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RADIO SPECTRUM POLICY GROUP

RSPG Report on Spectrum Sharing
A forward-looking survey

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Index

1. Introduction

One of the key roles of the Radio Spectrum Policy Group (RSPG) is to assist and advise the European Commission and other EU institutions on radio spectrum policy issues, on coordination of policy approaches, on the preparation of multiannual radio spectrum policy programmes and, where appropriate, on harmonised conditions with regard to the availability and efficient use of radio spectrum necessary for the establishment and functioning of the internal market.

In its Programme of activities for the years 2020 and beyond, the RSPG recognized that spectrum sharing needs a specific focus, especially with regard to its potential to achieve a more efficient use of radio spectrum, and to give incentives for innovation. A specific sub-group was then created within the RSPG with the task of carrying out the work to lead to the subsequent adoption of an Opinion[1] on Spectrum Sharing – Pioneer Initiatives and bands, and the present accompanying Report.

This Report describes the background work and information that led to the recommendations and the policy views contained in the Opinion.

The Report first outlines the technical and regulatory context in which Spectrum Sharing is set. This section describes the various perspectives of this apparently simple concept: the use by more than one user of a spectrum resource (i.e. the possibility to transmit and/or receive in a given portion of frequencies, in a given place and time) for any practical scope.

Then the Report outlines the relation of this concept with the related concept of Infrastructure Sharing, showing the often blurred boundaries. In many practical circumstances, Infrastructure Sharing includes Spectrum Sharing. However, the two concepts are and should be treated differently from a regulatory point of view. While highlighting the need for regulators to also consider the competition aspects of spectrum (and infrastructure) sharing in assessing any specific case at hand, it must be clarified that the competition aspects of Spectrum Sharing are outside the scope of this Report.

A following section deals with the authorisation regimes behind Spectrum Sharing. The relevant provisions in the Code are recalled. While there is not a specific regime dedicated to Spectrum Sharing in the Code, it appears sufficiently flexible to allow any type of sharing to occur, provided that the appropriate rules are set. So, the two main categories of authorisations for the use of spectrum set in the Code, namely individual rights of use and general authorisations, can be accompanied by a set of rules and conditions that permit spectrum sharing to occur. Of course, the more innovative spectrum sharing scenarios may need a set of likewise innovative rules and conditions.

The Report also outlines the relation between spectrum sharing and a specific legal/administrative title foreseen in the Code, namely leasing, which many cases of spectrum sharing resemble in practice. So, the approaches used for authorizing a specific case of leasing should be considered also when dealing with spectrum sharing cases.

In the next section, an introduction to the various technologies and approaches for spectrum sharing is illustrated. It includes the more innovative ones, such as 5G-related, AI and Blockchain. The description is provided at a general and survey level, while more details are given in an Annex. The objective is to illustrate

[1] The detailed description of the work undertaken can be found in the RSPG Work Programme for 2020 and beyond, https://rspg-spectrum.eu/wp-content/uploads/2020/02/RSPG20-005final-work_programme_2020_and_beyond.pdf.

state-of-the-art of technologies, including an overview of those still at R&D level, and so compose a toolbox of possible approaches to consider when it comes to address both a specific decision and a policy orientation.

Finally, the Report touches upon the issue of the importance of information sharing on spectrum usage as an enabler for spectrum sharing, and the issues to be addressed by spectrum authorities when dealing with this matter.

The Annexes to the Report complement the information presented. In particular the Annex on initiatives and approaches on spectrum sharing in Member States illustrates concrete examples where spectrum sharing has been introduced or planned and the way the technologies mentioned above, or at least those ready for the market, have been implemented.

2. The evolutionary context of Spectrum Sharing

2.1. Spectrum Sharing in the various dimensions

Spectrum sharing can take many forms and can be defined in many ways. It depends not only on the technical features of the networks realizing the spectrum sharing, such as the architecture used (e.g. centralized vs distributed), model (e.g. coordinated vs uncoordinated), technology, protocols, etc. It also depends on the angle of analysis, which can be for instance regulatory, academic, standardization, legal, etc. Moreover, some definitions of spectrum sharing are typically confined to business agreements and contracts among companies in the mobile market. Although in many cases the final meanings do not differ much among the various angles, some nuances can be present.

From a regulatory angle, as reported in previous RSPG Opinions, spectrum sharing can be defined as the common usage of the same spectrum resource by more than one user, which can be realized with respect to all three domains: frequency, time and space.

Considering a point of view more oriented to technical and standardization aspects, the ITU considers that inter-service sharing exists when two or more radiocommunication services effectively use the same frequency band, and that any method used to facilitate spectrum sharing has to take into account four dimensions: frequency, time, spatial location and signal separation.

From a more legal prospective, article 2.26 of the EECC defines the 'shared use of radio spectrum' as the use of the same spectrum bands by more than one user under a defined sharing arrangement, authorised on the basis of a general authorisation, individual rights of use of spectrum or a combination thereof.

So, without the presumption to dictate definitions generally valid, for the purpose of this Report, spectrum sharing is the common utilization of the same frequency resources by more than one user *i*) at the same time in different geographical locations or *ii*) at the same geographical location in different times or *iii*) at the same time and the same geographical location. The application of signal transmission techniques for achieving signal separation in multi-user environments can be considered as an enabler for spectrum sharing. Multiple users can share spectrum for similar or different uses (e.g. fixed links and satellite earth stations, or governmental users and commercial users). Spectrum sharing may envisage the same or different level of priority among users or group of users (or different priority levels for multiple tiers of users).

According to this definition, spectrum sharing can be realized in different ways based on the considered type of spectrum band, method of assignment and services in the band. So, in many ECNS bands spectrum sharing is generally realized among spectrum users such as licensed operators, while in unlicensed bands spectrum sharing is more typically carried out among users such as devices. However, this distinction is starting to be blurred by new advances in radio technologies, so that also in licensed bands it might become possible to implement spectrum sharing among multiple tiers of spectrum users that can be authorised in different ways in the same band. This development of technologies makes it possible to implement new forms of spectrum sharing that offer an increasingly efficient use of this scarce resource, so that it seems possible to hypothesize a future scenario where sharing could be seen as the norm, rather than the exception.

This discussion is further developed in the following sections of this Report.

2.2. Relation between Spectrum Sharing and Infrastructure Sharing

In order to set the context and frame the analysis in this Report, the first aspect that should be highlighted is the distinction between spectrum sharing and infrastructure sharing, which is often blurred in many of the current discussion fora.

In the literature concerning infrastructure sharing, there is usually a distinction between passive sharing and active sharing. In passive sharing, the elements typically involved are sites (i.e. areas), masts, cabinets, power and other electrical facilities, but there are also other parts of the network that can be shared, such as backhauling[2] and core network[3]. Active sharing usually includes antennas, radio equipment (including baseband, feeder cables, transceivers, etc.), and often also includes spectrum. Actually, spectrum is not either active or passive *per se,* but an active part is needed to use spectrum[4].

When addressing forms of infrastructure sharing which include spectrum sharing, such as MOCN (see definitions in Annex), we are focusing on sharing from the point of view of infrastructure operators within the mobile/wireless electronic communications market. In such cases, we typically refer to licensed spectrum (i.e. assigned by individual authorisations) and then to MNOs. However, in the future this might not be the unique scenario, in light of the development of network infrastructure, where also unlicensed bands can be concerned (e.g. in the field of the so-called networked SRD/IoT).

So, infrastructure sharing and spectrum sharing, although they represent different types of resource sharing, are often intertwined and the creativity of market players and technology advances make it increasingly difficult to draw a clear boundary line. However, since spectrum use is subject to specific rules that are different from those in the infrastructure sharing arena, it is necessary for NRA/NSAs to make a careful assessment of the specific case at hand, both if the sharing case is put forward at the initiative of market players and if the case is one that an NRA/NSA would want to pursue and facilitate (i.e. when granting rights of use or setting a general authorisation framework). While evaluating spectrum sharing agreements, particularly in the case when they are generated by market players, NRAs/NSAs should assess whether spectrum usage is compliant with the regulatory framework including the national specific regulations.

For instance, based on the contents of a specific sharing agreement, the shared frequencies can be provided by one MNO or more MNOs involved in the deal, in the latter case configuring a MOCN with spectrum pooling. The shared/pooled spectrum solution under MOCN might give rise to regulatory and competition concerns on the part of NRAs/NCAs, since spectrum resources are typically assigned under individual licences

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[2] Usually, backhauling is considered within passive network, but in some cases, it is considered as a form of active sharing, in particular when, other than passive elements such as duct and poles, it includes also active data transmission components.

[3] The more the sharing involves additional network elements, the narrower the boundary between sharing and integration is, until getting to the point that the network scenario is better represented by the term 'integration' than sharing.

[4] It is to be noted that all the definitions provided in this paragraph as well as in other sections of this Report are illustrative of the state-of-the-art of the issue, and so functional to the Report, since technology advances make possible additional or different forms of sharing of the various network elements, and, furthermore, operators are free (upon authorisation where needed) to develop sharing agreements that do not fit into any of the definitions included here, in particular due to the recent development of new players in the value chain, such as asset providers, tower companies, etc.

and, moreover, are often associated with coverage commitments. So even if spectrum sharing agreements are not subject to specific authorisation, spectrum pooling agreements may have to be.

Extending this reasoning, wholesale access to a mobile (or more in general wireless) network by a different operator (infrastructure or virtual) can also be considered a form of active sharing including spectrum since, in the end, it includes the common usage of frequency resources.

After clarifying the context, and as foreseen in the Work Programme, in this Report the RSPG deals only with the Spectrum Sharing issue, even when infrastructure operators are involved. So all circumstances related to Infrastructure are out of its scope.

From the previous discussion, it follows that Spectrum Sharing also touches competition issues in particular when dealing with licensed spectrum. However, as also foreseen in the Work Programme, this Report and the related Opinion do not address competition issues.

2.3. Spectrum Sharing in the current EU Framework

The European Electronic Communications Code (EECC) establishes a harmonised framework to regulate electronic communications networks and services, associated resources and services and some aspects of terminal equipment. A series of procedures are introduced to ensure the harmonised application of the regulatory framework across the Union.

Spectrum sharing may contribute to achieving the main objectives of the Code, namely promoting competition, the internal market, end-user interests and connectivity among others. In this sense, the Code requires Member States to promote and set the conditions for the shared use of the radio spectrum, in accordance with competition law, granting priority to specific services so that, insofar as possible, other services or technologies could coexist in the same radio spectrum band (Recital (115)) or determining the most appropriate authorisation regimes for flexible access and use of radio spectrum (Recital (119)).

Since the Code calls for the promotion of efficient investments and of innovation of infrastructure, various cooperation agreements may be implemented and they must ensure compliance with market competition and non-discrimination principles (Recital 124). The Code prescribes that competent authorities shall not prevent the sharing of radio spectrum in the conditions attached to the rights of use for radio spectrum, in particular with a view to ensuring effective and efficient use of frequencies or promoting coverage (art. 47). When trading and leasing radio spectrum, the effective use by the original holder of the right should also be ensured (Recital (122)). Harmonization, promoted by the Code, is also needed to fully benefit from spectrum sharing approaches.

The Code allows for different combinations of sharing of network elements and spectrum that might constitute solutions for achieving specific objectives, for instance to deliver capacity and coverage in rural areas. So spectrum sharing might tackle some of the important challenges that electronic communications are facing nowadays due to the important growth in demand for spectrum resources for different kinds of services.

Together with the need to promote more spectrum sharing between similar or different uses of spectrum, and to assess the feasibility of such sharing (both at market players' initiative and at regulators' initiative) from a competition point of view, the Code offers the appropriate regulatory framework for setting rules allowing market players and users to share spectrum and, in particular recommending the preference for general authorisations whenever possible.

2.3.1. The EECC authorisation regimes behind Spectrum Sharing

The EECC offers an appropriate regulatory framework for setting rules allowing market players and spectrum users to share spectrum. It foresees two ways of authorizing the use of spectrum: general authorisation and individual rights of use. As seen, it encourages MS to promote the shared use of radio spectrum between similar or different uses of radio spectrum in accordance with competition law[5] and facilitates the shared use of radio spectrum under general authorisations, in general the preferred method, or using a combination of a general authorisation and individual rights of use.[6]

Broadly speaking, in the case of general authorisations, the regime for the use of a particular band is made known in advance, and conditions to be fulfilled by the (indefinite number of) users may only pertain to categories explicitly permitted by the Code. Usually, general authorisations do not foresee frequency planning and coordination.

In the case of individual authorisation for spectrum use, or rights of use, or licence as in the past but still used terminology, a specific title is granted to an operator by the NSA, including conditions that are specified at the time a procedure is adopted to assign the rights of use. Albeit those conditions are still categorized by the Code, they can be different and specific for a given assignee. Usually, individual rights of use foresee (professional) frequency planning and coordination. When it comes to putting into service and/or use specific radio equipment, Member States under the Directive 2014/53/EU (the RED), should ensure that manufacturers place radio equipment on the market that complies with the essential requirements (art. 3 of the RED), and may introduce additional requirements (art. 7 of the RED) for reasons related to: the effective and efficient use of the radio spectrum; the avoidance of harmful interference; the avoidance of electromagnetic disturbances; the public health. This applies to both assignment regimes of individual and general authorisation and helps regulators to develop the most appropriate spectrum sharing scenarios.

Generally, under the individual rights of use regime, only a limited number of users can get access to a given band, while in the general authorisation case the number of users is indefinite (potentially infinite). However, there are exceptions. For example, in the general authorisation case the number of potential users may be limited by the need to verify the fulfilment of the requirement of avoiding harmful interference, say in a particular area. Conversely, in the individual right of use category, an exception can be represented by the private commons case, where a licence is issued to one or a few spectrum holders, each allowing in its own portion of frequencies a potentially indefinite number of users based on pre-set rules.[7]

In the ECC Report 132, that aims to describe the possible types of regulatory regimes for the use of spectrum in Europe and that applies to both radiocommunication equipment licensing and spectrum authorisation, general authorisations may be divided into two sub-categories, light licensing and licence-exempt. However, neither of these sub-categories is defined or envisaged in the Code, so each MS can consider different approaches for them.[8] It is to be noted that, according to the ITU Radio Regulations, all radio equipment that is used should be subject to a form of authorisation, so the often-used term 'free use' is not intended as not

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[5] See art. 45 (2)(e)
[6] See art. 46).
[7] This may allow developing sort of a "private" SRD band.
[8] In this Report we consider light licensing as a form of general authorisation, while the ECC Report 132 introduces a light licensing category also in the authorisation regime under individual rights of use.

authorised.[9] The term “unlicensed” is also often used, and here it is considered as a synonym of licence-exempt.[10]

In the light licensing case, a form of notification/registration is necessary, and this may entail (but not necessarily) the obligation to verify whether the use in a particular area is allowed or not, based on the need to avoid harmful interference to other users[11]. The light licensing authorisation regime can then be especially exploited for increasing spectrum sharing.

So, the new possibilities for spectrum sharing, that technology advancements and network architectures make possible, do not seem to require changes in the current framework. However, NRA/NSAs may develop an authorising framework that is based on an appropriate mix of the current authorising methods and new single-tier or multi-tiered spectrum sharing approaches such as licensed club use, licensed shared access (LSA), authorised light licensing, licence-exempt, local access licence and shared access licence. Furthermore, additional commercial- or regulatory-based techniques can be exploited to share spectrum such as 5G slice-based use and wholesale access-based use. These approaches and the radio technologies enabling their application are described in section 3.

[9] It is a off-the-shelf device used in license-exempt bands, for example a door-opener equipment in a SRD band.
[10] Sometimes unlicensed is used as a synonym of general authorisation, others as a synonym of free-use.
[11] A case study example of this is in the 24 GHz SRR (Short Range Radar) decision 2005/50/EC. Other examples can be GPR/WPR imaging systems or Amateur/Maritime VHF.

2.3.2. Relation between Spectrum Sharing and Leasing

In discussions about spectrum sharing the relation between sharing and leasing is a topic very often misinterpreted. Since leasing can only apply to assigned rights of use, this argument is pertinent to licensed bands.

Leasing is a contract to let another party exercise the owner's rights to use the spectrum, governed by the licence terms and conditions.

With leasing the lessor grants the lessee(s) the use of the frequencies (assigned to the lessor). Unlike in transfer agreements[12] the ownership of the rights of use remains with the lessor.[13] The lessee, within the terms of the leasing agreement, may use the frequencies at his own discretion. However, the lessor is responsible for the fulfilment of spectrum obligations attached to the rights of use, such as the coverage obligation, before the NSA. The lessee(s) must operate within the terms of the lessor's licence and may become co-responsible for their fulfilment. The lessor is then generally the first port of call to handle interference problems among its lessees.

Sharing agreements are contracts that normally should be authorised by the NSA, where two or more parties agree to jointly use the same frequencies for their respective, distinct, commercial offers, and typically with agreed radio network roll-out plans (at least for some parts of their networks)[14]. This applies to agreements with or without spectrum pooling.[15]

However, from the customers' handling point of view, spectrum sharing and leasing can be similar. In fact, in some instances, spectrum sharing may not differ from leasing, for example when some operators make leasing agreements with wholesale back access. In this case, the lessee uses the lessor's spectrum and can pool it with their own spectrum, but grants the lessor the right to serve the latter's own clients with a wholesale access contract (or roaming or other access techniques), on its whole spectrum chunks. This means that the main practical difference between spectrum sharing and leasing is in the relative form of contracts chosen by the parties.

The Code specifically regulates spectrum leasing in art. 51, however, whilst it promotes spectrum sharing, the Code does not define or regulate spectrum sharing agreements or contracts. The Code only regards spectrum sharing as an engineering technique for using spectrum[16], so from a regulatory point of view spectrum sharing is distinct from leasing.

However, given the similarities with leasing, sharing agreements may still be subject to authorisation, in particular when employing spectrum pooling, whether the agreement is put forward at market players' initiative or if it is the NRA/NSA that want to facilitate specific agreements, for example setting rules or introducing specific provisions when the rights of use are issued.

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[12] Leasing and transfer are usually collectively called trading.

[13] With transfer, the ownership of the rights of use is transferred to the transferee(s) so that the seller has no more obligations (for the concerned frequencies) before the NSA.

[14] Some other differences between spectrum sharing and spectrum leasing may rise in the geographical scope of the agreements or in the use of mobile network identifiers.

[15] "Without pooling" generally means that active radio elements are shared, but each party maintains distinct the use of their assigned frequency blocks. On the contrary "with pooling" means that frequency blocks of the parties are put in common in the radio equipment and sum up in the radio channels. In many instances pooling allows to achieve a better efficiency in spectrum use.

[16] See for example art. 45, par. 4; art. 46, par. 1; art. 47, par. 2.

Depending on national rules, operators may then be required to submit authorisation requests for their sharing agreements, and NSAs should evaluate them on a case by case basis. However, it is opportune that NSAs monitor the developments of spectrum sharing agreements as a separate issue to the related infrastructure sharing agreement.

2.4. Information on spectrum usage

The availability of information on radio spectrum usage is relevant for efficient use of spectrum and feasible spectrum sharing models, spectrum trading and spectrum leasing.[17] In particular that information can be a powerful enabler for spectrum sharing, both in ECS harmonized bands and unlicensed bands. Actually, the knowledge of some unused spectrum from one side, and of the extent of systems that require protection from the other, can help by giving new players confidence to enter the market. However, save when information is voluntarily shared, for spectrum sharing the actual need for data availability and the specific modalities on how and to whom data is made available should be assessed by the spectrum authorities, usually on a case-by-case basis, in particular when the sharing framework for a given band is pre-defined.

A number of issues should be assessed when dealing with transparency of the use of spectrum by the competent regulator, including the protection of personal data, public security and defence and business confidentiality.

Firstly, currently existing and future solutions to spectrum sharing may require the processing of certain types of data that may include personal data, and therefore necessitate compliance with the GDPR[18] and ePrivacy Directive. As for the legislation on data processing currently in place, the specific case at hand should be analysed in this respect and, where needed, cleared at national level. A useful frame that may be used by national regulators in their assessment can be the performance of a task carried out in the public interest, for example those pertaining to the efficient use of radio frequencies or the objectives of international harmonisation.[19] It is also necessary to substantiate any proposed data processing by evaluating the proportionality, necessity and impact on data subjects.

Secondly, certain released data, such as that pertaining to critical infrastructures, may potentially represent risks for public security and defence.[20] Such data may be excluded from public access. Where needed, some information can be released on a “need to know” basis with access limited to appropriate “data rooms”.

Thirdly, data should not be released if it violates business confidentiality requirements, although the experience of those national regulations show that such risk is minimal.[21]

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[17] Based on the latest data available (CEPT questionnaire at https://www.cept.org/ecc/groups/ecc/wg-fm/efismg/client/meeting-documents/, document EFISMG(18)Info1), not all the countries make publicly available the detailed information about radio spectrum usage (e.g. channel bandwidth, frequency, GPS location, radiated power, licence holder). However there are many country examples of data provisions bot in EU and other countries.

[18] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of individuals with regard to the processing of personal data and on the free movement of such data.

[19] The frequency plans and harmonization objectives of the European Union, especially Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC (The Radio Equipment Directive) and Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonised technical conditions in the area of radio spectrum use for short-range devices.

[20] See also Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union and Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act).

[21] Consider for example Directive (EU) 2016/943 of the European Parliament and of the Council of 8 June 2016 on the protection of undisclosed know-how and business information (trade secrets) against their unlawful acquisition, use and disclosure.

In practice, the establishment of any publicly available databases necessitates the adoption of internal country-specific organizational and technical measures that minimise the risk of unlawful data processing, including cybersecurity measures and technical auditing. Good practices can be shared across the EU in this regard as well.

Carefully releasing information about radio spectrum use may bring many advantages and opportunities for spectrum sharing scenarios. It can enable self-coordination and self-regulation by users, thereby minimising the risk of harmful interference and resulting in a more effective and efficient use of radio spectrum. It can diminish the costs relating to efficient spectrum management by providing users with data and tools to resolve harmful interference directly, by mutual communication, negotiation, and agreement. It can bring wider societal benefits, including easy 5G and WAS deployment and authorisation of femtocells. As a spill-over effect, the regulation will generate an immense amount of useful information that can be re-used in the telecommunication sector, in particular in the development, production, and distribution of devices and other technologies. Among benefits, the availability of information about spectrum use facilitates transparency in the area of environmental issues and spectrum-related EMF issues. To protect personal data, business confidentiality, public security and defence, a national assessment and specific procedures might be needed.

3. Overview of Approaches and Technologies for Spectrum Sharing

In this section, a brief description of the approaches and the technologies which can be used to enable frequency sharing is provided for the purpose of this Report. This framework is not meant to have any regulatory objective, but it is illustrated with the aim to be as comprehensive and forward looking as possible. As mentioned previously, this overview is not limited in scope to ECNs, but encompasses also other services[22], both licensed and not.

3.1. Spectrum sharing approaches

Relying on appropriate radio technologies, several spectrum sharing approaches can be realised to foster innovative forms of dynamic use of spectrum resources, cumulatively referred to as Dynamic Spectrum Access (DSA).

Sharing approaches can be roughly categorised at a high level in terms of the number of tiers[23] (meant as priority of spectrum access) envisaged for spectrum sharing and the type of users/services involved in each tier, according to the following possible simplified framing:

- **'Single-tier' spectrum sharing (Horizontal Sharing)**:
    - sharing among 'peers' (no hierarchy between users);
    - intra-service and inter-service scenarios;
        - sharing between licensed stations/devices and/or MNOs in frequency bands with licensed use (e.g. sharing agreement between MNOs);
        - 'licence-exempt' radio devices in frequency bands with unlicensed use (e.g. WiFi, SRDs).
- **'Multi-tiered' spectrum sharing (Vertical Sharing):**
    - hierarchical spectrum access between users;
        - spectrum overlay (e.g. white space device in the UHF band, 5 GHz RLAN);
        - spectrum underlay (e.g. UWB);
    - typically for inter-service scenarios;
        - but also intra-service scenarios can be considered.

In the following paragraphs a brief description of these approaches is given.

3.1.1 'Single-tier' spectrum sharing approaches

Spectrum sharing can be performed by radio systems having the same rights in terms of priority to access spectrum, which means that there are no primary services and all the radio systems are in the same tier (i.e. horizontal sharing).

[22] Where needed, services are meant as defined in the ITU Radio Regulations 1.19.

[23] In case of single-tier, sharing is possible by dividing the available medium, so less resources are available for each user/service leading to graceful degradation if more users are present. In the case of multi-tiered, a method for sharing is to use resources by a user/service that are not in use by the other system/user, thus leading to a more efficient sharing but it is only possible between particular services, such as cellular vs licence-exempt.

This approach can be carried out in both intra-service and inter-services scenarios by licensed (e.g. MNOs, licensed stations) or licence-exempt (e.g. WiFi, SRDs) users/devices. There is also the case of the Licensed Assisted Access (LAA), in which an unlicensed band (e.g. 5 GHz) is used by both licence-exempt equipment (e.g. WiFi) and devices that combine radio connections in the unlicensed band with radio connections in licensed MFCN bands (e.g. LTE/NR at 1800 MHz, 2100 MHz, etc.).

Licensed spectrum users can access the shared spectrum within the same tier on a commercial basis by means of spectrum sharing agreements (provided, as seen in section 2.3.1, that such agreements are compliant with the regulatory framework set for the involved spectrum bands and with competition law)[24] or according to a concurrent shared access model set by the regulator, like the licensed "club use".

This latter envisages that a limited number of licensed operators in a given band have individual but not exclusive rights of use. Each licensee can dynamically use all the awarded spectrum in the band in areas where frequencies are not used by other licensees, with a preemption right for their own assigned block of frequencies. For this purpose, licensees can stipulate reasonable and non-discriminatory commercial agreements, proportionally sharing the costs. Moreover, licensees can assign to a trusted third party the task of managing the uses in order to avoid harmful interference as well as to determine the access scheduling over time.

Unlicensed spectrum users can access the shared frequency resources provided that they ensure compliance with the technological standards and usage conditions established for the shared spectrum in order to ensure both protection of other radio services (such as whenever applicable, vertical sharing) and fair access among licence-exempt devices (horizontal sharing).

According to an 'authorised light licensing' model, in a spectrum band used under a general authorisation regime, a registration mechanism, for network equipment, or user equipment, or both, ensures control on the maximum number of allowed devices in a given area. Authorisation can be given for a predefined time, after which a new registration will be needed. The new registration can have priority over any pending registrations. After a maximum number of devices is reached, a new device can be authorised based on certain circumstances: such as for example, when the authorisation period of an existing device has expired, and its registration, if required, has not been renewed. New equipment can also be authorised in a restricted

[24] The RSPG16-04Final, Report on Efficient Awards and Efficient Use of Spectrum, lists the potential benefits of spectrum sharing between licensed operators:

- Together with enhanced frequency re-use, it might allow the spectrum users to deliver larger channels, and thus better bitrates to mobile users;
- As network sharing more generally, it may materially reduce network costs for operators which may encourage faster rollout, increased coverage, particularly in previously underserved areas (by geographic or population metric) and lower prices for consumers;
- It delivers faster and deeper coverage for consumers;
- It allows the promotion of more efficient investment; in particular in areas where sharing spectrum can deliver the required quality and speed, costs previously devoted to coverage issue can be refocused as investment in network densification;
- It can ensure supply / liquidity / consistency of supply and conditions of supply and use which is needed to meet the needs of provision of low cost, local and wide area internet access;
- Dependent on the type of sharing model, the competitive situation on the market and the regulatory framework, it might lower market entry barriers for new players as it lowers the costs that are sunk.

mode, until "free space" is found. The authorisation process can be automated by means of cognitive technologies and/or assisted by a database or AI based functional blocks.

The 'single-tier' approach is normally used in a "cleared band" dedicated to a single service and assigned to licensed operators, or in a shared band for unlicensed use by a multitude of equipment and services.

3.1.2. 'Multi-tiered' spectrum sharing approaches

Spectrum can be shared by radio systems associated with different tiers, which means that there is a hierarchy in the access and usage of the shared spectrum (i.e. vertical sharing). In general, 'multi-tiered' spectrum sharing approaches can be adopted both in licensed and unlicensed bands.

Typically, these approaches are applied to inter-services scenarios (e.g. primary radar systems and secondary MFCNs), including those in which one tier is represented by licensed users and another tier is under a general authorisation (or light licensing) regime. However, in a broader perspective, intra-service scenarios can be considered.

Typically, multi-tiered spectrum sharing approaches in inter-services scenarios allow some frequency resources to be made available for additional users in a relatively short period of time compared to the time typically needed for relocating the existing users in other bands.

In general, a two-tiered approach can be realised in a static way by defining the appropriate restriction/protection/exclusion zones, or more dynamically in other scenarios (with or without the implementation of cognitive technologies).

Within a DSA framework, a multi-tiered sharing approach can implement the so-called Hierarchical Access Model (HAM) that allows unlicensed secondary services to detect and dynamically use portions of spectrum unused in time and space by licensed primary services. Secondary services can opportunistically access the licensed bands without harmfully interfering with the primary services. HAM can be typically realised by means of two schemes:

- "Spectrum Underlay". Underlay technologies operate at very low power density levels in spectrum that is used for other licensed or 'licence-exempt' use, for example by means of UWB technologies;
- "Spectrum Overlay", also known as Opportunistic Spectrum Access (OSA). An overlay approach permits higher power levels that could cause interference to existing users but overcomes this risk by only permitting transmissions at times or locations where the spectrum is not used. OSA can be realised by using cognitive radio technologies which can identify "unused" portions of spectrum and share that spectrum without causing harmful interference to the existing users. OSA can be considered a better performing solution than spectrum underlay in terms of spectral efficiency and achievable throughput, but it requires adaptive techniques taking account of the state of transmission of the primary services.[25]

[25] Indeed, secondary services have to be able to detect the activity of primary services in the spectrum band in order to back off when a primary service is present. To this aim, OSA can require that secondary CR nodes are assisted by a database and/or perform spectrum sensing in order to agree on which spectral resources they are reciprocally allowed to use without compromising performance of primary services.

For instance, TV White Spaces (TVWS) in the 470-790 MHz spectrum range is a two-tiered approach which allows secondary cognitive radio devices, assisted by a centralized database containing the information on spectrum availability, to opportunistically access the spectrum unused by the primary TV services. Another example is RLAN access to the 5 GHz band used by radars where RLAN devices have to use a sensing mechanism called dynamic frequency selection (DFS) to detect and vacate any channel used by a radar.

The aforementioned sharing approaches typically cannot provide secondary users with a predictable Quality of Service (QoS) level, due to the opportunistic manner of accessing spectrum when unused by primary services.

An approach that tries to overcome the issue of unpredictable QoS in vertical sharing is represented by Licensed Shared Access (LSA), which is a two-tiered spectrum sharing regulatory approach in which licensed MNOs can access, under an individual rights of use regime, the spectrum used (or expected to be used) by one or more incumbents according to a predefined sharing framework, established under the responsibility of the Administration/NRA; in particular, MNOs have to comply with rules and conditions on spectrum usage (in time, locations and/or frequency) included in their individual rights of use in order to ensure that all the authorised users (incumbents and LSA licensees) can provide services with a predictable QoS level. In this case protection/restriction/exclusion zones are predefined, or their activation is subject to a set of conditions defined in advance which enable the MNOs to quantify the sharing burden. LSA does not prejudge the modalities of the authorisation process to be set by the Administration taking into account national circumstances. In 2014, the 2300-2400 MHz band was harmonised for mobile at European level (CEPT) with reference to LSA as a means to maintain long term incumbent use of the band (which is currently sparsely used).

Leveraging on the LSA concept, evolved LSA (eLSA[26]) is a system developed along 5G directions. This is able to support spectrum access to local high-quality wireless networks operated by the vertical sector operators as expected in the 5G context. This is aimed at providing an automatic tool to facilitate spectrum sharing coordination between incumbents, NRAs and eLSA licensees (e.g. vertical sector operators).

The 'Local Access Licence' approach, adopted by Ofcom in the UK, represents a real case of two-tiered geographical sharing, since it enables the shared use of spectrum already licensed on a national basis to MNOs (e.g. 800, 900, 1800, 2600, 3400 MHz) in locations where a particular portion of frequencies is not being used or planned to be used. Currently, in these particular areas, access is granted to new licensees for a given period of time. In order to facilitate the coordination procedures between licensees in the same band and in order to make the process more automated, as well as to make spectrum sharing dynamic and more efficient, Local Access licenses would benefit from the application of DSA techniques, in particular cognitive radio technologies (e.g. for automatically adjusting transmission parameters in order not to cause harmful interference).

The 'Shared Access licensing' approach, again adopted by Ofcom in the UK, can be used in licensed bands[27], allowing other licensees to get access on a coordinated basis (thus ensuring it won't cause harmful interference to existing users, such as defence systems, amateur radio users, radio astronomy services, etc.). Typically, Shared Access Licensing is operated on a first come, first served basis, and for a predefined area.

[26] See ETSI 103 652-1

[27] This approach is currently available in four spectrum bands which support mobile technologies, namely 1800 MHz, 2390-2400 MHz, 3800-4200 MHz and 24.25-26.5 GHz.

The sharing framework depends on the specific band (due to the different characteristics of the related existing users which entail different interference risks). This may result in many limitations for the new licensed entrants compared with the incumbents (such as indoor restriction, requirement to keep an accurate record of all mobile terminals and the address of the site or building they are limited to operate within), including in particular the permitted power of equipment (base stations). This approach is another example of a two-tiered spectrum sharing arrangement with licensed existing users. However, compared to LSA, the shared access licensing currently applied is based on a more static scenario in terms of coexistence parameters, since it does not rely on the implementation of DSA mechanisms.

Recently the FCC in the USA adopted a two-tiered spectrum sharing solution for unlicensed use of the 6 GHz band in coexistence with primary services. In particular, the operation of an unlicensed standard access point is permitted only under the control of an Automated Frequency Controller (AFC), which ensures the protection of incumbent fixed microwave operations by establishing location and frequency-based exclusion zones.

An example of a three-tiered approach is represented by the Spectrum Access System (SAS), established again by the FCC in the USA so that the Citizens Broadband Radio Service (CBRS) could share the 3550-3700 MHz band. It is based on a three-tiered access and authorisation framework, which also includes the use of spectrum sensing technologies.

Therefore, it can be seen that a multi-tier approach is very promising for increasing sharing opportunities. Such approaches can be applied to a band already used by incumbents in order to allow the entrance of new users with different services. The protection of the incumbents can be ensured by static or dynamic mechanisms which allow the incumbents to claim extended protection when needed. In this case the incumbent is almost always a licensed user. The new users can be licensed or unlicensed, and the relative protection framework should be defined in advance and can be static or dynamic. This approach is also promising to open up the use of spectrum to private 4G/5G mobile networks deployed in wide and/or local areas by utilities, industries or enterprises. Indeed, multi-tiered spectrum sharing could be adopted to support the realisation of private mobile networks without the need for dedicated spectrum and, at the same time, without impacting the incumbent networks.

3.2. Technologies for spectrum sharing

Depending on the requirements of the considered spectrum sharing scenario, including the specific quality targets of each spectrum user/service within the considered type of sharing approach, many technologies characterised by different levels of complexity can be exploited. These can be more traditional technologies based on spectrum sensing techniques[28], cognitive technologies (in particular based on geolocation/database) or spread spectrum techniques for underlay transmissions.

There are also other radio technologies that, although not specifically devised for spectrum sharing, can also be applied to increase the opportunities for bringing about efficient shared use of frequencies. These could be technologies for interference mitigation, such as smart antennas (including beamforming), Collaborative Intelligent Radio Networks (CIRNs), filters, etc.

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[28] According to the RSPG report on “cognitive technologies” (RSPG10-306 Final), these technologies could be considered as “pre-cognitive” radio technologies, introduced as part of mitigation techniques to facilitate sharing in frequency bands which would otherwise not be possible.

Moreover, developments in technologies related to 5G, like network slicing, are expected to enable new sharing opportunities.

Finally, there are other technologies in the broader ICT sector, which might also be employed to realise innovative and more efficient spectrum sharing. Examples would include Artificial Intelligence (AI) and Blockchain technologies (especially when applied to cognitive radio systems).

In the following a brief overview of these technologies is reported, without the aim of providing an exhaustive list since this is a field of constant development, highlighting also the main related research activities conducted within some EU projects.

3.2.1. Basic spectrum sensing technologies

The more "traditional" spectrum sharing techniques are related to multiple-access techniques already used in many SRDs and more generally in "licence-exempt" bands to mitigate interference and allow coexistence among devices in the same frequency band. Some of these well-known technical solutions are contention-based protocols[29] such as the Listen Before Talk (LBT)[30], Dynamic Frequency Selection (DFS)[31] and Detect and Avoid (DAA)[32].

The management of coexistence between different services, or between multiple operators of the same service, as well as the maximum number of devices sharing a given frequency resource is also a key aspect in some smart metering applications. Here the problem of using a frequency band with unlicensed use while still being able to offer a minimum QoS is addressed at the application level.[33]

These basic technologies are at the moment the cornerstone of spectrum sharing in frequency bands with unlicensed use. They are constantly improving to permit an ever more sophisticated shared access and can also be employed in frequency bands with licensed use.

[29] According to the FCC definition (KDB 552295, §90.7), a contention-based protocol allows multiple users to share the same spectrum by defining the events that must occur when two or more devices attempt to simultaneously access the same channel and establishing rules by which each device is provided a reasonable opportunity to operate.

[30] The LBT protocol is a well-known CBP (e.g. used by WiFi systems), according to which devices listen for the channel occupancy by other devices on the network and transmit only if no other transmissions are detected in the channel.

[31] DFS reduces the transmission delay related to the period in which a device cannot access the desired channel due to the detected presence of other devices, compared with LBT. This technique envisages that the devices, that should be endowed with Adaptive Frequency Agility (AFA) feature, search for different free channels in the frequency band if the initial desired channel is detected as occupied during the listen time. For instance, Wi-Fi access points using DFS switch to another available frequency channel within the band if they listen for other users of the channel, such as radar services (in this case to protect existing spectrum users) or neighboring access points (in this case to improve performance of Wi-Fi networks).

[32] DAA technologies allow devices to mitigate interference caused to other radio systems sharing the same spectrum by detecting the presence of their signals and then, possibly, reducing the transmitted power to an acceptable level to ensure coexistence (underlay sharing) or switching to another frequency.

[33] In such cases, standard protocols like the Wireless Metering Bus (WMBus) mode "N" (e.g. operating at 169 MHz), considering also the absence of media access control methods, allows more reliable transmissions by preventing systematic collisions in accessing the shared spectrum through a cyclic access number that is randomly initialized on each device that so can slightly varies the time between two subsequent transmissions.

3.2.2. Cognitive technologies

As also highlighted in the previous relevant RSPG works, referenced in Annex 2, cognitive technologies allow a radio system to dynamically and autonomously adjust its operational parameters and protocols based on both its obtained knowledge of the operational environment and the results of a learning process, in order to achieve predefined goals when performing spectrum sharing[34].

Regulatory considerations on cognitive radio within the context of agenda item 1.19 of WRC-12 provide some useful guidance when investigating enhanced spectrum sharing solutions. The ITU-R adopted a definition for Cognitive Radio System (CRS) at an early stage which can be found in Report ITU-R SM.2152 (2009) and is still relevant today. Report ITU-R M.2225 (2011) also provides a useful description of different deployment scenarios for the use of CRS technology (depending on their compliance with national and ITU Radio Regulations). In these different scenarios CRS can be used:

- to guide reconfiguration of connections between terminals and multiple radio systems;
- as an enabler of cooperative spectrum access;
- as an enabler for opportunistic spectrum access in bands shared with other systems and services;
- by an operator of a radiocommunication system to improve the management of their assigned spectrum resource.

More recently, the ITU-R adopted the Report ITU-R SM.2405-0 (06/2017) on spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities. This report calls for detailed sharing and compatibility studies to be performed within expert groups of the service to be protected when developing a regulatory framework for DSA-based applications. Depending on the nature of the service or the radio application to be protected the performance of compatibility studies might be challenging.

Geolocation

Some spectrum sharing cognitive technologies[35] are based on the implementation of **geolocation** databases, which can provide devices with information to identify portions of spectrum available for sharing so that existing services are protected. This information can be information on which frequencies can be used at a certain time and/or in a certain location and with certain transmission parameters such as the maximum transmission power. The principle behind such technologies is frequency agnostic and thus can be applied for different spectrum bands.

The geolocation information on the availability of shared spectrum can be stored directly in the device according to a distributed approach or in a more centralised (e.g. regional) database which is then queried by devices. Based on the specific spectrum usage scenario, hybrid mechanisms can be also envisaged.

[34] Developments in Software Defined Radio (SDR) technologies can represent a booster for cognitive radio systems, but SDR is not an absolute necessity since cognitive radio systems could be built purely based on hardware.
[35] In the literature there are several classifications of cognitive spectrum sharing technologies. For instance, spectrum sharing techniques in cognitive radio networks can be classified under four different categories (https://bwn.ece.gatech.edu/surveys/cr_spect08.pdf): architecture (centralized or distributed spectrum sharing); spectrum access technique (overlay or underlay sharing); spectrum access behavior (cooperative or non-cooperative sharing); scope (intra-network or inter-networks sharing). See also previous works by RSPG referenced in the Annex 2.

One well-known application of geolocation databases for spectrum sharing is related to access to 'TV white spaces' (TVWS) within the 470-790 MHz spectrum range, which represents an emblematic example of opportunistic access to portions of spectrum that are unused in an area at that particular time. A device will contact a white space database (WSDB) and provide to it its location and technical characteristics. The WSDB holds information about the incumbents and can calculate what channels and power levels are available at any location. The database system will do this calculation for the specific location and technical characteristics provided by the device and will communicate the available channels and powers to the device which can then start transmitting. WSDs would normally connect to the WSDB over the internet.

One key feature of the European regulatory developments on TVWS is that a WSD may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by the National Regulatory Authority (NRA). This concept is well embedded in ETSI EN 301 598 V1.1.1 (2014-04), which provides a common set of radio parameters for WSDs and a single format for data exchange with national databases. Although there was no perspective for harmonisation at ECC level or further national authorisation of Wireless Access Systems operating within the 470-790 MHz frequency band in Europe, it can be noted that the key principles of this approach could be re-used and adapted to other spectrum sharing situations, particularly for licence-exempt regulatory framework[36].

Spectrum sensing

Spectrum sharing cognitive technologies may also rely on **spectrum sensing**[37] performed by devices to detect the status of availability of frequency channels for autonomous transmissions without the need to integrate or connect to a database. On the other hand, spectrum sensing may face a number of technical challenges compared to geolocation database solutions. Thus, some limits in terms of cost-effective spectrum sensing solutions still remain, especially when such solutions are based on sensing performed by specific stations (e.g. for CBRS) instead of devices (e.g. for DFS). In general, sensing may have performance degradation in some network scenarios (e.g. those based on energy detection) which implies the risk of false negative detection.[38] Moreover, Cognitive Radio devices cannot transmit while performing sensing, and this typically decreases the efficiency of spectrum sharing. Furthermore, a common control channel among secondary

[36] It is worthwhile to note that after the release of 700 MHz to mobile services, the importance of the white space approach has started to decrease and this decrease may be sharpened after the decision on the rest of the UHF TV spectrum, which is expected to be taken in WRC-23. Nevertheless, taking into account that this Report covers various cases of spectrum sharing mechanisms and according to the Article 4 of EU Decision 2017/899, 470-694 MHz will be available at least until 2030 for the terrestrial provision of broadcasting services, including free television, and for use by wireless audio PMSE on the basis of national needs, it is valuable to mention white space applications as this constitutes one area of spectrum sharing in terms of the database approach. Furthermore, today's practice of white space is on the TV broadcasting spectrum, the approach used for white space (database approach) can also be used in the frequency bands where the applications have static nature similar to TV broadcasting. Thus, white space applications could be used in various frequency bands having the nature above.

[37] There is also a third methodology for information seeking in CRS, the beacon transmission, that is not however widespread and is not further considered here. Indeed, beacon transmission has not been actively pursued because of the costly infrastructure that would likely be involved in setting up a network (that requires equipment for transmitting reliable beacons as well as the ability of devices to receive the beacon signals) and the inefficiencies caused by base stations having to transmit in dedicated frequencies within the allowed usable spectrum.

[38] In order to overcome this issue, the use of the beacon signaling transmitted by incumbent services to be protected could ideally be a helpful approach, but with the mentioned downsides. On the other hand, in a cognitive radio scenario without cooperation between primary and secondary networks, secondary CR devices performing spectrum sensing to access the shared spectrum may require the implementation of sophisticated techniques to increase the reliability of estimating the precise locations of the primary receivers.

nodes is usually required to facilitate the identification of transmission channels. For these reasons, spectrum sensing technologies are also sometimes used in conjunction with geolocation database technologies in a hybrid approach aimed at improving sharing efficiency while ensuring protection from harmful interference.

Cases of application of Cognitive Technologies

Cognitive radio technologies are in some cases advocated by operators of a radiocommunication service to improve the management of their assigned spectrum resources. This would enable an improvement in the quality of service of the different systems sharing spectrum where there is a need for coexistence between different devices in dense wireless networks. An improved, careful and efficient interference-aware resource allocation management will reduce interference, which is the main limiting factor for frequency sharing. Different protocols[39] have been developed to dynamically and efficiently allocate spectrum resources and predict network demands using cognitive technologies as well as AI and machine learning techniques.

In this regard, the ADEL Project tackles the three research problems in the LSA field: the allocation of spectral and power resources in a dynamic way, the QoS guarantees and the LSA network energy expenditure.

Cognitive Radio could also facilitate the deployment of Relay[40] networks, which offer more performance in terms of coverage and capacity. For example, there is a relay-assisted protocol for spectrum mobility and handover with minimum expected transmission times in cognitive long-term evolution networks. This relay assisted protocol allows unlicensed users to access not only the previous base stations but also the next base station, with the assistance of relay nodes. It thus achieves a significant reduction in total transmission time and spectrum mobility ratio, and provides increased throughput.

Further advances in cognitive radio systems can enable more efficient spectrum sharing, especially in terms of the capabilities of devices to identify frequency channels available for sharing and as a result either access or vacate them in a suitable way to avoid/limit interference.

Approaches that make use of cognitive technologies seem the most promising to obtain a more efficient spectrum sharing used in most situations. One of the typical scenarios where such an approach can be applied is in a frequency band with licensed use, in order to permit the introduction of a new service be it under licensed or unlicensed conditions, without the need to clear the band. Another scenario can be one of a cleared band to permit its use by unlicensed equipment, where the traditional access techniques show some limits. In this case the cognitive technologies can be exploited to realise a ‘light licensing’ framework.

However, there are other possible scenarios that depend on several factors, including the characteristics of the incumbent users and the propagation characteristics of the frequency band.

[39] Those protocols face three main challenges, namely: the different QoS of the coexisting wireless links; the dependence on the chosen resource allocation of other links in the network; and the fact that usually there is no central controller to perform the resource allocation (if the central controller exists, it must consider the information reported from the nodes).

[40] Relays is one of the features included in LTE-Advanced which, by relaying radio signals transmitted between a base station and a mobile device, can improve the in-band coverage/capacity within areas that suffer from high shadowing, and facilitate the provision of capacity in some areas which might have a significantly high traffic demand for short periods.

3.2.3. Other radio technologies and advancements for spectrum sharing

In the last few years new radio technology developments which can mitigate against interference have quantitatively and qualitatively extended the technical options for spectrum sharing. These new developments include advances in smart antennas, Collaborative Intelligent Radio Networks, etc. These can be employed in conjunction with new concepts in network architecture such as small cells, HetNet, etc. For instance, the advances in the field of smart antenna systems, which typically reduce the intersystem interference, can represent a technological driver to enhance spectrum sharing.

Beamforming

Within the smart antennas' domain, adaptive **beamforming** potentially increases the opportunities for spectrum sharing among multiple users and radio access technologies. Although spatial re-use of spectrum is not a new concept in wireless communication systems, the advances in beamforming technologies, which dynamically provide adaptive beams similar to "one-dimensional pins" rather than a beam pattern covering an area, can significantly reduce the interference range and thus enhance the degree of spatial spectrum sharing, especially for millimeter wave (mm-Wave) spectrum bands. When applied in a 5G context, this would facilitate the realisation of slicing scenarios.

Studies are ongoing on radio access schemes for coordinated beamforming transmission where the cooperating base stations exchange information on channel state and control to serve disjoint groups of users in a coordinated manner. Low-complexity cooperative techniques can then be derived and applied during the complex spectrum sharing setup of future networks, such as those considered in the European Commission's H2020 project Painless[41].

The second RSPG opinion on 5G also referred to the possibility of using beamforming to ease coexistence with other services: "*the antenna beam forming technologies being developed for 5G will be used to improve link quality and throughput to individual end users. It should be investigated where it is feasible for antenna beamforming technologies to also be used in a way that explicitly minimises radiation in specific directions, i.e. towards receiving stations of other services. If this is feasible then, when coupled with other technical approaches (e.g. database / geolocation technologies), it could potentially be effective in mitigating interference to other services. This may offer the possibility to deploy 5G stations closer to the existing stations to be protected than would otherwise be the case. However, such features would have to be implemented in the antenna beamforming and massive MIMO algorithms in a way that allows operators to define the radiation limitation in any given direction*."

Dynamic allocation of frequencies among technologies

Technological progress in the field of spectrum sharing has also paved the way to allow mobile operators realise dynamic allocation of frequency resources among devices with different radio access technologies, based on real-time conditions and network loads (e.g. Dynamic Spectrum Sharing, DSS). This is in effect an

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[41] PAINLESS was launched in 2018 with the visionary aim to establish a training and research platform to pioneer green, energy-autonomous portable network nodes which are self-subsistent and limitlessly scalable, to satisfy future demands with minimal infrastructure. See http://painless-itn.com/.

intra-operator spectrum sharing technique, which is currently proposed and implemented by many MNOs and vendors[42].

Receiver performance

Adequate receiver performance is increasingly important to facilitate spectrum sharing and has become increasingly necessary to facilitate the introduction of new systems, to extend sharing opportunities and to ensure efficient use of spectrum. The new Radio Equipment Directive explicitly covers receivers. Receiver parameters are included in harmonised standards for all equipment. Adequate receiver specification is necessary to ensure that radio equipment is protected from emissions of services in adjacent bands and should be continuously improved. In fact, the immediate impact could be the reduction of guard bands between services. It should be noted, however, that requiring more constraining receiver performance can imply additional costs.

Filtering techniques

The improvement of **filtering techniques** and of filters themselves has been essential for introducing new applications and to achieve a more efficient use of the spectrum. Those advancements have permitted the application of stringent Block Edge Masks (BEM) necessary for the compatibility with adjacent bands where used by particularly sensitive application. An example is the BEM for MFCN terminals in the 700 MHz band for the protection of TV receiver in the 470-694 MHz band. The introduction of active antenna systems (AAS) where the amplifier is part of the antenna has resulted in a challenge to filter unwanted emissions with a filter that will accomplish the task and physically fit into the AAS system with the necessary parameters (size, heating, etc.)[43].

Application-layer coexistence

Additional technologies that permit interoperability at protocol/application layer, thus allowing the coexistence of different technologies in unlicensed bands, can also be mentioned. Examples include those that are being developed for the ITS at 5.9 GHz (adopting polite protocols) and WiGig at 60 GHz (57-71 GHz) or those adopting interference mitigation technique such as APC (Adaptive Power Control)/DAA. Such APC and DAA are highly beneficial when trying to keep the overall interference probability low enough so that operation under a licence-exempt regulation is attractive for 5G application providers, such as for fixed wireless access solutions or backhauling and fronthauling to and from high capacity small cells using 5G technology.

It is worthwhile noting that the initial regulatory framework at 60 GHz was developed in 2009 to meet the demand for wireless personal area networks (WPAN), essentially indoor. The exclusion of fixed outdoor installations was agreed at that time as a means to ensure the protection of fixed service operated in some countries. In 2019 some work has been conducted in Europe towards achieving least restrictive, flexible and

[42] Existing FDD bands or new FDD bands are used in 5G networks to complement mid-bands for fast roll-out of 5G. New FDD bands at lower frequencies (e.g. 600, 700 MHz) could be used as dedicated 5G spectrum, or existing 2G/3G/4G FDD bands (e.g. 800, 900 MHz) could be shared with 5G through DSS, providing wider and deeper coverage for 5G. Other FDD bands can also be considered for this purpose (e.g. 1800 and 2100 MHz).

[43] For example, the filter cannot be inserted by the operator to address local adjacent band compatibility issues (e.g. close to a radioastronomy station). This issue has proved to be particularly challenging in the definition of BEM for 5G in the 2.6 GHz (protection of radioastronomy), 3.4 GHz (protection of radars) and 26 GHz (protection of the passive band).

streamlined regulations in the band 57-71 GHz which would accommodate 5G and WiGig technologies and applications, whilst also taking into account Intelligent Transport Systems (ITS) in this frequency range.
The new regulatory provisions as included in Annex 3 of ERC/REC 70-03 would fit the spectrum requirements for two different use cases sharing the frequency band 57-71 GHz:

- outdoor wireless access solution (e.g. small BS fixed at lamppost);
- wireless backhaul: higher radiated power is permitted, subject to minimum antenna gain.

Corresponding provisions have been inserted in Decision 2006/771/EC on short-range devices as amended by Decision (EU) 2019/1345, based on a proposal presented in CEPT Report 70.

Sharing testbeds has been tried in the Fed4FIRE testbed facility in Ljubjana (LOG-A-TEC). Under an open call programme, the facility provides access to the spectrum sharing platform.

3.2.4. 5G-related technologies

The developments of technologies related to 5G are expected to enable new sharing opportunities. Indeed, in 5G networks several spectrum sharing forms (including roaming) could leverage on network slicing mechanisms. It should be underlined that 5G slicing[44], although is not a spectrum sharing technology *per se*[45], may increase the opportunities for realising some innovative spectrum sharing scenarios, as already initiated by some operators in Europe (see Annex 5).

In ‘single-tier’ spectrum sharing approaches, 5G slicing is expected to offer new interesting opportunities for both intra-service and inter-service sharing among operators. 5G slice-based shared use of spectrum, so far, seems applicable to licensed bands, allowing one licensed mobile network operator to provide other mobile network operators and/or service providers with dedicated 5G slices. This solution makes it possible to share different 5G bands among licensed operators and/or service providers.[46] For instance, a MNO can share its frequencies and infrastructure with other MNOs and can provide them 5G slices suited to accommodate the requirements of their customers be they mMTC or eMBB; a concrete case could be a sharing agreement between two MNOs, where one operator has frequencies only in the lower bands and the other MNO holds spectrum only in the mid-band: network slices can be allocated to both MNOs on both networks, each operated by the MNO holding the frequency right of use, resulting in practice in spectrum sharing in both bands; additionally, all MNOs in the agreements may decide to pool their frequencies, in the manner described above, in one or more bands for 5G slicing, if this is allowed by the national regulatory framework. This results in an even more sophisticated sharing. Another example can be represented by a ‘neutral host’ mobile network model (e.g. for small cells in higher frequency bands) in which spectrum sharing can be managed by means of network slicing. A concrete case could be a mobile network realised in the 26 GHz band by one MNO or one asset provider by pooling all frequencies available in the band and giving access to the other MNOs through 5G slices. In practice the MNOs in that example would lease their spectrum rights

[44] Slicing allows creating multiple independent logical networks on a common physical infrastructure. According to the definition provided by 3GPP, a network slice is a logical network that provides specific network capabilities and network characteristics. Network slicing can be performed also at the RAN level while sharing the same radio resources. In particular, the frequency and time resources of the 5G NR can be tiled in order to be suitably and dynamically allocated for fulfilling the requirements of specific network slices.
[45] Even if, according to ITU definition SM.1132, 5G slicing can be seen as time/signal/frequency separation.
[46] Wholesale access-based use can be considered as an extension of the concept of 5G-slice based shared use of spectrum, in which the access granted by a licensed operator to other licensed operators or service providers in practice allows to share the spectrum resources where the access is granted.

to the network operator (or asset provider) who installs and maintains the equipment and then enables a "slice" for each of the "partner" MNOs on the resultant physical network.

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, dedicated to URLLC, mMTC and eMBB for MFCN and PPDR applications. Finally, 5G slicing can also address some vertical industry needs[47].

Another key aspect of 5G systems is the use of frequency bands with unlicensed use in combination with spectrum with licensed use in order to provide end-users with a boost of capacity performance[48]. Since work has already been done within 3GPP for LTE, Licensed Assisted Access (LAA) is also expected to be a coexistence technique for 5G networks, thus opening interesting and challenging scenarios in terms of spectrum sharing[49]. In this context, Coordinated Multipoint (CoMP) techniques for interference avoidance can also increase spectrum sharing efficiency.

5G-related technologies presuppose that spectrum sharing is realised among licensed operators, particularly MNOs, in licensed bands (save the possibility in the case of LAA to leverage an unlicensed band in order to achieve benefits mainly in terms of boosting capacity). They are then relevant for regimes such as Local Access Licenses and in general where sharing is based on voluntary agreements between operators, or through other means of access for network operators not having coverage at a location including roaming.

5G related spectrum sharing is also analysed in the 5GPPP phase 3 project, 5G Genesis, in the context of IoT services. In the COGEU project, an automatic spectrum-trading platform (an online booking tool) is provided, to date only for the Munich area.

3.2.5. Developments in Artificial Intelligence and Blockchain technologies applied to CR models

The latest spectrum management developments refer to application of technologies such as Artificial Intelligence (AI) and Blockchain in the context of spectrum sharing, in particular in the approaches based on cognitive access. In the following paragraphs a brief overview of such advances is given.

AI techniques are not per se spectrum sharing mechanisms but can favour, to a great extent, efficient spectrum use and sharing. Indeed, AI and supporting technologies applied to Cognitive Technologies improve and speed up the coordination processes, offering dynamic access to specific spectrum, in a responsive manner according to the needs of specific services (periods of use, range, capacity, etc.). Spectrum access

[47] For instance, 5G network slicing is expected to be a key mechanism to achieve the goal of using spectrum for delivering 5G services to the various use cases identified among a range of verticals. More in general, in the 5G context spectrum sharing can be an opportunity for verticals. As stated in the RSPG opinion on 5G implementation, many verticals usage would benefit from dedicated spectrum in local areas for "on-site" industry and 5G NR would provide the necessary performance in terms of capacity, latency and reliability. This local 5G deployment may share their spectrum with various spectrum users which may not need to have nationwide spectrum access or in higher frequency bands where some mitigation techniques such as indoor restrictions may be sufficient to allow for sharing.

[48] For instance, 5G NR-U is the standard for both licence-assisted and standalone use of unlicensed spectrum.

[49] Moreover, 3GPP has also agreed upon a number of LTE-NR sharing band combinations where the UL direction of some low frequency bands (e.g. 700, 800, 900, 1800 and 2100 MHz) is paired with the 3300-3800 MHz band (so-called supplemental uplink, SUL).

could be delivered for instance on demand or opportunistically while avoiding harmful interference using the information fed into the system This is especially true as regards information that is not generally utilised in more traditional cognitive systems, such as weather conditions, local spectrum uses, “busy hours”/periods when traffic is much higher than average, thus enabling the determination in a very sophisticated way the most appropriate parameters and technical restrictions for dynamic spectrum access.

AI techniques adopted together with a combination of sensing and database technologies could support the near-instantaneous granting of spectrum for ad hoc mobile access requirements such as those that might be needed for Internet of Things applications.

With the development of IoT, device location and other key spectrum occupancy parameters of sensors or other machines can be harvested at consumer scale in great detail. This richly detailed data about spectrum usage can be managed in cloud-based data hosting and processing platforms where AI tools find their best application. AI could identify significant features from potentially vast streams of data that comprise a live frequency occupation map. The results could be used to drive spectrum database updates, so that application requests can be met to the greatest extent possible at a given time in any location covered by the database. The same approach can be applied to dense small cell deployments that are typical of 5G scenarios.

Among the most current trends to facilitate spectrum sharing is that of obtaining a large amount of information through collaborative spectrum sensing. That information would be treated with Artificial Intelligence techniques so that spectrum could be dynamically and rapidly made available for a given use by one or more users in a certain area, as highlighted for instance by the Electrosense initiative (Open Spectrum Data as a Service)[50].

There are multiple projects currently being developed at the EU level that work on the basis of advanced collaboration. In the project EuWireless[51], spectrum sharing for research purposes is proposed by installing a “coordinator/operator of operators” who/which is in charge of allocating spectrum. In the Coherent project[52], LSA is considered in the framework of coordinated control and spectrum management between incumbent and two network operators.

AI techniques like machine learning and deep learning are also applied to advanced spectrum sharing schemes, Such AI techniques can be used for instance to frame models for the dynamic behaviours of the different users in a Cognitive Radio network with multiple primary services and multiple secondary services. These AI techniques can also be used to overcome new routing problems in ad-hoc cognitive radio networks in order to favour the path with the most balanced and/or the lowest spectrum utilisation by the primary services.

It is expected that the 6G wireless communications network being developed will go beyond mobile Internet and will be required to support ubiquitous AI based services from the core to the end devices, including

[50] Electrosense (Open Spectrum Data as a Service) is a collaborative spectrum monitoring network designed to monitor the spectrum at large scale with low-cost spectrum sensing nodes. The large set of data is stored and processed in a big data architecture and provided back to the community with an open spectrum data framework as a service model, that allows users to build diverse and novel applications with different requirements. See https://electrosense.org/#!/.
[51] See https://euwireless.eu/.
[52] See https://www.5gitaly.eu/2018/wp-content/uploads/2019/03/5G-Italy-White-eBook-ALL-PROJECTS.pdf. The key innovation of COHERENT is to develop a unified programmable control framework to coordinate the underlying heterogeneous mobile networks as a whole.

Virtual Reality (VR) and Augmented Reality (AR). It is likely that AI will play a fundamental role in designing and optimising 6G architectures, protocols and operations[53] as well and indeed R&D activities are already ongoing in this direction.

Blockchain technology, that falls within the Distributed Ledger Technology (DLT) category, can be applied to spectrum sharing. DLT is a decentralised form of database where no single party has control. For that reason it offers a secure, resilient, reliable and transparent way of validating, recording and manipulating data across all the nodes/users of a network and thus keeps the distributed ledger up to date.

The application of Blockchain technology can move the typical benefits of DLT to the shared use of spectrum, for example in terms of:

- decentralisation, since it can eliminate the need for trusted third parties such as spectrum licensees, band managers, and database/SAS administrators;
- transparency, due to the better localised visibility on spectrum usage and auditability of activity for effective implementation of spectrum sharing rules;
- permanence and non-variability, since permanent records prevent tampering, facilitate accurate auditing/enforcement, and can ensure accurate implementation of rules;
- availability, thanks to a more reliable access to spectrum sharing databases;
- security, since wireless systems need strong security against attacks and secure ledgers also foster reliable enforcement of sharing regimes.

However, the application of Blockchain to spectrum sharing can imply several issues to be considered. For instance, unlike fixed equipment, mobile devices are resource-constrained and are not always able to operate as full blockchain nodes due to their limited processing power and battery capacity. In addition, in order to allow the operation of the blockchain and to validate transactions, a suitable set of radio resources would typically need to be available at all times for the communications among nodes[54], increasing the overhead and reducing the available net capacity. This is especially true if the applied blockchain leverages on broadcast communications among devices (like in the case of bitcoin). Moreover, the stochastic nature of wireless channels could require adaptation of blockchain protocols to increase the system reliability, and then the resulting cost-benefit ratio of the application of this technology could be higher than that of the existing DB-based technologies for spectrum sharing, making it no longer financially and economically attractive.

Overall, it is evident that Blockchain, which despite being developed to secure asset transactions (where the asset was typically a cryptocurrency) found its way into a variety of sector applications including spectrum use in general, and spectrum sharing in particular. In the latter context one possible application of blockchain is in automating the building of contracts that may be given legal status. In other words, suppose a spectrum user wants access to particular spectrum, even if the intended use is designated as being unlicensed in the band. As seen in section 2.3.1, unlicensed does not mean “not authorised”, so depending also on the local regulation, it may need an authorisation, in particular when a so-called “light licensing” scenario is being used. If the spectrum in use changes very frequent, the authorisation process may become too burdensome for the NRA/NSAs. The spectrum right of use stored in the blockchain may be given the legal status of an

[53]See, inter alia, The Roadmap to 6G: AI Empowered Wireless Networks. IEEE Communications Magazine (Volume: 57, Issue: 8, August 2019).
[54] In case of trusted nodes, communication requirements are typically less stringent.

authorisation, making it enforceable not only under the frequency management element of protection from harmful interference, but also under all the typical regulatory aspects of customer protection, legal interception, data protection, and so on. Some other issues that need to be considered in this context are the contractual implications of the use of blockchain on customers' service (for example on QoS) and the right of appeal procedure where applicable.

Cognitive sharing technology can also benefit from the Blockchain concept to implement a decentralised database. Blockchain achieves transparency and traceability of the interactions or transactions and the use of a decentralised database increases the resilience of the sharing solution, the reliability of the data, as well as the confidence that rules are applied equally to all users.

3.2.6. Need for technological collaboration

***Licensing* (of property rights)**

The development of spectrum sharing technologies requires clarification of certain legal issues, especially as regards intellectual property rights. As a number of spectrum sharing solutions are created under proprietary regimes by one regulator, there is a demand for them to be tested and implemented by other regulators as well. Certain licensing models, such as open source licenses, may especially encourage further innovation and cooperation on new spectrum sharing technologies. Open source licenses, such as the European Union Public Licence[55] create advantages for the fast-evolving space of spectrum sharing. For example, open source licenses make the source code available publicly and equally to all (the private sector as well as other regulators). This allows for a high degree of flexibility and technological adaptation. Regulators may assist each other with software development and implementation and exchange gained know-how. If a new feature is sought, regulators may be able to develop such features collectively, reducing the extra costs involved in the development process.

Sandboxes

At the current stage of development of spectrum sharing technologies, further facilitation of innovation is needed. Regulatory sandboxes, bringing together the private sector and regulators, are becoming a fruitful testing ground for innovative approaches to spectrum sharing. In developing new spectrum management sharing approaches, regulators engage with operators to test these new approaches and to better understand their potential, as well as to stay abreast of developments in spectrum technologies. Although replicating a regulatory sandbox may seem complicated in the fragmented regulatory landscape of the EU, there are possibilities to engage multiple regulators and multiple operators in cross-border or multi-country proof of concept technology projects, such as via common R&D projects financed through EU funding frameworks.

In particular, in 5G sandbox projects comprising experts from industry, operators, ICT experts and academia, regulators may be able to i) receive feedback from use cases serving as inputs for AI algorithms, ii) tune up conditions for future network slicing (eMBB, mMTC, URLLC), iii) verify appropriate software-based user authentication tools and planning tools and iv) verify other technologies facilitating spectrum sharing. These experiences can be directly transferable from one administration to another.

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[55] Commission Implementing Decision (EU) 2017/863 of 18 May 2017 updating the open source software licence EUPL to further facilitate the sharing and reuse of software developed by public administrations. See https://joinup.ec.europa.eu/sites/default/files/custom-page/attachment/eupl_v1.2_en.pdf.

3.3. Conclusions

Today several radio technologies – already available as 'turn-key' solutions or under development – are mature enough to enable or devise many spectrum sharing schemes and architectures and in consequence open up many different opportunities for fostering the adoption and development of spectrum sharing. In this context the relevant regulatory and standardisation bodies[56] (ETSI, CEPT, 3GPP) have already delivered or have under study a number of technologies or approaches for previously identified spectrum bands. This group of 'state-of-the-art' technologies can be seen as a technical 'toolbox' available to spectrum users and NRA/NSAs to implement different spectrum sharing approaches in any given band ('single-tier' or 'multi-tiered', intra-service or inter-services, considering the same or different type of spectrum users, etc.). Depending on the identified application/use case, the specific performance requirements and the current band at hand, an increasing number of sharing scenarios can be developed. These can be both those that the spectrum users themselves would like to implement and those that the NRA/NSAs plan to develop.

It is also important to appreciate the role of research activities conducted in the field of spectrum sharing. The activity is predicated upon an intensive cooperation between national regulators, as well as regulators and the industry through concepts such as regulatory sandboxes – test systems under a regulator's supervision – as well as cooperation with academia[57]. Funds, such as Horizon 2020[58] and the upcoming Horizon Europe (2021-2027)[59], could play a decisive role in setting-up and supporting such collaborative efforts. As for the latter, the cluster for Digital, Industry and Space in Horizon Europe includes key enabling technologies for research that can improve spectrum sharing and management. The challenge is to create effective research collaborative schemes that allow sharing results between regulators and across borders. Technical cooperation platforms at the BEREC and CEPT level could provide a way forward. Open source licenses, such as European Union Public Licence, could further facilitate collaboration, sharing and reuse of software, algorithms and other tools developed by national regulators.

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[56] Spectrum harmonisation developed by administrations in close cooperation with industry (see EC Decisions developed on the basis on CEPT reports in response to EC mandates under the Spectrum Decision) and standardisation (ETSI, CENELEC) provides legal certainties for investment in Europe. An RSPG Report on Interference Management, following a corresponding RSPG Opinion on Streamlining the Regulatory Environment, describes the relationship between the harmonisation and standardisation process. Member States are involved in the drafting of Harmonised Standards through ETSI in response to requests made by the Commission for the application of harmonised legislation in the European Union. The regime in force in Europe to put radio equipment on the market is based on a declaration of conformity and does not include either type approval or registration of equipment. This unique framework at world-wide level supports innovation and reduces barriers for industry to access to the European market. Spectrum harmonization at European level could also trigger standardisation.

[57] See for example some projects related to spectrum matters under the umbrella of the 5G PPP: 5G-EVE, 5G-Vinni, 5Genesis: https://5g-ppp.eu/5g-ppp-platforms-cartography.

[58] Amongst the various H2020 research projects worth mentioning is 5GZORRO (a 5GPPP Phase 3 project), which will implement an evolved 5G Service Layer for Smart Contracts among multiple non-trusted parties. In particular, in its Dynamic Spectrum Allocation use case, 5GZORRO is designing a DLT-based Spectrum Market for real-time spectrum management and allocation among diverse business agents (spectrum owners). See https://www.5gzorro.eu.

[59] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en.

ANNEX 1 - Definitions

This section contains collected definitions of a number of terms and concepts that are widely used in the field of spectrum and infrastructure sharing. However, it is important to point out that the definitions reported here are only for the purpose of the present Report and they should not be considered as a regulatory definition (unless a definition is directly taken from a relevant binding legislative act, such as the EECC or the Commission's Decisions). [60]

Active sharing is the common use by two or more operators of active elements of their respective networks. Active elements are those which are able to generate, process, amplify and control signals. Examples of active elements are very diverse and include many different types of electronic equipment (hardware and software) capable of various functions (transmitters, receivers, amplifiers, decoders, etc.). While antennas have been traditionally classified as passive elements, technological advance has led to a paradigm shift to AAS, which are considered a key enabler for 5G networks. Such antennas (or antenna arrays) can also be considered as active when equipped with radio frequency units such as amplifiers and signal processing elements.

Collaborative Intelligent Radio Networks (CIRNs) represent a new approach for a more dynamic spectrum sharing, whose development took place in the Spectrum Collaborating Challenge (SC2) hosted by DARPA from 2016 to 2019. CIRNs can collaborate, to manage and optimize the radio frequency (RF) spectrum in a complex, dynamic, changing RF environment which can consist of other collaborative radio networks, non-collaborative radio networks (which are not able to adapt) and other potential interference sources. CIRNs typically apply machine learning techniques in order to optimize total spectrum usage by determining when, where and how to utilize frequency resources.

Collective Use of Spectrum (CUS) (from RSPG 11-392) is the spectrum access framework where an unlimited number of independent users and/or devices can access spectrum in the same range of designated frequencies/bands at the same time and in a particular geographic area under a well-defined set of conditions. Since the relevant characteristics of CUS is that in principle an unlimited number of users can access a given spectrum band, by definition a CUS band is a shared band. From a regulatory point of view, Collective Use of Spectrum refers to a framework where users and/or devices in most cases need only a general authorisation (free use is a particular case of general authorisation). No form of coordination is required, but registrations might be applicable[61].

Co-location (based on BEREC BoR(19)110) is a form of passive sharing where the operators share the same location (such as compound, base station sites, rooftops, etc.) for the construction of the base stations. It could be limited to a common access to the location. It could also include the use of common masts and other mounting/supporting constructions or cabinets including related installations (such as air conditioning, power supply, etc.).

Cognitive Radio System (CRS) is a radio system employing CRT.

[60] For instance, there could be network elements that given technological developments and the actual configuration of the networks of the involved parties can be swapped from a sharing category to another.
[61] However, it should be pointed out that individual licensing for CUS users is not ruled out. For example, the case of so-called private commons.

Cognitive radio technologies (CRT) (based on ITU-R) are technologies that allow a radio system: to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.

Core Network (CN) sharing is a form of sharing where operators agree to share elements of their core network, either on a standalone basis or in addition to sharing elements of their access network(s). CN sharing can be limited to a data transmission ring which connects the core network components and can extend to components themselves (such as switching centre with HLR, billing platforms and value-added services (VAS)). In this latter case it can be considered more than sharing, up to a form of integration.

Dynamic spectrum access (DSA) (based on RSPG11-392) is a spectrum sharing model that allows users to access spectrum for a defined time period or in a defined area. Users cannot exceed the terms of this access without reapplying a request for the frequency resources, for example by means of LBT, Duty cycle, etc.

Dynamic spectrum sharing (DSS) is an intra operator spectrum sharing technique allowing to dynamically manage the allocation of frequency resources among users/devices in time and space, which use different radio access technologies of an operator (e.g. LTE and 5G NR), based on network conditions and traffic needs.

Exclusion Zone (from ECC Report 254) is a geographical area within which licensees are not allowed to have active radio transmitters. An exclusion zone is normally applicable for a defined frequency range and time period.

Gateway Core Network (GWCN) sharing (from 3GPP TS 23.251) means the sharing of passive site infrastructure, radio resources and part of the Mobile Core Network (in particular some elements dedicated to mobility management).

Horizontal sharing (based on RSPG10-306 Final) is an alternative or complementary approach to vertical spectrum sharing in which cognitive radio technologies (CRT) have the same rights to access the spectrum. The established policies including the sharing conditions should be transparent and non-discriminatory. In this model, regulatory intervention is required to define the usage conditions to ensure appropriate protection for other users or devices.

Infrastructure Sharing refers to a network sharing scenario in which an operator uses some passive or active physical network elements (excluding spectrum) in common with another or more operators. Infrastructure sharing can be realized at different levels of the electronic communication network architecture (e.g. access network, backhauling, core network).

Licence Exempt (from ECC REP 132) is a general authorisation regime where neither coordination nor the registration of equipment is required. Free use lies within this category.

Licensed Shared Access (LSA) (from RSPG13-538) is a regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the LSA approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorised users, including incumbents, to provide a certain Quality of Service (QoS).

Licensed Assisted Access (LAA) is a technical feature that allows the use of the 5 GHz unlicensed band in combination with licensed spectrum to increase performance of mobile users. The commercial LAA solutions already available for LTE networks allow gigabit download speeds and can be considered an important step in the evolutionary path towards 5G.

Mast sharing (based on BEREC BoR(19)110) is a form of co-location where two or more operators agree to use the same mast or other supporting construction. Generally, each operator provides their own backhaul, cabinets and active equipment.

Multiple-Operator Core Network (MOCN) is a form of RAN sharing where a shared/pooled spectrum approach is generally used. MOCN leverages the virtualization of a single RAN on multiple Core Networks. MOCN allows end-users to access the services of their respective MNO through the shared frequencies, and each end user sees the Network ID of its subscribed operator (e.g. MNC in the case of mobile networks). Based on what a specific sharing agreement envisages, either one MNO shares its frequencies with the other MNOs involved in the deal, or more MNOs share their frequencies.

MOCN with spectrum pooling refers to a MOCN configuration in which more than one operator shares frequencies.

MOCN without spectrum pooling refers to an MOCN configuration in which the frequencies shared among the operators involved in the MOCN agreement are provided by only one operator. In such a case the operator(s) that have access in a given site, may or may not have their own frequencies assigned, but have decided not to share those at that site's level.

Multi-Operator Radio Access Network (MORAN) is a form of RAN sharing where the dedicated spectrum approach is generally used without spectrum sharing. MORAN involves the sharing of all access network equipment – including sites, masts, antennas, transceivers and, eventually, backhauling infrastructure (so both active and passive elements) – and the RAN components are integrated into a single network, to the point that the shared RAN can be seen as a single radio network connected to the core networks of different MNOs through interconnection points.

Network Sharing is a general term used when two or more operators use one or more resources in common that pertain to their electronic communication networks, e.g. physical resources or any management systems[62].

Networked short-range device (from Commission Implementing Decision (EU) 2018/1538) means a short-range device under the control of network access points in a data network, which potentially also covers wider areas.

Non-interference and non-protected basis (from 2006/771/EC as last modified by (EU) 2019/1345) means that no harmful interference may be caused to any radiocommunication service and that no claim may be made for protection of these devices against interference originating from radiocommunication services. This definition applies to SRD devices.

Open RAN is a vendor-neutral disaggregation of RAN at both the hardware and software levels on general purpose processor-based platforms. It implements an open interface between components using hardware- and software-defined functions. Recently some industrial collaborations have been announced (e.g. between GSMA and O-RAN Alliance) to accelerate the adoption of Open RAN products and solutions and to help avoiding fragmentation.

[62] Sometimes network sharing and infrastructure sharing are used interchangeably and sometimes they are used together, as Network Infrastructure Sharing (NIS).

Overlay Technology (from RSPG Report on CUS in EC, 2006) is an overlay approach which allows the use of higher powers that could cause interference to existing users, but overcomes this risk by only permitting transmissions at times or locations where the spectrum is not currently in use. This can be achieved either using technology (e.g. cognitive radio) or by regulatory means (e.g. only permitting use in certain geographic regions). Overlay use can be licensed or not. Overlay technologies can be exploited to perform vertical sharing.

Passive sharing (based on BEREC BoR(19)110) is the common use by two or more operators of passive elements of their respective networks. Passive elements are those which are not able to process or convert telecommunication signals in any way and which are not integrated parts of the system dedicated specifically to the conveyance of signals. Passive elements are sometimes referred to as 'unpowered components' as these elements usually do not require a power supply. This is, however, not always the case. For instance, air conditioning for cooling equipment might be considered a passive element, but usually requires an external power supply. Passive sharing can encompass the sharing of passive backhaul elements.

Polite protocols refer to rules/methods aiming at avoiding increased interference and eventually limited usefulness of spectrum in a license-exempt spectrum band, and/or other proper co-channel sharing mechanisms ensuring implementation of priority rules adopted for competing technology/services. Polite protocols were required in the OJEU under RTTED for EN 300 328 with the following words: "*The equipment shall implement an adequate spectrum sharing mechanism, e.g. LBT (Listen Before Talk), DAA (Detect And Avoid), etc., in order to comply with the requirement specified in clause 4.3.5 of this version. Such a mechanism shall facilitate sharing between the various technologies and applications which currently exist and in case of congestion, users will be ensured equal access (and as a consequence a graceful degradation of service to all users).*"

Protection Zone (from ECC Report 254) is a geographical area within which victim receivers will not be subject to harmful interference caused by interferer transmissions. A protection zone is normally applicable for a defined frequency range and time period.

RAN Sharing is a form of active sharing where two or more operators use their own core networks and share the same access network equipment, including base station and possibly the antennas. RAN sharing includes all the active and passive access network elements and can envisage either dedicated or shared/pooled spectrum usage.

RAN sharing with dedicated spectrum means that in RAN sharing, the radio equipment is shared, but transmitting on separated carriers for each operator/party. The customers of each operator are served only with the spectrum assigned to their respective operator. Traffic collected by the shared RAN can be split at backhauling level or, if also backhauling is shared, at an interconnection point before the core networks.

RAN sharing with shared/pooled spectrum means that in a RAN sharing scenario the operators/parties share their spectrum resources allowing customers of both operators to access the shared/pooled spectrum.

Restriction Zone (from ECC Report 254) is a geographical area within which licensees are allowed to operate radio transmitters, under certain restrictive conditions (e.g. maximum *e.i.r.p.* limits and/or constraints on antenna parameters). A restriction zone is normally applicable for a defined frequency range and time period.

Roaming is a form of active sharing where an operator, at a given site, has the complete access to that site and radio resources, including spectrum. Roaming is purely asymmetric since the hosted operator fully depends on the equipment deployed by the host operator and its spectrum[63].

Site sharing (based on BEREC BoR(19)110) is a form of co-location where two or more operators agree to deploy their masts or other supporting constructions in the same location. Typically, each operator provides their own mast, backhaul, cabinets and active equipment.

Smart antennas (also known as adaptive array antennas, MIMO and multiple antennas) are antenna arrays endowed with smart processing algorithms used to identify and use spatial signal signature, such as the direction of arrival (DOA) of the signals, to estimate beamforming vectors used to track and locate the antenna beams on the mobile users. A smart antenna takes advantage of diversity effect at the source (transmitter), the destination (receiver), or both. Such diversity effect involves the transmission and/or reception of multiple radio frequency (RF) waves to increase data speed and reduce the error rate. Smart antenna technology can overcome these capacity limits as well as improve signal quality and let mobile devices operate on less power.

Software Defined Radio (SDR) (based on ITU-R) is a radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard. SDR can be considered as an important enabler for CRs, but it is not an absolute necessity since CRs could be built purely based on hardware.

Spectrum pooling refers to spectrum sharing in which the frequencies of more than one operator are used, and where the end users of the operators sharing their frequencies can access the services of their respective MNO through the sum of all the shared frequencies in the access network.

SRD - Short Range Device (from ECC Rec 70-03e) is a term intended to cover the radio equipment which have low capability of causing interference to other radio equipment. SRDs are not considered a "Radio Service" under the ITU Radio Regulations (Article 1). For Short Range Devices individual licenses are normally not required unless this possibility is stated within the relevant regulation. Under the decision 2006/771/EC short-range device is defined as a radio device which provides either unidirectional or bidirectional communication and which receives and/or transmits over a short distance at low power. SRD fall in the CUS category and the bands used by these devices can be considered shared bands. SRD is the most known CUS use.

Underlay Technology (from RSPG Report on CUS in EC, 2006) operates in spectrum that is used for other licensed or licence-exempt use but at very low power levels. This allows the underlay use to share or collectively use the spectrum. Underlay use is not licensed but may require registration. Ultra Wide Band (UWB) is an example of an underlay technology which transmits information spread over a large spectrum bandwidth. Underlay technologies can be exploited to perform horizontal sharing.

Ultra Wide Band (UWB) equipment (from (EU) 2019/785) means equipment incorporating, as an integral part or as an accessory, technology for short-range radiocommunication, involving the intentional generation

[63] Considering a specific mobile site, the main high-level differences between roaming and MOCN without spectrum pooling are the following: *i*) at that site the customers of the operator that have the access by means of MOCN “see” the network of their respective subscribed MNO; ii) roaming is generally confined to mobile networks, while MOCN can have a wider application.

and transmission of radio frequency energy that spreads over a frequency range wider than 50 MHz, which may overlap several frequency bands allocated to radiocommunication services.

Vertical sharing (based on RSPG10-306 Final) is an approach to share spectrum where the cognitive radio (CR) shares spectrum with the existing users. The CR is only allowed to use frequencies within the band as long as the existing user(s) is not affected, i.e. the cognitive radio must not cause harmful interference to existing users. Depending on the spectrum rights of the primary service(s), the conditions under which the CR devices can operate are to be defined in advance by the regulator or could be left to the primary service.

White Space (WS) (based on CEPT Report 24) is a label indicating a part of the spectrum, which is available for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering/non-protected basis, with regard to primary services and other services with a higher priority on a national basis. Very often the spectrum, where WS is considered, is the broadcasting band, then the existing uses are Digital Terrestrial Television (DTT), including local TV, and Programme Making and Special Events (PMSE).

ANNEX 2 - Background

A2.1 RSPG past work

Other than by the public consultation on the RSPG Work Programme for 2020 and beyond (see Annex 6), the present Report has been informed by previous RSPG works that have touched the issue of Spectrum Sharing in the widest meaning.

The list of the relevant work from RSPG is the following.

- RSPG10-306 Final - report on "cognitive technologies"
- RSPG10-348 Final - Opinion on cognitive technologies
- RSPG11-392 Final - Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches
- RSPG13-538 - Opinion on Licensed Shared Access
- RSPG16-004-Final - Report on Efficient Awards and Efficient Use of Spectrum
- RSPG19-007 Final - Opinion on 5G implementation challenges (RSPG 3rd opinion on 5G)
- RSPG19-031 Final - Report on European Spectrum Strategy

All this material is published on the RSPG website at https://rspg-spectrum.eu/rspg-opinions-main-deliverables.

During the work on the present Report, some documents published by BEREC have also been consulted as background information. This material is more focused on the Infrastructure Sharing side and competition assessment.

The list of the relevant work by BEREC is in the following:

- BoR (11) 26 - RSPG11-374 - BEREC-RSPG report on infrastructure and spectrum sharing in mobile/wireless networks
- BoR (18) 116 - BEREC Report on infrastructure sharing
- BoR (19) 110 - BEREC Common Position on Mobile Infrastructure Sharing

This material is published on the BEREC website at https://berec.europa.eu.

A2.2 The European Electronic Communication Code

The new Code establishes radio spectrum rules to ensure that radio spectrum users derive the full benefits of the internal market and that Union interests can be effectively defended globally. In this way, the Code promotes a multiannual radio spectrum policy programme for strategic planning, coordination and where appropriate, harmonization at Union level (considering 31). This insight of harmonization is also needed to fully benefit from spectrum sharing approaches.

Spectrum sharing is an opportunity to take the most effective advantage and to be implemented when possible, within its different modalities, and to help the achievement of the main objectives of the Code, namely promoting competition, the internal market, end-user interests and connectivity among others. In this sense, the Code requires Member States to promote and set the conditions for the shared use of the radio spectrum, in accordance with competition law, granting priority to specific services so that, insofar as possible, other services or technologies could coexist in the same radio spectrum band (considering 115) or determining the most appropriate authorisation regimes for flexible access and use of radio spectrum (considering 119).

The Code addresses the need to apply technical measures, such as solutions to improve receiver resilience which might enable the use of general authorisations or radio spectrum sharing, and possibly avoid systematic recourse to the non-interference and non-protection principle (considering 120).

In relation to the secondary market where different modalities allow spectrum sharing in the Code, it is established that when trading and leasing radio spectrum, the effective use by the original holder of the right should be ensured (considering 122).

According to the Code, Member States shall promote the shared use of radio spectrum between similar or different uses of radio spectrum in accordance with competition law (art. 45, par. 2(e)) and shall facilitate the shared use of radio spectrum under general authorisations, limiting the granting of individual rights of use to situations where such rights are necessary to maximise efficient use in light of demand, also taking into account the development of reliable conditions for radio spectrum sharing, where appropriate, and the need to minimise problems of harmful interference, considering, where appropriate, a combination of general authorisation and individual rights of use (art. 46).

Competent authorities shall not prevent the sharing of radio spectrum in the conditions attached to the rights of use for radio spectrum, in particular with a view to ensuring effective and efficient use of radio spectrum or promoting coverage (art 47).

ANNEX 3 - CEPT/ECC relevant activity and cooperation with ETSI

Pursuant to the spectrum Decision (676/2002/EC), the Commission issue mandates to CEPT for the development of technical implementing measures for the harmonization of spectrum. Therefore, CEPT is in charge of carrying out all necessary sharing and compatibility studies enabling the introduction of a new application in a band. Such activity extends beyond the EC Mandate and CEPT has introduced spectrum sharing also in bands which are not subject to EU harmonization and has provided guidelines to its membership on the implementation of spectrum sharing solutions.

CEPT's objective is to develop spectrum sharing, where technically feasible, as a way to facilitate effective and efficient use of spectrum in both licensed and unlicensed bands. The ECC Strategic Plan for the period 2020 – 2025 approved by the ECC at its meeting in July 2020 includes sharing as one of its principles: "it can promote innovation by enabling easier and more rapid access to spectrum than some traditional models of making spectrum available (such as clearance). Moreover, the emergence of new technologies such as cognitive radio and geolocation databases may enable the implementation of licensing frameworks based on the licensed or unlicensed shared use of spectrum. The increasing demand for higher frequency bands, taking into account propagation characteristics, may also promote interest in spectrum sharing. The ECC will consider opportunities to promote spectrum sharing through its technical and regulatory work, including when undertaking compatibility analyses and defining coexistence conditions."

CEPT has paved the way to several sharing scenarios:

- sharing between different categories of short range device;
- short range device as underlay of primary services, including for Ultra Wide Band systems;
- Dynamic Frequency Selection implemented for the protection of radars from RLAN in the 5 GHz band;
- framework for white space device in the TV bands;
- sharing of uncoordinated earth stations in bands used by the fixed service;
- sharing of PMSE with primary services in several frequency bands;
- general authorisation framework for the shared use of existing fixed and wideband technologies with new outdoor wireless access solution and wireless backhaul in the frequency band 57-71 GHz.

Therefore, the expertise of CEPT will be needed to assess innovative sharing solutions, to specify the technical conditions and to help in implementing them.

To support efficient use of spectrum and sharing, the ECC also identifies in cooperation with ETSI the appropriate spectrum-sharing conditions, including their relevant characteristics for both transmission and reception, to ensure coexistence in co-channel bandwidth and in adjacent frequency bands. The ECC will develop or update ECC Recommendations on appropriate characterisations of both transmitters and receivers and will also monitor implications of increases in the general noise floor. In undertaking this work, the ECC will seek to intensify its co-operation with ETSI in order to foster the development of efficient sharing conditions in the future.

The ECC has a long-established tradition of working collaboratively with a wide range of partners and sharing best practice and knowledge. In some cases these relationships with external partners are formalised, either through a Memorandum of Understanding (MoU) or a Letter of Understanding (LoU). Further information on the ECC's MoUs and LoUs is available here and more details on ECC co-operation with ETSI, the European Commission and ITU is included in Annex 1 of the ECC Strategic Plan.

The ECC works in close partnership with ETSI to ensure new radio equipment entering the market uses the spectrum efficiently (see https://www.cept.org/ecc/ecc-and-etsi).

Today, ETSI deliverables support various technical tools that are used for spectrum-sharing in different contexts: duty cycle limitations, sensing solutions (e.g. LBT, DAA, DFS), Geo-location database solutions, etc.[64]

ETSI and CEPT deliverables can be used in the future to support dynamic spectrum sharing and facilitate the introduction of cognitive radio technologies (in particular those relying on databases).

[64] Some examples of spectrum sharing techniques standards:
- Fixed duty cycle limitations (e.g. EN 302 571 (2017-02): "percentage of the transmitter total 'on' time on one carrier frequency, relative to 1 second period";
- "Detect and Avoid" (e.g EN 300 328 (2019-07)) "mechanism which mitigates interference potential by avoiding use of frequencies upon detection of other transmissions on those frequencies";
- "Listen before Transmit" (e.g. EN 300 220-1 (2017-02)): "mechanism by which an equipment applies Clear Channel Assessment (CCA) before transmission (also known as Listen Before Talk)";
- Dynamic Frequency Selection (DFS) (e.g. EN 301 893 (2017-05)): "radar detection and evasion algorithm employed by RLAN equipment to prevent RF interference into radars (TR 102 631 (2008-09)";
- Co-operative reception (e.g. TS 103 358 (2018-06)) "the ability of a single UL transmission to be received simultaneously by several base stations";
- Manual sharing (allowing user to select bands from a tuning range which are known not to be in use at that location) (e.g. radio microphone sharing with UHF Digital Terrestrial Broadcasting);
- Geo-location database (e.g. EN 303 145 (2015-11): "database approved by the relevant national regulatory authority which can communicate with White-Space Devices (WSD) and provide information on TVWS channel availability");
- Spatial sharing to avoid sensitive receivers (e.g. TS 102 792 (2015-06)) to protect DSRC from ITS in 5,9 GHz: combines Geolocation databases and use if beacons to define "quiet zones".

ANNEX 4 - Relevant Works by world Regulatory Bodies

In this Annex, some of the most relevant approaches to Spectrum Sharing as adopted worldwide are reported. Here we consider only the cases that are already defined and implemented.

A4.1 FCC

CBRS: Citizens Broadband Radio Service

The Citizens Band (CB) Radio Service is a private, two-way, short-distance voice communications service for personal or business activities of the general public. In 2015, the Federal Communications Commission (FCC) adopted rules for shared commercial use of the 3550-3700 MHz band (3.5 GHz band). The Commission established the Citizens Broadband Radio Service (CBRS) and created a three-tiered access and authorisation framework to accommodate shared federal and non-federal use of the band.

Access and operations will be managed by an automated frequency coordinator, known as a Spectrum Access System (SAS). When managing spectrum access, SASs may incorporate information from an Environmental Sensing Capability (ESC), a sensor network that detects transmissions from Department of Defense radar systems and transmits that information to the SAS. Both SASs and ESCs must be approved by the Commission. SASs will coordinate operations between and among users in three tiers of authorisation in the 3.5 GHz band: Incumbent Access (Tier 1), Priority Access (Tier 2), and General Authorised Access (Tier 3).

Incumbent Access (IA) users include authorised federal users in the 3550-3700 MHz band, Fixed Satellite Service (space-to-Earth) earth stations in the 3600-3650 MHz band, and, for a finite period, grandfathered wireless broadband licensees in the 3650-3700 MHz band. IA users receive protection against harmful interference from Priority Access Licensees (PALs) and General Authorised Access (GAA) users.

The Priority Access tier consists of PALs that will be licensed on a county-by-county basis through competitive bidding. Each PAL consists of a 10 MHz channel within the 3550-3650 MHz band. PALs are 10-year renewable licences. Up to seven PALs may be licensed in any given county, subject to a four PAL channel aggregation cap for any licensee. PALs must protect and accept interference from IA users but receive protection from GAA users.

GAA tier is licensed-by-rule to permit open, flexible access to the band for the widest possible group of potential users. GAA users can operate throughout the 3550-3700 MHz band. GAA users must not cause harmful interference to Incumbent Access users or Priority Access Licensees and must accept interference from these users. GAA users also have no expectation of interference protection from other GAA users.

In Sept 16, 2019, the FCC approved the first initial commercial deployments for Citizens Broadband Radio Service. Under the new spectrum-sharing arrangement, CBRS users were able to share frequency allocations on the 150 MHz of spectrum in the 3.5-3.7 MHz range with incumbent Defense Department users' shipborne radar applications. The commercialized services were sold under the "OnGo" branding umbrella for a variety of applications, from rural broadband connections to enterprise wide in-building cellular coverage to sports stadiums and private networks. The approvals marked the first commercial applications for the CBRS spectrum.

The 3.5 GHz Priority Access Licence auction was carried out in July 2020 and assigned county-sized licenses in 10 MHz blocks (more than 22.000 PALs in total) that are renewable like traditional licenses. The auction made these mid-band licenses available for 5G and other next-generation wireless services.

AFC: Automated frequency coordination

The FCC issued on April 23, 2020 a Final Order for the 6 GHz band making 1,200 MHz of spectrum in the band for unlicensed use, enabling data transfers of up to 10 Gbps. In the United States, the 6 GHz band is used for satellite uplink as well as by licensees to provide microwave links for utilities, public safety, transportation and other uses (including carriers and MVNOs, who have deployed thousands of point-to-point microwave links to backhaul network traffic). There are similar usages in Europe and in most part of the world. CEPT is also developing, in response to an EC mandate rules for 6 GHz unlicensed operation in the lower part (500 MHz) of this band.

The FCC order defines two classes of access point: the standard-power (36 dBm eirp) and the low power indoor (30 dBm eirp). The FCC also published a further notice of proposed rulemaking for an additional class of very low power device (14 dBm).

The operation of standard-power access point is permitted only under the control of an automated frequency controller (AFC) which will ensure the protection of incumbent fixed microwave operations by establishing location and frequency-based exclusion zones. The AFC system will determine the available frequencies and the maximum permissible power in each frequency range at their geographic coordinates prior to transmitting. Any device will have to register with the AFC system by providing the following parameters: geographic coordinates, antenna height, FCC identification number, and unique manufacturer's serial number. Contact will be necessary at least once per day. Security measures will prevent accessing AFC systems not approved by the FCC, will ensure that unauthorised parties cannot modify the device to operate in a manner inconsistent with the rules and that AFC systems are secure to prevent corruption or unauthorised interception of data as well as protected against unauthorised data input or alteration of stored data.

This AFC will be simpler than the SAS for the operations in the 3.5 GHz CBRS band and the FCC will designate one or more AFC system operators which may charge fees to the users. A multi-stakeholder group has been established to administer AFC system requirements and standards.

A4.2 Ofcom (UK)

Local licensing, shared access to spectrum supporting mobile technology

On 25 July 2019, Ofcom published a Statement, *Enabling wireless innovation through local licensing*[65], which sets out two new licence products to make it easier for a wider range of users in the UK to access radio spectrum on a shared basis: the *Shared Access licence*, which gives access to four spectrum bands which support mobile technology and the *Local Access licence*, which provides a way for other users to access spectrum which has already been licensed to the UK's Mobile Network Operators (MNOs), in locations where an MNO is not using their spectrum.

[65] See https://www.ofcom.org.uk/__data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf.

Local access to the offered bands could support growth and innovation across a range of sectors, such as manufacturing, enterprise, logistics, agriculture, mining and health (for example, manufacturers connecting machinery wirelessly, farmers connecting agricultural devices such as irrigation systems and smart tractors wirelessly, enterprise users setting up secure private voice and data networks within a site, as well as rural wireless broadband connectivity using fixed wireless access (FWA)).

The *Local Access Licence* provides access to spectrum that is already licensed to mobile operators but which is not being used or planned for use in a particular area within a period identified in the next three years. Parties can apply to Ofcom for a licence and, if the application is successful, and unless the operator raises a reasonable objection, will pay a small amount set at £950 per licence, which allows them to use the spectrum for three years. The requester can ask for a different period and this can be agreed with the existing licensees.

Ofcom anticipates that spectrum is only likely to be available to share in remote areas, but it could be used in these locations to support, for example, private networks or wireless broadband services. There may also be other locations that are not served by the existing mobile network, for example underground mining operations, where mobile technology could be used to support a private network without impacting the incumbent networks or their future plans.

The licence will be available within any frequency band covered by the Mobile Trading Regulations. Currently, these are:

- 791-821 MHz paired with 832-862 MHz (“800 MHz band”);
- 880-915 MHz and 925-960 MHz (“900 MHz band”);
- 1452-1492 MHz (“1400 MHz band”);
- 1710-1781.7 MHz and 1805-1876.7 MHz (“1800 MHz band”);
- 1900-1920 MHz (“1900 MHz band”);
- 1920-1980 MHz and 2110-2170 MHz (“2100 MHz band”);
- 2350-2390 MHz (“2300 MHz band”);
- 2500-2690 MHz (“2600 MHz band”); and
- 3410-3600 MHz (“3.4 GHz band”).

The local licence will cover the deployment of transmitters only at the defined location, or in an area defined in the licence. Depending on the request received Ofcom may authorise a single base station, multiple base stations or a local area. Each request will be dealt with on a case by case basis with the licence reflecting the agreed transmission location or service area details.

To minimise the risks of interference the Local Access licence will include the following provisions:

- Ofcom standard requirements for the licensee to abide by any coordination procedures, both national and international;
- The provision that the licensee must liaise and co-operate with other holders of licences in the same frequency band(s). This may require adjusting transmission power and other technical parameters of transmission in such a way that harmful interference is not caused by one network deployment to that of another licensee within the band (this condition is also included in the Shared Access licences); and
- Where a licensee is deploying a mobile service, Ofcom will expect them to follow the appropriate in block and out of block power limits. The licence could also include, when deploying TDD systems outdoors or in a shared indoor location, the requirement to synchronise with other users in the band or use a restrictive transmission mask. In such cases these provisions will likely mirror those in the incumbent licensee’s authorisation.

The incumbent operator's rights to deploy, even after a new user is issued with a licence, will not be affected. Regarding the *Shared Access Licence*[66], it's 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.

Parties can apply to Ofcom for coordinated access (this ensures they won't cause interference) to these bands on a first come, first served basis and will pay a licence fee that reflects Ofcom's cost of issuing the licence.

Where mobile terminals are deployed in the 3.8-4.2 GHz band, licensees will be required to keep an accurate record of all mobile terminals and the address of the site or building they are limited to operate within. In this band no national shared licence is envisaged.
Ofcom also outlined that for medium power users in the 3.8-4.2 GHz band, they would only permit fixed terminal stations, due to the existing equipment ecosystem in the band and the uses they predicted.
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. Users will have the flexibility to move their base stations around within the licensed area without requiring further coordination by Ofcom.
- Medium power licence. This authorises a single base station and the associated fixed, nomadic or mobile terminals connected to the base station.

The low power licence product could be suitable for industrial and enterprise users looking to deploy their own private networks. This could be to support voice and text applications or other wireless data applications around their sites; it could also potentially be used for indoor mobile coverage extension schemes, for example through a neutral host model.

Users looking for the flexibility to place base stations anywhere within a larger area can apply for multiple low power licences, which could be contiguous or spaced out over a larger area.

There will be an indoor-only option available, as well as an indoor/outdoor option for users looking to deploy either partly or wholly outdoors.

Base stations covered by the low power Shared Access licence can connect to fixed, nomadic or mobile terminals.

The medium power licence could be suitable for users who need a longer transmission range from their base station, but don't expect to need to change the locations of base stations once they're deployed. This could suit providers of Fixed Wireless Access (FWA) services in rural areas, along with industrial or enterprise users with sites spread over a larger area, such as ports, agriculture or forestry. It could also be suited to providing mobile coverage extension schemes in rural areas.
The medium power licence will authorise a single base station. The base station can connect to fixed, nomadic or mobile terminals.

[66] See https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/shared-access.

Medium power base stations are generally only permitted in rural areas, as their increased power and transmitting range mean that if they were deployed in urban areas, they could potentially prevent a large number of low power users from deploying.

Figure below shows how the two types of licence differ, with the low power licence authorising an area where the base stations could operate, and the medium power licence authorising each base station individually.

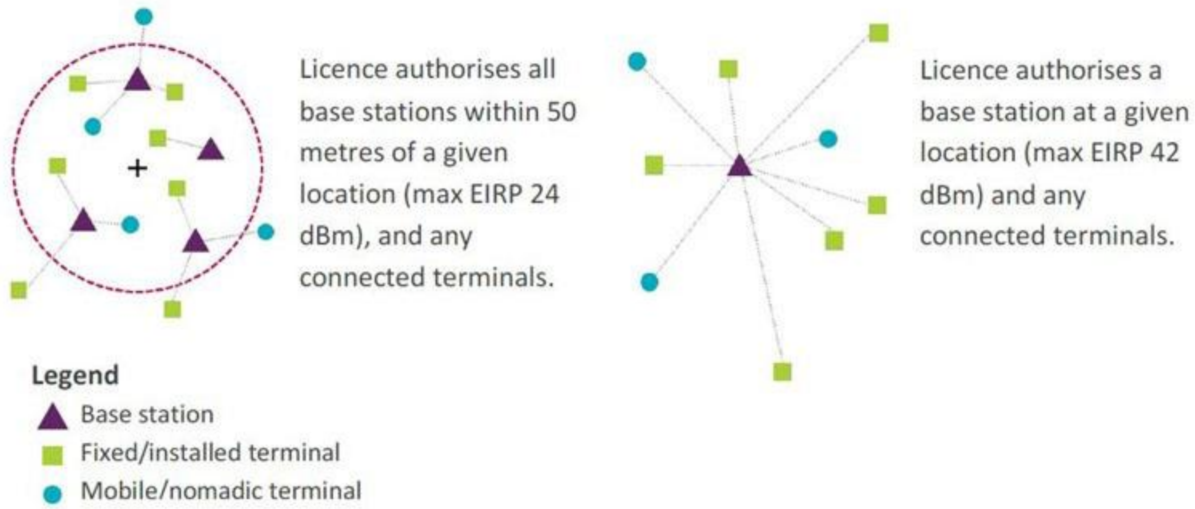

Figure A5.1: Low Power (left) and medium power (right) Shareed Access Licences (Source Ofcom).

The Shared Access licence is indefinite; as long as the party pays the licence fees each year and does not break any of the licence terms and conditions.

If, however, the party would like a licence of less than one year, Ofcom can issue a short-term licence. Other provisions will ensure effective usage by the licensees that are not allowed to maintain spectrum idle, and the usual revocation possibility by Ofcom for spectrum management purposes.

Ofcom additionally interrogates on a possible DSA approach, considered as a concept whereby access to spectrum is only authorised when equipment is transmitting, and spectrum becomes available to others when it is no longer required by the previous users. However, for the time being Ofcom concluded that further time is needed to implement a DSA approach supported by a fully automated authorisation database where radio equipment used is capable of communicating with the database. So, the shared licensing as depicted will stand, but it would be an interim measure that should be later reassessed.

For DSA introduction Ofcom considers that the specification of the communication between the radio equipment and database is best done in collaboration with industry, particularly equipment vendors. This would allow appropriate consideration of the costs and complexity of implementation, both in relation to the radio equipment and the spectrum assignment database

'Spectrum Access: EHF' licence above 100 GHz

Another example of multi-tiered spectrum sharing is represented by the new 'Spectrum Access: EHF' licence recently introduced in the UK. In particular, Ofcom established rules to make available 18 GHz of radio spectrum across three bands, namely 116-122 GHz, 174.8-182 GHz and 185-190 GHz bands, for terrestrial use. According to Ofcom's decision, this approach will support innovation by enabling easier, longer-term, cheaper and more flexible access to these spectrum bands above 100 GHz by devices that would be authorised subject to technical conditions designed to protect Earth Exploration Satellite Services (EESS) from undue interference. These constraints included maximum EIRP levels for indoor and outdoor use. For this latter use, in order to ensure there would be reduced emissions towards EESS sensors Ofcom also set limits to the EIRP at increased angles relative to the main beam in the elevation plane of the antennas, with a further limit on the elevation of the main beam.

At this stage Ofcom did not introduce provisions to authorise devices to operate on a licence-exempt basis in these bands, recognising the importance of ensuring the maximum protection of the weather and climate data collected by EESS.

A 'Spectrum Access: EHF' licence will allow use of multiple devices within a specified band across the UK on an uncoordinated shared basis. Licensees would be able to use any part of their selected band and there would be no limit to the number of devices which a licensee could deploy in the band, subject to compliance with the technical provisions set by Ofcom. Moreover, licensees will be required to keep records of locations of use and of the antenna elevation angle for outdoor use, and to provide this and other information to Ofcom on request with the aim of monitoring spectrum use and enabling quick enforcement action, if necessary.

It is worthwhile to observe that in its statement introducing this regulation Ofcom recognises that requiring new spectrum users to hold a licence does not offer all the potential benefits of a licence exemption regime, such as facilitating wide scale innovation and consumer device availability through there being no requirement for each user to secure a spectrum authorisation. However, Ofcom considers that the light-touch requirements of the 'Spectrum Access: EHF' licence are unlikely to create barriers over the next few years as technologies using these frequencies are at an early stage of development. On this basis, for the coming time period Ofcom considers that requiring a licence to access these bands is unlikely to constrain innovation and device availability.

ANNEX 5 - Spectrum sharing initiatives and approaches in EU

A5.1 Czech Republic

5.8 and 60 GHz bands (and other bands under preparation)

In the Czech Republic, the role of wireless technologies to facilitate internet connection and telecommunications is significant. Several SRD and RLAN technologies (especially IEEE 802.11 family) are designed for self-coordinated usage based on general authorisation. However, in specific situations (congested areas, sharing with different technologies), the efficiency of spectrum usage (incl. reduction of interference risk) can be facilitated by an additional managed approach. That is why the Czech administration conducts several national projects on database systems related to light licensing[67]. A first non-public trial portal on WAS/RLAN registration was launched in 2018 in the 5.8 GHz band, which was shared by various applications (SRD, ISM, satellite service, radiolocation service and others). In order to manage the coexistence, the portal was designed for outdoor high-power[68] WAS/RLAN access points registration (general authorisation). In addition to this, the management of exclusion zones to protect toll gates (or other places) and remote automatic radio spectrum sensing[69] system were implemented. The intention to open the band was announced in 2020[70], public implementation[71] will be uncovered in early 2021.

In 2018, the Czech administration also commenced the preparation of conditions on shared use of the 57-66 GHz band (60 GHz) by two different technologies: MGWS/WiGig (802.11 family) in addition to existing Fixed Service links[72]. As studies showed[73], such usage would cause an interference risk in congested areas. Therefore, the administration decided to introduce a managed approach on band coordination based on light licensing via a new web portal. New conditions for the use of the 60 GHz band have been introduced in January 2020 by issuing a new general authorisation. The innovative approach is based on a new obligation imposed on the band users to register a certain set of data on a newly established portal. The portal is designed to enable users in the 60 GHz band to communicate with one another (via messaging) and coordinate their steps, for example by optimally planning technical configurations and managing their newly installed stations. In particular, users in the 60 GHz band can choose geographical locations of their stations and specify antenna radiation. All stations are coordinated via an automatic Coordination Calculator, comprising basic Fixed Service coordination algorithms.[74] The overarching ambition has been to create conditions for the use of the 60 GHz band under which users can resolve possible harmful interference by mutual coordination and reach agreement on the basis of self-regulation. Secondly, the data collected through the portal is significant for the regulator as it allows effective inspection and management of the radio spectrum.

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[67] Free of charge use of spectrum bands.

[68] Up to e.i.r.p. 1 W.

[69] First publicly available spectrum sensing has been introduced in the Czech Republic in 2018 in relation to protection of meteorological radars (https://radar4ctu.bourky.cz/Ruseni.html). Here, identified RLAN interferers towards meteoradars are published online. It is upon on RLAN operators to adjust the RLAN radiation when identified by the radar operator.

[70] See https://www.ctu.cz/informace-ceskeho-telekomunikacniho-uradu-o-zameru-rozsireni-pasem-urcenych-pro-systemy-wasrlan-v.

[71] See https://rlan.ctu.cz; the usage is free of charge.

[72] Based on ECC Recommendation (09)01, ECC Recommendation (05)02.

[73] ECC Report 288.

[74] Detailed description is in the bookmark “User Guide” in the above portal.

The data collected through the portal consists of three types: (i) personal data, (ii) technical data, and (iii) metadata. Certain data are publicly available: the GPS coordinates of station locations, the radiated power, the frequency used, and certain metadata (the date of the first registration, the protection period for record expiration, and the automatically assigned Station number). Certain data are available exclusively to the regulator: MAC addresses of stations, name, surname, and home addresses of portal users. The rest of the data are available to other portal users indirectly, without its disclosure: e-mail addresses. The messaging system can be used in anonymous mode.

Information about radio spectrum usage

The availability of information about radio spectrum usages is one of the prerequisites for flexible radio spectrum usage including spectrum sharing. However, the Czech Electronic Communications Act effective before 2020 does not allow releasing technical radio stations data or the identification of radio spectrum users (with the exception of public mobile networks and TV transmitters). Therefore, in order to meet the need for flexible spectrum usage, in 2015 the Czech government adopted a Radio Spectrum Management Strategy comprising a task[75] to work out an appropriate proposal for an amendment of the Czech Electronic Communications Act.

Based on the government task, in the past 5 years, the Czech regulator has led extensive consultations about how to make available information regarding the radio spectrum usage. The regulator also conducted a regulatory impact analysis that assessed whether the current legal regime under which only a very limited amount of information on the radio spectrum use is publicly available is satisfactory from the perspective of effective radio spectrum management. A legislative proposal amending the Czech Electronic Communications Act is pending in the national Parliament, and if adopted will provide the public with access to certain information on radio spectrum use via an online portal and based on a controlled access to information.

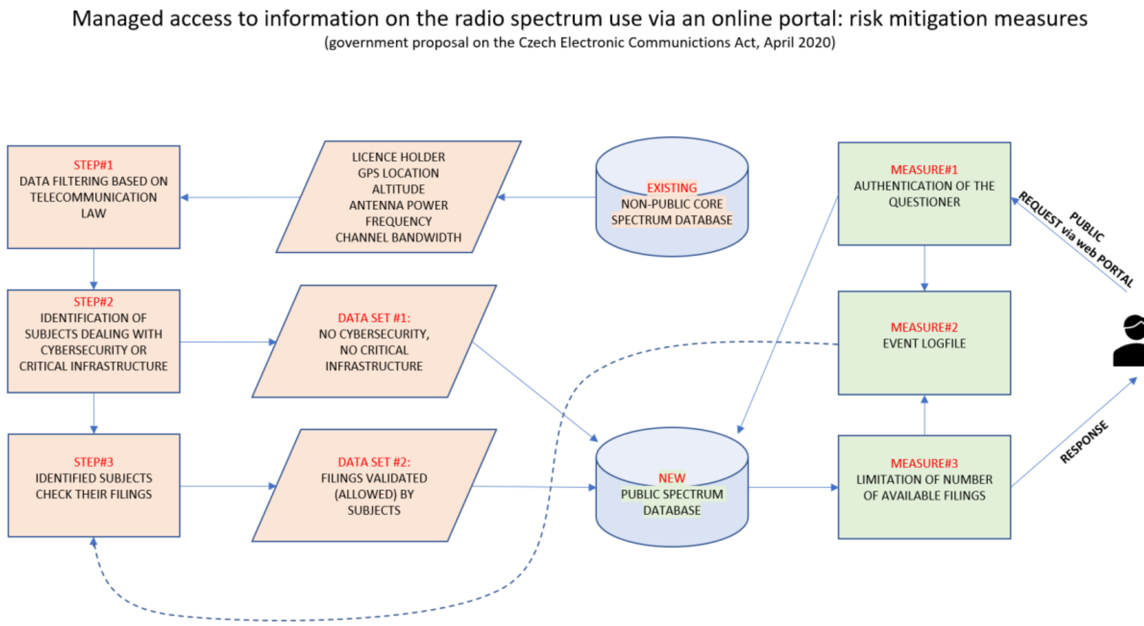

Figure A7.2: Risk mitigation within the Czech Spectrum Information Portal (system design)

[75] See Chapter 3.4 of the Strategy at https://www.ctu.eu/radio-spectrum-management-strategy.

In the proposal, the controlled access to information is based on two basic elements: First, radio spectrum users may ask the regulator to exclude certain information[76] from the public database (portal) if they conclude that the release of information will increase the cybersecurity risk of particular radio links. The risk assessments will not be examined by the regulator, but a non-binding methodology of the risk assessments will be published. Second, the information regarding the identification of the licence holder will only be made available to registered portal users. Registration to the portal will require personal electronic identification (authentication). To further decrease the cybersecurity risk, the regulator will be statutorily empowered to periodically transfer information on portal users to the radio spectrum user whose information was accessed by portal users (based on log files). This, in turn, will be required to create a specific legal basis for the data processing in the proposed amendment to the Czech Electronic Communications Act[77].

The role of general authorisation in innovative approaches

The general authorisation is issued as a measure of general nature in accordance with the Electronic Communications Act and the Administrative Procedure Code. One of the limitations of such measures is the standard empowerment test which means that measures of general nature cannot impose obligations beyond the principal act (the Electronic Communications Act) and cannot replace statutory instruments. However, the Czech Electronic Communications Act and the Administrative Procedure Act reposes on generally broad principles of regulation that may give a green light to new and pioneering regulatory initiatives in spectrum sharing. These acts provide for sufficiently broad regulatory principles against by which new solutions can be measured: non-discrimination, objectivity, technological neutrality, transparency and proportionality in the fulfillment of regulatory objectives such as the use of effective radio spectrum. Moreover, the general authorisation is always subject to public consultation which enables to further tune in the desired features of new regulation and filter out the undesired ones.

A failure to comply with a general authorisation amounts to an administrative offence punishable by a fine. However, in the case of the 60 GHz band, a combination of self-regulation and command-control regulation has been used. Such combination presupposes trust and a balanced approach, as well as the deployment of new technologies (e.g. remote sensing and coordination engine). Resorting to the powers of the regulator to carry out inspection in order to identify and eliminate interference sources is considered only as a secondary spectrum management means.

Sandbox in the 26 GHz band and 5G NR trials

In October 2020, based on public consultation, CZE released an initial 1 GHz sub-band of the 26 GHz band for experimental 5G purposes.[78] The aim is to observe the coexistence of 5G radios outdoors (including inter-operator 5G coexistence), semi-outdoors and indoors, consider initial TDD frame structures, discover opportunities for business cases and future verticals. The experience could shape future authorisation schemes respecting easy and timely availability of 5G frequencies, and various opportunities for the 5G mm wave usage. CZE has preliminarily considered the first-come-first-served authorisation and the light-licensing

[76] Or, complementary, to allow certain information to be released.
[77] The Act was adopted by the Parliament in Autumn 2020.
[78] See https://www.ctu.cz/sites/default/files/obsah/ctu/sdeleni-o-vydani-opatreni-obecne-povahy-casti-planu-vyuziti-radioveho-spektra-c.pv-p/2/10.2020-10-pro-kmitoctove-pasmo-2425-275-ghz/obrazky/pvrs-2p.pdf [translation expected].

approach for future outdoor 5G radios, and licence-free operation of indoor 5G radios within the 26.5-27.5 GHz.

A5.2 Denmark

In 2012, the Danish mobile network operators Telenor and Telia entered into a nationwide network and RAN sharing agreement in a joint company called "TT-netværket" ("The TT Network").

The RAN sharing agreement comprises sharing of the physical RAN-infrastructure (masts and antennas) and frequency resources. The cooperation via the network sharing agreement involves all mobile technologies. The parties will not share the "intelligent" part of their respective mobile networks (i.e. the core networks) where the different services and customer data are defined, as well as some parts of their individual transmission capacity. The parties remain separate mobile operators on both the wholesale and retail markets.

The Danish Competition Council found that the network and RAN sharing agreement between Telenor and Telia entails a better and more efficient network for the operators' individual businesses. The improved coverage and availability of technology in the parties' networks were deemed beneficial to consumers.

However, the Danish Competition Council concluded that the cooperation agreement might have an anti-competitive impact on the market for access to sites (for mobile antennas), the wholesale market for mobile telephony and mobile broadband, the retail market for mobile telephony and mobile broadband and finally the market for purchase of frequency licenses.

Six specific issues gave rise to the above anti-competitive concerns. Five of these issues - collusive outcome on the wholesale market, tariff structure to recover the joint venture's costs, joint amount of frequency resources, reduction of the number of antennas and masts and risk of excess exchange of commercially strategic information - were solved by commitments offered by Telenor and Telia. According to those, the parties shall accept all requests from wholesale customers to buy mobile telephony and mobile broadband on customary and market conditions, will pay the commonly owned joint-venture for its supply of Radio Access-capacity according to a tariff structure that at all times reflects the underlying cost structure of the Radio Access network, are obliged to buy frequency licenses in common through the joint venture, are obliged to sell or let the antenna sites that prove to be superfluous to any interested player on the market, adopt a set of restrictions regarding the appointment of the members of the Board of the joint venture, the employment of the Management and employees of the joint venture, the information that may be exchanged within the joint venture and between the joint venture and the parties. Therefore, there were no grounds for action according to TFEU article 101(1).

The remaining issue - reduction of competition on significant parameters such as coverage and the development and spread of new technology - was solved by provision by the parties of sufficient proof that the criteria for individual exemption in TFEU article 101(3) were met.

Further information on the Danish Competition Council's decision (description of the network and RAN sharing agreement, the legal assessment and the commitments offered by the parties) is available on the Danish National Competition Authority's website[79]:

[79] See https://www.en.kfst.dk/nyheder/kfst/english/decisions/20120229-radio-access-network-sharing-agreement-between-telia-denmark-and-telenor.

A5.3 Finland

Spectrum pooling in the 2G/3G/4G bands

In Finland, there are three main public mobile network operators: Elisa, DNA and Telia. In 2014, the Finnish government allowed DNA and Telia to use a common network in Eastern and Northern Finland. The purpose was to improve telecommunications services in areas with low inhabitant densities, providing much higher bit-rate than the 2 Mbits/s requested as a minimum by Law. In whole Finland, the 2 operators' networks were to cover at least 80% of the population. The common network operates in the 2G/3G/4G bands. It provides high speed connection on its operation area, and the quality of experience is even higher, since the amount of simultaneous users is much lower than in the Southern and Western Finland, where spectrum pooling is not in use.

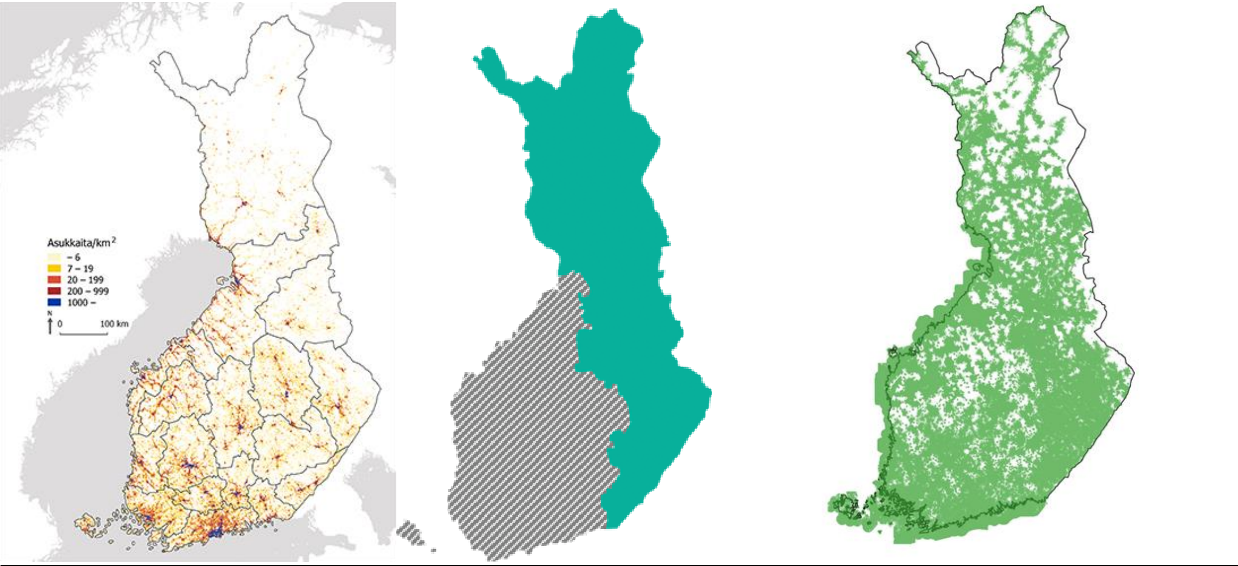

Figure A7.1: on the left, population density (/km^2) in Finland; in the middle, common mobile network area in Eastern and Northern Finland (covering 50 % of the country area and 15 % of the country population) where spectrum pooling is allowed; on the right, mobile network coverage (> 30 Mbit/s) in Finland.

Spectrum pooling in the 3.4 - 3.8 GHz band

In the 3.4 - 3.8 GHz band (3410 - 3800 MHz) three operators have each 130 MHz of spectrum and they are allowed to combine their spectrum resources as long as their own network covers at least 35% of the operation area.

A5.4 France

France is developing a proof-of-concept using blockchain for a geolocation database solution in 6 GHz band to protect incumbent services (FS) from the new WAS/RLAN devices. This solution acts as an interface between the detailed data, which do not have to be publicly available, and the devices, which require the knowledge on channels available locally as well as associated conditions of use.

This development could be used for other sharing scenarios in other frequency bands.

Under the planned approach for the 6 GHz band, a set of "protection zones" would be defined for each FS receiver that need protection, taking into account its specific characteristics (FS antenna height, antenna pattern, link azimuth, etc.). A protection zone is a geo-located area shape that is calculated in function of RLAN power and antenna height range.

The baseline algorithm to determine spectrum available for a RLAN device within its location relies on the summation of constraints associated with the various FS receivers to be protected. A given FS receiver entails a constraint for a device if the corresponding FS protection zone overlaps the RLAN operating zone that is declared in the system.

Within France, a database solution using the blockchain concept has been used for the first time during a special event in 2019[80]. It allowed the assigning of channels to individual microphone users in a decentralised manner.

Blockchains achieve transparency and traceability of the interactions. The key benefit is with respect to the level of trust that these technologies can confer on the reliability of the data that are handled in these Machine-to-Machine communications. Hybrid implementations that combine centralized and decentralized features may also be foreseen, as appropriate.

In the following text some more details are given on the above proof-of-concept.

Management of information on incumbent services

FS geo-located shapes will be introduced into the blockchain system and provide as such a set of reference precomputed technical and anonymous data on FS protection requirements.

Confidential information on the FS licence holder and antenna characteristics would not be fed into the blockchain.

Any change in the information on FS protection will be traced and known by the users of the blockchain.

As a matter of fact, new 6 GHz FS links may be authorised through regular national procedures and would lead to new frequency assignments in the corresponding national frequency assignment database, before the FS link is put into service.

The national frequency assignment database would provide the basis for computing the FS protection zones (geo-located shapes) associated with the new FS receivers (if specific protection is required), to be fed into the blockchain.

Interactions between the blockchain and LPI devices

On the WAS/RLAN side, the blockchain would collect relevant information on the RLAN device (RLAN operating zone, SSID, MAC address, power requirement, etc.).

The blockchain response to the RLAN device will specify the RLAN channels that may be used (possibly all channels in the absence of FS protection requirements locally) and ask the device to report on the channel that has been selected for operation.

The blockchain would overall store the following information:

[80] See https://www.anfr.fr/fr/toutes-les-actualites/actualites/la-blockchain-des-frequences-utilisee-pour-le-qatar-prix-de-larc-de-triomphe-2019.

- Query from the RLAN device
- Response from the blockchain
- Channel selected by the RLAN device

A RLAN device may also initiate another session to query for a different power.

Authorisation delivered to RLAN devices and enforcement matters

From a legal perspective, the response provided by the blockchain can be described as an authorisation that is limited in time. RLAN devices should indeed be required to re-check periodically (e.g. once a month) the blockchain in order to permit continued operations.

The authorisation delivered by the blockchain would apply only to the identified RLAN device. However, it is essential to note that a query from another RLAN device with similar characteristics (i.e. same pixel, antenna height range and power requirement) would deliver the same response and that there is no limitation on the number of WAS/RLAN users.

A5.5 Italy

Consultation on LSA

In April 2016, AGCOM approved with Decision 121/16/CONS a public consultation on LSA for wireless broadband systems. The goal of this consultation was twofold: on the one hand to verify the interest by the market players on LSA as a frequency agnostic tool to increase efficiency in spectrum usage; on the other hand to investigate the main aspects related to LSA concept, including the key benefits and the potential issues in defining the LSA sharing framework, the role and main responsibilities of the LSA stakeholders, the main opportunities for stakeholders deriving from the application of the LSA approach, the potential technical and market barriers to the introduction of LSA, the possible incentives for the adoption of LSA, the maturity and commercial availability of the technologies enabling the LSA approach, and the most interesting system architectures and technical features for implementing LSA. In the document submitted to public consultation, AGCOM also explored the possible scenarios of interest for LSA application, mainly focusing on: *i*) ECNS licensed frequency bands (e.g. 900 MHz band); *ii*) frequency bands not yet licensed to ECNS with at least one governmental incumbent (e.g. 2.3-2.4 GHz band) – for the so-called "vertical" LSA; *iii*) new frequency bands to be assigned to a new ECNS incumbent (with native LSA framework).

The participants in the consultation very much appreciated AGCOM's commitment to deepen the regulatory, technical and economic feasibility of the LSA approach. However, from the outcomes of the public consultation, an existing demand for LSA did not emerge. Indeed, few operators showed potential interest in "vertical" LSA applications on a voluntary basis in frequency bands not yet licensed to ECNS (e.g. 2.3-2.4 GHz band) and this interest was expressed only when the specific frequency bands cannot be released by the incumbents and refarming and exclusive assignment procedures be carried out. So, the latter remained the preferred scenario at the time of the consultation. Moreover, interference management (e.g. the definition of protection criteria) was still seen as one of the main issues in "vertical" LSA scenarios and a barrier to widespread adoption.

Club use at 26 GHz

In order to increase flexibility in the spectrum usage, AGCOM enforced in this band the assignment of individual but not exclusive rights of use of spectrum. In particular, with Decision n. 231/18/CONS, AGCOM introduced the so called "club use" model. According to this model, each of the 5 licensees holding 200 MHz can dynamically use all awarded spectrum (up to 1 GHz) in areas where frequencies are not used by other licensees. To this aim, licensees can stipulate commercially reasonable and non-discriminatory agreements, proportionally sharing the costs. Each licence holder has the pre-emptive right in favour on its assigned block of 200 MHz. Moreover, licensees can assign the task of managing the uses to a trusted third party in order to avoid harmful interference as well as the access scheduling over time. Therefore, club use is a spectrum sharing approach imposed by the national regulator, selecting a predefined number of licensees which have to coordinate among themselves to ensure coexistence in the band. In this sense, according to the terminology used so far in the present Report, the club use model falls within the DSA scope and, by simplifying, can be considered as a kind of OSA among peer licensed users. Currently the operators are dealing with an implementation model for the club use, also leveraging on data from some ongoing trials. In particular, one option currently discussed is based on the Self-Organizing Networks (SON) concept, which according to some operators could represent a more scalable and cost-effective solution in the long term with respect to more traditional solutions. Anyway, this discussion is still open, and will take into account also the definition of the EU regulatory framework for small cells.

A5.6 Netherlands

The Netherlands implemented an on-line booking system for PMSE in the 2.3 - 2.4 GHz band which is also in use by the Ministry of Defence that can be considered as a first step toward a complete LSA-system. The original objective for this booking system was to shorten the lead time for receiving spectrum assignments and to reduce interference problems. This objective has been achieved. This LSA based facility is obligatory for the PMSE sector to use and incorporated in the licenses of PMSE users in this band. Further development of the system will involve other existing users in the band, namely, government use and radio amateurs. A roadmap was drawn up to describe future possibilities and expected timelines of LSA in the Netherlands. This roadmap looks beyond the 2.3 - 2.4 GHz band and its users and will also consider other means of sharing the spectrum than via a manual booking in a web-application. Currently, the LSA booking facility is in the process of being further embedded in the ICT landscape of the Dutch Radiocommunications Agency (Agentschap Telecom). Until this is realised, the existing pilot software will remain in use. It is expected that the new embedded LSA system will become operational in the first quarter of 2021 for the first users in the first frequency band. The process is thus embedded as a regular process for dynamic frequency distribution and can subsequently be expanded with other suitable frequency bands and/or users.

The following bands could be promising for LSA usage in the future:

- 174-230MHz/470-698MHz (PMSE audio): to facilitate the portable and mobile audiolinks in these bands which are primary in use for broadcast. The use of PMSE audio is already possible in these bands, but the use of LSA would improve the QoS of the audio links and makes it more dynamic;
- 2070 – 2110 (PMSE video): this is a frequency band which is in use by Ministry of Defence. PMSE video is possible on a case by case basis. The use of LSA would improve the QoS for PMSE video while maintaining the existing QoS for the use by the Ministry of Defence.
- 146 - 174MHz/410 - 430MHz/450 - 470 MHz (temporary use for narrow band usage): PMSE service links and PMR for events are using the 146 - 174MHz/410 - 430MHz/450 - 470 MHz bands. LSA could improve the present situation by increasing the response time for an application which now done manually.

In addition to the above, some considerations are being made on making more efficient use of spectrum for radars and develop new planning methods. Traditional radar systems are in use for military and maritime use. In The Netherlands, a substantial increase of new type of radar systems is expected, for example in autonomous sailing/flying objects, bird detection, drone-detection fields, etc. Research is going on to see if it is possible for different types of radar systems to share spectrum, though there are differences in the use of technology (modulation, etc.). Basically, this is done by identifying radar system technologies which do not interfere each other and which might be used without planning in the same bands (e.g. pulse-radar), while keeping separation with radar system technologies which do interfere (e.g. FMCW).

A5.7 Portugal

The "Study on the Licensed Shared Access (LSA) Spectrum-Sharing Model" in Portugal was launched on 10 January 2018, involving ANACOM and a number of strategic partners:

- Mobile Operators: MEO, NOS, Vodafone Portugal;
- Television operators: RTP, SIC, TVI;
- Industry: Huawei, Nokia and Fairspectrum;
- Research and development (R&D): IT - Instituto de Telecomunicações (Institute of Telecommunications).

The study was conducted with the aim of analysing alternative spectrum management scenarios and models, specifically the LSA in the 2.3 - 2.4 GHz band.

The outlined methodological approach made it possible to explore and acquire knowledge, from a solid experimental basis, about the technologies and interrelationships among the various actors in the processes associated with the implementation of the LSA spectrum-sharing model, including control and management of the identified spectrum uses.

In this context, one objective in particular was to assess whether, in what form and to what extent, Programme Making and Special Events (PMSE) and mobile systems may coexist in the 2.3 - 2.4 GHz band, given their specific characteristics.

The final phase of the study, promoted by ANACOM, was conducted in January 2019, at the University of Aveiro campus, with the development of a technological demonstrator as proof of concept of the system.

This pilot test network deployed in Aveiro, comprised:

- 2 base stations (eNode-B's) from NOS and MEO, with LTE-TDD technology from Nokia and Huawei;
- 2 prototypes of warning sensors to indicate the need to release spectrum for priority use (of incumbent operators, in the Portuguese case, television operators), comprising technology all developed by the Portuguese Institute of Telecommunications;
- 2 systems for the transmission and reception of digital radio links from RTP and TVI, and respective systems for capturing sound and image and for monitoring operations;
- core test network of NOS, controlled by its management and operations support centre (located in Póvoa de Santo Adrião);
- 1 LSA controller and repository of Fairspectrum (located in Ireland and Finland);
- mobile terminals (smartphones) and their SIM cards, made available by NOS and MEO and configured especially for this pilot test network.

In an environment of beneficial and close collaboration between all partners, the prototype of the warning sensor was successfully tested, proving itself fundamental should the LSA model be implemented in Portugal.

Calls were successfully made between mobile terminals using the pilot network and, in addition, it was verified that all implemented control mechanisms functioned as expected - in particular, disconnection of the mobile network, whenever the television operator indicated their intention to use the spectrum previously occupied by the mobile network, as well as reconnection of the mobile network once television operations ceased.

Based on the results[81] of the pilot project, the following conclusions were drawn, as summarised below:

- The LSA concept was proven, and the LSA Warner system functioned successfully, allowing the deployment of basic features that can enable the introduction of the LSA model, tailored to the scenario of spectrum use in the 2.3 – 2.4 GHz band in Portugal;
- The LSA Warner detected LTE TDD signals and activated control mechanisms, responding as desired to the LTE eNodeB;
- The tests demonstrated that the LTE TDD and PMSE signals (DVB-T and LMS-T) are not compatible, regardless of the signals' bandwidth;
- The Warner therefore becomes a crucial component in deploying the LSA concept tailored to the Portuguese reality;
- The LSA controller was able to communicate both with the LTE eNodeB and with the LSA Warner;
- The LSA controller's response time was measured at less than 30 seconds (calculated from the time of the Warner's receipt of the request). The processing time for requests received by the LSA controller was negligible;
- From a technology standpoint, and based on the pilot tests conducted in Portugal, the LSA concept was validated and enable sharing of the spectrum, in the 2.3 – 2.4 GHz band, without further constraints on the conditions considered.

Areas for improvement in a potential deployment of the LSA model in Portugal

Despite the positive results obtained, it must still be noted that the detection and warning system (LSA Warner) and the LSA controller developed and deployed in this project are merely prototypes, and not final commercial solutions. As such, potential improvements exist on the horizon. During testing, several important aspects were found and require attention so that the LSA model can be implemented in Portugal in a robust and reliable manner, thereby safeguarding the operations of the spectrum users involved.

A5.8 Slovenia

In Slovenia, active sharing and frequency pooling, including dynamic spectrum sharing, is allowed within a framework that does not limit infrastructural competition. For example, sharing of active equipment and frequency pooling are permitted when passive sharing is not sufficient, for example in challenging areas and in case of network densification.

In the context of a public tender with auction for the award of radio frequencies for the provision of public communications services, dynamic spectrum sharing is considered between licence holders and/or licence holder and its lessees at specified location. Spectrum between them can be dynamically reused/shared.

[81] The final report is published at https://www.anacom.pt/render.jsp?contentId=1563344.

The Agency for Communication Networks and Services of the Republic of Slovenia will follow market development and technology trends. In the case of significant changes and based on licence holder's requirements the Agency may modify licences as appropriate.

Frequency pooling and active sharing, including dynamic spectrum sharing are allowed in challenging areas of Slovenia, such as:

- settlements in Triglav National Park and settlements of 2nd priority (settlements in other areas difficult to reach),
- road and railway tunnels,
- critical road sections (motorways, highways, main roads and regional roads category I and II, regional roads category III touristic roads),
- in regions of Slovene border and Piran bay,
- in regions exceeding 60% of active railways with passenger,
- in regions exceeding 60% of main roads and regional roads category I and II,
- on historical monuments and other buildings under protection of Cultural heritage provisions,
- for small cells if there is a restriction on space interventions/building restrictions and
- indoor.

In areas of network densification where there is the needs to secure very high capacity base stations offering gigabit speeds:

- road and city infrastructure (e.g., lamp posts, traffic lights …),
- railway and energy infrastructure,
- in dense venues (convention centres, concert halls, stadiums, bus and train stations, shopping malls, factories, ports, airports…)

frequency pooling and active sharing, including dynamic spectrum sharing, are allowed as well.

Sharing as defined above is allowed in accordance with competition law principles.

For the 26 GHz band frequency pooling and active sharing, including dynamic spectrum sharing, is allowed everywhere between licence holders, with a pre-emptive right in favour of the licence holder on its assigned sub-band.

Another possibility to introduce spectrum sharing is in the frequency bands where part of the spectrum is occupied by a local ICT provider while the rest will be auctioned on national basis, such as in 3,4 – 3,8 GHz band. With spectrum sharing the national operator could then use a larger contiguous block.

Sharing could be allowed only if all licence holders meet all the prescribed tender conditions regarding quality of service, in such a way that the quality of the user experience is not reduced.

ANNEX 6 – Views from stakeholders

During the period from 11 October 2019 and 29 November 2019, the RSPG publicly consulted on its draft Programme for 2020 and beyond, including the mandate for the work on Spectrum Sharing.

The RSPG has deeply considered the response received from all participants while developing the Opinion on Spectrum Sharing RSPG21-006 and this Report. A summary of the relevant contributions to the Spectrum Sharing work item during this public consultation is described in the following. For more information refer to the original answers published at https://rspg-spectrum.eu/public-consultations.

Representatives of the automotive industry (**ACEA** and **CLEPA**) stressed the need for ETSI, CEPT and RSPG to continue their studies to allow the use of the whole 5.9 GHz band for the C-ITS services.

Copsey Consult requested more protection for SRD users.

Digital Europe highlighted that while clearing spectrum for mobile broadband remains the preferred option for the public network providers, where this is not possible then spectrum sharing would be the most efficient option, in particular where the incumbents are not fully using the spectral resource geographically or spectrally. They remarked that ETSI is current working on an evolution of the LSA standard called eLSA, addressing vertical industrial needs specifically.

ETNO highlighted that individual and exclusive use of spectrum remains crucial for ensuring quality of service. So, also in case of sharing, it is important to meet the needs of the services intended to share the spectrum, and even any LSA solution should be at the initiative of the licensed operators and not be imposed.

Facebook suggested that a tiered spectrum sharing model (TSSM), along the lines of the US projects such as Automated Frequency Coordination (AFC) for 6 GHz and Citizens Broadband Radio Services (CBRS), can be a very effective mechanism for enabling important new use cases and increasing spectrum utilization. In TSSM a regulator can allow new users to access spectrum licensed to incumbent users while incumbent operations are protected from interference. By allowing new users to access spectrum in local areas, such users can fill in network gaps, bring service to areas that are not effectively covered, such as underserved rural areas, and deploy specialized local and private networks. And by allowing these users to access spectrum in specific geographies that would typically be licensed nationally, new users can address local connectivity needs on a smaller scale and in a way that is financially sustainable.

In addition to ensuring the efficient use of spectrum resources, Facebook observed that sharing can also enhance competition and rural connectivity. For example, through the use of a neutral host platform, spectrum sharing can increase competitive options for network capacity. A neutral host platform that shares both passive and active resources such as spectrum, Radio Access Network (RAN) edge node (*e.g.* LTE eNodeB) or a Wi-Fi access point in managed or private spaces (*e.g.* stadiums, commercial buildings) can have several advantages. Neutral host networks reduce capital expenses for hosted operators and have the potential to reduce operating expenses as well. In addition, depending on the specific active and passive components shared among hosted operators, neutral host networks can ultimately benefit consumers through better connectivity (e.g. Ofcom's low power shared access licence).

Moreover, according to Facebook, spectrum sharing can be used to extend rural coverage and make the provision of service to rural areas economically sustainable. To this end, spectrum policies should be sufficiently flexible to allow for spectrum use by multiple parties in high-cost rural areas. Similarly, national regulatory authorities can establish special spectrum licenses that allow access to licensed mobile spectrum that is not currently in use in rural areas (e.g. Ofcom's shared access licence).

Facebook also agreed with the RSPG's view that the facilitation of trials can help to advance spectrum sharing as well as to improve collaboration among Member States.

In addition to further developing spectrum sharing, Facebook suggested that the RSPG considers the importance of a balanced approach to licensed, licence-exempt, and lightly licensed spectrum. Licence-exempt would continue to be a vital part of the general mobile ecosystem, notwithstanding that a great deal of the total traffic will be off-loaded onto fixed networks through Wi-Fi or femtocells. While lightly licensed coordinated access to spectrum could support technologies and applications like neutral host platforms that could complement 5G. In addition, lightly licensed spectrum will be critical to support faster coverage, especially in high population density areas.

GSMA stressed the need to promote a properly functioning secondary market for spectrum rights. In this sense, spectrum authorities can play a role by intermediating and aggregating demand, especially in the initial stage. MNOs will have a role as potential suppliers in the secondary market, sharing the national usage rights where and when they are not used, through leasing, LSA or other means.

GSMA also challenged the assignment solutions with a reserved portion of bands directly to verticals or in general to site owners (local reservation), arguing that this would result in inefficiencies in most cases without any evident benefit for the vertical industry, compared with a more traditional model. 5G already offers many ways of addressing this kind of sharing needs.

Huawei considered that it might be helpful to frame the discussions in terms of inter-service (i.e. between users of different services) and intra-service (between users of the same service) sharing, rather than static vs. dynamic sharing. Dynamic may not always be the right solution, especially when important quality of service requirements need to be met. With the growing demand for spectrum, and the fact that frequency re-planning or clearance of existing users are not always viable options, increasing levels of inter-service spectrum sharing will be inevitable going forward. Such inter-service spectrum sharing can be facilitated through coordination (assisted by databases provided by administrations, if required) and/or through the use of advanced radio technologies such as AAS. Administrations' decisions on the feasibility of sharing should rely on compatibility studies which adopt the most accurate modelling (including for path loss, clutter loss and building penetration loss) of radio interference.

Regarding intra-service sharing, the existing authorisation categories of individual licensing (including national, regional, or local licensing) and general authorisation (or licence exemption) – complemented by the possibility of market-led trading or leasing of spectrum usage rights at specific locations – can cater for all foreseen cases in this context. As a complement to intra-service spectrum sharing, a number of measures should be further exploited in the context of 5G within the individual national licensing regime to ensure that different users can benefit from the same (scarce) spectrum resource. Such measures may include provision of wholesale 5G capacity by MNOs to new players, indoor coverage by neutral hosts using MNOs' licensed spectrum and in cooperation with the MNOs, and spectrum leasing (including "*use-it-or-lease-it*") in circumstances where other parties might require connectivity in areas where the MNOs do not consider it economically viable to invest.

The association of Amateur Radio (**IARU**), as a secondary users of spectrum (notably in the 430 MHz – 10 GHz range) was concerned about ongoing policies favoring primary and tertiary (licence exempt/SRD) users with little consideration of secondary use and its societal value – despite it being the original regulatory mechanism for spectrum sharing. The sharing model in the US has a much more coherent view encompassing Primary, Secondary and Tertiary layers and then within each regulatory layer considering how flexible usage may be implemented while avoiding interference to the layer above. Consistency is then needed in the sharing thresholds, access mechanisms and out-of-band emissions, etc., beyond which harmful interference occurs. Radio amateurs currently implement dynamic usage/sharing within their allocated frequency bands by band plan mechanisms which are regularly updated and urge the RSPG to consider how secondary usage can be better recognized as part of sharing scenarios.

Nokia, on the same line as other manufacturers in sustaining sharing, focused on the need to share the 470-694 MHz band between the mobile and the broadcasting usage, possibly through a macro cellular layer with downlink capability, and in line with the planned review of the band by 2025 as established in WRC-19.

NXP suggested, while introducing innovation in sharing techniques, to consider the needs of UWB applications, that usually do not cause interference to incumbent systems but are very much affected by new licensed or unlicensed applications in close proximity that use transmitters with higher power level.

Qualcomm suggested combining vertical and horizontal sharing techniques to improve coexistence and increase spectrum efficient use. According to Qualcomm vertical sharing means techniques used to enable sharing between systems that have some form of hierarchy in terms of priority (e.g. LSA), While horizontal sharing techniques are used to enable access to spectrum by users who are in the same tier in terms of priority (e.g. LTE-Unlicensed and Wi-Fi in 5 GHz band).

Shure highlighted the fact that sharing is not always beneficial to all applications. In particular specific application such as PMSE in UHF and VHF bands might be adversely affected by the reduction of an allocated band and by an increasing of sharing by other and different applications. At the moment the needs of the PMSE industry require access to sufficient interference-free spectrum. Current developments, also in 5G context, do not fully address the requirements of PMSE and further studies and innovations are needed. So Shure would caution RSPG on not considering sharing always the best solution.

SoS (Save our Spectrum) is on the same line of Shure.

Spectrum Consult wished that sharing use be promoted by means of increasing use of general authorisations (such as Wi-Fi) rather than individual authorisations, as foreseen in the EECC.

Veron suggested that when identifying a band for prospective sharing, the current use of the band should be carefully examined. There are some use, such as amateur radio, terrestrial and satellite, whose usage is very difficult to measure and to predict. The special characteristics of those services should then be included in the analyses for the identification of possible bands for sharing.

The Wi-Fi Alliance wished to stress that the RSPG should promote the increase of bands available to RLAN technologies such as Wi-Fi, one of the greatest success story in technology, particularly in the range of 6 GHz; current Wi-Fi bands have become increasingly saturated, yet Wi-Fi is a very efficient means to share spectrum.

Zerofiber wishes to promote the sharing use of 3.8-4.2 GHz band and 26 GHz, the former with a view of implementing local licences for pan-European vertical industries.

GLOSSARY

3GPP	Third Generation Partnership Project
5G	Fifth Generation
AAS	Active Antenna System
AFA	Adaptive Frequency Agility
AFC	Automated Frequency Coordination
AFC	Automated Frequency Controller
AI	Artificial Intelligence
APC	Adaptive Power Control
AR	Augmented Reality
BEM	Block Edge Mask
BEREC	Board of European Regulators on Electronic Communications
CBP	Contention Based Protocols
CBRS	Citizens Broadband Radio Service
CEPT	Conférence Européenne des administrations des Postes et des Télécommunications
CIRN	Collaborative Intelligent Radio Networks
CN	Core Network
CoMP	Coordinated Multi Point
CR	Cognitive Radio
CRS	Cognitive Radio Services
CRT	Cognitive Radio Technologies
CUS	Collective Use of Spectrum
DAA	Detect And Avoid
DB	Data Base
DLT	Distributed Ledger Technology
DFS	Dynamic Frequency Selection
DSA	Dynamic Spectrum Sharing
DSS	Dynamic Spectrum Sharing
DTT	Digital Terrestrial Television
EC	European Commission
EECC	European Electronic Communications Code
ECC	Electronic Communications Committee

ECNS	Electronic Communications Networks and Services
ECS	Electronic Communications Services
EESS	Earth Exploration Satellite Service
EHF	Extremely High Frequency
EIRP	Equivalent Isotropic Radiated Power
eMBB	Enhanced Mobile Broad Band
EMF	Electro Magnetic Field
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communication Commission
FDD	Frequency Division Duplex
FS	Fixed Service
FSS	Fixed Satellite Service
FWA	Fixed Wireless Access
GDPR	General Data Protection Regulation
GPR	Ground Probing Radar
GPS	Global Positioning System
HAM	Hierarchical Access Model
ICT	Information and Communications Technologies
IoT	Internet of Things
ISM	Industrial Scientific and Medical
ITS	Intelligent Transport System
ITU	International Telecommunication Union
LAA	Licensed Assisted Access
LAL	Local Access Licence
LBT	Listen Before Talk
LSA	Licensed Shared Access
LTE	Long Term Evolution
M2M	Machine to Machine
MAC	Media Access Control
MFCN	Mobile and Fixed Communications Network
ML	Machine Learning
mMTC	Massive Mobile Type Communication

MIMO	Multiple In Multiple Out
MNO	Mobile Network Operator
MOCN	Multi Operators Core Network
MORAN	Multi Operator Radio Access Network
MS	Member State
MVNO	Mobile Virtual Network Operator
NCA	National Competition Authority
NIS	Network Infrastructure Sharing
NR	New Radio
NRA	National Regulatory Authority
NSA	National Spectrum Authority
OSA	Opportunistic Spectrum Access
PMSE	Programme Making and Special Event
PPDR	Public Protection Disaster Relief
QoS	Quality of Services
R&D	Research and Development
RAN	Radio Access Network
RED	Radio Equipment Directive
RF	Radio Frequency
RLAN	Radio Local Access Network
RSPG	Radio Spectrum Policy Group
SAL	Shared Access Licence
SAS	Spectrum Access System
SDR	Software Defined Radio
SON	Self Organising Network
SRD	Short Range Device
SRR	Short Range Radar
SUL	Supplemental Up Link
TDD	Time Division Duplex
TSSM	Tiered Spectrum Sharing Model
TVWS	TeleVision White Spaces
UHF	Ultra High Frequencies
URLLC	Ultra Reliable Low Latency Communications

UWB	Ultra Wide Band
VR	Virtual Reality
VHF	Very High Frequencies
WAS	Wireless Access System
WiFi	Wireless Fidelity
WMBus	Wireless Metering Bus
WPAN	Wireless Personal Area Network
WPR	Wall Probing Radar
WRC	World Radio Conference
WSD	White Space Device
WSDB	White Space Data Base