ASCENT strategic recommendations: Spectrum sharing between satellite and terrestrial systems

White paper

Demonstrator for license assisted spectrum access satellite networks

(ESA Contract No. 4000123000/18/NL/WE)

05/10/2020

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1 INTRODUCTION

The "Demonstrator for license assisted spectrum access satellite networks (ASCENT)" project (ESA Contract No. 4000123000/18/NL/WE) considered the implementation of the lisenced shared access (LSA) mechanism to facilitate spectrum sharing between mobile terrestrial networks and satellite system.

During the two years study, different sharing scenarios in several frequency bands have been investigated. The investigations consisted in a first analysis of the sharing scenario to define the most reliable use cases and in a second step the project developed a demonstrator to support the initial theoretical findings. The findings of the study allows to:

- Draw several conclusions on the feasibility of the sharing,
- Identify some issues related to the considered radio services, to sharing scenario and to the LSA mechanism,
- Identify some possible new opportunities either in further developing the considered use cases or investigating other new ones.

Starting from the main results of the project, the purpose of this document is to define some strategic recommandations to, in one hand, promote the conclusions of the project and on the other hand, to develop the preliminary conclusions in order to further improve the considered sharing scenario or to identify new sharing oppportunities which could be handled in a similar manner.

Future integrated satellite-terrestrial architectures will be layered and they will form a 3-dimensional network consisting of terrestrial communications, drones, high-altitude platforms and satellites in different orbits. The different connectivity links in this integrated airborne-terrestrial system will be generated by use of radio frequency and/or optical technologies. The high-level architecture is shown in Figure 1, including a common core network functionality. The ASCENT project work created some technical building blocks for the system.

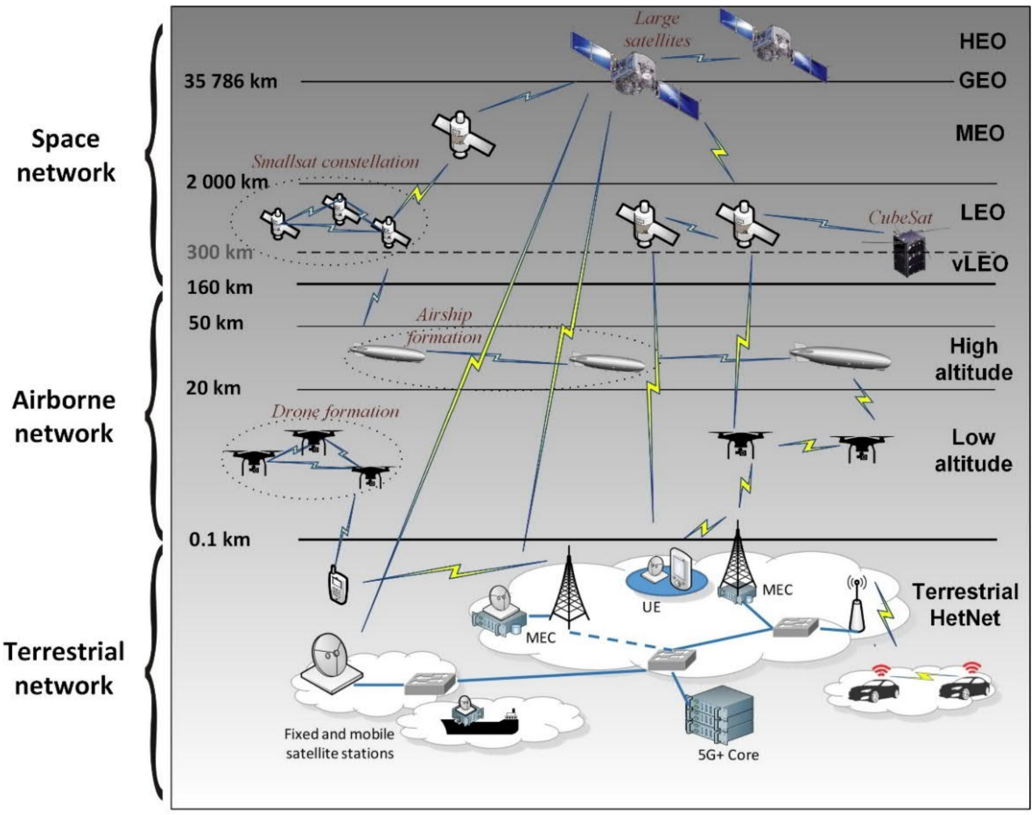

Figure 1. Layered architecture of 5G and Beyond systems.

2 MAIN CONCLUSIONS AND EVIDENCES FROM ASCENT PROJECT

2.1 On considered radio services

The ASCENT project focused on spectrum sharing scenarios where the frequency band could be shared between satellite and International Mobile Telecommunication (IMT) terrestrial networks. Whereas the IMT terrestrial network deployment is well-known and is assumed to be deployed ubiquitously with public terminals, which could be everywhere, the satellite network deployment is different according to the nature of the satellite service, which is considered.

In particular, it is important to understand the different kind of satellite application types which reflect deployment scenario and as such mitigation techniques to be used for spectrum sharing are different. The main satellite applications are:

- Fixed satellite service (FSS): A radiocommunication service between Earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radiocommunication services.
- Mobile satellite service (MSS): A radiocommunication service:
    - o Between mobile Earth stations and one or more space stations, or between space stations used by this service; or
    - o Between mobile Earth stations by means of one or more space stations.

  This service may also include feeder links necessary for its operation.
- Earth exploration satellite service (EESS): A radiocommunication service between Earth stations and one or more space stations, which may include links between space stations, in which:
    - o Information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites;
    - o Similar information is collected from airborne or Earth-based platforms;
    - o Such information may be distributed to Earth stations within the system concerned;
    - o Platform interrogation may be included.
    - o This service may also include feeder links necessary for its operation.
- Broadcast satellite service (BSS): Radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-satellite service, the term “direct reception” shall encompass both individual reception and community reception.

From that situation, the ASCENT study carefully analysed, defined and selected most suitable use cases for spectrum sharing studies. The focus has been in investigating how LSA could be used to enable coexistence of different systems in the same frequency.

During the course of study we have used available information in scientific literature, in regulatory documents and some part of information from public regulatory database. Since the study has considered also future communications systems that were not available, we have defined the sharing systems partly based on technical assumptions. In particular, it was assumed that meeting the adequate protection criteria to ensure coexistence with satellite service, the reliability of the IMT service is still viable. In general, ASCENT project focused on the development of the LSA system that is able to estimate interference effects, and dynamically control the secondary system in order to protect the primary system from interference. The developed system includes a database associated to a software to actively control IMT network. The feasibility of spectrum sharing was studied with radio interference viewpoints, but e.g. assessment of quality of service (QoS) degradation was not considered.

In the 5th generation (5G) cellular system pioneer bands (3.6 GHz and 26 GHz), the sharing scenarios which have been considered in the project are sharing situations between a 5G terrestrial network and FSS like satellite deployment. This has been studied in different bands, investigating both satellite downlink and uplink use cases. The project has also considered the case where satellite systems is a secondary user of the current IMT spectrum in ultra-high frequency (UHF) bands providing MSS, FSS or BSS services.

Further to deployment information, the ASCENT project also identifies that whereas the IMT network are primarily a national network, the satellite network is more often a global service which encompasses operation in multiple countries or even worldwide. In terms of frequency use rights, mobile network operators (MNO) have national rights and in that situation individual licencees conditions have to be managed on a national basis. With regard to the satellite side, frequency use rights are completely different and a satellite operator obtains national authorization through an international process and it appears difficult to define different conditions on country to country basis taking into account that the satellite coordination process takes into consideration global regulatory constraints to protect terrestrial services (such as power flux density (pfd) limits). From these coordination procedures, a satellite operator obtains frequency use rights associated to technical conditions for all the coverage area.

In conclusion, the nature and specificities of the two radio services which are subject to the study causes challenges in finding good sharing mechanisms. IMT terrestrial networks use their spectrum efficiently locally, limiting sharing with other radio services mostly to geographical separation. Satellite services already benefits from some sharing mechanisms for which the efficiency have already been demonstrated to share spectrum with fixed services and between satellite service (geo synchronous orbit (GSO) versus non-geo synchronous orbit (NGSO)) but not with mobile services. Satellite versus IMT spectrum sharing is a quite new scenario and for the time being the only real situation in Europe is in the band 3.4-3.6 GHz. The spectrum sharing is based on exclusion zone around satellite Earth stations (only few in Europe) and aims at providing satellite receiving Earth station protection. It is important to note that, in this particular case, some administrations prefer to avoid burden and they just don't renew the licence for the Earth station and therefore there is no real sharing situation.

The main Recommendations which could be drawn from the project regarding the radio services are:

- It is important to consider the appropriate satellite service and especially to be precise in the conclusions of the study. A situation where the spectrum sharing could work with FSS deployment cannot be generalized to other satellite services where other deployment figures, other protection criteria, other assumptions and other mitigations techniques must be considered.

2.2 On considered sharing scenarios

ASCENT project started with investigating scenarios to assess the feasibility taking into consideration the different situations where IMT and satellite service could coexist in a same frequency band. The frequency band selection of ASCENT project relies on the investigation of the European frequency pioneer bands and the goal was to investigate how satellite services operating in 3.4-3.6 GHz and 26 GHz could share with IMT services:

- C-band sharing (space-to-Earth): In this use case, a cellular network interferes a receiving earth station. Satellite is at geosynchronous or geostationary orbit approximately 36000 km above the Earth. The incumbent user is the FSS (fixed-satellite service) satellite operator. Depending of the nature of the IMT base station (Micro, macro, nano cells) and characteristics of the Earth station protection distances around satellite Earth stations could vary from tens of kilometers to 1 km.

- Ka-band sharing (Earth-to-space): The 24.65-25.25 GHz and 27-27.5 GHz bands are used for fixed satellite service, in the Earth-to-space direction. The devices to be protected are the satellites that receive the signals (e.g. feeder link) from the Earth station in this band.
- Ka-band sharing (space-to-Earth): Sharing in Ka-band between Earth exploration satellite and space research (space-to-Earth) operated in the 25.5-27 GHz band in all the regions. The devices to be protected are the receiving Earth stations. Some of these are registered, although the antennas diameter is not always provided. There are also many typical Earth stations, which positions are not known. Protection of the fixed receiving Earth stations could be based on the definition of exclusion zones as proposed for the C-band. However, protection zones allow more efficient sharing.

In the context of the ASCENT project, 5G network uses a time-division duplex (TDD) technology where base stations and mobile terminals transmit on the same frequencies. When considering the protection of fixed satellite Earth station at known position with regards to the impact of base stations, it is worth noting that in addition to facilitate the management of exclusion zones, the LSA could enable the deployment of base stations with the concept of protection zones. Exclusion zone is a geographical area within which LSA licensees are not allowed to have active radio transmitters; Protection zone is a geographical area within which incumbent receivers will not be subject to harmful interference caused by LSA licensees' transmissions. The LSA system controls the terrestrial base stations so that they do not exceed the limit of harmful interference at Earth stations. The control means adjusting the transmission power levels of the cellular users over the protection zone so that there is no interference. Mechanisms based on exclusion zones and LSA could be imagined to protect the satellite systems from mobile terminals but have not been investigated during the project. When considering private 3GPP Long Term Evolution (LTE)/5G networks instead of nation-wide mobile operator, LSA could help taking into account both fixed and mobile element from the IMT network but information related to all the exisiting networks need to be known.

From these first use cases, the following recommendations could be drawn:

- The LSA is essentially beneficial when considering at stations (from the primary or the secondary use) which change in geography (e.g. mobile terminals), time or frequency. In addition, the LSA could also help in managing the interference estimation based on the aggregated interference coming from all transmitters of the secondary user and in controlling the emission of the IMT network.
- LSA could only work if all minimum data such as station locations and updated emission characteristics are available.

One of the main objectives of the ASCENT project was to make available more spectrum opportunities for satellite operation in addition to study the possibility to introduce 5G systems in already allocated satellite spectrum. Therefore, the ASCENT project introduced an additional use case which investigates how new satellite application could be introduced in “native” IMT frequency bands. In this use case, IMT systems remain primary users and a satellite system is a secondary user of the spectrum.

The preliminary simulations done to assess this concept confirmed that the IMT spectrum can be shared with satellite downlink systems without causing harmful interferences to IMT systems:

- Pfd limits that guarantee the protection of the IMT system have been determined. These limits depend on the satellite band allocation direction and polarization.
- These limits are compatible with a wide range of satellite services including IoT, MSS and BSS applications.

Recommendations from this use case are to continue investigation on this promising scenario, which could lead to new or extended satellite services and facilitate the integration of satellite and terrestrial systems in the future. Further studies should be carried on to:

- Define the best direction and polarization for the satellite bands and possibly identify satellite technologies that could be used in these bands.
- Define the method to guaranty the protection of the IMT system in the uplink (Earth-to-space) direction.
- Work with stakeholders (operators, standardization and regulatory bodies) to define the sharing criteria and type of services.
- Define the interest, opportunities and main characteristics of an LSA system to serve this sharing case.
- Evaluate the possibility and impact of using non-geostationary Earth orbit (GEO) systems in these bands.
- Evaluate interest of sharing spectrum for integrated satellite-terrestrial systems.

2.3 On results of measurements and simulation

During the demonstrations and performance evaluations, we have measured and proved the scalability of the testbed. By scalability we mean that the developed LSA system is able to handle a large amount of controlled equipment including real and simulated base stations. Measurements done with the testbed and conducted simulations have shown the potential for spectrum sharing both in the 5G pioneer bands and in the current IMT bands taking into account limitations which are inherent to the asumptions of the study (e.g. in the study, locations of the satellite Earth stations are known, simulated 5G base stations and real 4G base stations have been used).

The current testbed has some known limitations that must be taking into account to avoid mis-interpretation of the results of the study:

- The testbed estimates the interference level at the satellite receiver using predefined models of transmitters, channels and receivers. The result of the simulation is highly dependent on the accuracy of the models (free space loss, rain models, HATA, etc.) with regards to a real system. This limitation could be overcomed by introducing a feedback loop from the satellite receiver to the LSA system and does not enable to use the LSA system in real conditions.
- The models used are static models used generally for dimensioning purposes. They do not enable to estimate precisely the interference of a real system (traffic model are not taken into account). However, the testbed is able to adapt power and frequency of each base station in order to keep aggregate interference at the acceptable level.
- The demonstration carried in the project proposed application examples of the LSA system in different environments (rural, urban, dense urban). These examples should be refined (number and characteritics of base station , location of the satellite receiver) to be as close as possible to a real system and identify a scenario which could be proposed for a trial on a real network with real equipment. In Ascent real 4G equipment have been used since 5G equipment were not available.

In the IMT sharing use case, we obtained preliminary results that confirmed the possibility of sharing in downlink but did not use the LSA testbed. The need to continue the work and refine the specification of the LSA for that use case was identified.

Finally, the ASCENT project did not study non-GEO systems, which use satellite tracking. This should be part of future studies

The first recommendation from the result of the ASCENT project is to further investigate all the different use cases with real satellite and 5G equipments.

The study restricted these investigation to the technical implementation of the LSA regulatory approach and the administrative licencing including the feasibility of the analysed concept (e.g. availability of the data, data privacy restrictions) has not been taken into account. In addition, to further improve the situation it could be relevant to carry out some business model investigations to identify if such scenario are viable.

Recommendation regarding the results from ASCENT study is that technical investigation should be accompanied by regulation analysis and also possible business model to evaluate the viability of a LSA mechanism to share spectrum.

3 GENERAL CONSIDERATION ON LSA PRINCIPLE

In general, the LSA mechanism is associated to a licencing framework and a technical implementation, which could imply the use of specific technology and/or mitigations techniques.

3.1 Regulatory status

The LSA is a regulatory mechanism which has been defined in a Radio Spectrum Policy Group (RSPG) opinion [1] as follows:

"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the licensed shared access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorised users, including incumbents, to provide a certain quality of service (QoS)."

The LSA mechanism is attached to the licencing approach which means that the mechanism is essentially a national issue. In that context, it is challenging to try to define harmonisation measures based on LSA approach. In that context and regarding the sharing scenario as retained in the ASCENT project, it is worth noting that all systems in this sharing scenario have multi-country coverage and therefore defining a LSA sharing scheme could be very challenging in particular with regard to the national licence definition. LSA is a national regulatory mechanism which provide some spectrum right of use to a secondary user.

3.2 Technical implementation

ASCENT project has been developed around the classical technical structure as depicted in European Telecommunications Standards Institute (ETSI) standards [2], [3] and [4] for the 2.4 GHz and Conference Européenne des Postes et Telecommunications (CEPT) [5]. LSA technology provides a way to control that only licensed users are allowed to use the spectrum. A limited number of users obtain the right to use the band, and the LSA controller, using the information from the database called LSA repository, ensures predictable QoS for all license holders. For example, the incumbent user may set a number of frequency channels that can be accessed, request multiple protection areas, define a type of protection based on the used services and devices, and remove the protection from the LSA repository if it is not using those resources anymore. The information is communicated from the database to the secondary licensed terrestrial system using an LSA controller. All the frequency rights, protection criteria and priorities has been agreed by the proponents (incumbent, secondary user and administration) and validated in the licensing conditions.

In this technical approach using a database, three main non-technical issues need to be further investigated:

1- Security aspect, data update and data privacy. Even in the ASCENT project the security aspect has been introduced and that data update is recognised as essential, it could be beneficial first to identify what would be the impact in case of security aspect failure or in case of a failure of the data update. Associated to the security aspect, data privacy is a real issue, which is most often tackled at a national level.

2- Impact of erroneous or missing data in the database on the incumbent protection, both from the incumbent and the secondary users.
3- Business models. Noting that the ASCENT project focused on 3.4-3.6 GHz and 26 GHz band and that World Radio Conference 2019 (WRC-19) concluded on some regulatory constraints to allow IMT and satellite FSS system to operate in a same frequency band without creating interferences, it could be beneficial to identify some business models in this sharing situation in order to identify how the LSA could benefit to these sharing scenario. The situation is similar for the use case 4, it could be highly beneficial for such sharing scenario to identify how the LSA could bring benefit to both satellite and IMT community to demonstrate that this approach is viable (economically, social benefit, other type of benefit).

3.3 Existing implementation

Since 2011, when LSA concept was initiated, LSA has been tested in Spain in October 2015, in Italy in November 2016 [7] [8], in France in October 2016, in Finland in March 2016 [9], and in Portugal in March 2019 [10] [11]. In fact, one official implementation is now incorporated in the regular process of the Radiocommunications Agency of Netherlands as indicated in the CEPT website [12]. This LSA implementation is compulsory for the programme making and special events (PMSE) sector to use the LSA booking system in the 2.3-2.4 GHz band. This obligation is incorporated in the licenses of PMSE users in this band. There have also been several other LSA pilots, which have not been reported on the CEPT website: e.g. many pilots in Finland [13] [14] [15] [16] [17] [18] [19] [20], Russia [21], Poland [22], Netherlands [23], Greece [24], and Scotland [25].

Ofcom in the UK considers an LSA-like Dynamic Spectrum Access to be applied on the bands, which were opened under Statement: Enabling wireless innovation through local licensing in 2019 [26]. A few other European countries have also assigned or planned assigning a part of LTE and 5G bands for local licensing, e.g. Finland, Germany, France, Netherlands and Sweden. Licensed shared access is considered when the shared band has dynamic spectrum users.

Originally, LSA was planned to be a tool for mobile network operators (MNO) to get access to under-utilized spectrum bands. In Europe, the national regulatory authorities have either been able to clear LTE and 5G bands in the extent that MNOs have not needed in dynamically shared frequency bands. In the US, where the availability of spectrum is more scarce, the MNOs are expected to be very interested in CBRS Priority Access Licenses (PAL) in CBRS spectrum auction on July 23, 2020.

4 STRATEGIC RECOMMENDATIONS

Following the results and roadmap of ASCENT, we recommend:

- For sharing in 3.6 GHz pioneer band (C-band)
    - To validate and demonstrate the concept in rural, urban and dense urban areas focusing on 3.6 GHz. This could be made with the current LSA system, which could be interfaced with real regulatory data base from Agence Nationale des Fréquences (ANFR) or Ficora (during the project, only some piece of information from regulatory database have been used) and help to define a trial with real equipements.
    - To develop a new testbed based on ASCENT testbed including a satellite receiver and feedback loop from the satellite receiver to calibrate the LSA system and guarantee the protection of the satellite reception.

    - To take into account regulatory constrains and non technical issues (security, reliability, business) identified in §3.
- For sharing in IMT bands (use case 4)
    - Continue research and development activities on this sharing use case defined in [6], which could lead to new or extended satellite services and facilitate the integration of satellite and terrestrial systems in the future.
- For sharing at 26 GHz (Ka-band)
    - Condition and plan activities according to the sharing results at 3.6 GHz and availability of real 5G equipments in this band.

The roadmap showing completed studies as well as recommended ones based on the ASCENT findings is given in Figure 2. It is also proposed to analyze carefully the regulatory situation and define new frequency bands to study related 5G/6G systems. Finally, as is seen in Figure 1, the future operations will be based on multi-layered systems. It should be investigated how those 3-dimensional networks could most efficiently use the spectrum resources.

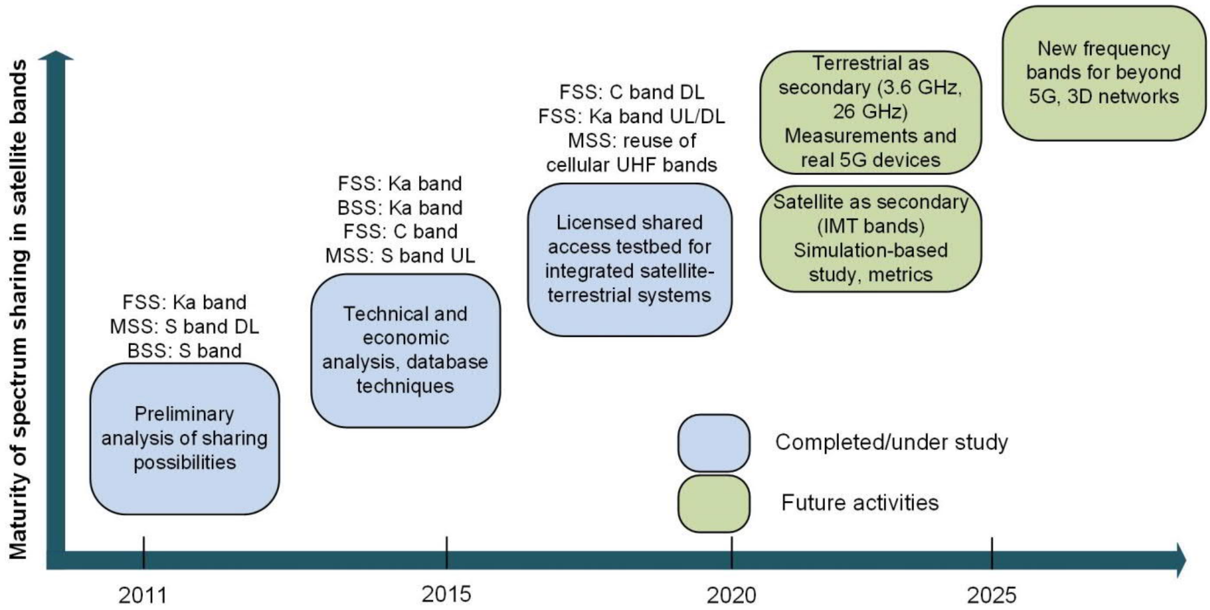

Figure 2. Roadmap for satellite-terrestrial spectrum sharing.

5 REFERENCES

[1] RSPG Opinion on Licensed Shared Access, November 2013, ref. RSPG13-538.

[2] ETSI TR 103 113: System Reference document (SRdoc); Mobile broadband services in the 2 300 MHz – 2 400 MHz frequency band under Licensed Shared Access regime.

[3] ETSI TS 103 154: System requirements for operation of Mobile Broadband Systems in the 2 300 MHz - 2 400 MHz band under Licensed Shared Access (LSA).

[4] ETSI TS 103 235: System architecture and high level procedures for operation of Licensed Shared Access (LSA) in the 2 300 MHz - 2 400 MHz band.

[5] ECC Report 205 on “Licensed Shared Access.”

[6] ASCENT D5.1 Annex A: “Use case 4 proof-of-concept and demonstration.”

[7] D. Guiducci et al., "Sharing under licensed shared access in a live LTE network in the 2.3–2.4 GHz band end-to-end architecture and compliance results," in Proc. 2017 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Piscataway, NJ, 2017, pp. 1-10.

[8] D. Guiducci et al., "Regulatory pilot on licensed shared access in a live LTE-TDD network in IMT band 40," in IEEE Transactions on Cognitive Communications and Networking, vol. 3, no. 3, pp. 534-549, Sept. 2017.

[9] M. Matinmikko et al., "Field trial of licensed shared access (LSA) with enhanced LTE resource optimization and incumbent protection," in Proc. 2015 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Stockholm, 2015, pp. 263-264.

[10] Anacom. Press release. Fairspectrum participated with the Portuguese regulator Anacom, Mobile operators: MEO, NOS, Vodafone Portugal; Broadcasters: RTP, SIC, TVI; Network manufacturers: Nokia and Huawei; and Academia: Telecommunications Institute (IT) in LSA testing in Portugal on Jan 28-30, 2019. Jan 31, 2019.

[11] H. Kokkinen et al., "Results of the demonstration of licensed shared access with sensing of secondary signal," in Proc. 2019 IEEE DySPAN 2019, Newark, NJ, USA, November 11-14, 2019.

[12] CEPT. LSA Implementation. [Online]. Available: https://www.cept.org/ecc/topics/lsa-implementation

[13] S. Yrjölä and H. Kokkinen, "Dynamic spectrum manager for a 5G industrial automation micro operator on 3.4-3.8 GHz in Europe," in Proc. 2017 European Conference on Networks and Communications: Radio Access Technologies Towards 5G (RAT), Oulu, June 2017.

[14] J. Kalliovaara et al., "Designing a testbed infrastructure for experimental validation and trialing of 5G vertical applications." In: Marques P., Radwan A., Mumtaz S., Noguet D., Rodriguez J., Gundlach M. (eds.) Cognitive Radio Oriented Wireless Networks. CrownCom 2017. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 228. Springer, Cham, 2018.

[15] S. Yrjölä and H. Kokkinen, "LSA evolution enables local high-quality wireless networks," in Proc. Winncomm 2017, San Diego.

[16] T. Jokela, J. Kalliovaara, H. Kokkinen, J. Ojaniemi, A. Kivinen, T. Lakner, J. Hallio, and J. Paavola, "Trials of spectrum sharing in 2.3 GHz band for two types of PMSE equipment and mobile network," in Proc. IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB 2018), Valencia, Spain, June 6–8, 2018.

[17] T. Tuukkanen, H. Kokkinen, S. Yrjölä, J. Ojaniemi, A. Kivinen, and T. Jokela, "Demonstration of shared spectrum access of different user groups," in Proc. Crowncom 2018, Ghent, Belgium, September 18-19, 2018.

[18] H. Kokkinen, et.al., "Licensed shared access (LSA) evolution deploying US CBRS protocols and sensing the secondary user," in Proc. Winncomm 2018, Melbourne, Florida, US, Nov. 14-15, 2018.

[19] M. Höyhtyä, K. Lähetkangas, J. Suomalainen, M. Hoppari, K. Kujanpää, Kien Trung Ngo, T. Kippola, M. Heikkilä, H. Posti, J. Mäki, T. Savunen, A. Hulkkonen, and H. Kokkinen, "Critical communications over mobile operators' networks: 5G use cases enabled by licensed spectrum sharing, network slicing and QoS control," IEEE Access, 2018.

[20] M. Höyhtyä et al., "Licensed shared access testbed for integrated satelliteterrestrial communications: The ASCENT project," in Proc. International Communications Satellite Systems Conference (ICSSC), Okinawa, Japan, October 2019.

[21] Fairspectrum. English translation of C News article. [Online]. Available: https://www.fairspectrum.com/propagating-thoughts/fairspectrumwithnokiamegafonandniirinlsapilotinrussia

[22] A. Kliks et al., "Application of the CBRS model for wireless systems coexistence in 3.6–3.8 GHz band," In: Marques P., Radwan A., Mumtaz S., Noguet D., Rodriguez J., Gundlach M. (eds.) Cognitive Radio Oriented Wireless Networks. CrownCom 2017. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 228. Springer, Cham, 2018.

[23] Fairspectrum. Press release. May 31, 2016. [Online]. Available: https://www.fairspectrum.com/propagating-thoughts/fairspectrumpilotslsaserviceforwirelesscamerausersinthenetherlands

[24] J. Ojaniemi, H. Kokkinen, A. Kivinen, G. Agapiou, S. Perdikouris, A. Hoxha, and A. Kliks, "Coexistence of LTE networks under LSA paradigm in 2.6 GHz band," in Proc. Crowncom 2018, Ghent, Belgium, September 18-19, 2018.

[25] Strathclyde University. Dynamic Spectrum Sharing in 5G RuralFirst project. [Online]. Available: https://www.5gruralfirst.org/project/dynamic-spectrum-sharing/

[26] Ofcom. Statement: Enabling wireless innovation through local licensing. Jul 25, 2019. [Online]. Available: https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation

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