spectrum pooling	700 MHz and 2100 MHz	The spectrum pooling framework outlined in the auction guidelines for a 2019 multi-band spectrum auction allows pooling for underserved municipalities, for newly deployed sites and for a low share of existing sites. The overall share of sites eligible for pooling is also subject to a limit. The pooling is subject to approval and must comply with competition law. These limits do not apply to operators holding low amounts of spectrum rights (i.e. less than 10% of nationwide spectrum rights in several IMT bands).
Canada	Shared use model to be defined	3900-3980 MHz	ISED agreed to designate 80 MHz for shared use. The licensing framework will be developed through future consultation; ISED proposes to follow a "modernised sharing licensing approach".
Czech Republic	Obligation to lease	3.4-3.6 GHz	Certain 20 MHz frequency blocks auctioned in the 3400-3600 MHz band carry requirements, which apply for the licence's duration. Winning bidders of these blocks must lease the assigned spectrum to interested parties, for a limited geographic area, for the purpose of operating local private networks.
Denmark	Leasing obligation	3740-3800 MHz	Part of the 3.5 GHz-spectrum is subject to a leasing obligation intended to enable stakeholders other than mobile operators (such as enterprises, public institutions and universities) to lease spectrum from the mobile operators, in order to establish private networks. The terms and conditions was specified prior to the award process.
Finland	Shared use allowed but model not yet defined	1427-1518 MHz (inter-service sharing)	Dynamic shared use of 14271518 MHz for electronic communication services and military applications. Shared rules would be determined in the future if spectrum were to be assigned in the future for IMT use, to protect the existing military use of spectrum in isolated locations.

Germany	Obligation to negotiate	3.4-3.7 MHz	Licensees holding unused spectrum in the 3400-3700 MHz band in some areas are obliged to negotiate with parties interested in leasing this spectrum. This does not, however, constitute an obligation to lease, but rather an obligation to negotiate, and the Bundesnetzagentur must approve the leasing arrangement.
Italy	Licensed Shared Access (LSA) trial	2.3-2.4 GHz (inter-service sharing)	Trial to pilot the LSA model in the 2300 – 2400 MHz band to promote shared access by mobile broadband services without interfering with the incumbent users in the band (Fixed service, PMSE, governmental use).
Italy	Concurrent Shared Access ("club use")	26 GHz (intra-service sharing)	Licensees are granted 200 MHz each and can use up to all of awarded spectrum (1 GHz) when frequency is not used by other licensees. Licensee has a "pre-emptive" right on its assigned 200 MHz block. All licensees in the band (whose number is defined by regulator) must coordinate to ensure coexistence.
Italy	"Use-it-or-lease it" policy	3.6-3.8 GHz	Eligible third parties can apply to lease unused spectrum in order to provide service to municipalities on the "free list", a list of municipalities with less than 5 000 inhabitants that are not included in the coverage obligations of winning licensees.
Japan	Licensed shared access	2.3 GHz (2330-2370 MHz) (inter-service sharing)	One mobile operator is granted access to the 2.3 GHz band on a shared basis with incumbent users (broadcasting and governmental use), using a dynamic spectrum sharing management system, whereby incumbent users input their use into the system and mobile operators apply for use of frequency. Depending on the request and availability, the system decides whether the mobile operator can access the spectrum. MIC has assigned a licence to KDDI Group for five years in May 2022.
Netherlands	Licensed shared access (LSA) trial	2.3-2.4 GHz (intra-service sharing)	Electronic News Gathering/Outside Broadcasting (mobile video connections) sharing trial based on LSA "booking system", which allows video users to reserve temporary frequency use. Booking system is still in use for video, with plans to expand to include other existing users (services) of the band.
New Zealand	Light licensing model	2575 MHz - 2620 MHz	New Zealand's Managed Spectrum Park (MSP) licence, established in 2010, allows the shared use of 40 MHz (plus a 5 MHz guard band) of spectrum from 2 575-2 620 MHz to encourage local and regional broadband communication services. MSP licences are administered on a rolling basis and have low licence fees. MSP licencees are expected to coordinate with one another to avoid harmful interference.
Norway	Obligation to offer leasing option to industrial players	3.4 – 3.8 GHz	The 3.6 GHz band (3.4 – 3.8 GHz) auction rules include an obligation for licensees to offer tailored solutions for private networks *or* the possibility for the private network to lease frequencies for a limited geographic area so that the private player can develop the private 5G local network itself. The obligation applies where the business actor has a need for 5G networks and services and where the use of the 3.6 GHz band is required, or the most favorable frequency band for establishing the network or service.
Portugal	Licensed shared access (LSA) trial	2.3-2.4 GHz (inter-service sharing)	Coordinated spectrum sharing in licensed bands is still under analysis. A 2020 study on the Licensed Shared Access (LSA) spectrum sharing model was conducted in the 2.3-2.4 GHz frequency band, allowing IMT to share the band with incumbent use (PMSE). Prototype hardware developed for sensing and geolocation capabilities ("Warner LSA").
Slovenia	Concurrent Shared Access ("club use")	26 GHz (intra-service sharing)	Pre-emptive right in favour of the licence holder on its assigned sub-band and active sharing between all licence holders as well as between licence holders and those leasing capacity.
Slovenia	Spectrum pooling	700 MHz, 1500 MHz, 2100 MHz, 2300 MHz, 3600 MHz	As defined in its multi-band auction guidelines, pooling is permitted where it does not limit competition, especially in "challenging areas" of the country and in cases where network densification needs are expected to be high.
United Kingdom	Light licensing model	All mobile bands covered under the UK's mobile trading regulations (intra-service sharing)	Local access licences allow other users to access spectrum that was licensed to an MNO but not in use in certain areas (expected to be rural areas). Interested parties must apply to Ofcom for the right to use the spectrum for a limited time period (default of 3 year licence terms) in a limited geographical area that is not currently in use by an MNO. Low licence fees. Local access licensees must protect incumbent mobile operators and not constrain their future operations. Potential uses include private networks, mobile coverage (rural/indoor), fixed wireless access.

United Kingdom	Light licensing model	1781.7-1785 MHz/1876.7-1880 MHz; 2390-2400 MHz; 3.8-4.2 GHz; and 24.25-26.5 GHz (indoor only) bands (inter-service sharing)	There are two types of Shared access licence, a low power or a medium power licence, with different technical constraints. Licenses are issued for an indefinite amount of time, in a specific location (individual per location licences) and subject to annual licence fees. Applications are first come, first served and Ofcom coordinates access (e.g., a medium power licence will typically only be granted in rural areas due to the higher power limits/range and increased chance of interference and applications in the 24.25-26.5 GHz band will be restricted to indoor low power licences). Potential uses include private networks, mobile coverage (rural/indoor), fixed wireless access.
United Kingdom	Light licensing model	116-122 GHz, 174.8-182 GHz and 185-190 GHz (inter-service sharing)	Uncoordinated shared access under the Spectrum Access: EHF licence, which allows users to access the bands nationally on a non-protection, non-interference basis. Users must comply with technical constraints to protect Earth Exploration Satellite Services. Licensees can use any part of the band and there are no limits to number of potential users. Users must record location and antenna elevation angle for Ofcom monitoring and compliance checks.
United States	Tiered-based spectrum access system	3.5 GHz band (3 550 - 3 700 MHz, "CBRS band") (inter-service sharing)	Three tiers of service: i) Incumbent Access (IA), ii) Priority Access Licence (PAL); and iii) General Authorised Access (GAA), with decreasing priority and protection (e.g., PAL and GAA protect IA, GAA protects PAL, no protection for GAA). PALs are licensed through competitive bidding, with a limited number possible per county. GAAs can use the band without authorisation (unlicensed) but must not cause harmful interference to other tiers and must accept interference. Automated frequency coordinators (system access systems, SAS) incorporate information from Environmental sensing capability systems (ESCs), which detect Incumbent signals, to facilitate sharing between and among the three tiers.
United States	Light licensing model (auction not yet completed)	2.5 GHz (inter-service sharing)	The 2.5 GHz band auction will offer “flexible use geographic overlay licences” of unassigned spectrum in smaller local areas (i.e., on a county basis). Equipment can operated anywhere in the geographic area, however they must protect the licensed areas of incumbents. Any service may be provided under a terrestrial fixed or mobile allocation according to the national frequency allocation table.

Note: Illustrative examples highlighting different approaches; some examples may contain aspects of different approaches. *Sources*: OECD based on questionnaire responses supplemented by national sources. Australia: ACMA (2020[195]), *Applicant information pack - Allocation of apparatus licences in the 26 GHz and 28 GHz bands*, https://www.acma.gov.au/sites/default/files/2020-10/Applicant%20information%20pack_Allocation%20of%20apparatus%20licences%20in%20the%2026%20and%2028%20GHz%20bands_0.docx; ACMA (2022[196]) *Allocation of AWLs in the 3.4-4.0 GHz band in remote Australia*,https://www.acma.gov.au/consultations/2022-02/allocation-awls-34-40-ghz-band-remote-australia-ifc-112022, ACMA (2022[197]), *Allocating the 3.4–4.0 GHz band*, https://www.acma.gov.au/allocating-34-40-ghz-band . Austria: RTR (2019[123]), *Tender Document in the procedure for awarding spectrum in the 700, 1500 and 2100 MHz ranges*, https://www.rtr.at/TKP/was_wir_tun/telekommunikation/spectrum/procedures/Multibandauktion_700-1500-2100MHz_2020/TenderDocument-700_1500_2100_MHz-F_1_16_EN-non-binding-trans.pdf. Canada: Government of Canada (2021[198]), *Decision on the Technical and Policy Framework for the 3650-4200 MHz Band and Changes to the Frequency Allocation of the 3500-3650 MHz Band*, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11699.html. Czech Republic: CTU (2020[79]), *Invitation to Tender for granting of the rights to use radio frequencies to provide electronic communications networks in the 700 MHz and 3400-3600 MHz frequency bands*, https://www.ctu.eu/sites/default/files/obsah/ctu/announcement-invitation-tender-granting-rights-use-radio-frequencies-provide-electronic/obrazky/invitationtotenderen.pdf. Denmark: Danish Energy Agency (2021[80]), *Information Memorandum: 1500 MHz, 2100 MHz, 2300 MHz, 3.5 GHz and 26 GHz Auction*, https://ens.dk/sites/ens.dk/files/Tele/information_memorandum_1.pdf. Finland: Ministry of Transport and Communications (2021[199]), *Government Decree LVM/2021/49*, https://valtioneuvosto.fi/paatokset/paatos?decisionId=0900908f8071a23f. Germany: Bundesnetzagentur (2018[120]), *Decision of the President's Chamber of the Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen of 26 November 2018 [Decisions III and IV, unofficial translation]*, https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/FrequencyAward2018/20181214_Decision_III_IV.pdf?__blob=publicationFile&v=3. Italy: Ministry of Economic Development (2016[98]), *LSA Pilot: Sharing analysis in a live LTE network in the 2.3-2.4 GHz band*, https://www.mise.gov.it/images/stories/documenti/Report_LSA_05_rev.pdf; Agcom (2018[119]), *Delibera [Resolution] No. 231/18/CONS*, https://www.agcom.it/documentazione/documento?p_p_auth=fLw7zRht&p_p_id=101_INSTANCE_FnOw5lVOIXoE&p_p_lifecycle=0&p_p_col_id=column-1&p_p_col_count=1&_101_INSTANCE_FnOw5lVOIXoE_struts_action=%2Fasset_publisher%2Fview_content&_101_INSTANCE_FnOw5lVOIXoE_asse. Japan: MIC (2021[102]), *"Technical conditions for mobile communication systems in the 2.3 GHz band" among "Technical conditions*

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Notes

[1] Spectrum managers also seek to guarantee spectrum availability for science services, such as Earth Exploration Satellite Services, which are important to monitor climate change, deforestation, etc. This includes frequency and time signal, space research (SRS), space operation, earth exploration-satellite (EESS), meteorological-satellite (MetSat), meteorological aids (MetAids) and radio astronomy (RAS) services. See Science Services, International Telecommunications Union.

[2] Dynamic allocative efficiency enables the use of the most innovative services, while static allocative efficiency assigns spectrum to the undertakings that value it most. Previous OECD work also included third form of efficiency, productive efficiency, a notion that entails reducing production costs of networks (OECD, 2014[6]).

[3] According to the ITU-R Radio Regulations 2020, ***spectrum allocation*** refers to the "*Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more terrestrial or space radiocommunication services or the radio astronomy service under specified conditions. This term shall also be applied to the frequency band concerned.*" ***Spectrum assignment*** refers to the "*Authorization given by an administration for a radio station to use a radio frequency or radio frequency channel under specified conditions."* (ITU-R, 2020[15]).

[4] This type of licence has been used in recent auctions in the United States for mid-band spectrum (e.g. Auction 110 for the 3.45 GHz band in 2021-22, and Auction 107 for the 3.7 GHz band in 2020 – 21), and mmWave spectrum (e.g. Auction 102 for the 24 GHz band in 2019, Auction 101 for the 28 GHz band in 2018-19, among others), whereby licensees may provide any services permitted under terrestrial fixed or mobile allocations, according to the national frequency allocation table.

[5] See Auction 108 for the 2.5 GHz Band in the United States, and auction results released 1 September 2022.

[6] Ofcom in their Spectrum Strategy document (Ofcom, 2021[12]), state the following in pg. 9, para. 2.18:

> *"Where demand for spectrum exceeds supply, we may deploy specific market mechanisms, including:*
>
> - *Spectrum pricing, to incentivise users to make efficient use of spectrum;*
> - *The principle of greater* ***licence flexibility ('liberalisation'), to enable types of use, to evolve where possible, without the need to request a technical licence variation from Ofcom****; […]".*

[7] See also Ofcom's "Spectrum Access: EHF Licence: Licensing guidance document", pg. 3, para. 1.3 (Ofcom, 2021[204]).

[8] Ofcom in their Spectrum Strategy document (Ofcom, 2021[12]), state the following in pg. 16, para. 3.17: *"Spectrum for pioneers: we will make more spectrum available for innovation before its long-term future use is certain, using* ***flexible technical options and by retaining an ability to change licence terms****."*

[9] Ofcom refers to flexibility in its frameworks for the shared access bands in their 2019 document "Enabling Wireless innovation through local licensing", which states: "*We also want to ensure that our* ***licensing approach is sufficiently flexible to rapidly respond to changing demand***" (Ofcom, 2019[70]).

[10] It is worth noting that the concept of *prime spectrum* evolves over time. In the early 2000's, the frequency ranges up to 3 GHz was deemed to be prime. At present, up to 6 GHz is considered prime, so the notion of prime spectrum might continue to evolve in the future.

[11] See ITU-R "Radio Regulations" (ITU-R, 2020[15]).

[12] According to the ITU: "The decisions taken at the International Telecommunication Union (ITU) World Radiocommunication Conferences (WRC) drive long-term international harmonisation and balanced allocation of spectrum among competing services. For those decisions to be implemented at the national level, and for new services to flourish, national governments must proactively integrate the WRC decisions into their national regulatory frameworks" (ITU, 2020[7]).

[13] APT Conference Preparatory Group for WRC-23 (APG-23) | Asia-Pacific Telecommunity.

[14] OAS/CITEL: About CITEL.

[15] CEPT.ORG.

[16] The ITU-R's Radio Regulations have established three different types of interference, when referring to international frequency co-ordination between administrations: i) "permissible" or predicted interference, which complies with quantitative and sharing criteria established by the regulation, ii) "accepted", interference at a higher level than "permissible", but which has been agreed upon between two or more administrations, and iii) "harmful": which endangers the functioning of a radio navigation services or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service (ITU-R, 2020[15]). See ITU Radio Regulations 2020, Chapter 1, Section VII – Frequency sharing, 1.166-1.169**.**

[17] As defined by the ITU-R's Radio Regulations, services with a secondary allocation may not cause harmful interference to or claim protection from services with a primary allocation (see Chapter II, Article 5) (ITU-R, 2020[15]). Considering cross-border interference, "stations of each service in one Region or sub-Region must operate so as not to cause harmful interference to any service of the same or higher category in the other Regions or sub-Regions" (see Chapter 11, Article 4) (ITU-R, 2020[15]). Therefore, secondary services are *not* protected from harmful interference from primary services in another region or sub-region, but primary services would be protected from both primary and secondary services across borders.

[18] Some stakeholders expressed that modified ITU RR allocations takes normally take at least two WRC cycles, i.e. minimum of 6 years. Previous OECD work (OECD, 2014[6]) highlighted that harmonising spectrum at a regional or global level usually includes the following tasks:

i) reaching agreements on the lower and upper edge of band covered;

ii) guard band definition or, generally speaking, the band's segmentation;

iii) the technology and duplexing techniques that may be used in each of the segments/blocks of the bands (e.g. FDD, TDD);

iv) arrangements to provide interference protection from adjacent blocks or bands; v) re-allocation and re-planning of existing users and services;

vi) channelling; and vii) other technical conditions judged necessary to allow service operation in a given band, including sharing conditions.

19 The WRC 2023 agenda can be found here: Microsoft Word - Resolution 1399.docx (itu.int).

20 According to the FCC´s Table of frequency allocation table: https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation

21 The term "incentive auction" was coined in reference to the 2016 auction in the United States, where "incentive payments" to broadcasters were determined in the reverse auction, giving them an "incentive" to free up spectrum that was then offered in the forward auction to companies for wireless uses.

22 A licence does not grant ownership over this vital national asset, but rather specifies the rights of use for spectrum during a certain period of time with terms and conditions attached (ITU, 2020[7]).

23 This proof by Milgrom (2000) applied to auctions is based on an important result in mechanism design theory known as the "Myerson-Satterthwaite theorem", which states that in the presence of asymmetric information, and when two negotiating parties have different probabilistic valuations for a good, there is no way of achieving an efficient bilateral trade.

24 In most OECD countries, spectrum pricing is based on a one-time only, up-front payment levied upon winning bidders. While most countries use an initial auction to determine the total price of spectrum, over the lifetime of a licence, some countries may allow bidders to spread payments over a number of years, which may ease capital market constraints for some players.

25 That is, network deployments built from the ground up where none existed before.

26 The RSPG notes that when setting aside spectrum, it is important to ensure that the "type and amount of spectrum reserved is optimum" taking into account how to encourage entry with the lowest opportunity cost of spectrum (RSPG, 2016[38]).

27 Some may consider the United Kingdom as an exception, which placed annual licence fees on spectrum in the 900 megahertz (MHz) and 1 800 MHz bands (Ofcom, 2015[47]). However, Ofcom, as part of its spectrum pricing principles, only establishes annual licence fees for spectrum that was not initially auctioned with the aim of reflecting the opportunity cost of using spectrum efficiently in bands facing high-usage demand (Ofcom, 2010[48]). For spectrum that has been auctioned, the rationale for not using annual licence fees is that the auction mechanism already promotes the most efficient use of the spectrum band, reflected in the willingness to pay of the player that acquires the licence, and thus, no additional fees are required as long as the licence has not expired procedure (Ofcom, 2015[47]; Ofcom, 2010[48]).

28 While operators take into account the net present value of these annual fees when bidding in an auction, introducing uncertainty in this contract or licence would not allow the process to distinguish the true value of spectrum, as operators have no incentive to properly reveal their valuation if contracts can potentially be renegotiated and if they are unsure about whether the annual fees will remain constant. In other words, if authorities "know" that a bidder has a high valuation for spectrum, which they discover through the tender process, they may have an incentive to raise the fees in the next period. Therefore, operators will not want to reveal in the first place how much they "truly" value spectrum. This is known in the economic literature as the "ratchet effect", or the lack of commitment in dynamic contracts (by the principal), which results in a "bunching of types" (Laffont and Tirole, 1988[50]). This renegotiation does not need to take place ex post, but just the mere fact that operators think that it will happen ex ante can lead to this result. That is, this effect depends on an expectation around potential change.

29 The determination of the annual fees for spectrum use are established by the Mexican Congress based on a proposal by the Ministry of Finance (SHCP) and must be paid each year over the lifetime of the licence. This scheme came into effect in 2003. Bearing in mind that the Congress in Mexico changes every

three years, fees set by Congress could potentially translate into to six to seven changes in the annual fee structure in the lifetime of a spectrum licence (which lasts 15 to 20 years).

30 Mexican Congress (2021), Ley Federal de Derechos [Annual Fees Law], Congreso de los Estados Unidos Mexicanos, *Diario Oficial de la Federación*, last reformed on 12 November 2021, https://www.diputados.gob.mx/LeyesBiblio/pdf_mov/Ley_Federal_de_Derechos.pdf .

31 Neutral hosts, such as Boingo in the United States, can be defined as "a service provider that builds and operates an integrated technology platform that is solely for sharing purposes", (Lähteenmäki, 2021[203]),and they usually operate at a wholesale level serving third-party carriers (OECD, 2022[59]).

32 The European 5G observatory tracks the latest 5G developments, focusing mainly on Europe, but also examining major international markets such as the United States, Japan, the People's Republic of China and Korea (European Commission, n.d.[205]).

33 The fastest average download speed of mmWave 5G download was 692.9 Mbps using Verizon's mmWave network, followed by AT&T and T-Mobile with 232.7 Mbps and 215.3 Mbps, respectively (Opensignal, 2021[62]).

34 The average experienced 5G download speed in OECD countries was 155.6 Mbps in Q4 2021, according to Opensignal data in 4Q 2021. These speeds ranged from 75.7 Mbps (Poland) to 433.2 Mbps (Korea) for OECD countries where data was available. Each source measuring broadband performance and quality of experience has its own methodology offering a different picture of the Internet. According to the 5G QoS measurement implemented at the end of 2021 by the MSIT in Korea, 5G average download speeds were 801.48 Mbps and upload speed was 83.01 Mbps. This result rose up 16% and 31%, respectively, compared to the previous year (2020). See https://www.msit.go.kr/bbs/view.do?sCode=user&mId=115&mPid=111&bbsSeqNo=86&nttSeqNo=3179854.

35 Spectrum availability and the stage of deployment of 5G networks in each country may also influence another relevant indicator from the perspective of 5G user's experience: the percentage of time a 5G signal is available.

36 In the European Union, although the European Electronic Communications Code (EECC) required European Union member countries to assign the 26 GHz by end of 2020, only a handful of countries has done so, while other are currently studying the issue.

37 See Spain's public consultation on the 26 GHz band published by the Ministry of Economy and Digital Transformation (MinEco) on 26 September 2022 (Government of Spain, 2022[207]).

38 Since 2021, it is possible to apply for local licenses in the lower part of this band in Sweden, but it is not yet certain if there will be national licenses in the remaining part of the band. PTS is planning to consult the market about the demand for this in 2022.

39 According to Ofcom in their Shared Access Licence Framework of 2019 (Ofcom, 2019[68]), shared access licence are:

> *"The shared access licence is part of a new framework for enabling shared use of spectrum, aiming to make it easier for people and businesses to access spectrum for a wide range of local wireless connectivity applications. The shared access licence is currently available in four spectrum bands which support mobile technology:*
>
> > - *1800 MHz band: 1781.7 to 1785 MHz paired with 1876.7 to 1880 MHz;*

> - *2300 MHz band: 2390 to 2400 MHz;*
> - *3800 to 4200 MHz band; and*
> - *24.25-26.5 GHz. This band is only available for indoor low power licences.*
>
> *Two types of licences are available:*
>
> - *Low power licence. This authorises users to deploy as many base stations as they require within a circular area with a radius of 50 metres as well as the associated fixed, nomadic or mobile terminals connected to the base stations operating within the area.*
> - *Medium power licence. This authorises a single base station and the associated fixed, nomadic or mobile terminals connected to the base station."*

[40]See Ofcom's "Local Access Licence Guidance Document": https://www.ofcom.org.uk/__data/assets/pdf_file/0037/157888/local-access-licence-guidance.pdf.

[41] Details of the Australian Parliament's intended policy in relation to certain community broadcasting services and open narrowcasting television services can be found in section 96A and 96B of the Radiocommunications Act 1992.

[42] The data set from the GSA excludes non-3GPP networks (e.g. Wi-Fi, Sigfox, LoRa and proprietary technologies), as well as implementations using solely network slices or the placement of virtual networking functions on a router.

[43] In Europe, the RSPG has classified in 2019 connectivity solutions for what they call "industry verticals" into three categories: 1) Mobile operators solutions for verticals, 2) Spectrum that may be dedicated to different vertical groups (including wide area network-dependent verticals and local area "on-site" industries), and 3) pan-European verticals using EU harmonised bands (e.g. Intelligent Transport Systems [ITS] and Railway Mobile Radio [RMR]) (RSPG, 2019[92]).

[44] In Denmark, part of the 3.5 GHz band is subject to a leasing obligation intended to enable stakeholders other than mobile operators (such as enterprises, public institutions and universities) to lease spectrum from the mobile operators, to be used for private 5G networks. For more information please see: https://ens.dk/sites/ens.dk/files/Tele/information_memorandum_1.pdf.

[45] Parties applying to lease spectrum may only use them to operate a private network for its own purposes, or those of its business group, on its own real estate or on land it is entitled to use (e.g., based on a real estate leasing contract) (CTU, 2020[79]).

[46] The obligation applies where the business actor has a need for 5G networks and services and where the use of the 3.6 GHz band is required, or the most favorable frequency band for establishing the network or service (Nkom, 2021[81]).

[47] A "substation" is a part of the system of electrical generation, transmission, and distribution that transforms energy.

[48] For example, article 3.3 states: "*Transmitting and receiving equipment intended to be used in a given part of the frequency spectrum should be designed to take into account the technical characteristics of transmitting and receiving equipment likely to be employed in neighbouring and other parts of the spectrum, provided that all technically and economically justifiable measures have been taken to reduce the level of unwanted emissions from the latter transmitting equipment and to reduce the susceptibility to interference of the latter receiving equipment*" (ITU-R, 2020[15]).

[49] DSS is an enabler of standalone (SA)-5G network deployment by helping operators balance spectrum between 4G and 5G traffic, in real-time, removing the need for spectrum re-farming. That is, DSS allows for 5G to run simultaneously on the same spectrum bands as 4G, as it allows the operator to dynamically manage its frequency resources among users/devices based on network conditions and traffic needs (RSPG, 2021[8]).

[50] The first use case defined under the EU's LSA framework is to provide additional spectrum for mobile broadband services, as LSA licensees, in the 2.3-2.4 GHz band (CEPT, 2014[95]).

[51] Paul Milgrom, an economist specialised in auction design, has made a strong case against using administrative selection. He points out that if the good is initially allocated to the "wrong hands" in the primary market, there is no way of designing a private bargaining process (i.e. secondary market) without delays or failures (Milgrom, 2000[42]; Hazlett, Munoz and Avanzini, 2011[111]).

[52] In the UK, trading is available to most licence classes, but IMT licenses may be subject to a competition assessment before a trade can be authorised. Spectrum leasing is available to only certain types of licenses and a licence variation is needed to gain permission to offer leasing. IMT Licenses (covered under the Mobile Trading Regulations) are not permitted to be leased, however Ofcom allows access to some spectrum through the Local Access Licence.

[53] The "free list" is the list of municipalities with less than 5,000 inhabitants that are not covered by the coverage obligations of the winning bidders of the 3.6-3.8 GHz band spectrum (Agcom, 2018[119]).

[54] According to Ofcom (2021[12]), "*Dynamic Spectrum Access is a technology for a variety of reconfigurable radio equipment allowing it to select the frequency on which it will operate at a given location and over a given period of time to optimise the use of available spectrum and avoid interference with other radios or other systems*." According to the RSPG (2011[202]), "*Dynamic Spectrum Access is a spectrum sharing model that allows users to access spectrum for a defined period or in a defined area. Users cannot exceed the terms of this access without reapplying a request for the frequency resources*."

[55] For example, SASs protect incumbent access (IA) users from interference from priority access licences (PALs) and general authorised access (GAA) users and protect PALs from GAA interference.

[56] Six entities are approved to be SAS administrators: Amdocs, CommScope, Federated Wireless, Google, Key Bridge and Sony, of which four are also approved ESCs: CommScope, Federated Wireless, Inc., Google, and Key Bridge (FCC, 2021[104]).

[57] The LSA information sharing framework consists of an LSA repository and an LSA controller. The Repository acts as a database for information on spectrum availability and the conditions of use (e.g., the level of protection required to protect the incumbent's services), which must be updated by the incumbent as that information changes over time. The LSA controller shares the information and updates from the Repository with the LSA licensee and manages the LSA Licensee's spectrum access according to sharing rules and the Repository's information (CEPT, 2014[95]).

[58] The incumbent would define the sharing terms and conditions for the local private network LSA licensee when leasing is allowed nationally (ETSI, 2020[132]).

[59] According to the RSPG (2011[202]): "*5G slicing can also be a potential enabler for 'multi-tiered' spectrum sharing in some scenarios such as when a 5G operator offers access to other operators providing the same or different services. A concrete case here could be when a MNO which uses frequencies in the lower bands realises different slices with different priorities for different applications*".

60 A balanced sharing harmonised framework has been developed, see Decision (EU) 2021/1730 of September 2021 on the use by Railway Mobile Radio, while preserving a safe harbour for Defense use. See Decision (EU) 2021/1730 at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021D1730. Railways were also harmonised in Decision (EU) 2018/1538 related to SRDs, see http://data.europa.eu/eli/dec_impl/2018/1538/2022-02-09.

61 Short-range devices are often mass-market devices that transmit and receive over a limited distance (hence their name) and at low power, on a non-interference and non-protected basis (European Commission, 2019[142]).

62 Technologies that make use of the IEEE 802.11 standards for communications.

63 Among OECD countries, unlicensed use in Australia is technically illegal, however class licenses act as a standing authorisation for services that would be unlicensed in other countries. A number of class licenses are in place authorising shared spectrum use under specific circumstances. Please see https://www.acma.gov.au/class-licences for more information.

64 Wi-Fi 6 refers to the networking standard IEEE 802.11ax.

65 Wi-Fi 7 refers to the networking standard IEEE 802.11be.

66 Unlicensed standard-power access points are also prohibited from pointing in the direction of space station receiver (e.g. incumbent FSS operations) (FCC, 2020[152]).

67 The FCC is in the process of authorising AFC system operators and called for applications on September 28, 2021 (FCC, 2021[206]).

68 In Colombia, recent changes to the sectoral law in 2019 and Ministerial Resolutions allow for access to spectrum for technical trials that last up to six months with an additional renewal for additional six months at very low cost. See Ley TIC 2019 and The ICT Ministry issued Resolutions 467 and 468 of 2020.

69 In Mexico, the Federal Telecom and Broadcasting Law includes the temporary use of spectrum for trials and experimental trials. (LFTR. Art 67, section III). Mexico's legal framework also includes licenses for experimental uses (private concessions for experimental use). Through this figure, IFT has granted several experimental concessions for trials such as:

- **TVWS**, to experiment with equipment using technology known as TV White Spaces, which will allow for dimensioning the benefits of new technologies to provide broadband Internet, making an efficient use of the spectrum for these segments.
- **5G**, to check the feasibility of using 5G technology as an alternative to the use of other satellite or terrestrial means, which, if feasible, would generate benefits by reducing operating personnel, mobile units and equipment that is normally transferred to various locations in the country to produce audio-visual content.

70 An overview of these 5G trials is available on the Arcep website.

71 See the Canadian regulators (ISED) Decision on Releasing Millimetre Wave Spectrum to Support 5G.

72 See: Industrial 5G Testbeds and Trials: Competition Guidance and Supporting Documents - GOV.UK (www.gov.uk).

[73] See: https://www.3gpp.org/specifications/67-releases

[74] High Altitude Platform Stations (HAPS) are defined by the ITU's Radio Regulations as radio stations located on an object at an altitude of 20-50 kilometres and at a specified, nominal, fixed point relative to the Earth (ITU-R, 2020[15])

[75] The OECD Council Recommendation on Broadband Connectivity [OECD/LEGAL/0322] states the following:

> *"**IV. RECOMMENDS** that Adherents minimise negative environmental impacts of communication networks, by:*
>
> *1. Supporting and promoting smart and sustainable networks and devices.*
>
> *2. Encouraging communication network operators to periodically report on their environmental impacts and initiatives*

[76] Spectrum managers also seek to guarantee spectrum availability for science services, such as Earth Exploration Satellite Services, which are important to monitor climate change, deforestation, etc. This includes frequency and time signal, space research (SRS), space operation, earth exploration-satellite (EESS), meteorological-satellite (MetSat), meteorological aids (MetAids) and radio astronomy (RAS) services. See Science Services, International Telecommunications Union.

[77] Irish Climate Action and Low Carbon Development (Amendment) Act 2021 states that a relevant body shall, in so far as practicable, perform its functions in a manner consistent with government climate policies.

[78] In Costa Rica, in accordance with article 39 of Law 8660, one of the functions of the MICITT is "Ensure compliance with applicable national environmental regulations and the sustainable development of telecommunications in harmony with nature." Also, one of the obligations of SUTEL (regulator) in accordance with article 60 is: "To ensure environmental sustainability in the exploitation of the networks and the provision of telecommunications services".