



TECHNICAL REPORT

**Reconfigurable Radio Systems (RRS);
Feasibility study on existing spectrum sharing frameworks
for temporary and flexible spectrum access**

Reference

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Reconfigurable Radio Systems (RRS).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the [ETSI Drafting Rules](#) (Verbal forms for the expression of provisions).

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Executive summary

The present document provides information on use cases of vertical sectors with specific characteristics of spectrum usage and access, such as audio PMSE, e-health, wireless industrial automation, PPDR, intelligent transport system, car test track, and drone control and payload, and introduces various spectrum sharing frameworks, including standardized architectures, such as LSA, eLSA, and CBRS, standardized technology specific protocols, e.g. Listen Before Talk, Detect And Avoid, and Dynamic Channel Selection, and spectrum allocation procedures, such as audio PMSE frameworks and National Local Licensing.

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:

- 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.

Proposed next steps are to:

- 1) develop envisaged adjustments for AFC, eLSA and CBRS (adding, removing, and/or modifying features); and
- 2) consider the creation of a SRdoc for spectrum sharing for local private networks.

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 specific zones and time slots, leaving spectrum underutilized.

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 the specific needs of private networks to share 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 generally efficient spectrum sharing as well as user-friendly operability. The term "local private wireless network" refers not only to wireless broadband connectivity controlled and managed by a private organization, but also to a network with special characteristics and a high level of Quality of Service (QoS) that a public network typically cannot provide. Similar to a public network, a private network needs access to spectrum but in contrast to public networks it shares the spectrum with e.g. incumbents or other secondary users. It can either use spectrum that is assigned to a spectrum owner or use unlicensed spectrum. The use of unlicensed spectrum conflicts with the need for a high level of QoS. Therefore, the present document focuses on access to licensed 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.

1 Scope

The present study addresses technical approaches for automated spectrum access to support dynamic, temporary, and flexible spectrum sharing. Existing spectrum sharing frameworks (e.g. CBRS, LSA, etc.) are evaluated with regard to their suitability for temporary and flexible spectrum access. To evaluate such suitability, the study identifies and assesses properties and parameters (e.g. for scalable localized dedicated networks) that need to be considered. It includes a gap analysis to identify possible for spectrum access for on-demand use cases. This scope includes nomadic deployments.

The applications and use cases described claim a certain, typically high Quality of Service (QoS) but are often limited in range and differ in the duration of operation which can vary from short-term (e.g. some days to some weeks) to long-term (e.g. some weeks to some years). Some use cases allow for prior network planning, others demand very short-term deployment without a prior planning phase.

To support the use cases described, the study evaluates:

- suitability of sharing frameworks for temporary and flexible spectrum access to support ad hoc and on-demand use cases;
- procedures and functionalities for automated spectrum negotiation, assignment, and application specific QoS guarantee;
- suitability for the support of scalable localized dedicated networks;
- suitability for the support of fixed, nomadic, or mobile deployments; and
- characteristics, system architectures and high-level procedures for spectrum access for use cases described.

If needed, this study proposes evolution and improvement of the existing technical approaches or develops new technical solutions for spectrum sharing.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

dBm	deciBel-milliwatts
GHz	GigaHertz
MHz	MegaHertz
mW	MilliWatt

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	Third Generation Partnership Project
4G	4 th generation technology standard for broadband cellular networks
5G	5 th Generation technology standard for broadband cellular networks
AFC	Automated Frequency Coordination
AP	Access Point
BNetzA	Bundesnetzagentur
BVLOS	Beyond Visual Line Of Sight
CBRS	Citizens Broadband Radio Service
CBSD	Citizens Broadband Radio Service Device
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications
CIM	Computer-Integrated Manufacturing
CRC	Cyclic Redundancy Check
C-V2X	Cellular Vehicle-to-Everything
DAA	Detect And Avoid
DCS	Dynamic Channel Selection
DECT	Digital Enhanced Cordless Telecommunications
DFS	Dynamic Frequency Selection
DL	Downlink
DoD	Department of Defence
DP	Domain Proxy
DPA	Dynamic Protection Area
DSS	Dynamic Spectrum Sharing
ECC	Electronic Communications Committee
EIRP	Effective Isotropic Radiated Power
eLC	evolved Licensed Shared Access Controller
eLR	evolved Licensed Shared Access Repository
eLSA	enhanced Licensed Shared Access
EN-DC	E-UTRA-NR Dual Connectivity
ERC	European Radiocommunication Committee
ESC	Environment Sensing Capability ITM Irregular Terrain Model
E-UTRA	Evolved Universal Mobile Telecommunications System Terrestrial Radio Access
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FHSS	Frequency Hopping Spread Spectrum
FR1	Frequency Range 1
FR2	Frequency Range 2
FSS	Fixed Satellite Service
FT	Fixed Terminal
GAA	General Authorized Access
GPS	Global Positioning System
GWPZ	Grandfathered Wireless Protection Zone
HD	High Definition
ID	Identifier
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
ITS	Intelligent Transport System
ITS-G5	European standard for vehicular communications based on IEEE 802.11p standards
KPI	Key Parameter Indicator
LBT	Listen Before Talk
LC	Licensed Shared Access Controller
LOS	Line Of Sight
LPI	Low Power Indoor

LR	Licensed Share Access Repository
LSA	Licensed Shared Access
LSRAI	L Spectrum Resource Availability Information
LTE	Long Term Evolution
MAC	Medium Access Control
MBSFN	Multimedia Broadcast Single Frequency Network
MCS	Modulation Coding Scheme
MFCN	Mobile/Fixed Communications Network
MNO	Mobile Network Operators
NGMN	Next Generation Mobile Networks
NLL	National Local Licensing
NM	Network Management
NPN	Non-Public Network
NR	New Radio
NRA	National Regulatory Administration
NSA	Non-Standalone
NTIA	National Telecommunications and Information Administration
OFCOM	Office Of Communications
PAL	Priority Access Licenses
PLMN	Public Land Mobile Network
P-MFCN	Public Mobile/Fixed Communications Network
PMSE	Programme Making & Special Events
PNI-NPN	Public Network Integrated Non-Public Network
PNO	Private Network Operator
PPDR	Public Protection & Disaster Relief
PT	Portable Terminal
QoS	Quality of Service
R&O	Report and Order
RAT	Radio Access Technology
RF	Radio Frequency
RLAN	Radio Local Access Network
SA	Standalone
SAS	Spectrum Access System
SHNI	Shared Home Network Identifier
SIB2	System information block type 2
SNPN	Standalone Non-Public Network
SP	Standard Power
SPRM	Standalone, Private Mobile/Fixed Communications Network
SRD	Short Range Device
TC	Technical Committee
TDD	Time Division Multiplex
TDMA	Time Division Multiple Access
TV	Television
TVWS	Television White Space
TVWSD	Television White Space Device
UAS	Unmanned Aerial Services
UAV	Unmanned Aerial Vehicles
UE	User Equipment
UHF	Ultra High Frequency
UL	Uplink
URLLC	Ultra Reliable Low Latency Communication
USA	United States of America
V2X	Vehicle-to-Everything
VHF	Very High Frequency
VLOS	Visual Line Of Sight
VLP	Very Low Power
VSP	Vertical Sector Player

4 Use cases and their characteristics

4.1 Introduction

This clause analyses the needs and characteristics of selected vertical sectors, e.g. Culture and Creative Industry (audio PMSE), Public Protection & Disaster Relief (PPDR), e-Health, Industrial Automation, etc.

Each use case is analysed based on the parameters listed in Table 1.

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 such as frequency change, MCS change, etc.	Various values
Spectrum access mode	The way in which spectrum access is provided	Planned, ad-hoc
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 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 [i.47]. A Public MFCN (P-MFCN) refers to a communication network for the specific purpose of providing data transmission services for the public, e.g. a PLMN, 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 public MFCN.
- IPRM: private MFCN which is integrated into and managed by a P-MFCN.

Is the SPRM based, for example, on 5G, it is called SNPN.

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

4.2 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.

PMSE equipment is divided into:

- video PMSE: wireless cameras;
- audio PMSE: wireless microphones, In-Ear Monitor systems (IEM), wireless conference systems, talkback; and
- remote control: wireless light and effect remote controls.

The individual user of audio PMSE equipment configures a system according to the actual needs of the production i.e. number of performers, musical instruments, sound effects and location with careful consideration of the link budget. 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. Further considerations are:

- the tuning ranges of the available equipment;
- co-located events at the location;
- other wireless equipment in use e.g. security, etc.; and
- the total number of audio channels, which fits into a given amount of spectrum. Many manufacturers now offer modes which double or triple the channel count, but this currently comes at a price of reduced coverage, robustness or audio performance.

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 use will be limited to the range of frequencies identified for audio PMSE nationally or geographically and the audio PMSE equipment will be operated in accordance with the related national regulatory conditions.

Audio PMSE equipment's primary frequency band is 470 MHz - 694 MHz which is globally available.

Professional use of audio PMSE needs detailed frequency planning in advance to make spectrum sharing possible and to guarantee interference-free operation with the broadcast service which is the primary user in the 470 MHz - 694 MHz band in most countries of the world. Spectrum that is useable for professional audio PMSE needs to be:

- observable, e.g. by spectrum scanning procedures or other information; and
- predictable, e.g. stable in its operational times and frequency for the PMSE event time and location.

Table 2 summarizes characteristics of different use cases of audio PMSE.

Table 2: Characteristics of different use cases of audio PMSE

Parameter	Live Audio Production/Special Events		Electronic News Gathering
Deployment	Nomadic	Fixed	Nomadic; mobile
QoS levels	Very high reliability (no audible disturbance allowed) Ultra-low latency	Very high reliability (no audible disturbance allowed) 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	See clause 5.3	See clause 5.3	See clause 5.3
Spectrum demand	[i.15]: approximately 96 MHz in sub 1 GHz for daily use [i.16]: average spectrum needs from 42 MHz (small events) to 115 MHz (large events); major events need 174 MHz		

Today, TV UHF spectrum from 470 MHz to about 900 MHz is best suited for audio PMSE operation for the following reasons:

- low ambient RF noise level;
- high antenna efficiency for antennas used with small portable devices, e.g. wireless microphones and small body receivers;
- efficient propagation in both indoor and outdoor spaces over short distances; and
- ability to pass through moderate amounts of clutter, e.g. stage equipment and scenery, without excessive losses.

4.3 E-Health

The term e-health summarizes the use of information and communication technology in support of health and health related fields. It encompasses a wide range of uses, from mobile health (m-health), which describes the use of mobile wireless technology for health, to telehealth/telemedicine, which describes the use of telecommunications and virtual technology to deliver health care outside of traditional health care facilities, and increasingly underpins, supports, and enhances all critical medical applications and health care activities.

According to 3GPP TR 22.826 [i.3], critical medical applications can be categorized as follow:

- static - local: medical team and patient are collocated; devices are not moving while the care is delivered;
- moving - local: medical team and patient are collocated; devices are moving while the care is delivered;
- static - remote: medical team and patient are not collocated; devices are not moving while the care is delivered; and
- moving - remote: medical team and patient are not collocated; devices are moving while the care is delivered.

Use cases under the static - local category take place in so called hybrid operating rooms of hospitals which include image guided surgery and teleoperation. Going wireless brings the following benefits:

- equipment sharing between operating rooms in the same hospital;
- on-demand addition of complementary imaging equipment in case of incident during a surgery; and
- suppression of a range of cables connecting a multitude of medical devices, constituting many obstacles.

The moving - local category summarizes all uses of wireless equipment which is needed for all kinds of health monitoring and medication controlling of patients moving around inside hospitals or care facilities, e.g. cardiac telemetry. Similar to the static - local category, the use cases focus on a local wireless network deployment because the patient stays in a hospital for a while or resides in a care facility for a period of time.

Static - remote use cases are about telemedicine, whose definition as adopted by the World Health Organization is as follows:

"The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities".

The main difference between telemedicine and telehealth is that products and services offered as part of telemedicine are regulated by Health laws. This is important to understand that as by their intrinsic nature, those services may cross national boundaries and regulatory systems.

Typical application of telemedicine is for emergency care in the ambulance or outpatient care. Ultrasound examination, for example, improves the management of prehospital care (first diagnosis, intervention and triage) and reduces the "door to diagnosis and therapy time", which is one of the most important factors in improving medical assistance and survival (as described in [i.4]).

Another application is remote surgery or telesurgery, which is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location. It promises to allow the expertise of specialized surgeons to be available to patients worldwide, without the need for patients to travel beyond their local hospital.

Moving - remote use cases are similar to moving - static use cases with the difference that the patient is not located in a hospital or care facility, but his health is monitored remotely in his daily life. In addition, monitoring/providing continuous care to injured patients in a moving ambulance while they are being transported to a hospital also belongs to this category.

Table 3 summarizes characteristics of the different e-health use cases.

Table 3: Characteristics of e-health use cases

Parameter	Static - local	Moving - local	Static - remote	Moving - local
Deployment	Fixed	Fixed	Fixed	Fixed
QoS levels	Ultra-high reliability; ultra-high service availability; ultra-low to low latency	Ultra-high reliability; ultra-high service availability	Mid to high reliability; high to ultra-high service availability; low latency	Ultra-high reliability; ultra-high service availability; ultra-low to low latency
RAT	Standardized	Standardized	Standardized	Standardized
Network architecture	SPRM; IPRM	SPRM; IPRM	P-MFCN	P_MFCN
Network coverage	Local	Local	Transnational	Transnational
Usage period	Several years	Several years	Few hours to few months	Few hours to few months
RF channel holding time	To be defined	To be defined	To be defined	To be defined
Spectrum access mode	Planned	Planned	Planned	Planned
Spectrum access	To be defined	To be defined	To be defined	To be defined
Spectrum bands	To be defined	To be defined	Assigned to MNOs	Assigned to MNOs
Spectrum demand	To be defined	To be defined	To be defined	To be defined

4.4 Wireless industrial automation

The manufacturing industry is currently subject to a fundamental change [i.28], which is often referred to as the "Fourth Industrial Revolution" or simply "Industry 4.0" [i.29]. 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. The 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 ([i.30] and [i.31]).

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 [i.29]. 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 [i.28] of paramount importance are:

- **Factory automation:** Factory automation deals with the automated control, monitoring and optimisation of processes and workflows within a factory. This includes closed-loop control applications (e.g. based on programmable logic or motion controllers) and robotics, as well as Computer-Integrated Manufacturing (CIM). Factory automation generally represents a key enabler for industrial mass production with high quality and cost-efficiency. Corresponding applications are characterised by highest requirements on the underlying communication infrastructure, especially in terms of communication service availability, determinism, and latency. In the Factories of the Future, static sequential production systems will be more and more replaced by novel modular production systems offering a high flexibility and versatility. This involves many increasingly mobile production assets, for which powerful wireless communication and localisation services are needed. Specifically, motion control, control-to-control communications, and mobile robots [i.28], etc. are designated as the exemplary use cases in this area. These subsystems need a means of communicating with the central control system capable of operating at very short cycle times in the single-digit millisecond range and will be ideally implemented without using cable drag chains, rotary feedthroughs, slide contacts or other conventional connections which have numerous disadvantages like the restriction of the mobility of the subsystems and limitation of the possibilities for expansion. In addition, wireless real-time communication makes applications such as human-robot or robot-robot collaboration possible and with that open a brand-new field of possible new applications in industrial scenarios.
- **Process automation:** Process automation is the control of production and handling of substances like chemicals, food & beverage, pulp, etc. Process automation improves the efficiency of production processes, energy consumption, and safety of the facilities. Sensors measuring process values, such as pressures or temperatures, are working in closed loops via centralised and decentralised controllers. In turn, the controllers interact with actuators, e.g. valves, pumps, heaters. Also, monitoring of attributes such as the filling levels of tanks, quality of material, or environmental data are important, as well as safety warnings or plant shutdowns. Workers in the plant are supported by mobile devices. A process automation facility ranges from a few 100 m² to several km², and the facility may be geographically distributed. Depending on the size, a production plant may have several 10 000 measurement points and actuators. Self-sustained device power supply for years is needed to stay flexible and to keep the total costs of ownership low. Specifically, close-loop control, process and asset monitoring, and plant asset management [i.28] are exemplary use cases in this area.

Table 4 summarizes characteristics of some wireless industrial automation use cases.

Table 4: 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; [FR2]	ISM; 3,7 GHz - 3,8 GHz; FR1; [FR2]	ISM; 3,7 GHz - 3,8 GHz; FR1; [FR2]
Spectrum demand	To be defined	To be defined	To be defined

4.5 Public Protection & Disaster Relief (PPDR)

Public Protection and Disaster Relief (PPDR) communications are designed to respond to disasters 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 (e.g. through drones), etc.

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).

Currently, PPDR's frequency allocations are currently non-homogeneous: in Region 1 the band 380 MHz - 470 MHz (and, within, the preferred core 380 MHz - 385 MHz/390 MHz - 395 MHz) is harmonized for permanent protection activities. Such bands is mostly used to address emergency warnings, but cannot deliver video streaming. In Region 2, the bands 746 MHz - 806 MHz, 806 MHz - 869 MHz, 4 940 MHz - 4 990 MHz are allocated, whereas, in Region 3, 406,1 MHz - 430 MHz, 440 MHz - 470 MHz, 806 MHz - 824 MHz/851 MHz - 869 MHz, 4 940 MHz - 4 990 MHz and 5 850 MHz - 5 925 MHz [i.42].

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.

Table 5: Characteristics of PPDR use case

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; [FR2]
Spectrum demand	Low	High

4.6 Intelligent Transport Systems

In this clause a technology neutral approach is taken and one example ITS use case is considered in order to illustrate how ITS spectrum can be complemented by temporarily/spatially available shared spectrum to improve QoS. This basic principle could be applied to other ITS use cases as well. A presentation of more ITS use cases can be found in ETSI TR 101 607 [i.44].

The spectrum requirements for C-V2X use case was studied by the 5G Automotive Association [i.35]. In the case of sidelink, 70 MHz - 75 MHz of ITS spectrum in the 5,9 GHz band (as presently allocated in many regions and under consideration in other regions) is needed to support the basic safety and advanced use cases under consideration today.

On the other side, to meet the positioning requirements for V2X use cases as per another study from 5GAA [i.36] additional spectrum is needed if sidelink positioning is used. According to 3GPP TR 38.855 [i.33] positioning study, a signal with at least 100 MHz bandwidth is needed in outdoor scenarios to support V2X applications. The exact spectrum needs for sidelink positioning depending on the accuracy requirements is currently being studied by 3GPP [i.32] and [i.34].

It is clear, that there is no sufficient bandwidth available in the ITS band to support on the same time V2X use cases and high accuracy positioning technologies. From a technology neutral perspective, there are two possibilities here:

- 1) Spectrum sharing of communications and positioning signals in the ITS band to support use cases with medium to high data rate requirements, but with lower positioning requirements.
- 2) Reservation of the ITS band for V2X communications and spectrum sharing of the sidelink positioning signals with other signals in another band, for example, unlicensed or licensed bands.

Table 6: Characteristics of V2X use case

Parameter	V2X
Deployment	Fixed; mobile (sidelink)
QoS levels	High reliability; very high service availability low latency
RAT	Standardized
Network architecture	SPRM; IPRM; P-MFCN
Network coverage	National; transnational
Usage period	Several years
RF channel holding time	Few to several hours
Spectrum access mode	Planned; ad-hoc (sidelink)
Spectrum access	Licensed: shared and coordinated; licensed: not shared
Spectrum bands	5 850 MHz - 5 925 MHz
Spectrum demand	Mid

4.7 Car test track

Classic usage of spectrum has been generally oriented towards a strong Downlink (DL) frame structure. However, many applications cannot efficiently exploit DL subframes/slot and even may not be able to function if a large portion of the band is not dedicated to Uplink (UL) transmissions.

When doing real-time analysis of test data captured on a car test track wirelessly, there is a need for high throughput in UL with low latency. Such tests are generally performed on specific car test tracks in which vehicles are put under stress, and the acquired test data are uploaded to a central server. The large amount of data acquired needs to be uploaded timely, i.e. with little latency. This can be guaranteed only by occupying almost all the available band for UL transmissions for the time of the testing. According to car manufacturer in NGMN alliance, a throughput spanning from 150 Mbps to 900 Mbps in UL, in very limited areas only during specific times is needed [i.35].

Geographically, such test is generally driven either in a urban context or in specific, dedicated tracks. Currently, when real-time upload is not feasible, tests are performed by storing the data inside hard drives in the auto vehicles and then retrieved and elaborated in a second phase. However, it is important to be able to access the data in real time, to enhance the testing speed and its effectiveness. In both the cases of urban and dedicated zone testing, large throughput is demanded in UL, which contrasts with classic choices in terms of frame structure from mobile operators.

Usually, the location of such application is known and very limited, and their time exploitation can vary from a few hours a day to full days. However, in order to avoid harmful cross interference generated by different TDD frame structures (e.g. interference generated on an UL from a high-power DL) spectral separation and dedicated bands are necessary, as much as location separation.

An automated interference estimation could, along with automated frequency planning, allow for an efficient spectrum usage and flexible association.

Table 7: Characteristics of Car test tracks use case

Parameter	Car test track
Deployment	Fixed
QoS levels	High throughput; low latency;
RAT	Standardized
Network architecture	SPRM; IPRM; P-MFCN
Network coverage	Local; national; transnational
Usage period	Few minutes to few hours
RF channel holding time	Few minutes to few hours
Spectrum access mode	Planned
Spectrum access	License-exempt; licensed: shared and coordinated
Spectrum bands	FR1
Spectrum demand	High (mainly UL)

4.8 Drone control and payload

Growing demands for Unmanned Aerial Vehicles (UAVs) and Unmanned Aerial Services (UASs) yielded demand for spectrum to correctly 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, there 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. there exists a Line Of Sight (LOS) between the control and the drone) and Beyond Visual Line Of Sight (BVLOS), i.e. there is no direct path between control and drone, hence a wireless network support is needed

When direct links are not available, both drone control channel and payload channel need specific connection with guaranteed QoS. Large throughput demanded for payload can be obtained only by 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 LTE-5G bands (exploiting MNOs networks):

- Unlicensed band (e.g. 2,4 GHz and 5 GHz Wi-Fi® 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 is necessary, regulation requires that guaranteed QoS is delivered for BVLOS operations. In such cases, specific licensed bands for professional drones are under investigation (e.g. 5 040 MHz - 5 091 MHz in the US).
- In the case in which professional drones might be in need of temporary and localized access to cellular network to guarantee BVLOS operations when, for instance, the LOS between the controller and the drones is temporarily blocked. This would allow for continuous operations and would apply to both the control channel and the payload delivery.
- For professional drones requiring constant BVLOS operations, a constant attachment to public MNOs network can be envisaged. However, capacity might not be sufficient to guarantee the large payload, due to limited bandwidth in lower bands and in uplink.

Drones application can also make use of dedicated reliable payload that is activate on demand. Such supplementary UL/DL can be necessary to deliver high-throughput traffic from HD thermal cameras, or URLLC traffic from lidars.



Figure 1: Visual Line Of Sight (VLOS) and Beyond-visual-Line-Of-Sight (BVLOS) drones operations

Table 8: 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	FR1; [FR2]
Spectrum demand	Low	High

4.9 Minimum parameter set extracted from all use cases

From all above use cases the minimum parameter values are summarized in Table 9. It contains the most challenging value of each parameter. This parameter set is used for analysis and evaluation later in clause 6.4.

Table 9: Minimum parameter set

Parameter	Value	Conclusion
Deployment	Mobile	The network cell moves during operation which needs to be considered depending on the sharing dimension.
QoS levels	<ul style="list-style-type: none"> Ultra-high reliability Ultra-high service availability Ultra-low latency High throughput 	<p>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.</p> <p>Reliability contrasts with low latency because, for example, frequency agility or data re-transmission are not easy or even impossible to implement.</p> <p>No use case can easily tolerate losing connection.</p>
RAT	Proprietary	A technology neutral approach is needed, i.e. MAC protocols are not the preferred solution.
Network architecture	SPRM	<p>When using a P-MFCN, the operator is responsible for managing spectrum access.</p> <p>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.</p>
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 physical 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	License-exempt	Licensed access needs to be also supported.
Spectrum demand	High	Audio PMSE, for example, needs approximately 96 MHz in sub 1 GHz for daily use.

5 Introduction to existing frameworks for spectrum sharing

5.1 Licensed Shared Access/enhanced Licensed Shared Access

5.1.1 LSA

Licensed Shared Access (LSA) offers a complementary spectrum management tool to the existing spectrum release mechanisms such as re-allocation and clearing. 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.

The first practical use cases for LSA aimed to provide access to additional spectrum within the 2,3 GHz - 2,4 GHz band for Mobile/Fixed Communication Networks (MFCNs) including IMT services but has not been commercially deployed until now apart from the Netherlands which is the first and only European country to deploy a permanent LSA service based on ETSI specifications in the 2,3 GHz - 2,4 GHz band in 2019. Here, it does not enable the deployment of cellular services as secondary spectrum users but enables ENG teams using audio/video PMSE in the field to share the use of spectrum.

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.

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. The details of the sharing framework will be determined at national level and will depend on the particular use case. This case-by-case definition of the LSA sharing framework makes the LSA concept generally applicable to any target band, even though the technical specifications were originally defined for the specific 2,3 GHz - 2,4 GHz band. For the 3 600 MHz - 3 800 MHz range, ECC Report 254 [i.9] provides operational guidelines for National Regulatory Administrations (NRAs) on the implementation of LSA.

According to ETSI TS 103 154 [i.5], ETSI TS 103 379 [i.7] and ETSI TS 103 235 [i.6], a deployment of an LSA system requires the introduction of two architecture building blocks: the LSA Repository (LR) and the LSA Controller (LC). Figure 2 shows the LSA architecture reference model [i.6] with its interfaces. Only the LSA₁ interface and its corresponding interface functions were defined by ETSI.

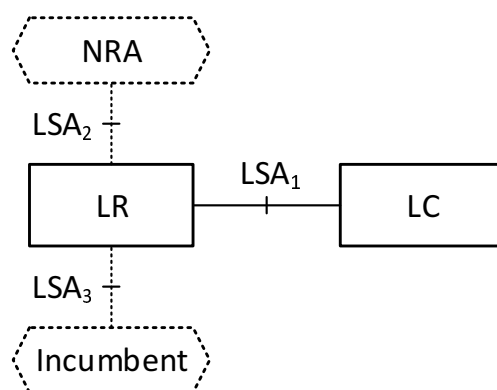


Figure 2: LSA architecture reference model (ETSI TS 103 235 [i.6])

LSA repository (LR): the LR supports the entry and storage of information describing incumbent's usage and necessary protection [i.3]. It can convey the related availability information to authorized LSA Controllers and is also able to receive and store acknowledgement information received from the LSA controllers. The LR also provides means for the NRA to monitor the operation of the LSA system [i.5], and to provide the LSA System with information on the sharing framework and the LSA licensees. The LR ensures that the LSA system operates in conformance with the sharing framework [i.8] and the licensing regime and may in addition realize any non-regulatory details of the sharing arrangement.

LSA Controller (LC): the LC is located within the LSA licensee's domain and enables the LSA licensee to obtain LSA spectrum resource availability information from the LR, and to provide acknowledgment information to the LR. The LC interacts with the licensee's MFCN in order to support the mapping of availability information into appropriate radio transmitter configurations and to receive the respective confirmations from the MFCN.

Incumbent: the incumbent is the current holder of spectrum rights of use. He stores usage of his spectrum in the LSA system.

National Regulatory Administrations (NRA): the NRA defines and controls the application of the sharing framework.

The LSA₁ interface provides support for the exchange of LSA Spectrum Resource Availability Information and respective acknowledgement information between LR and LC, and for maintaining and recovering synchronization of such information between LR and LC.

Based on the ETSI standardization work for LSA in the 2,3 GHz - 2,4 GHz band, 3GPP initiated its own study [i.10] to investigate the impact of LSA on its specifications. The interoperation between the LSA system and 3GPP Mobile Network Operators (MNOs) is addressed in [i.11] to [i.13]. The solution envisages that the LC is located within the LSA licensee domain (i.e. within the mobile network operator domain in 3GPP terms). The LC interacts with the PLMN Network Management (NM) system to translate spectrum-resource-availability-information (LSRAI in ETSI RRS terms), from the LSA system, into appropriate radio transmitter configurations and receive the appropriate acknowledgements from the PLMN.

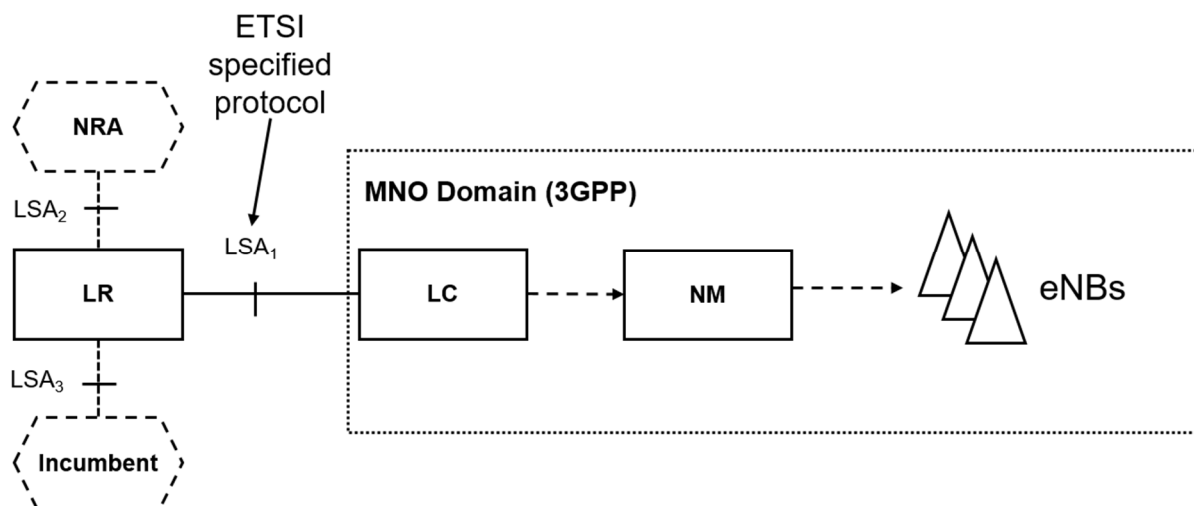


Figure 3: Basic deployment scenario for the interaction between the LSA Controller (LC) and 3GPP PLMN at the Network Management (NM) level
The functional split between LC and NM is discussed in ETSI TS 128 302 [i.12]

Several field trials (see list of trials in ETSI TS 128 302 [i.12]) have successfully demonstrated the feasibility of LSA. In the meantime, however, it's fair to say that the commercial development of LSA never got off the ground. Currently, in Europe, only the Netherlands has an official implementation of an LSA-like spectrum access regime, and even that only for the specific case of spectrum access registrations for wireless devices for Program and Special Events (PMSE), such as mobile wireless cameras [i.12].

5.1.2 eLSA

Enhanced Licensed Shared Access (eLSA) is the further development of LSA to support the concept of local high-quality wireless networks as described in ETSI TR 103 588 [i.14]. 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 ETSI TS 103 652-1 [i.20], local high-quality wireless networks refer to Mobile/Fixed Communication Network (MFCNs) capable of supporting different use cases with following commons:

- 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 behaviour, reliability, and latency, etc.;
- 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. Evolution took place at:

Regulatory level:

- extension of the secondary licensing spectrum access approach in LSA to includes two additional spectrum access methods: local area licensing and local area leasing;
- broadening the role of eLSA licensee beyond MNOs, including private network operators (Vertical Sector Player (VSP) in terms of ETSI TC RRS); and

- simplifying the LSA license process.

Technical level:

- establishing allowance zones, i.e. geographical areas within which an eLSA licensee is allowed to operate on its assigned spectrum resources for a certain period;
- supporting automatic and dynamic request/release of local spectrum resources, deployment durations may range from several hours to several years; and
- delivering deterministic and predictable channel allocation (e.g. fixed channel plans) to satisfy the stringent QoS levels of local high-quality wireless networks.

The eLSA architecture reference model [i.21] is shown in Figure 4. It is based on the architecture reference model for LSA defined in [i.6] and supports additionally the spectrum access schemes for local area licensing and the local area leasing. Reference points shown in dashed format indicate that the respective interfaces and corresponding interface functions are not defined.

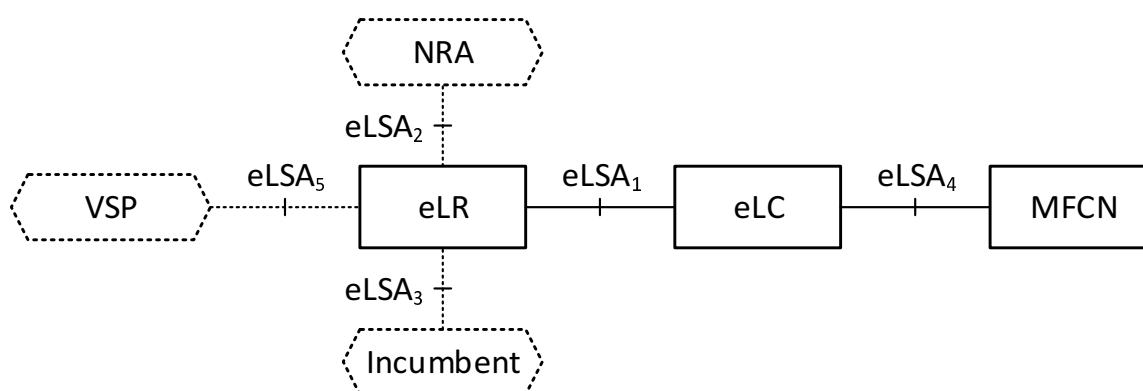


Figure 4: eLSA reference architecture model (ETSI TS 103 652-2 [i.21])

The logical elements of the eLSA architecture are the following:

eLSA Repository (eLR): the eLR supports the entry and storage of information describing the shared spectrum resources as well as incumbent's and VSP's usage and necessary protection. It is able to convey spectrum resource information including related availability information to eLSA controllers. The eLR also provides means for the NRA to monitor the operation of the eLSA system (see ETSI TS 103 652-3 [i.22]) and to provide the eLSA system with information on local area licensing and local area leasing. The eLR ensures that the eLSA system operates in conformance with the sharing framework and the licensing regime and may in addition realize any non-regulatory details of the sharing arrangement.

eLSA Controller (eLC): the eLC is associated with the VSP's domain. The eLC enables the VSP to obtain eLSA spectrum resource and availability information from the eLR. The eLC interacts with the VSP's MFCN in order to support the mapping of spectrum resource and availability information into appropriate radio transmitter configurations and receive the respective confirmation from the MFCN.

The eLSA₁ interface provides support for the exchange of eLSA spectrum resource availability information and respective acknowledgement information between eLR and eLC, and for maintaining and recovering synchronization of such information between eLR and eLC. This interface is also designed to support operation in a detached mode, i.e. that the VSPs operate and control their MFCN without a permanent network connection to the eLSA system.

The eLSA₄ interface supports the exchange of appropriate radio transmitter configuration information between eLC and VSP's MFCN. It can be temporarily disconnected.

LSA/eLSA represent a European generic technical platform able to support any national regulative framework, by adjusting the underlying spectrum-sharing framework. This means LSA/eLSA are not limited to any set of licensing rules or set of frequency bands.

5.2 TV White Space

From June 2016, the UK permitted TV White spaces devices to share the TV band (470 MHz - 694 MHz) with the existing uses, Digital Terrestrial Television, Programme Making and Special Events (PMSE), including in particular wireless microphone users. The sharing takes place dynamically, controlled by Ofcom (UK) approved databases which hold information on the location of Digital Terrestrial Television and PMSE users and white space devices. This information is used to allow white spaces devices access to the spectrum band, without causing harmful interference to the existing users of the spectrum.

There are two ECC reports which address TV white space devices:

- ECC Report 186 [i.23]; and
- ECC Report 159 [i.24].

The latest revision of the European harmonised Standard for TV White Space Devices is ETSI EN 301 598 [i.25].

In the United States, unlicensed white space devices are permitted to operate in portions of the VHF and UHF broadcast television bands [i.26] as shown in Table 10.

Table 10: Frequency range of TV white space in USA

Device category		Permissible frequency bands of operation						
		54-72 MHz	76-88 MHz	174-216 MHz	470-614 MHz (see note 4)	617-652 MHz ⁴	657-663 MHz	663-698 MHz (see note 5)
Fixed		✓ See note 1	✓ See note 1	✓ See note 1	✓	✓	✓	✓
Mobile		✓ See note 1	✓ See note 1	✓ See note 1	✓ See note 2			
Personal/ portable	Mode I				✓	✓	✓	✓
	Mode II				✓	✓	✓	✓
	Sensing only				✓ See note 3			
	Narrowband (≤ 100 kHz)				✓ See note 2			
NOTE 1: Only mobile white space devices and fixed white space devices that communicate only with other fixed or mobile white space devices are permitted to operate on available channels in these bands.								
NOTE 2: Narrowband and mobile white space devices are permitted to only operate on frequencies below 602 MHz.								
NOTE 3: Sensing only devices are permitted to transmit on any available channels in 512 MHz - 608 MHz range.								
NOTE 4: White space devices are not permitted to operate in the 488 MHz - 494 MHz band in Hawaii.								
NOTE 5: Limited to areas where 600 MHz band licensees have not commenced operations.								

In order to ensure protection of incumbent radio services (e.g. digital television stations, fixed broadcast auxiliary service links, radio astronomy services) in the bands, white space devices rely on either white space database or spectrum sensing (see Table 11). White space devices that rely on white space database incorporate geolocation capability and provide its geographic coordinates to a white space database. The white space database determines a list of available channels based on the device's geographic coordinates, other necessary device information and pre-determined separation distances or exclusion zones for protection of incumbent radio services, and the white space database provides it to the white space device. White space devices that rely on spectrum sensing (i.e. sensing-only device) determines a list of available channels based on the results of detection of the incumbent radio signal.

Table 11: Interference mitigation mechanism of TV white space

Device Category		Geolocation capability	Source of channel availability	
			White space database	Spectrum sensing
Fixed		✓	✓	
Mobile		✓	✓	
Personal/ portable	Mode I		✓ (see note)	
	Mode II	✓	✓	
	Sensing only			✓
	Narrowband (≤ 100 kHz)	✓	✓	
NOTE: Mode I devices do not access to a white space database but do obtain a list of available channels on which it may operate from either a fixed device or Mode II device. A fixed or Mode II device are permitted to provide a Mode I device with a list of available channels only after it contacts its database, provides the database the FCC Identifier (FCC ID) of the Mode I device requesting available channels, and receives verification that the FCC ID is valid for operation.				

5.3 Shared spectrum framework for audio PMSE

Audio PMSE equipment operates on a tuning range basis. A tuning range is the frequency range in which audio PMSE equipment is able to operate. Within this tuning range, the use will be limited to the range of frequencies identified for audio PMSE nationally/geographically within that country and the equipment will be operated in accordance with the related national regulatory conditions and restrictions. In Europe, such equipment complies with ETSI EN 300 422-1 [i.27].

Frequency bands identified for audio PMSE including their restrictions are given in ERC Recommendation 25-10 [i.1] and ERC Recommendation 70-03 Annex 10 [i.2]. Implementation of the frequency ranges listed in the recommendations apart from the 470 MHz - 694 MHz, the 823 MHz - 832 MHz, and the 1 785 MHz - 1 805 MHz range are not harmonised for use throughout CEPT.

The band 470 MHz - 694 MHz, which is available worldwide, is the primary band for high quality audio PMSE applications. This frequency band has been allocated on a primary basis to broadcasting and on a secondary basis to audio PMSE. Other frequency ranges used by audio PMSE are considered Short Range Device (SRD) with corresponding national SRD regulation.

Table 12 lists the frequency ranges for audio PMSE including their restrictions according to [i.2].

Table 12: Regulatory parameters for audio PMSE [i.2]

	Frequency band [MHz]	Power [mW]
e	174 - 216	50
f1	470 - 694	50
f2	694 - 703	50
f5	733 - 758	20/100 (see note)
f3	821 - 826	20/100 (see note)
f4	826 - 832	100
h1	1 350 - 1 400	20/50 (see note)
h2	1 492 - 1 518	50
h3	1 518 - 1 525	50
j	1 785 - 1 805	20/50 (see note)
NOTE: Restricted to body worn equipment.		

- The implementation of the ERC recommendation is the responsibility of the European countries and may vary from country to country. The same applies to the licensing scheme. It may be license-exempt.
- Licensed, shared, and non-coordinated.
- And licensed, shared, and coordinated.

In countries, where license-exempt use is not allowed, the current process for gaining access to spectrum or for acquiring a temporary license is often manual, involving emails, telephone calls, and website visits. In almost all cases, spectrum is shared with other services, and audio PMSE users contact a frequency coordinator to obtain access, which requires some time to request and respond.

In the United States, FCC Rules permit both licensed and unlicensed operation in the core 470 MHz - 608 MHz band and some other bands including the 600 MHz duplex gap and guard band. Unlicensed operation is limited to 50 mW EIRP in 470 MHz - 608 MHz and 20 mW in the duplex gap 657 MHz - 663 MHz and lower guard band 614 MHz - 616 MHz, while licensed users may operate with up to 250 mW in 470 MHz - 608 MHz and 20 mW in the duplex gap 653 MHz - 657 MHz. Licensed operation is also permitted in certain other bands subject to additional conditions, including advance frequency coordination in certain cases. Licensed operation is covered under FCC Part 74 Subpart H rules [i.55]. Technical characteristics are found in section §74.861: Unlicensed operation is under FCC Part 15 Subpart C rules [i.56]. Certain rules specific to radio microphones can be found in section §15.236. Table 13 summarizes current frequency ranges permitted for wireless microphones in the United States.

Table 13: Current frequency ranges permitted for wireless microphones in the United States

Frequency range [MHz]	License condition	Notes
26,100 - 26,480	License Required (FCC Part 74 [i.55])	Rarely used due to long wavelength
54 - 72	License Required (FCC Part 74 [i.55]) Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Rarely used due to long wavelength
76 - 88	License Required (FCC Part 74 [i.55]) Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Rarely used due to long wavelength
88 - 108	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Rarely used due to very limited power and interference
161,625 - 161,775	License Required (FCC Part 74 [i.55])	Except in Puerto Rico or the U.S. Virgin Islands
169 - 172	License Required (FCC Part 90) [i.57]	Limited frequencies available
174 - 216	License Required (FCC Part 74 [i.55]) Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Shared with VHF TV Broadcast
450 - 451	License Required (FCC Part 74 [i.55])	Rarely used
455 - 456	License Required (FCC Part 74 [i.55])	Rarely used
470 - 608	License Required (FCC Part 74 [i.55]) Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Core PMSE band
614 - 616	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Lower guard band
653 - 657	License Required (FCC Part 74 [i.55])	Primarily ENG use
657 - 663	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Shared with White Space Devices
902 - 928	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Shared with ISM devices
941,5 - 952	License Required (FCC Part 74 [i.55])	Subject to coordination
952,85 - 956,25	License Required (FCC Part 74 [i.55])	Subject to coordination
956,45 - 959,85	License Required (FCC Part 74 [i.55])	Subject to coordination
1 435 - 1 525	License Required (FCC Part 74 [i.55])	Subject to coordination
1 920 - 1 930	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	DECT devices
5 725 - 5 850	Unlicensed Operation (FCC Part 15 Subpart C [i.56])	Shared with ISM devices; e.g. Wi-Fi®
6 875 - 6 900	License Required (FCC Part 74 [i.55])	Subject to coordination
7 100 - 7 125	License Required (FCC Part 74 [i.55])	Subject to coordination

5.4 Procedures for National Local Licensing (NLL)

Procedures for National Local Licensing allow coordination and therefore allow the use of frequency bands where large protection distances or deployment restrictions are needed to protect incumbent users.

Germany

In the mid-band auction 2019 for 5G, Germany associated 100 MHz between 3 700 MHz and 3 800 MHz for local use as well as the 26 GHz band (24,25 GHz - 27,5 GHz). The spirit of the association speaks for use-cases around private standalone 5G networks like factory automation. The band itself is assigned technology and application neutral, thus the technical implementation aims towards 3GPP based private networks such as 5G Standalone Non-Public Network (SNPN).

The German regulatory body (BNetzA) is responsible for coordination and assigning the license to operate a campus network. The owner of the premises applies for the license in a given area. Additional information like a spectrum usage concept and confirmation of specialist knowledge needs to be provided. The spectrum will be assigned in multiples of 10 MHz and only TDD operation is allowed. If necessary, the applicant needs to coordinate with their geographical neighbours about the planned deployment of base stations. Any guard bands are up to the license applicant to consider, with respect to the frequency usage below 3 700 MHz and to their local neighbour.

The fee for a local license in Germany is calculated via the following formula:

$$Fee (\text{€}) = 1\,000 + B \cdot t \cdot 5 \cdot (6 \cdot a1 + a2) \text{ with}$$

1 000 is the base amount in [€], B is the bandwidth in [MHz] (from 10 MHz - 100 MHz), t is the assignment period in years (for example ten years), a is the surface area in [km²], a1 is the factor for settlement and transport land, a2 is the factor for other types of land.

As of September 2022, there are currently 243 registered local private 5G networks operating in 3,7 GHz - 3,8 GHz in Germany. (Source: Bundesnetzagentur - Regional Netze).

UK

In 2019 Ofcom (UK) published its decision [1.45] to make spectrum available for local use under its spectrum sharing framework. This framework is made up of two different approaches:

- Shared Access: Coordinated (by Ofcom) access to defined frequency bands licensed on a first come, first served basis. The Shared Access bands are referred to as the 1 800 MHz band; the 2 300 MHz band; the 3,8 GHz to 4,2 GHz band and the 26 GHz band.
- Local Access: this allows access to spectrum already licensed to Mobile Network Operators (MNOs) that is not being used, or planned for use, in a particular area. All bands currently licensed to MNOs (via various spectrum awards) are eligible for Local Access licensing.

There are two licence products issued by OFCOM. The spirit of this spectrum sharing framework is understood as making innovation in the wireless realm possible. Thus, OFCOM organizes and maintains the spectrum assignment.

Local Access licence

The frequency ranges for this licence are:

- 791 MHz - 821 MHz paired with 832-862 MHz ("800 MHz band");
- 880 MHz - 915 MHz and 925-960 MHz ("900 MHz band");
- 1 452 MHz - 1 492 MHz ("1 400 MHz band");
- 1 710 MHz - 1 781,7 MHz and 1 805 MHz - 1 876,7 MHz ("1 800 MHz band");
- 1 900 MHz - 1 920 MHz ("1 900 MHz band");
- 1 920 MHz - 1 980 MHz and 2 110 MHz - 2 170 MHz ("2 100 MHz band");
- 2 350 MHz - 2 390 MHz ("2 300 MHz band");
- 2 500 MHz - 2 690 MHz ("2 600 MHz band"); and
- 3 410 MHz - 3 600 MHz ("3,4 GHz band").

To apply for a Local Access licence the potential user needs to complete the application form available on the Ofcom website. Ofcom will assess the likely impact of introducing a new user in that location and will discuss with the relevant MNO(s) before deciding whether to issue a new licence. The time taken for this engagement between Ofcom and the MNO(s) can be reduced if the applicant has already discussed and agreed access to the spectrum with the incumbent.

The Local Access licence is not restricted to the same technology as the incumbent but does force the user to comply with the licence conditions within the given band.

The default period for the licence is three years but other durations are available. Applicants wishing to have access for longer than three years will need the agreement of the incumbent licensee. The licence fee is £ 950.

Shared Access licence

The four frequency ranges for this licence are:

- 1 781,7 MHz - 1 785 MHz paired with 1 876,7 MHz - 1 880 MHz ($2 \times 3,3$ MHz), referred to as the 1 800 MHz band,
- 2 390 MHz - 2 400 MHz (was already available for PMSE), referred to as the 2 300 MHz band; this band is currently only available for low power indoor use only,
- 3,8 GHz - 4,2 GHz, referred to as the 3,8 GHz band, and
- 24,25 GHz - 26,5 GHz (for low power indoor only), referred to as the 26 GHz band. Bandwidth options are 50 MHz, 100 MHz or 200 MHz.

There are two types of Shared Access licence (distinguished primarily by permitted power levels) to cater for different types of potential uses:

- Low power licence (per area licence): This allows the license holder to deploy as many base stations as they wish within a 50 m radius with a maximum of 24 dBm EIRP, except for the 26 GHz band where the limit is 23 dBm/200 MHz. For large sites, people can apply for multiple areas to achieve the appropriate coverage area, and each 50m area needs a separate licence.
- Medium power licence (per base station licence): This licence is available for the 1 800 MHz and 3,8 GHz bands. It is issued on a 'pre base station' basis and authorises the use of a single base station at a maximum of 42 dBm EIRP. Given the higher transmit power and larger potential interference area, this licence is generally for deployments in rural areas only.

Fixed, mobile and nomadic terminal stations which connect to a base station are included in the associated Low or Medium Power licence with specific power limits.

To obtain a licence, users should follow the application process. The applicant provides certain information, for example, licence duration (if less than 12 months), location including whether it is indoor or outdoor use, low power or medium power, frequency band and bandwidth, antenna height and gain etc. The Shared Access application form is available on the Ofcom website.

For outdoor deployment in the 2 300 MHz band there is a TDD frame structure specified within the technical licence conditions to prevent interference with adjacent services. This rule is not in place for low power, indoor deployments.

The licences contain additional technical conditions which apply to frequency accuracy of the transmitted carrier and out of band emissions.

The cost for a licence depends on the requested bandwidth or channel size and is given in Table 14.

Table 14: License fees

Channel size	Price per channel
2 × 3,3 MHz	£ 80
10 MHz	£ 80
20 MHz	£ 160
30 MHz	£ 240
40 MHz	£ 320
50 MHz	£ 400
60 MHz	£ 480
80 MHz	£ 640
100 MHz	£ 800

The 26 GHz band licence fee is £ 320 regardless of bandwidth.

Japan Local 5G example:

In its Radio Act of 2020, the Japanese Ministry of Internal Affairs and Communications implemented a pioneering spectrum sharing approach in the 4,6 GHz - 4,9 GHz in the 28,2 GHz - 28,3 GHz and 28,3 GHz - 29,1 GHz bands to allow multiple coexisting Private Local 5G implementations by enterprises, etc. in small geographically limited coverage areas such as a factories, campuses, and municipalities (see [i.46]).

As of its 2020 Frequency Reorganization Action Plan, the Ministry has under various stages of study further geographic and dynamic spectrum sharing of the following bands:

- 1,2 GHz;
- 2,3 GHz;
- 2,6 GHz;
- 5,8 GHz;
- 5,9 GHz;
- 9 GHz;
- 26 GHz;
- 28 GHz;
- 38 GHz;
- 40 GHz."

5.5 Dynamic Frequency Selection (DFS)

In general, Dynamic Frequency Selection (DFS) is a channel allocation scheme to prevent primary users from interference. It is used by secondary users to detect such primary users in an occupied channel, stop transmission in that channel, monitor a new free channel and start transmission in this new channel. DFS was standardized in 2003 as part of IEEE 802.11h [i.49].

DFS is mandatory in parts of the unlicensed 5 GHz band to avoid co-channel operation with radar systems and to provide uniform utilization of available channels.

DFS according to IEEE 802.11h [i.49] provides the following functionalities:

- association of mobile terminals/stations with an access point in a basic service set or mesh basic service set based on the channels supported by the mobile terminals/stations;
- quieting the current channel so it can be tested for the presence of radar with less interference from other mobile terminals/stations;
- testing channels for radar before using a channel and while operating in a channel;
- discontinuing operations after detecting radar in the current channel to avoid interference with radar;
- detecting radar in the current and other channels based on regulatory conditions;
- requesting and reporting of measurements in the current and other channels; and
- selecting and advertising a new channel to assist the migration of a basic service set after radar is detected.

When starting operation and during operation the access point performs scanning periods to detect radar signals. If a radar signal is detected, the access point initiates a channel switch of the whole basic service set by broadcasting a switch channel event to all members of the basic service set. Mobile terminals are also able to detect radar signals during the silence phase and can send appropriate messages to the access point. In case of a mesh basic service set, the channel switch can be initiated by every station of the mesh network.

In Europe RLAN (Radio Local Area Network) equipment using the 5 150 MHz - 5 350 MHz and 5 470 MHz - 5 725 MHz frequency bands needs to implement DFS (see ETSI EN 301 893 [i.17]).

5.6 Access schemes of Intelligent Transport System (ITS) in 5,9 GHz

In this clause, ITS is understood as the service operated in the 5 GHz Band for direct communication between two vehicles or between a vehicle and infrastructure. In Europe this implemented in the frequency 5 855 MHz - 5 925 MHz. In US this is implemented in the frequency 5 895 MHz - 5 925 MHz. In Japan this is implemented in the frequency range 5 770 MHz - 5 850 MHz. A recommendation for harmonized frequency bands throughout the ITU-R regions for those ITS applications can be found in Recommendation ITU-R M.212-0 [i.43].

There are two competing families of technology aiming to be implemented for this application which cannot coexist due to their medium access mechanisms:

- 1) IEEE 802.11p [i.50] and IEEE 802.11bd [i.51]:
 - The IEEE 802.11p [i.50] standard was released in 2010 and based on IEEE 802.11a [i.53]. The successor IEEE 802.11bd [i.51] was approved in 2022 it is based on IEEE 802.11n [i.54]. The access scheme is based on an ad-hoc channel usage for broadcast messages without any coordination or requested retransmission.
 - In Europe, IEEE 802.11p [i.50] is the used technology for the ITS-G5 standard which implements a complete set of protocols for vehicle to vehicle and vehicle to infrastructure Use-Cases and applications. IEEE 802.11p [i.50] includes encrypted communication (via Public Key Infrastructure and certificates) as well as higher layer protocol definitions based on the use-cases.
- 2) C-V2X based on 3GPP Release 14+ sidelink:
 - Based on the sidelink system within 3GPP, C-V2X defines not only the physical layer but also scenarios and use-cases. The sidelink is a mode of wireless communication between 3GPP User-Equipment (UEs) directly in a device-to-device manner in dedicated spectrum. For sidelink operation this includes the ITS band, but is not limited to that band per se. There are in general two modes for Device-to-Device in 3GPP. With and without network infrastructure. For C-V2X, the UEs participating in the communication coordinate themselves. The time synchronization is based on GPS if applicable, if not, the UE needs to sense the band and look for a master UE. If no master UE is found, the UE needs to generate master UE signals. Based on 5G NR (Release 18+) a new disruptive sidelink communication will become available.

The messages exchanged in vehicle to vehicle and vehicle to infrastructure applications are independent from the technologies described in 1) and 2). Due to the channel access mechanisms the technologies described in 1) and 2) cannot coexist in the same channel at the same time in the same location. Possible solutions are under discussion in ETSI TC ERM TG 37. The ETSI TC ITS expert group is developing the description of the use cases, applications, and protocols.

5.7 Listen Before Talk (LBT)

Listen Before Talk (LBT) is a technique used in various wireless technologies and standards in which a wireless transmitter first senses its RF environment to determine the current state of the RF channel (idle or occupied) before starting transmission. If the device detects any activity on/energy above a certain threshold in the channel, it waits for a random period and transmits the data.

LBT belongs to the group of contention-based protocols which are used to allow many users of wireless communication systems to share the same RF channel without pre-coordination.

ETSI for example, specifies a LBT based channel access mechanism for RLANs or wideband transmission systems to detect the presence of other transmissions on an operating RF channel in the 5 GHz band (see ETSI EN 301 893 [i.17]) or in the 2,4 GHz band (see ETSI EN 300 328 [i.18]). Here, before transmission the equipment performs a Clear Channel Assessment check using energy detection. If the equipment finds the channel occupied, it is not allowed to transmit on this channel in that time slot. Depending on the equipment type, it waits a certain time and starts transmission, or it re-evaluates the channel availability.

Advantages of LBT:

- it reduces collisions in the RF channel when multiple transmitters intending to transmit at the same time;
- it utilizes the RF channel efficiently better than e.g. the Aloha protocol;
- it does not need pre-coordination between collocated RF systems; and
- in average it offers a fair resource allocation of the shared RF channel.

Disadvantages of LBT are the following:

- in case of hidden nodes, it determines the occupied RF channel as idle;
- it uses critical time resources over the air as the algorithm enforces transmitters to sense for some time and act accordingly to transmit or wait for random period till channel is idle;
- in case of energy detection, the threshold needs to be defined very carefully; and
- it cannot support predictable/isochronous time slot allocation.

5.8 Citizens Broadband Radio Service (CBRS)

5.8.1 Introduction to CBRS

United States Federal Communications Commission (FCC) issued a Report and Order (R&O) [i.37], adopting rules for commercial use of 150 MHz of spectrum in the 3 550 MHz - 3 700 MHz band (3,5 GHz Band). The R&O establishes a roadmap for making the whole 150 MHz available for commercial under the Citizen Broadband Radio Service (CBRS). The 3 550 MHz - 3 650 MHz band segment is allocated for use by US Department of Defence (DoD) radar systems. In 2010, the National Telecommunications and Information Administration (NTIA) proposed making the band available for shared use with commercial systems though large exclusion zone to protect DoD radar systems. In 2015, however, NTIA recommended the reduction of the geographic area of the zones by approximately 77 percent, and by using sensor technologies they permitted commercial use inside the zones. FCC issued two further Amendments in 2016 (FCC 16-55 [i.38]), and 2018 (FCC 18-149 [i.39]) in FCC dockets GN 12-354 and GN 17-258 [i.40]. The CBRS-specific rules themselves are codified in Part 96 of Title 47 the U.S. Code of Federal Regulations [i.41].

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 5). The DoD radar system along with FSS at 3 625 MHz - 3 650 MHz, and, for a finite period, grandfathered terrestrial wireless operations in the 3 650 MHz - 3 700 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. The 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 protect the incumbent system, and other PAL users, while being protected from General Access Authority (GAA) users. GAA users protect both PAL and incumbent users but will receive no interference protection from other users in the band. Figure 5 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 (3 550 MHz - 3 650 MHz). However, the rule allows the GAA use over the entire 150 MHz band.

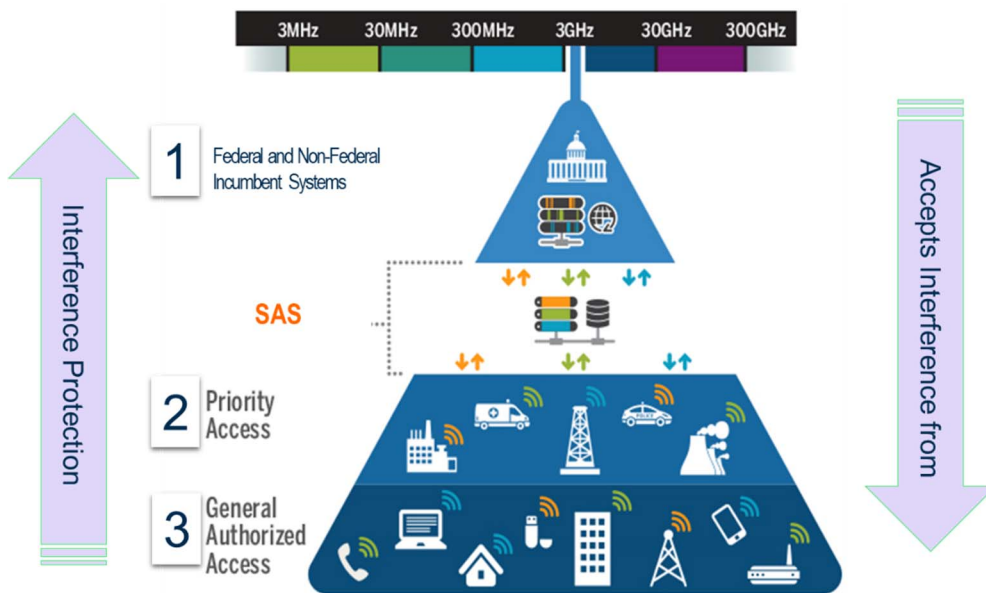


Figure 5: CBRS Hierarchical Architecture

5.8.2 SAS Functional Architecture and Protocols

Figure 6 depicts the SAS functional architecture. Any CBSD is using a standardized SAS-CBSD protocol to communicate its location, height, antenna characteristics, indoor/outdoor status, and other configuration parameters with its managing SAS, either directly or through a Domain Proxy (DP). A DP aggregates protocol messages from multiple CBSDs and exchanges them with the SAS on their behalf.

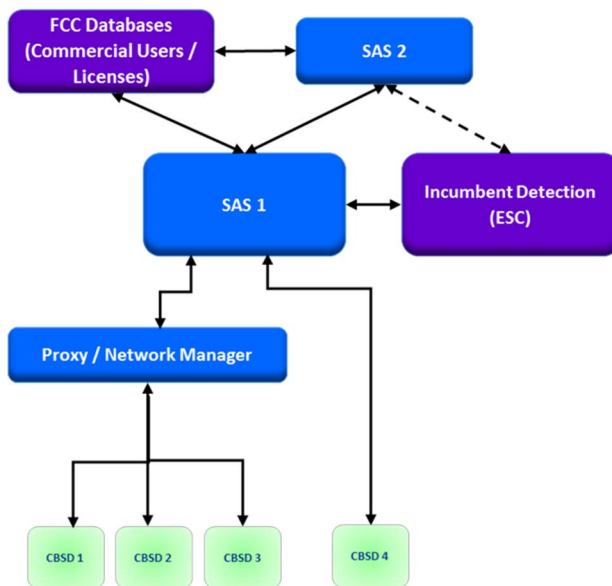


Figure 6: CBRS Functional Architecture

Figure 7 summarizes the SAS-CBSD/DP protocol messages.

The SAS obtains incumbent information and their updates from multiple sources, such as FCC Universal Licensing System, FCC Equipment Authorization System, and NTIA database Keyhole Markup Language files.

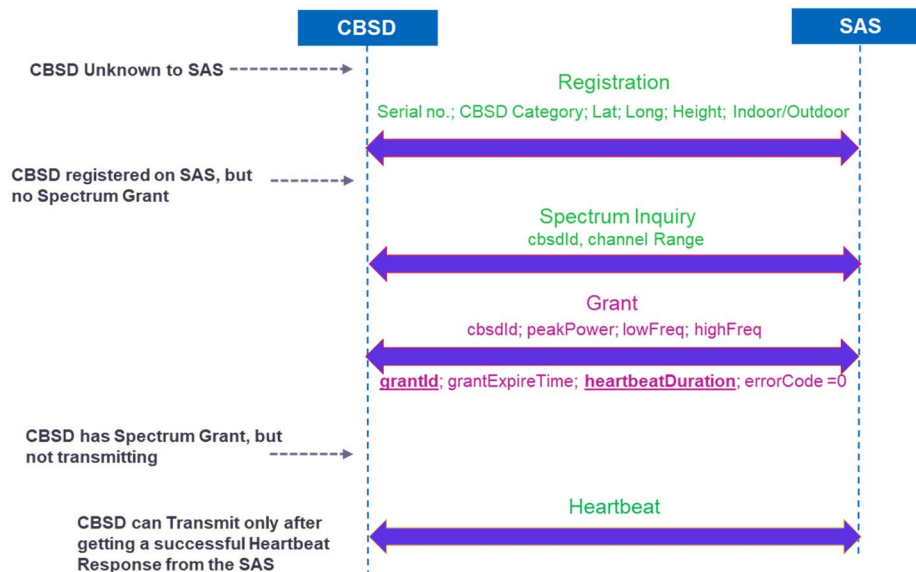


Figure 7: SAS-CBSD/DP Protocol Exchange

According to FCC Part 96, SAS Administrators obtain the information about Federal Radar operation, including their activation/deactivation from a network of sensors deployed and administered or commissioned by SAS Administrators. These sensors are called Environment Sensing Capability (ESC). Department of Defence (DoD) has agreed to provide the activation/deactivation of some Federal inland operation using Informing Incumbent system (e.g. Portals).

Finally, SASs are expected to synchronize their information and co-ordinate to apply aggregate interference to some of the incumbents (see clause 5.8.2). The information shared among SASs are CBSD information, ESC information, and PAL operations managed by each SAS. A periodic operation called Coordinated Periodic Activities Among SASs performed every midnight enables the synchronization and coordination among SASs.

5.8.3 Incumbent Protection

In order to apply incumbent protection, SAS determine the interference from any impacting CBSD to the incumbent or incumbent point (so-called Protected Entity), using the standardized propagation model, Irregular Terrain Model (ITM) point-to-point mode, and a hybrid model based on eHata and ITM. These standardized propagation models predict static propagation loss between the two points according to morphologies and terrains.

From the perspective of protection methodologies, CBRS incumbents are categorized into following classes:

- a) **Aggregate Interference protection:** All SASs apply aggregate interference protection to the incumbent from all CBSIDs regardless of which SAS manages them. To that end, neighbourhood areas are defined around the incumbent, for category A and category B CBSIDs, where all CBSIDs located within those areas, using a spectrum grant that overlaps with the frequency range occupied by the incumbent. Note that the aggregate interference is calculated using certain statistics of aggregate interference, such as median or 95-percentile of aggregate interference. Shore-based federal operation and some inland federal operations, FSS, PAL, GWPZ, and ESCs are protected using this mode of operation. Note that the license for grandfathered wireless users is expected to expire early 2023, and therefore no GWPZ protection is needed beyond that date.
- b) **Individual CBSD interference protection:** Each SAS, independently applies protection to some primary users of the band from individual registered CBSIDs, depending on their location, antenna characteristics and transmission power level. There is no synchronization and co-ordination needed among SASs. Some quiet zones (such as Colorado's Table Mountain), and international borders.
- c) **Exclusion zones:** For some primary users of the band, SASs generate exclusion zones around the incumbent, so that no CBSD can operate at any point within the exclusion zone, regardless of CBSD distance to incumbent, antenna characteristic, and power level. However, the exclusion zones are applied in a certain frequency range, and CBSIDs are allowed to operate outside those frequency ranges. Some inland federal operations, and some FSS operations using FCC Part 90 subpart Z (when a grandfathered wireless licensee is operating within 150 km of the FSS) are protected using exclusion zones. Note that the license for grandfathered wireless users is expected to expire early 2023, and therefore no Part 90 subpart Z exclusion zones are needed beyond that date.

5.8.4 Dynamic Protection Area (DPA)

The concept of DPAs is used to protect federal incumbent users from harmful interference due to secondary users sharing CBRS frequencies. They are pre-defined area (or a point) in/at which an incumbent operates on a dynamic basis (i.e. operations change with time and frequency). Shore-based DPAs in USA mainland are shown in Figure 8.



Figure 8: Shore-based DPAs in USA Mainland

When federal radars are operating within a DPA, secondary users in the neighbourhood of the DPA could be forced to change their operating parameters (frequency or power) to protect the incumbent.

A DPA neighbourhood is a pre-defined area surrounding the DPA in which a secondary user could in theory contribute to producing harmful interference to the incumbent, typically based on worst-case assumptions. Secondary users outside of the DPA neighbourhoods are not expected to cause interference and are not affected by the presence of the DPA activity. The size of the neighbourhood is based on assumed deployment models, the DPA interference criterion, and a standardized propagation model. It is important to note that the DPA neighbourhoods are not treated as exclusion zone.

5.8.5 DPA Activation

As the term DPA implies, the protection of federal operations within DPAs applies only when there is federal radar operation is detected within the DPA. This is referred to as DPA activation. During the time no federal operation are detected within DPAs (or after a certain time when DPA deactivates) no CBSD operation is impacted and DPAs are not protected.

However, SASs are expected to be notified about federal incumbent activity in a DPA. Part 96 has determined two approaches for DPA activity notification:

- **ESC monitored DPAs:** A network of sensors are deployed and are responsible for detection of DPA activity, after which they send a notification to the SAS about the DPA in which the incumbent is operating, and its operational frequency range. It is important to note that SASs limit the aggregate interference from CBSD operation at the sensor radio front ends to avoid raising the noise level at the sensor hardware. Raising noise-levels at ESC front-end deteriorates the sensor capability to detect radar operation within the DPA.
- **Portal-controlled DPA:** a DoD spectrum manager responsible for operations at the given portal DPA site logs into a calendar and specifies when, and at which frequencies, they plan to operate. SASs read the portal DPA calendars on a regular basis and protect the DPAs accordingly when an operating event is scheduled.

NOTE: If a SAS does not have access to an ESC or the ESC has suffered a failure, or there is a problem with the SAS accessing the portal, the respective DPA is assumed to be active on all unmonitored frequencies.

5.8.6 GAA Coexistence and TDD alignment

As described in clause 5.8.1, 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".

Proprietary solutions could be applied to enable GAA coexistence in the band. However, Graph-based methods based on creating "Connected Sets" are considered as primary solutions for GAA coexistence. Each individual CBSD (or a group of CBSDs belonging to some certain single frequency groups) are considered as the node of the graph. The edge between two nodes is determined when the two nodes have radio wireless coverage overlap with each other. Using these concepts, a Connected Set is a graph including CBSDs with directly or indirectly interference relation with other CBSDs in a connected set, i.e. a graph wherein there is a path between any two nodes of the graph. Figure 9 depicts the concept of Connected Sets.

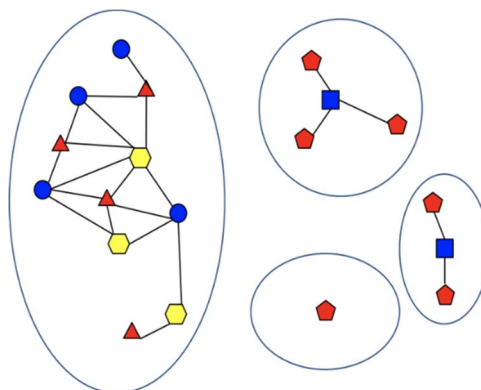


Figure 9: Connected Sets

Moreover, since the operation mode in CBRS band is using Time Division Duplex (TDD), it is essential to ensure alignment of TDD operation among CBSDs that are operating in the same geographical vicinity. To that end, protocols and procedure are defined to allow SASs ensure TDD alignment among CBSDs using 3GPP LTE, 3GPP 5G NR, and non-3GPP radio technologies in CBRS band.

5.8.7 CBRS Core Network Architecture

CBRS is a primary shared spectrum technology that enables the proliferation of Private Wireless Networks deployed using 3GPP LTE, 3GPP 5G NR, and non-3GPP radio technologies. To that end, certain features are requested in the core network architecture, especially for 3GPP LTE and non-3GPP radios. 3GPP 5G NR has developed the concept of Non-Public Networks (NPN) in Release 16, enabling private wireless deployment using two modes of operations:

- Stand-alone Non-Public Network (SNPN): operated by an NPN operator and not relying on network functions provided by a public operator (Public Land Mobile Network (PLMN)); and
- Public network integrated NPN (PNI-NPN): a non-public network deployed with the support of a public operator (PLMN).

3GPP private network deployment supports broadcasting PLMN ID, which are not available for by non-public operators and SNPNs. The combination of PLMN IDs and Network IDs are needed to enable network (re-)selection, overload control, access control and cell-barring.

To that end, Shared PLMN IDs, or Shared Home Network IDs (SHNI) are being managed by OnGo Alliance to enable shared spectrum private wireless deployment in CBRS. The value for SHNI is 315-010 (Mobile Country Code = 315 and Mobile Network Code = 010), which allows one block of 10 000 sub-IMSI-blocks with 100 000 unique IMSI each created. Since the SHNI is shared among multiple CBSDs core-network architecture and functionalities, such as roaming, network (re-)selection, etc., need to be customized to avoid any confusion.

3GPP has defined band 48 in LTE and band n48 representing CBRS operation, and meeting CBSD and UE CBSD radio specifications. Many major network and UE manufactures (such as Ericsson™, Nokia™, Apple™ and Samsung™) have selected to implement band 48 and n48 in their products. Moreover, 3GPP has enabled carrier aggregation and E-UTRA-NR Dual Connectivity (EN-DC) with many other bands. Figure 10 depicts some EN-DC use cases using b48 and n48.

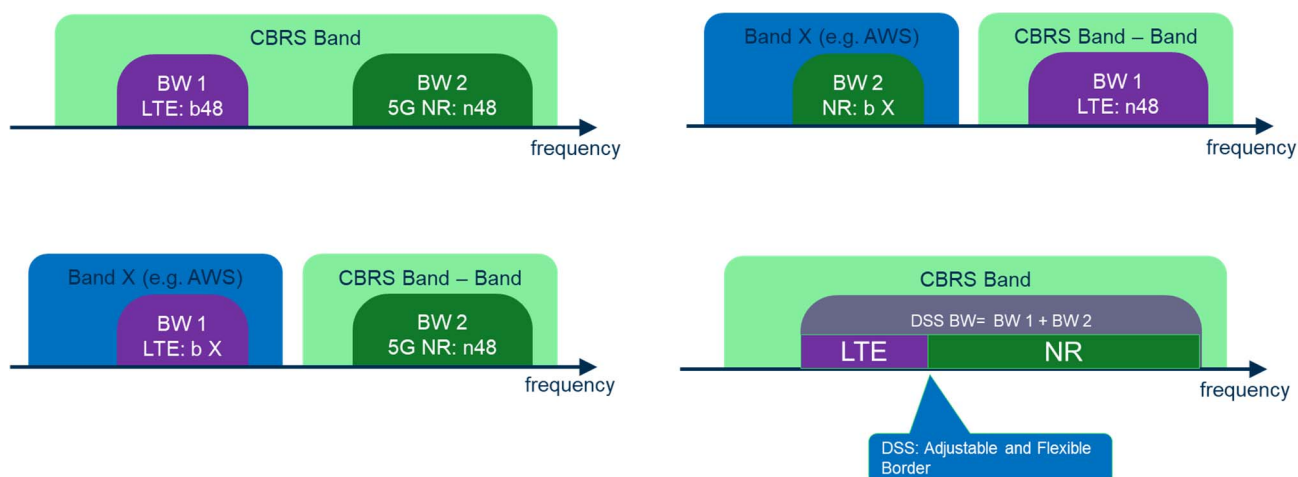


Figure 10: EN-DC combinations using b48 and n48

5.8.8 CBRS Standardization

Upon issuing the Part 96 Rule and Order (R&O) by FCC, Wireless Innovation Forum (Winn Forum or WinnF) was determined to define a set of technology rules for SAS, CBSD, and ESC operations, the standardized SAS-CBSD and SAS-SAS protocols, security aspects, and test and certification plan for CBRS operation.

It is important to notice that WinnF specifications and test/certification plans are radio technology agnostic and are applied regardless of underlying radio technology. To enable promotion of deploying of 3GPP-based technologies using CBRS shared spectrum, six companies (Ericsson™, Federated Wireless™, Google™, Intel™, Qualcomm™, and Ruckus Network™) initiated CBRS Alliance in 2016, joint by 190+ additional member companies including nation's largest mobile carriers (such as Verizon Wireless™, AT&T™, and Dish Networks™). The objective of CBRS Alliance was to define 3GPP network architecture, GAA coexistence, 3GPP radio performance, operational aspects of 3GPP-based CBRS deployment, and other marketing and business promotions of 3GPP deployment in CBRS band. In 2020, CBRS Alliance extended its objectives to include other shared spectrum developments in other spectrum bands inside and outside United States and changed its name to OnGo Alliance™.

5.8.9 Light Touch Leasing

Light Touch Leasing enables PAL holders to lease under-utilized spectrum to third parties to supplement GAA availability. The Spectrum Exchange provides an automated portal that gives organizations almost instant access to dedicated spectrum without the need for direct engagement with the FCC. It is a portal-based solutions to automatize spectrum negotiation and assignment. Although it would be more costly, a big advantage over GAA is that the spectrum is more predictable.

PAL licensees can partition and disaggregate their licenses. PAL licensees may also partially assign or transfer their licenses. Holders of PALs may enter into de facto transfer leasing arrangements for a portion of their licensed spectrum.

PAL licensees can engage in spectrum manager leasing for any bandwidth or duration of time within the terms of the license. An SAS Administrator may choose to accept leasing notifications and support leasing arrangements under a light-touch leasing procedure.

5.9 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. An AFC system protects incumbents operating both co-channel and adjacent channel to the SP device.

The regulatory classifications for 6 GHz RLAN devices are the following:

- Very Low Power devices (VLP): minimal signal power, and can operate outdoor across the band without AFC.

- Low Power Indoor-only devices (LPI): maximum output power = 30 dBm (5 dBm/MHz), and can operate across the band without AFC.
- Standard Power devices (SP): maximum output power = 36 dBm (23 dBm/MHz), can operate indoor and outdoor, and uses AFC.

AFC is mandatory for SP RLAN devices in

- U-NII-5 and U-NII-7 (5 925 MHz - 6 425 MHz and 6 525 MHz - 6 875 MHz) in USA.
- 5 945 MHz - 6 425 MHz in Europe.

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

- SP Access Points (APs) are capable of determining their geolocation automatically.
- SP APs request a list of available channels from AFC every 24h.
- A channel availability request includes 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.
- 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 and inter-AFC coordination/synchronization.

5.10 Dynamic Channel Selection (DCS)

In DECT (Digital Enhanced Cordless Telecommunications) the mandatory Dynamic Channel Selection (DCS) mechanism provides effective co-existence of uncoordinated private and public systems on the common designated DECT frequency band and avoid any need for traditional frequency planning. Each device has access to all channels (time/frequency combinations). When a connection is needed, the channel is selected, that at that instant and at that locality, is either free or is the least interfered available channel.

A channel may not be available because:

- the measured background signal in the channel is above a working limit;
- the Fixed Terminal (FT) is not able to receive on that frequency; or
- the Fixed Terminal cannot retune to that channel quickly enough (blind slot).

FTs advertise the slots where they will listen for connections. Portable Terminals (PT) choose which FT and which channel they will attempt to connect on.

The combination of the FT broadcasted map and the local PT map reduce the problem of hidden nodes. Additionally, the connection handshake needs to be completed with no CRC (Cyclic Redundancy Check) errors and no packet loss, or the selection process needs to be restarted. This allows resolution of simultaneous attempts to connect on the same channel through connection retry. Each PT maintains an ordered list of the 6 to 10 least interfered channels. This list, and information on strongest detected FT (to which the terminal has access rights), are regularly updated in order to detect changes in the local environment and to detect movement between FTs. The least interfered channel of its list is used for the first bearer set up attempt to the strongest accessible FT (see ETSI EN 301 175-3 [i.19]).

This approach is robust when all devices follow the same coexistence rules. If multiple independent FTs are transmitting independent beacons the traffic on each can slowly drift into each other's slots. These sliding errors can be detected using sync and Z field checking and usually a handover to non-clashing slots can be performed without interruption to payload streams.

Obviously, misalignment of slots can reduce the number of useable channels to some extent and the heavier users of the band will align their network's slot boundaries using wired synchronisation, GPS synchronization or synchronization over the air

The big advantage of this kind of channel selection is that the set-up of a new channel takes into account the local interference situation in that instant. The system is so-called self-adapting. There is no need for a pre-planning of the system, but different applications and different operators can share dynamically the same spectrum resource without prior distribution of channels to specific services or base stations/FTs.

5.11 Detect And Avoid (DAA)

In the 2,4 GHz band Detect And Avoid (DAA) is a technique that adaptive equipment uses to reduce the potential of interference by avoiding the use of frequencies where other transmissions have been detected.

During normal operation, the adaptive equipment evaluates the presence of a signal on its current operating channel. If it is determined that a signal is present with a level above a certain detection threshold that channel is marked as 'unavailable' and will not be used for a given time. After that time period the channel will be re-evaluated and depending on the measured energy marked as 'available' or still remains as 'unavailable' (see ETSI EN 300 328 [i.18]).

For example, adaptive Frequency Hopping Spread Spectrum (FHSS) equipment needs an implementation of either DAA or LBT.

5.12 Dynamic Spectrum Sharing (DSS)

Dynamic spectrum sharing (DSS) provides a very useful migration path from LTE over 5G NR NSA (5G New Radio Non-Standalone) towards 5G NR SA (5G New Radio Standalone) by allowing LTE and 5G NR NSA to share the same carrier.

The whole DSS process is based on LTE's capability to configure Multimedia Broadcast Single Frequency Network (MBSFN) subframes to allow the transmission of 5G NR's Synchronization Signal Blocks periodically. Six out of ten subframes forming the LTE radio frame can be configured by the network to become MBSFN subframes. These could be subframes #1, #2, #3 and #6, #7, and #8. System information block type 2 (SIB2) is used by the LTE network to broadcast the applied configuration. All LTE terminals would read in the MBSFN configuration from SIB2 and ignore the subframes configured for broadcast.

The network configured in this way provides three of these 40 subframes to be used for MBSFN, which reduces the LTE system capacity by 7,5 % as the LTE network can no longer use these subframes for standard data transmissions. These subframes are now used to carry 5G signals and channels, but do not provide any substantial capacity for any 5G NR deployment. To increase capacity, DSS enables the transmission of 5G NR in standard LTE subframes not configured for MBSFN.

To make these standard LTE subframes usable for 5G NR transmission, several signal components need to be avoided during transmission, even if the LTE scheduler does not intend to use these particular subframes for data transmission. This is guaranteed by the LTE scheduler by puncturing or shifting relevant resource blocks according to the capability of the 5G UE.

All these functionalities can also be performed dynamically depending on the capability of the scheduler to monitor the cell load, the type of services requested by the terminals, and the number of LTE and 5G devices connect to this cell. However, the dynamic aspect of DSS is a proprietary functionality of the used infrastructure provider.

DSS was included already in 3GPP Rel-15 and further enhanced in 3GPP Release 16.

6 Analysis of the existing frameworks

6.1 Introduction

In single-tier spectrum sharing frameworks (horizontal spectrum sharing), sharing happens usually between radio systems having the same rights in terms of priority to access spectrum (thus, between the same type of radio service/system). This is possible both in licensed and unlicensed bands (see examples).

- In licensed bands, spectrum users typically share the spectrum based on commercial sharing agreements, such as spectrum auctions for IMT which result in dedicated spectrum being allocated to specific MNOs for a specific period of time. Local licensing in dedicated bands is another example of horizontal sharing.
- In unlicensed bands, spectrum users usually ensure compliance with a technology standard (e.g. Wi-Fi®) and/or predefined usage conditions for the band. Those usage conditions aim to ensure fair access among spectrum users.

Multiple Access Techniques (e.g. CDMA, FDMA, or TDMA) are used to divide the available spectrum to the radio services in the same tier. As the number of systems in the same tier increases, the performance degrades:

- "Authorized light licensing" aims to control the maximum number of allowed unlicensed devices in a given area; it is based on a (automated) registration and authorization mechanism for equipment.

In multi-tier spectrum sharing (Vertical Spectrum Sharing), a hierarchy in the access and usage of the shared spectrum between users is to be defined, i.e. which tier pre-empts which other tiers. Usually, it is used for spectrum sharing between different services (e.g. primary and secondary). It can be adopted both in licensed and unlicensed bands.

An advantage of multi-tier spectrum sharing is that in a relatively simple way, i.e. outside the long re-farming processes at regulatory level, it allows additional users (secondary) to enter a band that is already allocated to a service (primary).

6.2 Evaluation parameters

Sharing dimension: sharing can be divided into the following four different dimensions that are divided to allow multiple users to send data through a single RF channel:

- in frequency - with individual licenses each with a specific channel, in contrast to simultaneous access to the same frequency range by several licensees;
- in geography - with licenses covering the whole country, or specific geographical areas, or defining the operational area of transmitting equipment by specifying technical characteristics, e.g. transmit power, antenna pattern, antenna direction, etc.;
- in time - some licenses have a short-term fixed duration, others a long-term fixed duration, or other use of time (e.g. different day times);
- in code - with different access coding schemes the spread information can be transmitted over a shared RF channel (e.g. CDMA); or
- in any combination of the previous four dimensions.

Sensing: sensing is a mechanism to evaluate the RF channel. In most cases, sensing is based on energy detection, i.e. above a certain energy threshold the channel is observed as occupied and will not be used. Depending on the sharing rules, the channel may be re-evaluated after a certain period or may be declared unusable. Sensing can be done not only in the beginning of operation but also during operation. Here, sensing is meant as part of the MAC access scheme and not as a high-level procedure performed before the network deployment. Depending on the framework sensing can be performed in a decentralized way, i.e. by all devices (e.g. the LBT mechanism in Wi-Fi® systems), or in a centralized manner by a centralized entity (e.g. the ESC connected to the SAS).

Coordination: spectrum coordination ensures coexistence based on knowledge of the radio systems involved, the RF environment, or a set of accepted rules for sharing. This can be done with the help of:

- a centralized entity such as a data base or a regulatory department;
- sensing;
- predefined static sharing rules (e.g. a random hopping sequence) in compliance with technological standard and/or usage conditions;
- decentralized sharing coordination (e.g. DECT); and
- any combination of the previous ones.

Minimum geographical dimension: the minimum geographical area in which the frequency bands used for the previous described sharing frameworks are available:

- worldwide;
- transnational (e.g. ITU regions);
- national; and
- local.

Access tiers: the number of different tiers for spectrum access:

- two tiers: one primary user shares its frequency band with secondary users;
- three tiers: three different user classes share the frequency bands with different sharing roles and priorities, generally divided into incumbent users (first tier), QoS guaranteed sub licensee (second tier) and best effort users (third tier); and
- single tier: sharing among users/stations of the same hierarchy level regarding spectrum access, e.g. coexistence/sharing in a license-exempt environment (Wi-Fi[®]) or commercial sharing agreements between MNOs in a licensed band.

Information exchange: if it is recommended for networks under the same sharing framework to exchange their information about current environment, what method is used to do so:

- exchange via a centralized data base;
- exchange via beaconing, i.e. every base station/access point transmits regular beacons containing information about the current network status;
- exchange via backhaul communication; and
- no exchange.

Spectrum allocation: one of the two general allocation protocols:

- contention-based - many users share the same RF channel without pre-coordination but ensure compliance with the technological standard and usage conditions established for the shared spectrum;
- schedule-based - a schedule determines which user may use which resource at which time;
 - scheduler characteristics:
 - manual - process is based on manual interaction, e.g. by email;
 - automated - process works without manual interaction;
 - during operation (dynamic) - scheduling happens before and dynamically during operation with a defined access/reconfiguration time;
 - before operation (static) - scheduling happens once before starting the system.

Classification: the set of functionalities which is defined and described by the sharing framework:

- data base - functions, structure, content, and management of a data base;
- data base access - interfaces, protocols, and roles;
- technology specific protocol - sharing protocols e.g. at MAC layer;
- set of sharing rules - predefined parameters/rules that need to be followed by each user;
- sensing - limits and measurement procedures for spectrum scanning;
- device conformity - specific device compliance test, e.g. described by harmonized standards; and
- interference prediction:
 - non - framework does not contain assumptions about interference;
 - static - interference calculation/prediction is based on predefined parameters such as power, coverage, duty cycle, etc.;
 - dynamic - interference calculation/prediction is adjusted to the changing RF environment.

Technology: the specific technology/standard to be used under the framework.

System administration: the body/organization responsible for managing the sharing system:

- National Regulatory Administration (NRA);
- Mobile Network Operator (MNO);
- Private Network Operator (PNO)/Vertical Sector Player (VSP);
- Third Party - this could be for example a SAS provider; and
- none.

Specifics: special functionalities/features of the framework, e.g. performance monitoring: the framework supports monitoring functionalities to analyse the behaviour/performance of systems using the framework.

6.3 Comparison of sharing frameworks

In Table 15, Table 16, Table 17, and Table 18, the parameters from clause 6.2 are assigned to the respective frameworks for comparison purpose.

Table 15: Comparison of LSA, eLSA, TV White Space, and audio PMSE

Parameter	LSA Value	eLSA Value	TV White Space Value	Audio PMSE Value
Sharing dimension	- frequency - geography	- frequency - geography - time	- frequency - geography	- frequency - geography - time
Sensing	No	no	yes	no
Coordination	centralized entity	centralized entity	centralized entity	- centralized entity - sensing - sharing rules
Deployment	national	local	national	- national - local
Access tier	two tiers	two tiers	three tiers	two tiers
Information exchange	centralized data base	centralized data base	centralized data base	no exchange
Spectrum allocation	schedule-based: - manual - before operation	schedule-based: - manual - automated - during operation	schedule-based: - automated - during operation	schedule-based: - manual - before operation
Classification	data base access	data base access	- data base - data base access - sensing - device conformity	- set of sharing rules - device conformity
System administration	NRA, MNO, PNO, or third party	NRA, MNO, PNO, or third party	NRA or third party	PNO
Technology	agnostic	agnostic	ETSI EN 301 598 [i.25]	ETSI EN 300 422-1 [i.27]
Specifics		geolocation capability mandatory	geolocation capability mandatory	- sensing before deployment - frequency planning

Table 16: Comparison of NLL, DFS, ITS, and LBT

Parameter	NLL Value	DFS Value	ITS Value	LBT Value
Sharing dimension	- frequency - geography	time	time	time
Sensing	no	yes	yes	yes
Coordination	centralized entity	- sensing - decentralized	- sensing - decentralized	- sensing - decentralized
Deployment	national	worldwide	national	worldwide
Access tier	two tiers	two tiers	single tier	single tier
Information exchange	no exchange	no exchange	no exchange	no exchange
Spectrum allocation	schedule-based: - manual - before operation	contention-based	contention-based	contention-based
Classification	set of sharing rules	- sensing - technology specific protocol - device conformity	- sensing - technology specific protocol - device conformity	- sensing - technology specific protocol - device conformity
System administration	NRA	none	none	none
Technology	agnostic	- IEEE 802.11h [i.49] - ETSI EN 301 893 [i.17]	- IEEE 802.11p [i.50] - IEEE 802.11bd [i.51] - 3GPP	- IEEE 802.11h [i.49] - ETSI EN 301 893 [i.17] - ETSI EN 300 328 [i.18]
Specifics				

Table 17: Comparison of CBRS, Light Touch Leasing, AFC, and DCS

Parameter	CBRS Value	Light Touch Leasing Value	AFC Value	DCS Value
Sharing dimension	- frequency - geography	- frequency - geography	- frequency - geography	time
Sensing	yes	yes	no	yes
Coordination	- centralized entity (SAS)	- centralized entity (SAS)	- centralized entity (AFC) - sharing rules	- sensing - decentralized
Deployment	- national - local	- local	- local	- worldwide
Access tier	three tiers	three tiers	two tiers	single tier
Information exchange	Backhaul communication	Backhaul communication	no	beaconing
Spectrum allocation	schedule-based: - automated - during operation	schedule-based: - automated - during operation	schedule-based: - automated - before operation	schedule-based: - automated - during operation
Classification	- data base - data base access - sensing - dynamic interference prediction	- data base - data base access - sensing - dynamic interference prediction	- data base - data base access - device conformity - static interference prediction	- sensing - technology specific protocol - device conformity
System administration	third party: SAS provider	third party: SAS provider	third party	none
Technology	agnostic	agnostic	Standard power RLAN (ETSI EN 303 687 [i.52])	DECT (ETSI EN 301 175-3 [i.19])
Specifics	Dynamic incumbent protection	Dynamic incumbent protection	automatic geolocation capability mandatory	

Table 18: Comparison of DAA and DSS

Parameter	DAA Value	DSS Value
Sharing dimension	frequency	time
Sensing	no	no
Coordination	decentralized	centralized entity
Deployment	worldwide	worldwide
Access tier	single tier	single tier
Information exchange	no exchange	backhaul communication
Spectrum allocation	contention-based	schedule-based: - automated - during operation
Classification	- technology specific protocol - device conformity	- technology specific protocol - device conformity
System administration	none	none
Technology	ETSI EN 300 328 [i.18]	3GPP: 4G and 5G
Specifics		

6.4 Evaluation results

This clause summarizes the results above, evaluating the capability of the existing sharing frameworks in fulfilling the various use case needs. By analysing the needs of each use case, the characteristics of an ideal incumbent are identified and then the characteristics of a preferred shared spectrum framework are detailed.

All use cases provide at least one high value for the QoS levels (see Table 9), 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 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.

None of the described use case is supported by a primary service, apart from PPDR in some dedicated frequency bands, and 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 LSA, TV White Space, CBRS, and Light Touch Leasing.

Due to the claim of technology neutrality, all sharing methods based on technology specific protocols are not considered further. Those include DFS, channel access scheme of ITS, LBT, DCS, DAA, and DSS (as defined in the present document). The usage of such protocols would introduce additional requirements onto the systems accessing the shared spectrum.

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 or by a certain set of sharing rules for a specific frequency band such as Audio PMSE or NLL or a combination of both. Concerning the automation of the spectrum access, eLSA and AFC offer significantly greater potential than Audio PMSE or NLL because both 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 (VSP, see clause 5.1.2) 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 during operation. Such a service could perhaps also be integrated into a database. 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 approaches that natively support automatic coordination between secondary users are CBRS and Light Touch Leasing (as described in clause 5.8.5). Here, coordination between secondary users refers to inter-system coordination, i.e. coordination between two different systems, and not to intra-system coordination, i.e. coordination within one system.

Automatic coordination between secondary users is a complex topic. The following functionalities is a non-exhaustive list of envisaged features:

- interference monitoring;
- interference/propagation calculation;
- protection criteria;
- exchange of information about the RF environment; and
- adaptivity of physical layer and/or MAC layer.

Here a compromise is necessary 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 19 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 19 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 19: 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 19 suggests the direction in which the existing frameworks, AFC or 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.

7 Conclusion

In the present document, high level use cases of selected vertical sectors, such as audio PMSE, e-health, wireless industrial automation, PPDR, intelligent transport system, car test track, 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 specialities are analysed and summarized by a common parameter set. In addition, various concepts, procedures, and techniques for spectrum sharing are described and compared with respect to predefined evaluation parameters.

The present document evaluates the benefits and disadvantages of the various sharing procedures with respect to the use cases described and 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 (see Annex B). 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 steps are to:

- 1) develop envisaged adjustments for AFC, eLSA and CBRS (adding, removing, and/or modifying features); and
- 2) consider the creation of a SRdoc for spectrum sharing for local private networks.

Implications for PMSE End User Devices:

PMSE End User Devices comply with the technical and operational requirements in Part 96 of the FCC Rules [i.41]. Here are a few notable points copied from this source:

- *"§96.41(a) Digital Modulation: Systems operating in the Citizens Broadband Radio Service must use digital modulation techniques.*
- *§96.41(b) Power Limits: Maximum EIRP (dBm/10 MHz): 23. Maximum Power Spectral Density (dBm/MHz): n/a*
- *§96.41(c) Power Management: End User Devices shall include transmit power control capability and the capability to limit their maximum EIRP in response to instructions from their associated Citizens Broadband Radio Service Device (CBSD).*
- *§96.47(a) End User Devices may operate only if they can positively receive and decode an authorization signal transmitted by a CBSD, including the frequencies and power limits for their operation.*
 - *§96.47(a)(1) An End User Device must discontinue operations, change frequencies, or change its operational power level within 10 seconds of receiving instructions from its associated CBSD."*

Some of the operational requirements for CBRS devices may limit the usefulness of the band for certain types of PMSE equipment at certain locations and under certain conditions. For example, wireless microphones are expected to provide continuous high-quality audio transmission with very low latency (typically less than 3 milliseconds). Interruptions caused by changes in transmission parameters (e.g. frequency changes) would not be acceptable for this type of use. On the other hand, other PMSE devices such as wireless conferencing and discussion systems might be able to accept a limited number of interruptions depending on timing and suppression of noise and audio artifacts.

Factors that would maximize the usefulness of CBRS spectrum for Audio PMSE operation include:

- It would be helpful if an Audio PMSE user could specify a preference for GAA channel assignments in the 3 650 - 3 700 band in locations where incumbents are not operating.
- It would be helpful if an Audio PMSE user could ask the SAS to minimize frequency changes whenever possible, to reduce audio disruptions.

Open Issues for further discussion:

- Since frequency changes can cause interruptions and noise in audio transmissions, could a PMSE user ask the SAS to minimize non-mandatory frequency changes during operation?
- Could a PMSE user ask the SAS to prioritize the use of the 3 650 - 3 700 band over operation in the 3 550 - 3 650 band?

Annex B: 3,8 GHz - 4,2 GHz activities at CEPT

The European Commission issued a mandate to CEPT in December 2021 to study the use of the 3,8 GHz - 4,2 GHz band by terrestrial wireless broadband systems providing local-area (low/medium power) network connectivity [i.48]. This mandate contains the following two tasks:

- "T1 Study and assess the technical feasibility of the shared use of the 3.8-4.2 GHz frequency band by terrestrial wireless broadband systems providing local-area (i.e. low/medium power) network connectivity. In this regard, consider sharing solutions, including innovative features, which ensure:*
- a. protection and the future evolution and development of incumbent users sharing this band, in particular receiving satellite earth stations and terrestrial fixed links,*
 - b. co-existence of terrestrial wireless broadband systems providing local-area network connectivity and uses operating in adjacent bands such as terrestrial systems providing wireless broadband electronic communications services in the 3.4-3.8 GHz frequency band and radio altimeters on board aircraft in the 4.2-4.4 GHz frequency band.*
- T2 Subject to the sharing solutions and the results of Task 1, as appropriate, develop a harmonised frequency arrangement as well as the least restrictive harmonised technical conditions for the shared use of the 3.8-4.2 GHz frequency band by terrestrial wireless broadband systems providing local-area connectivity. These harmonised technical conditions shall avoid interference, protect relevant incumbent uses within the band and in adjacent bands, and facilitate cross-border coordination.*

Based on the results of sharing studies within the 3.8-4.2 GHz frequency band and co-existence studies with uses in adjacent bands, the CEPT may include, where necessary, guidance on appropriate receiver characteristics for radio equipment as part of the harmonised technical conditions or/and recommend to ETSI to consider the results of those studies when developing relevant harmonised standards."

A work item on Task 1 was initiated by ECC Project Team 1 in March 2022 ("Feasibility and sharing studies on the shared use of the 3,8 GHz - 4,2 GHz frequency band by terrestrial wireless broadband systems providing local-area (i.e. low/medium power) network connectivity") with a target date of July 7, 2023. The result of this work item will be summarized in a CEPT report.

In parallel in FM60 ("Shared use of the 3,8 GHz - 4,2 GHz frequency band"), which was created in October 2022 by Working Group Frequency Management to develop the draft CEPT response to the mandate on shared use of 3,8 GHz - 4,2 GHz, the work item FM60_01 was initiated that focuses on Task 2. Start date was March 7, 2022 and target date is March 29, 2024. Expected outcomes are two deliverables: an ECC decision and a CEPT report.

Annex C: Change History

Date	Version	Information about changes
March 2023	1.1.1	First published version

History

Document history		
V1.1.1	March 2023	Publication