Spectrum sharing frameworks for temporary, dynamic, and flexible spectrum access for local private networks

1st Edition – June 2023

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Executive Summary

The present White Paper provides information on use cases of vertical sectors with specific characteristics of spectrum usage and access, such as audio Programme Making & Special Events (audio PMSE), wireless industrial automation, Public Protection & Disaster Relief (PPDR), and drone control and payload, and introduces various standardized spectrum sharing frameworks that are based on data base architectures, such as Licensed Shared Access (LSA), evolved Licensed Shared Access (eLSA), Automated Frequency Coordination (AFC), and Citizens Broadband Radio Service (CBRS).

This White Paper furthermore analyses gaps of the existing solutions that limit the usability of the use cases mentioned above.

After an extraction of the most challenging use case parameters and a comparison of all sharing frameworks against it, the present document summarizes the following features which need to be supported by a sharing framework for temporary and flexible spectrum access, namely:

- ensuring incumbent protection and inter-system coordination between secondary users,
- allowing for usage independent of specific frequency bands and RF technology, and
- introducing a high degree of flexibility and scalability to adapt to the specifics of the frequency bands, incumbents, and secondary users,

and proposes to develop envisaged adjustments for AFC, eLSA, and CBRS (adding, removing, and/or modifying features) as a next step to address the above-mentioned gaps.

Abbreviations

5G	5th Generation technology standard for broadband cellular networks
AFC	Automated Frequency Coordination
AP	Access Point
BVLOS	Beyond Visual Line Of Sight
CBRS	Citizens Broadband Radio Service
CDMA	Code Division Multiple Access
DCS	Dynamic Channel Selection
DECT	Digital Enhanced Cordless Telecommunications
DFS	Dynamic Frequency Selection
DoD	Department of Defence
EIRP	Effective Isotropic Radiated Power
eLSA	evolved Licensed Shared Access
FR1	Frequency Range 1
FR2	Frequency Range 2
FSS	Fixed Satellite Service
GAA	General Authorized Access
IEM	In Ear Monitor
IMSI	International Mobile Subscriber Identifier
IMT	International Mobile Telecommunications
IoT	Internet of Things
IPRM	public Integrated, Private Mobile/Fixed communications network
ISM	Industrial Scientific Medical
KPI	Key Parameter Indicator
LBT	Listen Before Talk
LOS	Line Of Sight
LSA	Licensed Shared Access
MAC	Medium Access Control
MFCN	Mobile/Fixed Communications Network
MNO	Mobile Network Operators
NRA	National Regulatory Administration
PAL	Priority Access Licenses
P-MFCN	Public Mobile/Fixed Communications Network
PMSE	Programme Making & Special Events
PNO	Private Network Operator
PPDR	Public Protection & Disaster Relief
QoS	Quality of Service
RAT	Radio Access Technology
RF	Radio Frequency
RLAN	Radio Local Access Network
SAS	Spectrum Access System
SNPN	Standalone Non-Public Network
SP	Standard Power
SPRM	Standalone, Private Mobile/Fixed Communications Network
TC	Technical Committee
TV	Television
UAS	Unmanned Aerial Services
UAV	Unmanned Aerial Vehicles
UHF	Ultra High Frequency
VLOS	Visual Line Of Sight

1 Introduction

Exclusive spectrum access is the predominant paradigm for spectrum access and guarantees high spectral efficiency and easy network planification for services requiring constant access to radio spectrum. However, many services only need access to the medium in certain zones, time slots, and user densities leaving spectrum underutilized. These services often use local private wireless networks.

As demand for local private wireless networks increases and regulators have begun to identify frequency bands for vertical use, appropriate spectrum sharing frameworks need to be adjusted to meet the specific needs of private networks with the goal of sharing the spectrum efficiently and to significantly simplify handling for the end user.

Depending on the nature and the characteristics of the local private wireless network, automatic, temporary, and flexible spectrum access can be a key component for efficient spectrum sharing as well as user-friendly operability. The term "local private wireless network" refers both to wireless broadband connectivity controlled and managed by a private organization and to a network with special characteristics and a high level of Quality of Service (QoS). Similar to a public network, a private network needs access to spectrum. This white paper focuses on access to temporarily licensed shared spectrum for local private networks. To optimize efficiency of spectrum sharing and support flexibility and high dynamic spectrum demand, the spectrum access procedure should be automated and reflect the different use case characteristics and levels of QoS.

The objective of this White Paper is threefold:

- Identify the use cases that require local private networks,
- Discuss existing spectrum sharing frameworks, and
- Analyze these sharing frameworks with respect to their suitability for the use cases described and for flexible and temporary local private networks.

This White Paper is a result of a collaboration between the Technical Committee Reconfigurable Radio Systems (TC RRS) of ETSI and the Wireless Innovation Forum (WInnF). It represents a summary of the two deliverables: ETSI TR 103 885 [1] and WINNF-TR-2011 [2]. Both organizations are working or have been working on spectrum sharing topics but in different regions of the world and with different objectives: TC RRS in Europe on Licensed Shared Access (LSA) and evolved Licensed Shared Access (eLSA), WInnF in the United States on Citizens Broadband Radio Service (CBRS) and Automated Frequency Coordination (AFC). To combine the expertise of both organizations and to evaluate spectrum sharing frameworks for local private networks, this cooperation has been initiated.

2 Use cases and their requirements

This clause analyses the needs and characteristics of selected vertical sectors that deploy local private networks, such as the Culture and Creative Industry, especially audio Programme Making & Special Events (audio PMSE), Wireless Industrial Automation, Public Protection & Disaster Relief (PPDR), and Drone control and payload. Each use case is characterized based on the parameters listed in **Error! Reference source not found.**.

Table 1: Description of use case parameters

Parameter	Description	Range of values
Deployment	The way the infrastructure is installed/used	Fixed: infrastructure is fixed installed, nomadic: infrastructure can be moved but is fixed during operation, mobile: infrastructure can be moved during operation
QoS levels	The specific KPIs of the use case	Various values
Radio Access Technology (RAT)	The kind of RAT which exists for the specific use case	Standardized, proprietary
Network architecture	The way the network is built to support the use case	P-MFCN: public MFCN SPRM: standalone, private MFCN IPRM: public integrated, private MFCN
Network coverage	The area where the service is available	Local, national, transnational, worldwide
Usage period	The overall time the use case occupies the spectrum	Various values
RF channel holding time	The time during which the RF channel is used continuously without free time slots for system adjustments, e.g., frequency change	Various values
Spectrum access mode	The way in which spectrum access is provided	Planned: a certain period between license application and operation ad-hoc: spontaneous, short-term operation
Spectrum access	The way/process how the spectrum is accessed	License-exempt; licensed: shared and coordinated, licensed: shared and non-coordinated, licensed: not shared
Spectrum bands	The frequency bands in which the service/use case is available	Various values
Spectrum demand	The total amount of spectrum needed for the use case	Various values

According to CEPT, the term "MFCN" (Mobile/Fixed Communications Network) includes International Mobile Telecommunications (IMT) and other communication networks in the mobile and fixed services [3]. A Public MFCN (P-MFCN) refers to a communication network for the specific purpose of providing data transmission services for the public, whereas a private MFCN describes local networks where restrictions and access rules are established in order to relegate access to a select few. Private MFCNs can be separated into:

- SPRM: standalone, private MFCN without any connection to a P-MFCN,
- IPRM: private MFCN which is integrated into and managed by a P-MFCN.

As an explicative example, a SPRM based on 5G is called Standalone Non-Public Network (SNPN).

Depending on the use case, the values in the following tables represent the state of the art and/or future realizations.

2.1 Audio Programme Making & Special Events (audio PMSE)

Programme Making and Special Events (PMSE) is a term summarizing front-end wireless applications used to support broadcasting, news gathering, audio and video production for film, theatre, and music, as well as special events such as sport events, culture events, conferences, and trade fairs. In general, PMSE equipment is divided into:

- video PMSE: wireless cameras,
- audio PMSE: wireless microphones, In-Ear Monitor systems (IEM), talkback, and

- service PMSE: wireless light and effect remote controls.

The individual user of audio PMSE equipment configures a system according to the actual needs of the production with careful consideration of the link budget, i.e., number of audio links, the needed QoS for each audio link, RF environment, production/stage setup and location. Available spectrum at a location has a major impact on the possible number of wireless microphone and IEMs. A lack of spectrum restricts the size and quality of the overall audio production. Usually, the use of audio PMSE frequencies in and around a location site is known. With these considerations and the observed use of radio spectrum the 'worst case' scenario of all equipment being in use can be assessed and calculated. This allows to establish a controlled interference scenario even in hotspot areas with dense audio PMSE use.

Audio PMSE equipment operates on a free tuning range concept. A tuning range is the frequency range in which equipment is able to operate. Within this tuning range, the audio PMSE equipment will be operated in accordance with the related national regulatory conditions.

Error! Reference source not found. summarizes characteristics of two different audio PMSE use cases, the live audio production use case that reflects all kinds of production scenarios on stages, in studios, in sports arenas, etc., and the Electronic News Gathering (ENG) use case, which describes a very spontaneous use in sudden events.

Table 2: Characteristics of two different audio PMSE use cases

Parameter	Live Audio Production/Special Events		ENG
Deployment	Nomadic	Fixed	Nomadic; mobile
QoS levels	Very high reliability; ultra-low latency	Very high reliability; ultra-low latency	High to very high reliability; low latency
RAT	Proprietary	Proprietary	Proprietary
Network architecture	SPRM	SPRM; IPRM	SPRM; IPRM; P-MFCN
Network coverage	Local	Local	Local; transnational
Usage period	Few days to several weeks	Few to several months	Few hours to few days
RF channel holding time	6h to 12h	6h to 12h	2h to 6h
Spectrum access mode	Planned	Planned	Planned; ad-hoc
Spectrum access	License-exempt; licensed: shared and coordinated; licensed: shared and non-coordinated	License-exempt; licensed: shared and coordinated; licensed: shared and non-coordinated	License-exempt; licensed: shared and coordinated; licensed: shared and non-coordinated
Spectrum bands	Today, TV UHF spectrum from 470 MHz to about 900 MHz		
Spectrum demand	Medium to high	Medium to high	Low

2.2 Wireless industrial automation

The manufacturing industry is currently subject to a fundamental change [4], which is often referred to as the "Fourth Industrial Revolution" or simply "Industry 4.0" [5]. The main goals of Industry 4.0 are-among others-the improvement of flexibility, versatility, resource efficiency, cost efficiency, worker support, and quality of industrial production and logistics. In order to realize this vision, numerous sensors and actuators are connected to each other and to their control unit wirelessly. This fourth industrial revolution will apply digital transformation to industrial production via enterprise-wide networks to capture data from and to exchange data between machines, devices, and people ([6] and [7]).

By using the Internet of Things (IoT) and cyber physical systems, conventional production will be transformed into a network of smart and interconnected devices. These devices and systems are going to improve flexibility, versatility, usability, and efficiency of future manufacturing [5]. By using communication networks, production cells will evolve into ecosystems sharing data for enhanced decision making and resource-efficient production. Further, data communication between devices, factories and suppliers will increase flexibility, enabling mass customization to meet customer needs in terms of quantity, quality, design, and configuration. Among several different application areas, two industrial automation areas [4] of paramount importance are:

- Factory automation: automated control, monitoring and optimization of processes and workflows within a factory,
- Process automation: process automation is the control of production and handling of substances like chemicals, food & beverage, pulp, etc.

Table 3 summarizes characteristics of some wireless industrial automation use cases.

Table 3: Characteristics of wireless industrial automation use cases

Parameter	Factory automation Motion control	Factory automation Control-to-control communication	Process automation Closed-loop control
Deployment	Fixed	Fixed	Fixed
QoS levels	Ultra-high service availability; very low latency	Ultra-high service availability; low latency	Ultra-high service availability; low to moderate latency
RAT	Standardized; proprietary	Standardized; proprietary	Standardized; proprietary
Network architecture	SPRM; IPRM; P-MFCN	SPRM; IPRM; P-MFCN	SPRM; IPRM; P-MFCN
Network coverage	Local	Local	Local
Usage period	Several years (lifetime)	Several years (lifetime)	Several years (lifetime)
RF channel holding time	24h	24h	24h
Spectrum access mode	Planned	Planned	Planned
Spectrum access	To be defined	To be defined	To be defined
Spectrum bands	ISM; 3,7 GHz - 3,8 GHz; FR1: 450-6000 MHz; [FR2: 24.25-52.6 GHz]		
Spectrum demand	To be defined	To be defined	To be defined

2.3 Public Protection & Disaster Relief (PPDR)

Public Protection and Disaster Relief (PPDR) communications are designed to respond to disaster and emergency situations. They are activated during emergency cases such as fire outbreak, terrorist attack, flooding with the goal of distributing emergency warnings to citizens, coordinate first response teams, improve deployment of police forces, monitor the emergency situations.

Whereas PPDR spectrum access can be considered a (hopefully) rare event, it is counterbalanced by rather large resource demands, since PPDR demands high QoS, in terms of throughput (video), latency (voice) and reliability (emergency messages).

While lower bands will need to continue to be allocated and used on a permanent basis for operational requirements, higher bands to provide capacity will be accessed in an opportunistic way and will be shared with other services. Administrations attentions at ITU levels have demanded for different spectrum portions to be allocated to PPDR. Given the impromptu spectrum access, the variability of the spectrum demands, and the non-homogeneous world-wide bands allocations, PPDR is a clear candidate use case for dynamic spectrum access features.

PPDR typical characteristics are listed in Table 4.

Table 4: Characteristics of PPDR use cases

Parameter	Emergency messages	Audio video (real time)
Deployment	Fixed; nomadic; mobile	Fixed; nomadic; mobile
QoS levels	Reliability; low latency	High throughput
RAT	Standardized	Standardized
Network architecture	SPRM; IPRM; P-MFCN	SPRM; IPRM; P-MFCN
Network coverage	Local; national; transnational	Local; national; transnational
Usage period	Few to several hours	Few to several hours
RF channel holding time	Few to several hours	Few to several hours
Spectrum access mode	Ad-hoc	Ad-hoc
Spectrum access	License-exempt; licensed: shared and coordinated; licensed: not shared	License-exempt; licensed: shared and coordinated; licensed: not shared
Spectrum bands	Parts of UHF below 1 GHz	FR1: 450-6000 MHz; FR2: 24.25-52.6 GHz
Spectrum demand	Low	High

2.4 Drone control and payload

Growing demands for Unmanned Aerial Vehicles (UAVs) and Unmanned Aerial Services (UASs) have resulted in a demand for spectrum to properly operate. UAVs can serve different purposes, from leisure to professional usage. Different purposes are characterized with various level of demands in terms of security and performance. One of the cornerstones for UAS success is risk management. Even if there is a consensus of the risk minimization in the UAS regulations, three is high variation in the national regulations and policies. The novel regulation adopted in Europe in 2020 introduced the proportional risk based UAS policy framework, defining open, specific, and certified operational categories. These different types of risks demand different types of performance from a network connection.

Drones can be operated in two modes: Visual Line Of Sight (VLOS), i.e. it exists a Line Of Sight (LOS)/direct connection between the control and the drone, and Beyond Visual Line Of Sight (BVLOS), i.e. there is no direct path between control and drone. In the latter case, both drone control channel and payload channel need specific connection with guaranteed QoS for e.g., large throughput or low latency. Guaranteed QoS can be obtained by dedicated spectrum allocated promptly when the drone is out-reaching.

Spectrum for drones communication can exploit four different approaches: unlicensed bands, dedicated spectrum, locally licensed or leased spectrum, and public mobile IMT bands (exploiting MNOs networks).

Unlicensed band (e.g., 2.4 GHz and 5 GHz bands) can be used for lowest risk operations but cannot guarantee neither performance nor connectivity due to the absence of harmful interference protection. For applications in which higher protection and QoS are necessary, dedicated spectrum is needed to deliver that guaranteed QoS for BVLOS operations.

Table 5 summarizes the characteristics of the drones control and payload use case.

Table 5: Characteristics of drones control and payload use case

Parameter	Drones control	Drones payload
Deployment	Fixed; nomadic; mobile	Fixed; nomadic; mobile
QoS levels	Reliability; low latency	Reliability; high throughput
RAT	Standardized	Standardized
Network architecture	SPRM; IPRM; P-MFCN	SPRM; IPRM; P-MFCN
Network coverage	Local; national; transnational	Local; national; transnational
Usage period	Few minutes to few hours	Few minutes to few hours
RF channel holding time	Few minutes to few hours	Few minutes to few hours
Spectrum access mode	Planned	Planned
Spectrum access	License-exempt; licensed: shared and coordinated	License-exempt; licensed: shared and coordinated
Spectrum bands	FR1: 450-6000 MHz	FR1: 450-6000 MHz; FR2: 24.25-52.6 GHz
Spectrum demand	Low	High

2.5 Minimum parameter set extracted from all use cases

From all above use cases the minimum parameter values are summarized in Table 6. It contains the most challenging value of each parameter. This parameter set is used for analysis and evaluation later in clauses 3 and 4.

Table 6: Minimum parameter set

Parameter	Value	Conclusion
Deployment	Mobile	The network cell/infrastructure moves during operation which needs to be considered depending on the sharing dimension.
QoS levels	• Ultra-high reliability • Ultra-high service availability • Ultra-low latency • High throughput	Not all QoS levels are needed simultaneously, but at least one. However, even to meet the strong levels of each QoS, the framework needs to guarantee free spectrum for a specific time. Reliability contrasts with low latency because, for example, frequency agility or data re-transmission are not easy or even impossible to implement. No use case can easily tolerate losing connection.
RAT	Both; proprietary and standardized	A technology neutral approach is needed, i.e., technology specific protocols are not the preferred solution.
Network architecture	SPRM	When using a P-MFCN, the operator is responsible for managing spectrum access. The user has direct responsibility for spectrum access and usage. The private network seems to be more suitable to meet the needed QoS levels and offers in addition isolation.
Network coverage	Local	The framework needs a high geographical scalability.
Usage period	Few hours	Spectrum assignment needs to be highly dynamic.

Parameter	Value	Conclusion
RF channel holding time	24 h	During that time, the system is not able to change its RF performance, e.g., its RF channel.
Spectrum access mode	Ad-hoc	The time a use case can wait before being assigned spectrum needs to be very short.
Spectrum access	Both: license-exempt, licensed	Both, licensed access and license-exempt access need to be supported.
Spectrum demand	High	Audio PMSE, for example, needs approximately 96 MHz in sub 1 GHz for daily use.

3 Analysis of available spectrum sharing frameworks

In this clause sharing frameworks are introduced and analyzed with focus on procedures that are technology agnostic and that are able to guarantee a predefined QoS level, in order to support different applications and network realizations. Therefore, sharing mechanisms that are based on technology specific protocols or are contention-based are not considered further. For example, Listen Before Talk (LBT), Dynamic Frequency Selection (DFS), Dynamic Channel Selection (DCS), and the like will not be covered in this white paper.

A detailed description of the parameters listed in Table 7 can be found in [1].

3.1 Existing spectrum sharing frameworks

3.1.1 (e)LSA

Licensed Shared Access (LSA) offers a complementary spectrum management tool to the existing spectrum release mechanisms such as re-allocation and clearing (see [8] – [10]). It fits under an individual licensing regime and aims to ensure a certain level of guarantee in terms of spectrum access and protection against harmful interference for both the incumbent and LSA licensees.

LSA focuses on nation-wide, long-term sharing arrangements between incumbents and LSA licensees. Within the national territory, the LSA system can establish the following different types of zones:

- exclusion zone: geographical area within which LSA licensees are not allowed to have active radio transmitters,
- protection zone: geographical area within which incumbent receivers will not be subject to harmful interference caused by LSA licensees' transmissions, and
- restriction zone: geographical area within which LSA licensees are allowed to operate radio transmitters, under certain restrictive conditions (e.g., maximum EIRP limits and/or constraints on antenna parameters).

Protection criteria and restrictive conditions are agreed between the LSA licensee/s and the incumbent under the oversight of the NRA. All zones are usually applicable for a defined frequency range and time period.

From a technological perspective, LSA is a centralized, coordinated approach to spectrum sharing which requires a central system element such as a database, that contains the operating parameters of the various systems (i.e., incumbents and LSA licensees), the environment, basic coexistence criteria, and a set of rules or models to apply these criteria to the various systems so that they can operate within acceptable levels of interference.

Evolved Licensed Shared Access (eLSA) is the further development of LSA (see [12] – [14]) to support the concept of local high-quality wireless networks as described in ETSI TR 103 588 [11]. This term is used to group together use cases that target local area services and require predictable levels of QoS, e.g., in vertical industrial sectors such as industrial automation, PMSE, PPDR and e-Health. Their need for predictable levels of QoS mostly preclude operation in a license-exempt spectrum, due to coexistence issues, and target exclusively licensed spectrum.

According to [12], local high-quality wireless networks refer to MFCNs (Mobile/Fixed Communication Networks) capable of supporting different use cases with the following common features:

- their operation is confined in a local geographical area,
- have short-term to long-term deployments,
- need predictable levels of QoS, particularly in terms of deterministic communication behavior, reliability, and latency, etc., and
- network infrastructure and management with a suitable combination of private and public networks for implementing specific security standards or due to privacy reasons.

The main advantage of eLSA over LSA is that it aims to ensure a predictable level of QoS at a defined location for all spectrum resource users, i.e., LSA licensees and incumbents. The LSA framework was designed to share spectrum resources between incumbents and LSA licensees acting as MNOs. The eLSA framework supports vertical local area service providers as a new type of LSA licensees, requiring more dynamic spectrum for very short- to long-term spectrum sharing with a predictable level of QoS.

3.1.2 Citizens Broadband Radio Service (CBRS)

The Citizens Broadband Radio Service (CBRS) band (3550–3700 MHz) is licensed spectrum that is coordinated, and interference managed through software automation providing deterministic spectrum access (see [16]).

CBRS uses a three-tiered sharing framework enabled by a Spectrum Access System (SAS), a centralized management system for spectrum that leverages sensor technologies (see Figure 1). The DoD (Department of Defense) radar system along with Fixed Satellite Service (FSS) at 3625-3650 MHz, and, for a finite period, grandfathered terrestrial wireless operations in the 3650-3700 MHz portion compose the highest tier of the sharing framework entitled "Incumbent" users. The second and third tiers encompass commercial services and are titled Priority Access Licenses (PAL) and General Authorized Access (GAA), respectively. The incumbents are protected from anybody else using the band.

Central role in allocating and vacating spectrum in the CBRS framework is assigned to the SAS. A SAS authorizes certain frequencies in any given location by the PAL or GAA. PALs are authorized to use a 10 MHz channel in a single county for ten years. PAL users will protect the incumbent system, and other PAL users, while being protected from General Access Authority (GAA) users. GAA users must protect both PAL and incumbent users but will receive no interference protection from other users in the band. Figure 1 depicts hierarchical structure of users in CBRS band. PAL users may be assigned in up to 70 MHz of the first 100 MHz portion of the band (3550-3650 MHz). However, the rule allows the GAA use over the entire 150 MHz band.

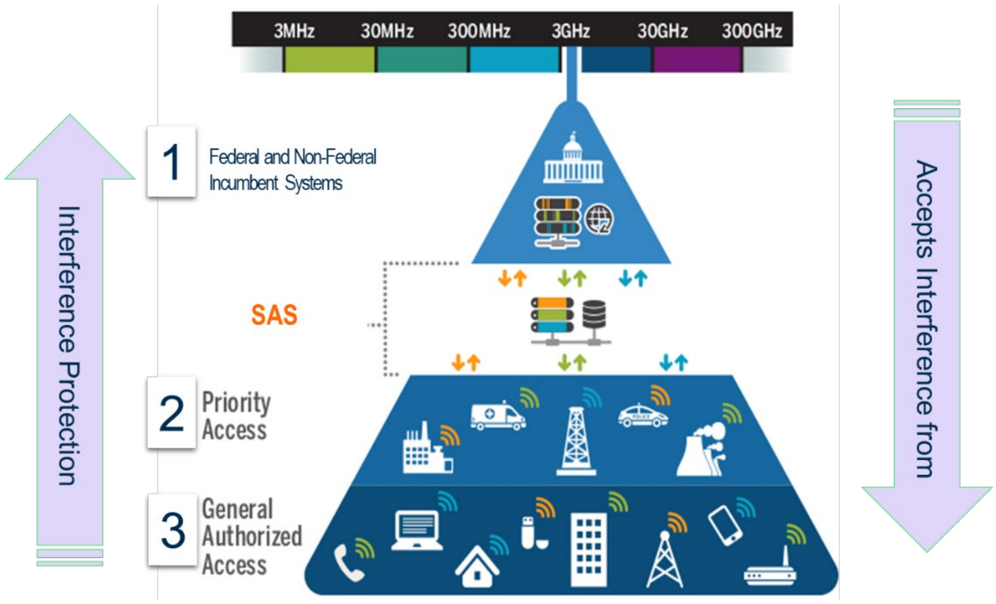

Figure 1: CBRS hierarchical architecture

GAA users are not entitled for interference protection from higher tier users in the band. However, to make the use of CBRS band efficient, SASs apply mechanisms to minimize or eliminate interference among co-channel GAA users. This process is called GAA Coexistence Management.

3.1.3 Automated Frequency Coordination (AFC)

Automated Frequency Coordination (AFC) enables unlicensed access to portions of the 6 GHz band by coordinating shared spectrum between Standard Power (SP) devices and incumbents, e.g., Fixed Microwave Fixed Satellite Service (FSS), which are mainly static.

AFC is mandatory for SP RLAN devices with transmission output power up to 4 W (36 dBm) in

- U-NII-5 and U-NII-7 (5925-6425 MHz and 6525-6875 MHz) in US,
- 5945-6425 MHz in Europe.

AFC is a centralized approach similar to SAS of CBRS and coordinates use of the 6 GHz spectrum according to regulatory rules/databases (see [15]). When deploying an AFC based network:

- SP access points (APs) must be capable of determining their geolocation automatically,
- SP APs must request a list of available channels from AFC every 24h,
- A channel availability request must include SP AP geolocation and vendor specific ID,
- AFC returns what is available at a given maximum output power and SP AP makes its own decision on operating channel and power, permissible power spectral densities and/or output power are determined from incumbent protection points inside uncertainty area and Radio Observatory and Border Protection constraints,
- SP AP does not report spectrum selected back to AFC, so AFC is not aware of the channel and operational power, and
- SP AP stops transmitting if it loses contact with AFC.

To protect the incumbents, each AFC calculates a protection zone in front of every incumbent's receiver which is based on the receiver antenna and the SP device output power.

AFC supports a two-tier model with incumbent (commercial and other non-federal incumbents) and unlicensed user without additional sensing requirements and inter-AFC coordination/synchronization.

3.2 Comparison of sharing frameworks

In Table 7 the parameters from the previous section are assigned to the respective framework for comparison purpose. A detailed description of these parameters can be found in [1].

Table 7: Comparison of (e)LSA, CBRS, and AFC

	LSA	eLSA	CBRS	AFC
Parameter:	**Value:**	**Value:**	**Value:**	**Value:**
Sharing dimension	- frequency - geography	- frequency - geography - time	- frequency - geography - time	- frequency - geography - time
Sensing	No	No	yes	no
Coordination	centralized entity	centralized entity	centralized entity (SAS)	- centralized entity - sharing rules
Deployment	national	Local	- national - local	local
Access tier	two tiers	two tiers	three tiers	two tiers
Information exchange	centralized data base	centralized data base	backhaul communication	no exchange
Spectrum allocation	schedule-based: - manual - before operation	schedule-based: - manual - automated - during operation	schedule-based: - automated - during operation	schedule-based: - automated - before operation
Classification	data base access	data base access	- data base - data base access - sensing - dynamic interference prediction	- data base - data base access - device conformity - static interference prediction
System administration	NRA, MNO, PNO, or third party	NRA, MNO, PNO, or third party	third party: SAS provider	third party
Technology	agnostic	Agnostic	agnostic	Standard power RLAN (ETSI EN 303 687)
Specifics		geolocation capability mandatory	dynamic incumbent protection	automatic geolocation capability mandatory

4 Analysis results

All use cases provide at least one high value for the QoS levels (see Table 6), most even more. Based on this commonality, the following preferable characteristics of an ideal incumbent can be derived:

- local unused spectrum,
- a static frequency allocation,
- a predictable spectrum access, and
- a local deployment.

Among the aforementioned characteristics, “local unused spectrum” is the necessary condition for shared spectrum, since spectrum bands fully occupied all the time cannot be the target of shared spectrum. These preferable incumbent characteristics can later be used to discuss frequency bands that can be used for temporary and flexible spectrum access for local private networks.

No use case explicitly demands a hierarchy of more than two levels. Although a three-tier system could be used in certain cases (e.g., multi-use case scenario), it can be concluded that a two-tier access scheme is sufficient in most of the cases and a three-tier system would be adopted only in specific cases. In addition, local deployment should be supported. This simplification allows the use of a simpler sharing method or, when applicable, simplified variants of (e)LSA or CBRS, where eLSA is the preferred variant compared to LSA, since local deployment is already supported here.

A spectrum access scheme can manage different levels of coordination. It can protect the incumbent user from being interfered by secondary users, or it can additionally coordinate secondary users among themselves. The first can be achieved, depending on the incumbent characteristics, by a two-tier data base approach such as eLSA or AFC. Concerning the automation of the spectrum access, both offer great potential, because they already include standardized procedures for machine type communication. From the point of view of complexity, eLSA shows a more elevated level of complexity with respect to AFC because an intermediate service layer is introduced, which acts as a private network operator. In the environment of professional applications, such a service is advantageous because it can increase the quality of the spectrum or the transmission reliability/level of QoS during operation. The disadvantage is that both approaches offer only a low dynamic access. AFC specifies an active channel request every 24h, whereas eLSA does not specify a mandatory channel request repetition time at all.

The only approach that natively supports automatic coordination between secondary users is CBRS. Here, coordination between secondary users refers to inter-system coordination, i.e., coordination between two different systems/services, and not to intra-system coordination, i.e., coordination within one system/service.

Here, a compromise needs to be found between framework complexity and efficiency of spectrum sharing. The appropriate level of complexity of the sharing frameworks depends on the specific frequency bands and specific incumbents.

Table 8 summarizes the desirable parameter values for both cases, the automatic incumbent protection and the automatic incumbent protection including coordination of secondary users. A parameter of Table 8 with multiple values combined with an "and" means that the optimal performance would be achieved if all values are met, but any combination of them would also be a possible solution.

Table 8: Summary of desirable parameter set

Parameter	Protection of incumbent	Protection of incumbent + coordination of secondary users
Sharing dimension	- frequency; - geography; and - time	- frequency; - geography; and - time
Sensing	No	Yes
Coordination	- centralized entity; and - sharing rules	- centralized entity; - sensing; and - sharing rules
Deployment	Local	Local
Access tier	two tiers	two tiers
Information exchange	no exchange	- backhaul communication; or - centralized data base; or - beaconing
Spectrum allocation	schedule-based: - automated; and - during operation	schedule-based: - automated; and - during operation
Classification	- data base; - data base access; and - set of sharing rules	- data base; - data base access; - set of sharing rules; - sensing; and - dynamic interference prediction
System administration	- NRA; or - PNO; or - third party	- NRA; or - PNO; or - third party
Technology	Agnostic	Agnostic
Specifics	geolocation capability mandatory	geolocation capability mandatory

Table 8 suggests the direction in which AFC, eLSA or CBRS would need to be changed or improved to optimize and automatize dynamic and flexible spectrum access for local private networks. A further combination of the improved concepts into a single framework, which combines both mentioned variations of coordination, would significantly increase the application possibilities and significantly increase the efficiency of spectrum utilization.

5 Conclusion

In the present document, high level use cases of selected vertical sectors, such as audio PMSE, wireless industrial automation, PPDR, and drone control and payload, are presented. All presented use cases demand high level of QoS and are limited in time and space. For each use case its specific characteristics and specialties are analyzed and summarized by a common parameter set. In addition, various concepts for spectrum sharing based on data bases are described and compared with respect to predefined evaluation parameters.

The evaluation of the benefits and disadvantages of the various sharing procedures with respect to the use cases described identifies AFC and eLSA as possible candidates for a sharing framework that ensures incumbent protection and CBRS as starting point for a sharing solution that natively supports inter-system coordination between secondary users. Adjustments of all procedures are envisaged to make the frameworks useable for various applications. This will accommodate for specific QoS levels and the common need for automation of local ad-hoc deployment of private networks. Based on the most challenging characteristics extracted from all use cases, a desirable parameter set for an envisaged sharing framework is presented that suggests further improvement of the frameworks discussed.

To make spectrum access for local private networks as efficient as possible, the sharing framework should not only ensure incumbent protection but, in addition, should support inter-system coordination between secondary users.

The preferable solution for spectrum access should be technology and frequency agnostic to support as many applications and future frequency bands as possible, e.g., as it is currently discussed for the 3,8 - 4,2 GHz band. In addition, it needs flexibility and scalability because the framework needs to be adapted to the specifics of the frequency bands, incumbents, and secondary users.

Proposed next step is to develop envisaged adjustments for AFC, eLSA, and CBRS (adding, removing, and/or modifying features).

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