Will 5G lead to more spectrum sharing? Discussing recent developments of the LSA and the CBRS spectrum sharing frameworks

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Abstract

This paper discusses two recent spectrum management frameworks, the Licensed Shared Access (LSA) developed in Europe and the Citizens Broadband Radio Services (CBRS) developed in the United States (US), which build their management approach on spectrum sharing. The importance of these two frameworks, besides their leading normative roles, is that recent debates have shaped them as cases to consider in the adoption of the upcoming fifth generation (5G) of mobile communications technology, in particular in the C-band. A discussion on these two frameworks is organised by following the four-step decision-making guide for spectrum management developed by Pogorel (2007), which requires spectrum authorities to make decisions in four areas of spectrum management: frequency harmonization, technology standardization, type of usage rights and assignment procedures.

Notwithstanding the similarities with respect to the four areas of spectrum management considered, the two frameworks differ on their implementation schedules. CBRS leads the way, with a handful of providers receiving government approval to manage spectrum access controllers, and as of mid 2020, scheduled to have allocated spectrum licenses on half of its available spectrum. On the contrary, European countries have shown scarce interest towards implementing the LSA, notwithstanding the extensive work carried out by regulatory and standardization bodies.

This may suggest that there are external contextual factors which influence the successful implementation of spectrum sharing frameworks. An interesting aspect which deserves further investigation is the institutional context in which decisions related to radio spectrum management are taken. Unlike the US authorities, European institutions do not possess coercive enforcement powers with respect to sharing framework. This key difference may contribute to explaining the different speed at LSA and CBRS are implemented.

1. Introduction: a renewed interest toward radio spectrum sharing

The increasing demand of radio spectrum for the provision of commercial mobile communications services has triggered a renewed interest in spectrum sharing (Beltrán, 2017). Operators, civil organisations and other parties have been mounting pressure on national regulatory authorities (NRAs) to open up spectrum bands, which are currently underutilized by government users, so avoiding re-farming processes (e.g. PCAST 2012). Cases where primary users do not fully use the spectrum resource, for which they have exclusive access, provide opportunities for secondary users to use the available spectrum in certain locations and/or points in time (Mustonen et al., 2017). Although access to radio spectrum for these services has traditionally been granted on an exclusive basis, supranational bodies and NRAs have recognised the importance of spectrum sharing to meet the growing spectrum needs of mobile communications (EC, 2012; FCC, 2015; Ofcom, 2014; PTS, 2014; RSPG, 2018a). Leading manufacturers have proposed several spectrum sharing solutions to alleviate the pressure built on spectrum supply by combining licensed and unlicensed spectrum (e.g. Ericsson, 2017).

Spectrum sharing is expected to become a key asset for NRAs to meet 5G spectrum needs (Marti, 2018), for three main reasons. Firstly, there might be insufficient spectrum to support all 5G use cases, if only exclusive access to spectrum was granted (Boccardi et al., 2016; EC, 2016a; Rebato et al., 2016). Secondly, the speed with which low and mid frequency bands need to be cleared up for its furnishing to suit 5G demands is a clear point of contention. Providers of 5G commercial services need to get assurance of the band availability in a short time, which may not sit well with the speed at which regulatory decisions are carried out. Re-farming processes would be needed to remove and relocate spectrum uses which currently occupy, to different extents, spectrum under consideration for 5G (CEPT, 2014a). Such processes can be time-consuming. Therefore, they constitute a less appealing solution to promptly finding spectrum for new services, with respect to sharing mechanisms which do not require incumbent users to be relocated to other bands. Thirdly, spectrum sharing can contribute to a better use of spectrum by making already assigned, but underused spectrum resources available, promoting efficient bandwidth utilisation and facilitating spectrum access for new users (Boccardi et al., 2016; EC, 2016a; Rebato et al., 2016).

The aim of this paper is to discuss recent developments of two spectrum sharing frameworks, namely the LSA and the CBRS, in the context of 5G. 5G services will likely use frequency bands both below and above 6 GHz. Wide bandwidth is expected to be available for 5G in high spectrum bands. On the contrary, the amount of spectrum available below 6 GHz is rather limited, because it is largely occupied by various incumbent users. Spectrum authorities in Europe and US are considering the implementation of respectively, the LSA and the CBRS, in the sub-6 GHz spectrum to cope with the problem of limited spectrum availability.

In 2012, the Authorized Shared Access (ASA) concept, initially proposed by Qualcomm and Nokia (Ingenious Consulting Network, 2011), was welcomed and extended into the LSA framework by European institutions, including the European Conference of Postal and Telecommunications Administrations (CEPT), the European Commission (EC) and the Radio Spectrum Policy Group (RSPG) of the European Union (EU). The LSA sharing framework was developed to facilitate the introduction of new users in already occupied frequency bands, while maintaining existing incumbent services on a long-term basis (CEPT, 2014b; ETSI, 2018a). While ASA was limited to International Mobile Telecommunications (IMT) use, LSA was designed to promote spectrum sharing between any type of wireless radio system (EC, 2012; Yrjölä et al., 2015). Although technology neutral, the first practical application of the LSA framework was sought in the 2.3-2.4 GHz (2.3 GHz) band, which is globally allocated to the mobile service (ITU-R, 2012a: 178) and identified for IMT (ITU-R, 2016a: 113). More recently, LSA has been proposed as a suitable instrument to support 5G use cases in the so-called vertical sectors, such as industrial automation, utilities and e-health (ETSI, 2018a). In particular, the feasibility to implement the LSA sharing framework is currently explored in the 3.4-3.8 GHz band to enable coexistence between incumbents and 5G applications (CEPT, 2016).

CBRS was born out of the US Federal Communications Commission's (FCC) decision about developing a spectrum sharing solution in the 3.5 GHz band, following the report issued by the President's Council of Advisors on Science and Technology (PCAST) (PCAST, 2012). The CBRS sharing framework would allow for 150 MHz of spectrum, from 3550 to 3700 MHz, to be shared between incumbent military radars and satellite earth stations, and two groups of commercial users, one with individually licensed access and one with unlicensed opportunistic spectrum access. CBRS is aimed to enhance the availability of spectrum across the US for wireless broadband services. The FCC's creation of CBRS has been considered a pioneering decision aimed to address the spectrum shortage for the expansion of broadband services in the country.

Agnostic, in principle, regarding the particular technology to be deployed, CBRS has been regarded by the largest mobile network operators (MNOs) in the country as a primary way to deliver home and enterprise broadband services, first via the fourth generation (4G) of mobile communications technology, in a transition towards 5G (AT&T, 2018). However, this will be possible only after licenses are auctioned for a portion of the band. Meanwhile, a large number of interested non-MNO parties is working on testing and adapting compatible devices to carry on with so-called private 4G/5G services, which would attend to the needs of sectors such as manufacturing, utilities, and transportation (Federated Wireless, 2019). In particular, first deployments start to occur as private LTE networks are being rolled out over neutral host providers offering private LTE, among other services. Also, operators using the FCC's 3.65 GHz band, which face licenses expiration in April 2020, are seeking upgrade to the full capabilities of CBRS with simple over-the-air upgrades approved by the FCC (Yahoo Finance, 2020).

This paper discusses the LSA and the CBRS sharing frameworks by using Pogorel's four-step decision-making guide for spectrum management (Pogorel, 2007). Such guide recommends spectrum authorities to make decisions in four areas of spectrum management: frequency harmonization, technology standardization, type of usage rights and assignment procedures. A new sharing framework is generally the outcome of a complex development process which involves various stakeholders and takes account of different regulatory levels (Mustonen et al. 2017). The application of Pogorel's four-step decision-making guide allows to break down the LSA and the CBRS sharing frameworks into their constitutive elements and identify potentially relevant similarities and differences.

The rest of this paper is organized in seven sections. Section 2 reviews existing literature on decision-making for spectrum management frameworks. Section 3 provides an overview of 5G spectrum requirements. Section 4 presents the four-step decision guide to design a spectrum management approach, which is then used in section 5 and section 6 to discuss, respectively, the LSA and CBRS spectrum sharing frameworks. Section 7 compares the LSA and the CBRS sharing frameworks based on the work developed by Pogorel (2007). Section 8 concludes the discussion highlighting the importance of investigating whether the institutional context influences the potential implementation of sharing frameworks in a specific region or country.

2. The choice of Pogorel's four-step decision-making guide: a brief literature review

Research on decision-making for spectrum management is rather limited (Freyens, 2009; Mustonen et al., 2017). To the authors' best knowledge, the process proposed by Pogorel (2007), is one of a handful which offer general decision-making criteria for spectrum authorities to identify various spectrum management options. Other researchers in the field of radio spectrum management depart from the work of Pogorel to discuss the main attributes of spectrum management frameworks (e.g. El-Moghazi et al., 2017).

An important contribution to the discussion on the constitutive elements of spectrum approaches is the work of Bauer (2002), which, however, mainly focuses on usage rights and assignment procedures, discussing them in connection to the evolution of the mobile communications industry. Equally relevant is the work of Freyens (2009), which departs from the work of Bauer (2002) and Pogorel (2007) to widen the umbrella of spectrum management possibilities.

Freyens (2009) revisits the four dimensions of spectrum management discussed by Pogorel (2007) and adds other dimensions. A new dimension called technology flexibility is defined, which is another way to indicate the principle of technology neutrality. Technology neutrality applies when the spectrum user can freely choose the technology to adopt to provide services (European Parliament and Council of the EU, 2002). Another dimension is usage flexibility, which basically refers to whether the principle of service neutrality is in place, whereby spectrum users are free to choose which services to provide (European Parliament and Council of the EU, 2002). In addition, a much-elaborated discussion is provided on responsibility with respect to interference management, distinguishing between government control and self-control operated by spectrum users. Freyens (2009) also refines the work of Bauer (2002) proposing a more articulated distinction of various spectrum commons approaches.

Without questioning the seminal contribution of Freyens (2009) to a taxonomy of spectrum management approaches, the guide proposed in Pogorel (2007) was considered more suitable for this study, for three main reasons. First of all, it was considered relevant to maintain a discussion on frequency harmonization and technology standardization, as these are two relevant aspects of spectrum management which often support one another when they concern mobile technology. In Freyens (2009), frequency harmonization and technology standardization are considered limitations to the technology flexibility dimension. Second, the usage flexibility dimension is not discussed in this paper. In connection with LSA and CBRS, usage is discussed in terms of existing incumbent and mobile communications usage. Third, distinguishing between government control and self-control when it comes to interference management does not appear suitable for this study as both control mechanisms are, to some extent, envisioned in the two sharing frameworks.

More recently, Mustonen et al. (2017) developed a process model for the introduction of spectrum sharing solutions into practice. In particular, a general process model for the design of spectrum sharing concepts was proposed based on the analysis of existing spectrum sharing frameworks, including LSA and CBRS, Particular attention was paid on the activities performed by the stakeholders involved in the different phases of the process. This paper is partly inspired by the work of Mustonen et al. (2017). Nevertheless, their choice to discuss in detail the specific activities performed by various stakeholders that are part of what they call "the ecosystem of sharing" is considered beyond the scope of this paper.

3. Radio spectrum for 5G

Future 5G networks are expected to support the provision of a wide variety of services, which are not limited to traditional multimedia applications, but include applications in various industries, such as media, transport, health, manufacturing, energy, and logistics (EC, 2016b). Examples of these services include autonomous vehicles, critical infrastructure management and remote medical procedures. The Radiocommunication Sector of the International Telecommunication Union (ITU-R) has provided a broad classification of potential 5G usage cases, which helps reduce the complexity associated with the rich environment 5G intends to provide. In particular, services have been categorized in enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC), and massive machine type communications (mMTC) (ITU-R, 2015a).

eMBB can be considered an extension of the previous fourth generation (4G) mobile broadband services. It is expected that eMBB will enable 360-degree video streaming and immersive virtual reality and augmented reality, among others. All this will be possible because eMBB will be delivering a triad of highly sought attributes such as: higher capacity, enhanced connectivity, and higher user mobility. URLLC, also referred to as mission-critical communications, encompass those applications that necessitate reliability and low latency to guarantee instant reaction. URLLC will facilitate industrial automation; remote medical surgery; smart grids; public protection and disaster relief; and intelligent transport systems (NGMN, 2015). mMTC refers to uses cases where a large number of intelligent devices are interconnected with the network, exchanging low power and short-range data transmissions (ITU-R, 2015a). The wide variety of applications expected from mMTC include industrial automation, industrial control, intelligent transportation, smart-grid, smart environment, and e-health (Sharma and Wang, 2018).

To satisfy 5G performance requirements, a combination of spectrum bands below 1 GHz, in the microwave range between 1 to 6 GHz and in the millimetre wave (mmWave) range between 24-86 GHz is considered crucial (ITU-R, 2016b). Spectrum bands below 1 GHz will be needed to satisfy coverage requirements, in terms of wide-area coverage and outdoor-to-indoor coverage. Mid spectrum between 1-6 GHz will be utilized to accommodate capacity demands (ITU-R, 2015a; Verma et al., 2016). Attractiveness of high spectrum bands above 24 GHz is due to two main elements: wide bandwidth available and global harmonization. At the same time, high spectrum bands in mmWave range suffer from propagation limitations and penetration loss. Transmissions cannot reach long distances, as signals cannot pass through obstacles. For this reason, high bands will be useful to support applications which require high data capacity, high peak data rate, and low latency, in limited geographical areas (Rysavy Research, 2017).

Sub-section 2.1. provides an overview of potential 5G spectrum bands in the low, mid, and high spectrum ranges currently under examination in Europe and the US. Sub-section 2.2. contains details about the C-band portion between 3.4-3.8 GHz, which is where LSA and CBRS may find application to support 5G use cases in vertical industries.

3.1. Pioneer bands for 5G in Europe and US

Table 1 shows the bands which have been considered for 5G deployment on both sides of the Atlantic, on the three band levels.

Europe	US
Low bands	
700 MHz band	600 MHz band
Mid bands	
3.4-3.8 GHz	2.5 GHz/3.5 GHz band
High bands	
24.25-27.5 GHz	24 GHz/28 GHz bands

40.5-43.5 GHz band	37 GHz/39 GHz bands
	47.2-48.2 GHz band
66-71 GHz band (*)	64-71 GHz band (*)

Table 1. 5G pioneer bands in Europe and the US
(*) Unlicensed spectrum
Source: CEPT, 2018a; FCC, 2017a

In Europe, the 700 MHz band is the primary band in the low spectrum range, which is expected to be used for 5G services, in particular for the provision of wide-area coverage, both geographic and indoor. In the mid spectrum range, the C-band between 3.4-3.8 GHz has been identified as the primary spectrum band for the introduction of 5G communications networks. In particular, it will be employed to satisfy the capacity needs of 5G (RSPG, 2018a). The 24.25-27.5 GHz band has been identified as the 5G pioneer band in the high spectrum range because of the potential availability of 3 GHz of contiguous spectrum (CEPT, 2018b). This band will be mainly used to satisfy ultra-high capacity requirements (RSPG, 2018a). The 40.5-43.5 GHz and the 66-71 GHz bands have also been identified as potentially suitable for 5G in Europe. Nevertheless, less attention has been devoted to these bands as demand for spectrum from 5G service providers is expected to be absorbed by the 24.25-27.5 GHz band (RSPG, 2018a).

In the US, some of the largest mobile companies hold spectrum in the 600 MHz and 2.5 GHz bands to develop their 5G plans starting in 2019 and 2020, which they have publicly announced in recent years. Low and mid bands in the US are being targeted by the largest carriers for 5G rollouts. Also, as indicated in Table 1, the US designated high-frequency spectrum bands for 5G networks in the 24 GHz, 28 GHz, 37 GHz, and 39 GHz bands for licensed use, and the 47 GHz and 64-71 GHz bands for unlicensed use (GSMA, 2018).

3.2. Focusing on the C-band

The C-band generally indicates the spectrum range which extends between 3.4 and 4.2 GHz. This band is considered the primary band for satellite communications (APSCC, CASBAA, ESOA and GVF, 2018). Its attractiveness is due to the fact that is allows wide area coverage and good performance under adverse weather conditions, such as heavy rains (TNO, 2018). Due to differences in national spectrum allocation and usage, the C-band is generally treated by policy-makers and NRAs as the combination of different portions, which host primary and secondary services (ITU-R, 2016b; ESOA, 2019), as shown in Table 2.

<table>
<tr><td rowspan="5">Region 1</td><td colspan="4">3.4-3.8 GHz</td></tr>
<tr><td colspan="4">FS and FSS (primary)</td></tr>
<tr><td colspan="2">3.4-3.6 GHz</td><td colspan="2">3.6-3.8 GHz</td></tr>
<tr><td colspan="2">Mobile service (co-primary)</td><td colspan="2">Mobile service (secondary)</td></tr>
<tr><td colspan="4">Radiolocation (secondary)</td></tr>
<tr><td rowspan="6">Region 2</td><td colspan="4">3.4-3.8 GHz</td></tr>
<tr><td colspan="4">FS and FSS (primary)</td></tr>
<tr><td>3.4-3.5 GHz</td><td>3.5-3.6 GHz</td><td>3.6-3.7 GHz</td><td>3.7-3.8 GHz</td></tr>
<tr><td colspan="4">Mobile service (co-primary)</td></tr>
<tr><td colspan="3">Radiolocation (secondary)</td><td></td></tr>
<tr><td>Amateur (secondary)</td><td colspan="3"></td></tr>
</table>

Table 2. Allocation of the 3.4-3.8 GHz band in ITU Region 1 and 2 (simplified)
ITU-R (2016b)

Currently, the 3.4-3.8 band is allocated on a primary basis to fixed service (FS) and fixed-satellite service (FSS) in both ITU Region 1, which comprises Europe, and in ITU Region 2, which includes the US. In addition, the 3.4-3.6 GHz band is allocated to the mobile service on a co-primary basis and identified for IMT in both ITU Region 1 and in ITU Region 2. The 3.6-3.8 GHz band is allocated to the mobile service on a co-primary basis in ITU Region 2 (the portion between 3.6-3.7 GHz is also identified for IMT in the US), while the mobile service has secondary allocation in ITU Region 1.

Primary allocation to the mobile service of the 3.6-3.8 GHz band was opposed by African and Arab countries at the World Radiocommunication Conference held in 2015, which wanted to preserve the use of the band for satellite use (Ofcom, 2016). On the contrary, the EU harmonised both portions of the C-band between 3-4-3.6 Ghz and he 3.6-3.8 GHz for mobile broadband use already in 2008 (EC, 2019). In addition, the recently adopted European Electronic Communications Code requires the EU member states to reorganise the use of the 3.4-3.8 GHz band to make available large blocks of spectrum for 5G services by 31 December 2020 (EC, 2019).

In ITU Region 2, which covers the US, the 3500-3700 MHZ band is allocated to FS, FSS and the mobile service (except aeronautical mobile) on a primary basis, and radiolocation services on a secondary basis (ITU-R, 2016b). Before the creation of the CBRS in 2012, the 3500-3600 MHz band was occupied by the US Navy and used for non-federal radiolocation services on a secondary use basis. The other half, the 3600-3700 MHz portion, was used by FSS with the upper 50 MHz enabled since 2005 for Wireless Internet Service Providers (WISPs) (FCC, 2012). The mix of incumbents and expectation for new bands for broadband services led to a wholly new framework for spectrum utilisation based on prioritised shared use.

4. A four-step decision guide to design a spectrum management approach

In a 2007 article, Gérard Pogorel proposed a set of four decision criteria to guide spectrum authorities in the design of spectrum management approaches (Pogorel, 2007). A spectrum management approach generally includes governing rules for allocation of radio spectrum frequency bands to services, for assignment of radio spectrum usage rights to different spectrum users, and for technology production and use (Webb, 1998). Pogorel's (2007) decision-making guide requires spectrum authorities to address trade-offs in the following areas of spectrum management: frequency harmonization, technology standardization, type of usage rights, and type of assignment procedure. While choices on frequency harmonization and technology standardization generally require some forms of cooperation between countries, decisions on the third and fourth criteria are generally undertaken at the national level. Different radio spectrum management approaches result from the combination of all possible choices for each of the four criteria. With respect to both spectrum harmonization and technology standardization dimensions, spectrum authorities can adopt a "yes or no" position, while they can choose between different positions with respect to type of usage rights and of assignment procedure (Freyens, 2009). The four decision criteria are further explained below.

4.1. Frequency harmonization

The first question spectrum managers need to address is whether frequencies should be harmonized. Frequencies are harmonized when they are allocated to the same service(s) or category of services at international or regional levels. Harmonization is usually preferred for it facilitates spectrum management and planning, as well as cross-country coordination, reducing the risk of cross-border interference. In addition, harmonization is advantageous for equipment and device manufacturers, which can benefit from economies of scale.

Spectrum harmonization leads to lower equipment costs, expanded equipment availability and increased interoperability (ITU-R, 2015b; Mazar, 2016a). Harmonized frequencies may also facilitate technology standardization (ITU-R, 2015b, Pogorel, 2007). Downsides connected to spectrum harmonization may include sub-optimal use of the spectrum resource in certain countries. This can happen when providers of the service for which the spectrum is harmonised do not demand additional spectrum. As a result, the spectrum is left unused or partially used. In these circumstances, spectrum may be better used by services which fulfil national needs (RSPG, 2016). Also, the innovation process may be negatively affected as harmonization would slow down the introduction of more advanced technologies and services which require a flexible environment to emerge (Pogorel, 2007).

Spectrum harmonization is a key objective of the country members of the ITU-R (ITU-D, 2015; Ofcom, 2018). Decisions on spectrum allocation are generally made at WRCs attended by national administrations and various spectrum stakeholders to review and update existing spectrum allocations. As stated in ITU-R Recommendation 34 (ITU-R, 2012b), WRCs "should wherever possible, allocate frequency bands on a worldwide basis (aligned services, categories of service and frequency band limits) taking into account safety, technical, operational, economic and other relevant factors." At regional level, spectrum harmonization is promoted by various multi-country organizations.

4.2. Technology Standardization

The second issue spectrum authorities need to consider is whether technology should be standardized (Bohlin et al., 2010). Broadly, a standard explains how technology should be developed (Tadayoni et al., 2018). Benefits of technology standardization include enhanced compatibility and interoperability of equipment and services for mobile service providers and economies of scale for manufacturers. Technology standardization is also considered necessary to ensure safety, reliability and certainty regarding technologies in use and their expected performances (ETSI, 2019). Similar to spectrum harmonization, technology standardization reveals also some challenging aspects. In particular, the process of selection between competing technologies may conclude with the adoption of an inferior standard. Moreover, technology standardization may bring restrictions to the introduction of innovative technologies, creating a lock-in situation into old standards (Stango, 2004; Freyens, 2009). Nevertheless, technology standardization is considered pivotal for mobile network deployment and service provision (Mazar, 2016b).

In the matter of mobile cellular technologies, there has been an increasing engagement in technology standardization processes. Standardization of wireless systems includes, for instance, technical specifications of transmitters, receivers and antennas (Mazar, 2016b). Although it is true that several standards may coexist in certain markets, standard wars that characterize mobile technology advancement generally conclude with the identification of one or very few standards (Tadayoni et al., 2018). Numerous entities at international, regional and national level work on radio technology standardization (Mazar, 2016b). In particular, the ITU-R generally coordinates the standardization process of mobile technology at international level.

4.3. Type of usage rights: exclusive, with easements and collective use

At the assignment level, spectrum managers need to decide which type of usage rights are to be assigned to service providers. Pogorel (2007) distinguishes between exclusive property rights, property rights with easements and collective use. In the case of exclusive property rights, service providers obtain exclusive access to the spectrum resource, with certainty of protection from harmful interference. Assigning exclusive property rights has become the standard approach to interference management to guarantee separation between the different users (Cave et al., 2007). Property rights with easements were initially proposed by Faulhaber and Farber (2003). They would entail some forms of spectrum sharing between primary and secondary users, taking advantage of certain technologies which enable a dynamic use of the spectrum resource (Pogorel, 2007). Holders of property rights with easements would have access to specific frequencies, and benefit from protection from harmful interference. However, they would not have exclusive access to spectrum, which would be used by other services, as long as no interference problem is caused (Faulhaber and Farber, 2003). The spectrum commons approach – or collective use - relies on technology to enable simultaneous spectrum use by different applications, on a community self-regulated use or a rule-based approach set by the NRA (Freyens, 2009). In the case of self-regulation, common property rights are granted to a limited number of users, which are in charge of co-managing spectrum usage. The NRA assigns and enforces such common property rights, but it is not responsible for managing the spectrum (Buck, 2002; Freyens, 2009). In the second case, access to spectrum is generally unrestricted, meaning that spectrum can be used by various types of services and applications. No usage rights are assigned to users. Nevertheless, users are required to comply with certain rules defined by the NRAs to guarantee equitable access (Noam, 1995; Freyens, 2009).

4.4. Type of assignment procedure: administrative versus market-based procedures

An additional element to be defined by NRAs is the type of assignment procedure whereby usage rights are granted. Pogorel (2007) distinguishes between administrative procedures and market-based procedures. Under the administrative approach, NRAs grant spectrum usage rights to individual users, specifying portions of spectrum band, coverage areas and other usage conditions, including power limits. When demand for access a spectrum band is limited, usage rights are given on a first-come-first-served basis (Faulhaber and Farber, 2003). In case of spectrum demand exceeding supply, comparative hearings or beauty contests are held in order to select potential spectrum users, among competing applicants (Faulhaber and Farber, 2003). Users are selected based on a number of predefined criteria, including available financial resources of the applicants, proposed technical conditions for radio spectrum use and planned infrastructure development and service provision. An additional administrative approach includes the use of lotteries, awarding licences through random selection (Faulhaber and Farber, 2003). Administrative procedures have been the conventional way of authorising radio spectrum access (Freyens, 2009; McLean Foster and Co., 2007; Prat and Valletti, 2000).

Since the 1990s, market-based procedures, in particular auctions, took over the administrative approach in many countries, to overcome flaws of administrative-based assignment procedures. Such flaws would include scarce flexibility to changing spectrum demands and technology advancements, long delays in the assignment of usage rights, risk of political interference, and lack of economic and social valuation of spectrum (Bauer, 2002). The market-based approach usually entails the auctioning of usage rights to spectrum users and the trading of these usage rights in secondary spectrum markets (Cave et al., 2007; Freyens, 2009; Pogorel, 2007). The main goal of employing auction mechanisms is the efficient assignment of spectrum (Bohlin et al., 2010; Madden et al., 2014). The price paid by auction winners for the usage rights is determined by the auction administrator after the interaction encouraged by the auction between spectrum supply and spectrum demand. Usage rights are granted to those bidders holding the highest bids; bidding the highest price is akin to having the highest value for the spectrum (Bohlin et al., 2010).

Spectrum auctions are more transparent (Cramton, 2002) and less prone to political influence (Noam, 1995), while spectrum is readily made available to spectrum users. Notwithstanding successful outcomes in terms of assignment efficiency, spectrum auctions have been criticised as a vehicle for governments to raise revenues (Cave and Nicholls, 2017; Hazlett and Munoz, 2009; Pogorel, 2018). Unsatisfactory outcomes of spectrum auctions have also been caused by imperfections in the design itself of the assignment mechanism. Over time, regulatory and research efforts have led to a proliferation of auction designs, some of which have often become quite complex (Bichler and Goeree, 2017; Cave and Nicholls, 2017).

5. The four-step decision-making guide applied to the LSA sharing framework

The aim of this section is to apply the four-step decision-making guide described in section 3 to the LSA sharing framework to understand which choices spectrum authorities have made with regard to frequency harmonization, technology standardization, usage rights and assignment procedure.

5.1. Frequency harmonization

The first practical application of the LSA framework was sought in the 2.3 GHz band, which is globally allocated to the mobile service and identified for IMT. Identification for IMT was decided at the World Radiocommunication Conference held in 2007. However, the 2.3 GHz band was not made available for mobile applications in Europe due to incumbent uses (CEPT, 2014c; ITU-R, 2007). European countries currently use all or parts of the 2.3 GHz band for a variety of governmental applications, including terrestrial and aeronautical telemetry and unmanned aircraft systems; PMSE applications; and also radio amateur services as a secondary service (CEPT, 2014a; CEPT, 2014c; RSPG, 2013). In this context, the LSA sharing framework emerged as a solution to open up the 2.3 GHz band to mobile use, while at the same time preserving incumbent usage.

More recently, the LSA sharing framework has been considered for application in the 3.6-3.8 GHz band. The 3.6-3.8 GHz band is currently allocated to FS and FSS, on a primary basis, in all three ITU regions. In addition, this band is allocated to the mobile service in Europe and identified for IMT (CEPT, 2016). European countries show diverse national preferences regarding the usage of this band, at national, sub-national and local level (CEPT, 2018c; Yrjölä and Kokkinen, 2017). Incumbent users occupy different portions of the 3.6-3.8 GHz band in different European countries and possess licenses of different types and durations. Because of the existence of incumbent primary services in the 3.4-3.8 GHz GHz, it is foreseen that some forms of sharing will be introduced to guarantee interference-free coexistence between incumbents and with new 5G services (CEPT, 2018d). In particular, 5G deployment in this band will be mostly based on small cells for the provision of services over limited urban and suburban areas.

According to the CEPT, LSA appears as a feasible mechanism to enable spectrum sharing between new and incumbent users, such as FSS, because their usage is relatively static, which guarantees spectrum availability for new users at known periods of time (CEPT, 2016; Yrjölä and Kokkinen, 2017). According to the CEPT, using the 3.6-3.8 GHz band on a harmonised frequency arrangement would "maximise the opportunities and benefits for end users and society, will benefit capital expenditure for operators, will reduce development and implementation costs of manufacturing equipment […] will secure future long terms investments by providing economies of scale and […] will reduce complexity in cross border coordination" (CEPT, 2018e: 4). Given also the technology standardization process which led to the development of new 5G radio interfaces, the CEPT initiated a review of existing technical and regulatory conditions for the use of 5G in the 3.4-3.8 GHz. As shown in Report 281, the CEPT assesses existing frequency arrangements and presents the definition of the most appropriate frequency arrangement for 5G whereby to handle the concern of coexistence with incumbent users (CEPT, 2018f).

5.2. Technology standardization

The LSA sharing framework has been developed as a generic one, which allows sharing between any type of wireless radio systems (Yrjölä et al., 2015). As stated in ETSI (2013: 30): "A beneficial by-product of the LSA concept is the fact that it can apply indiscriminately for any cellular technologies. This is given by the fact that no new radio protocol or functionality is envisioned." More specifically, ETSI clarifies that broadband wireless systems which can be used in the 2.3 GHz band may have "different technologies basis and originate from different standard bodies" (ETSI, 2013: 15). In particular, broadband wireless systems would encompass both IMT-2000 and IMT-Advanced technologies (ETSI, 2013: 15). IMT-2000, IMT-Advanced and the upcoming IMT-2020 are three mobile technology standards families which have progressively been elaborated by the ITU (ITU-R, 2018). The 3GPP is one of those initiatives which is currently developing 5G standards to be included in the IMT-2020 family (3GPP, 2018b).

Interestingly, the LSA architecture has been subject to a standardization process, in particular with regard to the LSA Controller and the LSA Repository and their interfaces, to which both the ETSI and the 3GPP have been contributing (Mueck et al., 2015). The LSA repository and the LSA controller are two main functional blocks of the LSA architecture which would enable sharing between incumbent and new users (CEPT, 2014b). The LSA Repository would contain information provided by the incumbent users on their spectrum usage and requested level of protection. This geo-location database would work together with the LSA Controller, which would retrieve information on spectrum availability and access conditions from the LSA repository and grant permission to the new users to use the available spectrum accordingly (ETSI, 2013; Yrjölä et al., 2015). ETSI (2018) has recently suggested some enhancements of the LSA architecture to open up the LSA sharing framework to vertical sectors.

5.3. Type of usage rights

LSA was initially developed as a two-tier sharing framework, whereby incumbents and a limited number of new users, generally called LSA licensees, would be assigned individual spectrum rights of use, both groups of users being entitled to exclusive access to a portion of spectrum at a given time and location (CEPT, 2014a; RSPG, 2013). Geographical sharing would be realized where incumbent users only operate in certain geographic areas, opening up opportunities for additional users to access the same frequency bands in other geographic areas. Similarly, time sharing would take place where incumbents only use their assigned spectrum at certain times. In this case, there might be possibilities for additional users to use the available capacity at other times (RSPG, 2013). The relationship between incumbents and LSA licensees can be seen as a nation-wide, long-term leasing relationship (Mueck et al., 2015), where incumbents lease part of their spectrum to new users, while maintaining long-term control over their spectrum (Massaro, 2017).

The applicability of the LSA sharing framework to support 5G use cases in vertical industries is calling for the introduction of a third tier of users. In addition to incumbents and a second category of nationally licensed users, typically Mobile Network Operators (MNOs), spectrum would also be shared with industry players, each responsible for their own private network or third-party service providers which would run several private networks, in specific geographical areas.

According to ETSI (2018a: 16), this third category of users would require access to the spectrum resource in geographically limited areas, for a variable period of time, not necessarily long-term. These users will need exclusive access to spectrum, which is considered necessary to meet the requirement of predictable levels of Quality of Service (QoS), excluding licence-exempt spectrum use (ETSI 2018a: 16). MNOs may play the role of service providers for vertical sector players (Huawei, 2018). Alternatively, MNOs may sublease their spectrum for the operation of local wireless networks. An additional scenario would be to license spectrum directly to new service providers, which will then develop their own private local high-quality wireless networks, without the involvement of MNOs. Enterprises in vertical industries seem to be particularly interested in having dedicated spectrum without the need to request MNOs to lease spectrum (Huawei, 2018: 7). In all scenarios considered, this third category of users would be granted individual licenses with exclusive access to the spectrum resource, although geographically limited, guaranteeing predictable QoS at all layers (GSA, 2017; ETSI, 2018a; Yrjölä and Kokkinen, 2017).

In order to support the introduction of a third category of vertical sectors players, ETSI (2018a) has recently suggested some enhancements of the LSA architecture, in particular of the LSA repository and the LSA controller. The LSA architecture was originally developed to allow incumbents and LSA licensees acting as MNOs to share spectrum according to predefined rules which ensure protection from harmful interference and the possibility to provide guaranteed QoS to both groups of users. The LSA repository and the LSA controller are the two functional blocks which would enable such sharing arrangements (CEPT, 2014a). The LSA repository would contain information provided by the incumbent users on their spectrum usage and requested level of protection. This geo-location database would work together with the LSA controller, which would retrieve information on spectrum availability and access conditions from the LSA repository and grant permissions to LSA licensees to use the available spectrum accordingly (ETSI, 2013; Yrjölä et al., 2015).

An evolved LSA (eLSA) system architecture is under development to allow licensed sharing between incumbents, nationally licensed MNOs and local and temporarily-flexible vertical players (ETSI, 2018a; ETSI, 2018b). eLSA differs from LSA in that it allows the spectrum resource to be shared by three groups of users. In addition to incumbents and MNOs, a third group of users supporting the vertical industries would access the spectrum on a short-term basis and in geographically limited areas (ETSI, 2018a). eLSA seems to be taking some distance from its predecessor LSA, moving closer to the CBRS (Marti, 2018). ETSI is planning to automate the management of the spectrum resource by making the LSA architecture able to process the requests of vertical players to access a certain amount of spectrum, in specific geographical areas and for a limited period of time, and to check corresponding availability of spectrum (Marti, 2018; ETSI, 2018a).

5.4. Type of assignment procedure

In the context of 5G, ETSI highlights the necessity to implement a simple assignment procedure which would be able to handle a high number of licensees (ETSI, 2018a). Although trials have been carried out in several EU countries, the LSA sharing framework has not been implemented yet (CEPT, 2019). In particular, there is still no clear understanding as to how usage rights would be awarded. Although auctioning licenses to new users has been proposed (Marsden and Ihle, 2016), it may also be the case that licenses will be awarded by administrative means (Massaro, 2017), as auctions generally sustain the existing market structure, if pro-competitive measures are not in place to foster competition (Cramton et al., 2011).

6. The CBRS spectrum sharing framework

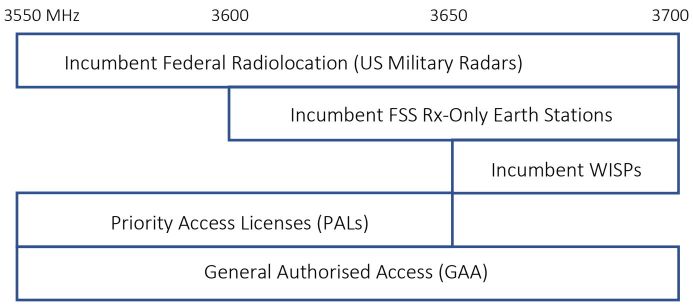
This section mirrors the previous one, applying the four-step decision-making guide described in section 4 to the CBRS sharing framework.

Under the CBRS, the 3.5 GHz band is a three-tiered spectrum sharing space (see Figure 1) with federal aeronautical users, non-federal FSS, and WISPs,[1] which occupy the upper Incumbent Access (IA) tier; critical access users like hospitals, utilities and governmental users and noncritical users e.g. mobile network operators,

[1] FCC's decision ruled that no more WISPs licenses would be issued. Furthermore, as WISPs lose their incumbency status in 2020, they are expected to relocate in the band as lower tier users.

would feature in the second tier and will be known as Priority Access Licensees (PALs). and General Authorised Access (GAA) devices in the bottom tier. Figure 1 shows the band sharing scheme in the CBRS sharing framework.

Figure 1. The CBRS sharing framework
Source: CBRS Alliance, 2018



Access and use coordination are mediated and controlled by a Spectrum Access System (SAS), an automated frequency coordinator, owned and operated by an independent third party. A SAS determines the available frequencies at a given location to be assigned to CBRS devices and the maximum permissible radiated transmission power level (Senza Fili, 2017). The SAS registers and authenticates the identification information and location of CBRS devices, enforcing exclusion zones to protect incumbent operations. It also protects PAL licensees from GAA users' potential interference from their opportunistic use of the spectrum (Yrjölä et al., 2015). Information needed for such assignments will be provided by an approved Environmental Sensing Capability (ESC), a system capable of detecting and informing of the presence of signals from incumbent users to a SAS. The ESC component is associated to the SAS geo-location database to dynamically determine spectrum availability for GAA users when no primary signals are detected (Cave and Webb, 2015; ITU, 2012b). As of early 2020, the FCC had approved five Spectrum Access Administrators to begin their initial commercial deployments and approved three ESC Sensor registrations[2] (FCC, 2020).

6.1. Frequency Harmonization

In its 2012 Order, the FCC announced the creation of the CBRS in the 3550-3650 MHz band, later extended to 3700 MHz in a 2014 ruling (FCC, 2014). At the time, the 3400-3600 MHz band had already been identified for IMT in ITU Region 1 and several countries in ITU Region 3. In ITU Region 2, which covers the US, the 3500-3700 MHZ band had been allocated to FS, FSS and the mobile service on a primary basis, and radiolocation services on a secondary basis (ITU-R, 2016). The terms under which the CBRS was created faced changes due to the pressure exerted by CTIA (CTIA-The Wireless Association) and T-Mobile in 2017. The FCC argued that changes to existing conditions were necessary to "maintain U.S. leadership in the global race for 5G" (FCC, 2017b). It was then clear that over recent years throughout the world the 3.5 GHz band had started to play a significant role as a core mid-range band for 5G, and a range of countries were discussing making the band available for 5G. Consequently, in 2017 the FCC reopened the study of the conditions for the CBRS, releasing a decision on new conditions in late 2018.

6.2. Technology Standardization

The CBRS sharing framework is technology agnostic. In fact, its success will depend on the variety and breadth of the devices that will use the spectrum..

[2] The approved SAS are: Google, Federated Wireless, Amdocs, CommScope and Sony. The approved ESC registrations were issued for Google, Federated Wireless and CommScope.

6.3. Type of usage rights

The right a device has to operate in the CBRS band depends on the tier to which it belongs. The choice FCC made with regard to the type of usage rights to be granted combines incumbent protection, licensed access and opportunistic access.

In particular, the FCC envisions different forms of usage rights for PAL and GAA users. Incumbents have the highest priority and their exclusive access is granted regardless of other types of users that may need to use the band. PALs' use of the band is also granted via licensed access. GAA devices can use up to 100 MHz of spectrum on an opportunistic basis, which basically allows them dynamic access when the spectrum is not used by primary users (Cave and Webb, 2015).

Access and use coordination are mediated and controlled by SAS. The SAS coordination mechanism will provide incumbent users with protection from interference potentially caused by lower tier users. The SAS registers and authenticates the identification information and location of CBRS devices, enforcing exclusion zones to protect incumbent operations. It also protects PAL licensees from GAA users' potential interference. While incumbent have the highest priority and their access is granted regardless of other types of users that may need to use the band, the SAS determines when the GAA device can opportunistically access the band (Yrjölä et al., 2015). The ESC component is associated to the SAS geo-location database to dynamically determine spectrum availability for GAA users when no primary signals are detected (HTNG, 2018). SAS also dynamically allocates 10-MHz channels to those PALs that hold licenses to the CBRS.

6.4. Assignment procedure

FCC's Auction 105, scheduled for mid-2020, will assign up to 70 MHz of the 150 MHz in the CBRS band to PALs. The original FCC ruling stipulated conditions for the license terms and renewal of PALs, geographic license areas, and some specific auction rules (FCC, 2015). What was understood to be a final ruling turned into a yearlong dispute between the mobile cellular sector and the wireless internet service providers. In mid-2017, the FCC accepted a petition submitted by CTIA and T-Mobile in which several changes were proposed to the original rules on PALs. In essence, the challengers sought longer license terms, renewal of PALs, larger geographic license areas, and changes to some of the proposed auction rules. The petition mainly sought to minimise the risk to their investments. In late October 2018, finding a middle ground the FCC ruled that the geographical area a single PAL would cover would be a county, the PAL term would be ten years with licenses being renewable, and up to seven PALs would be available in each license area (FCC, 2018).

The 2015 rules had established a three-year license term for PALs at the end of which the license would expire with no renewal. However, the initial application allowed applicants to apply for up to two consecutive three-year terms for a given PAL. Lastly, the geographical area that a license would cover would be a US census tract. The original rules also established that up to 70 MHz, initially to be subdivided into 10-MHz blocks, wold be assigned to PALs with the remaining portion of the band available for GAA users. In areas with no incumbents and where no PAL operated, GAA users would have the full 150 MHz available. In addition, on a given geographical area, when "mutually exclusive" applications for PALs that exceeded the block availability were filed, the FCC would use auctions. When two or more applicants sought to obtain PALs in a given area, the FCC would make available one less PAL than the total number of PALs in that area, up to a maximum of seven with an auction following. When there is only one applicant, no PALs will be assigned in the area. The FCC's 2018 ruling (FCC, 2018) the new PAL coverages area, a county, the new PAL term, ten years with licenses being renewable, and the limit on the maximum number of PALs in a county, seven. Also, PAL would face end-of-term performance requirements. The ruling also would allow for partitioning and disaggregation of PALs, facilitating transmission over wider channels.

7. Discussion

The LSA and the CBRS sharing frameworks reveal similar degrees of consideration and assessment of the four criteria to design spectrum management approaches, based on the work developed by Pogorel (2007). The paper's findings are summarised in Table 3 and further discussed below.

	Frequency harmonization	Technology standardization	Usage rights	Assignment procedure
LSA	Yes	Technology neutrality	Easements	Administrative Market-based
CBRS	Yes	Technology neutrality	Easements	Market-based

Table 3. The decision-making criteria in the two selected cases

European institutions conducted extensive work to guarantee harmonization of frequencies where implementation of the LSA was sought. Harmonised technical and regulatory conditions, as well as operational guidelines, have been developed by the CEPT to support European countries in the implementation of the LSA sharing framework first in the 2.3 GHz band and then in the 3.4-3.8 GHz GHz band, both bands allocated to mobile services and identified for IMT in Europe.

The US took a slightly different approach towards frequency harmonization. Although conforming to the WRC 2007 designation of the 3500-3700 MHz band in ITU Region 2, the US embraced a recommendation that sought to expand the availability of spectrum access via spectrum sharing (PCAST, 2012). This was preceded by the FCC's 2005 ruling that allowed WISPs to exploit the segment 3650-3700 MHz, which would then be shared with military uses. As a result, the US embarked in a pioneering experiment that culminated in the 2015 decision that created the CBRS band. Backpedalling its decision two years later due to the expressed manifestation of the mobile cellular industry, the FCC's modification of the original conditions for the CBRS exemplifies the conflict likely to arise between harmonization and innovation. While pushing for an environment that would incentivize innovation, the FCC seemed to stand oblivious to developments occurring in other parts of the world, whereby the 3.5GHz band was being shaped as the most prominent 5G mid-band. In its 2017 ruling, which substantially modified basic aspects of the CBRS market design, the FCC openly stressed that its decision would "foster an investment environment for the band to flourish in the US, as other nations target these frequencies for 5G and next-generation technologies" (FCC, 2017b).

Both the LSA and the CBRS sharing frameworks are technology neutral. However, mobile standards are considered crucial elements to guarantee interoperability between devices and all the different parts of the mobile network infrastructure (Tadayoni et al., 2018). For this reason, it is expected that the implementation of these sharing frameworks will include the use of recognised mobile standards, such as those officially approved by the ITU and included in the IMT standard families. Mobile networks generally combine different mobile technologies. In particular, 4G and 5G technologies are expected to coexist in the future (Kalliovaara et al., 2018). Technology standardization has been also important with respect to the development of the LSA and CBRS architectures, including various components, functionalities, interfaces and protocols (Mustonen et al., 2017). These standardization activities play a crucial role in creating business opportunities and, therefore, in guaranteeing the commercial success of sharing arrangements.

Determining the optimal usage rights for a given band is a very challenging issue. Both the LSA and the CBRS sharing frameworks seek to open the spectrum to new players by restricting incumbents' exclusive access, taking advantage of advanced technologies which enable a dynamic use of the spectrum resource. In the case of the LSA, incumbents' licences may be understood as property rights with easements, where incumbents maintain access to the assigned frequencies, while, at the same time, other users are granted easements to use the same frequencies, making sure not to cause interference. While generally understood as tools to enable secondary unlicensed use, easements take the form of individual licences in the context of the LSA framework. New users would be granted individual licences to access certain frequencies according to sharing conditions agreed upon together with the incumbents and approved by the NRA. Even in the event of a third category of wireless network providers to support vertical industry players, the spectrum would be sub-licensed, granting individual licences on a sub-national basis, providing exclusive spectrum access to limited geographical areas.

In the CBRS sharing framework, usage rights depend on the tier to which the spectrum user belongs. Incumbents will possess property rights with easements, these easements being individual licences in the case of tier-2 users and spectrum commons in tier-3. The mix allows tiered usage rights that protect higher-tier users from interference originated in transmissions from lower-tier users. As cellular operators seek to become tier-2 users or PALs in order to provide 5G services, the traditionally held spectrum exclusivity will no longer be a characteristic of their operation on the CBRS band. To be fair, largely extended parts of the continental US will pose no problem to a tier-2 user, as tier-1 users are absent. WISPs in the US have been putting up a fight against their removal from incumbency in the upper part of the CBRS band but their migration to the lower tiers is imminent. The new conditions brought about by the FCC's 2018 order are now more favourable to traditional cellular operators. They have also reduced the complexity of the sheered number of licenses that the original ruling had envisioned. The latter also softens the burden that a large number of licenses would have imposed on the SAS.

Regarding assignment procedures, major telecommunications providers, in particular cellular giants, are keen on keeping the status quo represented by auctions. They vie for auctions, mainly due to the experience already gained on previous assignment procedures of such kind, their financial muscle, and the fact that most auctions have assured exclusivity in the exploitation of the radio spectrum. Both regulation and technology are making progress towards facilitating spectrum sharing and with it moving the use of spectrum towards higher efficiency. Perhaps the major question is who is to obtain usage rights in the context of 5G. Given the rising pressure exerted over existing spectrum in most countries, the adoption of a market mechanism able to remove the spectrum sharing question off the NRA's shoulders and pass it on to the market needs be seriously considered.

8. Final Remarks

This paper discussed two spectrum management frameworks, the LSA the CBRS, which may open up opportunities for various spectrum-sharing scenarios. These frameworks, originally intended for accommodating the increasing demand for spectrum from mobile communications providers, have been subjected to pressing interests emerging from the fast pace with which 5G standards have been agreed and its technological manifestations favoured. In particular, sharing frameworks such as the LSA and the CBRS may facilitate rapid access to sub-6 GHz bands, currently occupied, but not fully utilised by incumbent users, for the provision of eMBB and mMTC, the latter including IoT and mission critical technologies that support operations in a wide range of industries.

Recent developments in the American market signal so. A strong response from parties registering their interest in Auction 105 (CBRS PAL auction) with FCC (April 2020); the approval and initial deployments of 5 SAS and 3 ESCs (second half of 2019); announcement by the CBRS Alliance to incorporate 5G into the CBRS standards for the 3.5 GHz band (February 2020); and the FCC announcement that CBRS GAA is authorized for full commercial deployment (Early 2020). The latter means bandwidth availability for mobile devices in closed spaces, such as buildings, and public spaces, such as stadiums, regardless of whether the spectrum operator is a mobile operator or any kind of private company (Blackman, 2019).

Technically and economically attractive and outside the realm of mobile network operators, the designation of the entire 150 MHz in the CBRS band as unlicensed spectrum for tier-3 users provides the conditions for private networks to flourish. In particular, enterprise coverage and neutral host can find in the GAA tier of CBRS the necessary capacity to leap over the limitations that current Wi-Fi enterprise networks are reaching. Industry analysts and entrepreneurs alike confidently signal at LTE and 5G NR indoor and outdoor coverage on enterprise buildings, high QoS network for mission critical needs, and high-security networks as innovative business models in the new ecosystem. Be it the deployment of new 5G NR or the co-existence of LTE and 5G NR, these moves represent the embodiment the principles that sustain the introduction of CBRS, which have sought to provide higher bandwidth availability in low use bands by means of an innovative mixed licensing scheme and an spectrum access controller. . As such unlicensed spectrum scheme begins to realise its potential, CBRS awaits the intricate auction process for PALs in the second half of 2020, which will take to completion the assignment stage of the CBRS buildout. The conjunction of policy, regulatory decisions, and market response and participation presage CBRS will be an essential platform for the introduction of 5G services in the US. .

Quite different is the situation in Europe. The LSA sharing framework proved to be poorly successful among European countries, notwithstanding the extensive work carried out by the EU, the CEPT and the ETSI (CEPT, 2019). Limited national achievements may be due to the fact that LSA was essentially created to operate in the 2.3 GHz band to find additional shared spectrum for existing MNOs, whereas MNOs are generally not interested in shared spectrum (Marti, 2018), exclusive access considered by them as the only way to guarantee predictable QoS (Mumford, 2017). Other use cases for LSA were not foreseen (Marti, 2018).

Only recently, LSA has been proposed as a suitable sharing framework to support 5G use cases in the so-called vertical sectors, with a particular focus on the C-band. The provision of services is expected to take place with or without the involvement of existing MNOs. In the first scenario, MNOs would either directly provide services to vertical players or lease spectrum to new providers, also granting access to their infrastructure in the case of new providers not owning network resources. In the second scenario, new providers would directly be assigned the radio spectrum and build their own private networks.

As matters stand, implementation of the LSA in the C-band for the provision of 5G services in vertical industries is open for discussion. The scenario where radio spectrum would be reserved to verticals is highly discouraged by existing MNOs, which claim that radio spectrum may end up being underutilised. MNOs consider themselves as "the best placed to provide the wide variety of services envisaged" (GSMA, 2019: 3). Regardless of where MNOs stand, reserving spectrum for verticals remains a national decision. In this regard, the added value of using LSA seems to be unclear to NRAs in Europe.

Several European countries have already auctioned the C-band or plan to conduct auctions in the near future (Leins, 2018; European 5G observatory, 2019). In Sweden, PTS appears hesitant to implement LSA in the C-band portion between 3.7-3.8 GHz because incumbents may be unwilling to share certain information on their spectrum use to be included in the LSA repository. Instead, PTS is considering setting aside radio spectrum for verticals in the C-band for local use, while maintaining incumbents in the band (PTS, 2019). Ofcom, the UK national regulator, has decided to auction the band portion between 3.6-3.8 GHz to provide national mobile broadband in the UK (Ofcom, 2019). It has also decided to reserve the 3.8-4.2 GHz band for local private use (Marti, 2019). Although there will be a need to ensure that incumbents using the same portion of the C-band will not suffer from harmful interference, Ofcom does not show a particular interest towards LSA. Ofcom plans to adopt an approach whereby access to spectrum is granted on a first-come-first-served basis, allowing as many local users as possible to use the band, technically coordinated by Ofcom (Ofcom, 2019).

While existing MNOs have expressed their concern with regard to set-aside spectrum, they seem to be willing to lease spectrum to verticals who want to build their own network or to third service providers which would provide networks and services for vertical industries (GSMA, 2019). If NRAs decide not to set aside spectrum, they need to consider that currently leasing is quite unpopular. Although studies suggest that leasing will become key in the 5G era, turning spectrum in an "easily tradable commodity" (ABI research, 2019), it is unclear how functioning secondary markets will emerge, considering that secondary markets for spectrum rights of use have been quite unsuccessful in Europe.

Overall, the implementation of the LSA appears to be unlikely because MNOs are not willing to share spectrum with incumbents. Although an interest seems to emerge towards easements in usage rights, it is clear that cellular incumbents very much prefer the award of exclusive rights. It has been stated quite forcefully by MNOs that availability of large contiguous spectrum blocks is critically important for the efficient introduction of 5G services. MNOs claim that exclusive access to radio spectrum should be granted by assigning licences for exclusive use (Huawei, 2018, GSMA, 2019). MNOs expect that spectrum bands which have been identified for 5G use will be re-farmed, migrating incumbents to other parts of the radio spectrum (GSMA, 2019).

CBRS is currently being implemented whereas LSA is still being held up, notwithstanding the similarities between these two frameworks with respect to the four areas of spectrum management considered. This suggests that the successful implementation of spectrum sharing frameworks depends not only on their inner characteristics, but also on other elements. An interesting aspect which deserves further attention is the regulatory powers of the institutions involved in radio spectrum management. Unlike the FCC, European bodies such as the CEPT and the EU institutions, have no coercive and enforcement powers, playing a mere advisory and coordinating role when it comes to sharing approaches. Although spectrum sharing has been praised as essential for 5G, actual implementation of the LSA sharing framework in the C-band in Europe remains a national decision. In this regard, European NRAs have shown limited interests towards the LSA in the context of 5G.

A comparative analysis of LSA and CBRS allows the authors to reach the conclusion that while LSA and CBRS are in principle very similar, they differ in terms of degree of implementation. A reflection that can be made on this conclusion is that while the frameworks are similar, the institutions which take decisions related to spectrum management have different regulatory powers in US and Europe. Further research should be conducted to investigate how the institutional and regulatory context in the US and Europe differ and to what extent that can have an impact on the implementation of spectrum sharing frameworks.

This paper highlights how recent regulatory activities in Europe made LSA much similar to CBRS. Nevertheless, LSA seems not to have reached an implementation phase, contrary to CBRS. In this regard, a reflection is made on why CBRS seems to be more successful than LSA, focusing on the different regulatory powers that European and US institutions possess. The question that is raised is whether the fact that European institutions have no coercive power impacts on the degree of implementation of LSA at national level.

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