Dynamic LSA for 5G networks

The ADEL perspective

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Abstract — **Exploiting additional radio spectrum is key to respond to the unprecedented capacity demands of mobile broadband communication systems in recent years. In fact, most of the frequency bands suitable for mobile communications are already in use by other radio services, and spectrum refarming is usually not possible or constitutes a highly time-consuming procedure. At the same time, several field measurement campaigns have shown that the occupied spectrum below 6GHz is severely underutilized, i.e. there exist "spectrum holes" in the time, frequency, and space dimensions, pointing to the possibility of using spectrum sharing as a mean to better exploit additional spectral resources. Licensed shared access (LSA) is a recent spectrum licensing paradigm that allows licensees to share the licensed spectrum of incumbents without causing harmful interference and ensuring a certain quality-of-service (QoS) for both types of players. The EU-funded project ADEL aims to enhance the current LSA paradigm by introducing 1) dynamic radio resource management (RRM), 2) sensing reasoning, based on database-assisted collaborative sensor networking, and 3) an extension to the LSA architecture that allows a more effective RRM, increasing QoS satisfaction and policy enforcement for all players, finally leading to an overall improved spectrum utilization. The key features of ADEL's enhanced LSA paradigm are outlined throughout the remainder of this paper.**

Keywords—Dynamic spectrum sharing, LSA, database-assisted sensing, collaborative sensing, network architecture, dynamic radio resource management, wireless service scenarios.

I. Introduction

The advent of the mobile Internet has led to phenomenal growth of the mobile data traffic over the past few years. As the features of the envisioned technologies and services of the future fifth generation (5G) mobile communication systems dictate, this trend is expected to continue for the years to come. In order to address the corresponding wireless capacity demand, it is required to allocate additional spectrum for mobile broadband (MBB) communication services. This goal can be reached with the following methods:

- Clearing (a.k.a. refarming) spectrum and allocating it to MBB.
- Sharing spectrum between existing incumbents and mobile network operators (MNO).
- Using millimeter wave (30GHz-300GHz) technology.

Refarming is seen as a rather troublesome solution, as most of the useful frequency bands are already occupied by other radio services and cannot be cleared in a reasonable timeframe. Besides, several technological challenges have to be addressed before millimeter wave technology can be applied in the MBB field – an advent that is unlikely before 2020.

Spectrum sharing, on the other hand, is seen by national regulators, in both Europe and USA, as a viable solution for allocating additional spectrum to MBB in a timely fashion, since technologies that are capable to implement it already exist. There are three main approaches in spectrum sharing:

- Exploitation of TV white spaces (TVWS) by uncoordinated unlicensed secondary users (SU). The lack of provisioning QoS guarantees to the SUs has rendered this solution unattractive to MNOs.
- Authorized Shared Access / Licensed Shared Access (ASA/LSA) [1][2]. In ASA, MNOs can use (on an exclusive basis) the licensed spectrum owned by other incumbents when and where these incumbents are not using it. In this way, the incumbents are protected from harmful interference and the licensees benefit from the provision of predictable QoS [1][2]. LSA intends to extend this concept to non-MNO licensees [3]-[6]. The band under consideration for LSA use is 2.3-2.4GHz in Europe.
- Spectrum Access Systems (SAS), which, in addition to highest-priority incumbents and high-priority licensed users, also allow low-priority unlicensed users to access the spectrum on a shared basis, as long as they do not interfere with higher priority users [15][16]. However, for the latter type of users there are no QoS guarantees. The band foreseen for SAS deployment is the 3.5GHz band in the USA.

This paper focuses on LSA development for 5G networks, presenting the major technical components of the ADEL (<u>A</u>dvanced Dynamic spectrum 5G mobile networks Employing Licensed shared access) research project funded by the European Commission under the 7th Framework Programme. The paper is organized as follows: Section II presents the regulation and standardization activities with major impact on LSA. These regulations constitute the foundations upon which ADEL further builds. Section III explains ADEL's proposals, Section IV ADEL's reference scenarios, Section V ADEL's suggested enhanced (LSA based) network architecture that incorporates the new features of dynamic RRM and sensing reasoning. Finally, Section VI draws the conclusions.

II. LSA: CURRENT STATUS

A. Regulation

LSA is a licensing approach wherein licensed users, called LSA licensees, can access underutilized licensed spectrum on an exclusive basis, thus enjoying predictable QoS, when it is not being used by the incumbent, hence protecting it from harmful interference.

The current definition of LSA is based on several assumptions [7]-[10]:

- Only vertical sharing is considered, i.e., the incumbent and the LSA licensees shall deploy different radio services. In this context, LSA is seen as a step to introduce new services in bands that cannot be immediately refarmed.
- Long-term, static over time, sharing arrangements.
- The sharing conditions must align with the guidelines of the Sharing Framework defined by each country's National Regulatory Agency (NRA).
- Incumbent protection may be implemented through exclusion zones, protection zones and restriction zones according to the incumbent type.
- Implementation of LSA requires, at least, the introduction of two network modules: LSA repository and LSA controller. Currently, the LSA architecture reference model is under development.
- According to its regulatory interpretation, LSA framework is supposed to be agnostic to the choice of access technology or application of spectrum usage. It is seen as a two-step process of (1) allocations and (2) assignments/authorizations in which allocation is applied to a certain incumbent without prejudging the modalities of authorizations for the new entrants. In principle, LSA framework is generic enough to allow different kinds of providers to act as LSA Licensees but in practice, the Licensee is seen as traditional MNO.

B. Standardization

In November 2012, the European Commission (EC) issued a standardization mandate to the European Telecommunications Standards Institute (ETSI) [11] to develop technical specifications of reconfigurable radio systems that could be allowed to operate in TVWS (unlicensed operation) or in LSA (licensed operation). ETSI standardization activities regarding LSA include a number of technical reports and specifications, such as ETSI TR 103 113 [12], ETSI TS 103 154 [13] and ETSI TS 103.235 [14] (draft), that define technologies, scenarios, applications, requirements and a system architecture under an LSA framework in the 2.3-2.4GHz band.

III. LSA: THE EXTENSIONS PROPOSED BY ADEL

Clearly, there is space for more flexibility in the restrictive LSA rules currently defined:

- Dynamic sharing could be used, where both the incumbents and the licensees may change their spectrum usage over time, thus allowing the exploitation of the sharing opportunities that emerge to the maximum extent possible.
- Cognitive Radio (CR) capabilities, such as database-assisted sensing and collaborative spectrum sensing networks, should be explored for LSA to improve the accuracy of RRM and enhance the system dynamicity.
- LSA licensees do not have to be only MNOs as implied by current LSA implementations and regulatory activities – different kinds of entrants could be introduced in the LSA band, e.g. virtual operators, professionally operated TVWS or small scale operators with no high coverage demands, etc.
- LSA could encompass unlicensed users, similar to SAS [15][16] taking into consideration that combining licensed and unlicensed users in the same band would imply changes in the EU regulation (i.e., incentive system, licensing regime, need for more flexible allocations etc.). Under standardization in 3GPP is currently a model named Licensed Assisted Access (LAA) in the form of unlicensed LTE (LTE-U). It accommodates the tier of unlicensed users but does not take into account the complexity of managing and controlling diversity of users and sharers that would be scattered around three-tiered future LSA model.
- LSA could be implemented in other underutilized frequency bands than 2.3-2.4GHz across the European Union (EU), for which the potential for harmonization is already identified.
- Sharing scenarios could move forward from a one-to-one configuration only to one-to-many setups (e.g. one incumbent in a sharing agreement with multiple licensees or one licensee with multiple incumbents). The more extreme case of multiple incumbents and multiple licensees scenario could also be considered, e.g. for the 2.3 GHz band, where incumbents of similar types (services and applications) can be found in certain countries.
- Assignment of the LSA licenses could range from simple rule-based to auctions held at specific time intervals to dynamic-spot auctions. Currently, in LSA framework long-term licenses are issued but there could be space for shorter-term and cheaper licenses, opening the secondary market within the LSA scheme. How successful the hybrid licensing model (a mixture of long-, medium- and short-term) would be, depends on transaction costs, regulatory framework and limitations of sharing rules. Interpreting the hybrid in the terms of hierarchical, tiered model of users for future LSA framework means having administrative licensing, rights of use model and license-exempt model under the LSA umbrella.

In ADEL we aim to explore the above mentioned opportunities.

IV. REFERENCE SCENARIOS

Although LSA constitutes a step forward to improve the efficiency of spectrum utilization, the current (rather conservative and static) LSA regulation [7]-[10] leads to suboptimum spectrum sharing. ADEL's view is that it is possible to follow a more dynamic sharing approach and still be able to provide to both incumbents and licensees the predictable QoS level targeted by the current regulation.

TABLE I. (extracted from [17]) shows a list of all radio services that may arise in the vertical sharing situation under the LSA framework in Europe. These services vary significantly in the periodicity of resource allocation and the coverage/service areas. Based on these characteristics, we have defined three reference scenarios which we believe capture the major challenges that may arise in LSA in most of the real world situations. Although our focus is on MBB applications, we have considered scenarios involving any type of incumbents and LSA licensees, as illustrated in TABLE II, in order to indicate the flexibility and broad scope of the proposed LSA system.

TABLE I. RADIO SERVICES

• Aeronautical	• Meteorology
• Broadcasting	• Radio astronomy,
• Defense	• Radiolocation
• Fixed	• Satellite
• Land mobile	• Short range devices
• Maritime	• Other (Amateur, ISM, land radio navigation, etc.)

TABLE II. ADEL'S LSA REFERENCE SCENARIOS

Scenario ID	**Scenario Name**	**Resource allocation periodicity**	**Coverage Area**	**Use case example**
Scenario 1	Railway	Fast (seconds)	Large (kilometers)	Communication on board of trains.
Scenario 2	Macro cells	Slow (minutes)	Medium-Large (from hundreds of meters to kilometers)	Communication in vehicular networks.
Scenario 3	Small cells	Very Slow (hours)	Very Small (tens of meters)	Communication in dense urban networks

A. *Scenario 1 – Railway Communications*

In this scenario, a railway operator acts as a LSA licensee that uses access points placed along the railway track to fulfil certain communication needs of the passengers (e.g. on-board internet access, on-line gaming, social networking etc.), as well as to support operational tasks that do not involve risk of life (e.g. monitoring and message services, CCTV video monitoring etc.).

As the train may be moving with speeds reaching 100 m/s, this scenario may require very fast spectrum assignments to cover the areas near the railway track. In terms of allocation speed this is the most demanding scenario. However, as the train trajectory and schedule are known, it may allow these allocations to be defined in advance.

Note that we distinguish two traffic classes:

- Low-bandwidth / high-occurrence / high-priority messages for signaling.
- High-bandwidth / low-priority for passengers' traffic.

Obviously, these different communication needs are constrained by the resources available along the track:

- When the train passes through an urban area it will face several access points, some of them placed close to the railway track. As a result, services with high bandwidth needs or low latency requirements will be available (CCTV video monitoring, passengers traffic).
- When the train passes through a low density area, or rural area, where the number of possible access points becomes lower, and the distance of these access points to the train track becomes larger, only services requiring low bandwidth and supporting reasonable latency will be available.

B. *Scenario 2 – Macrocellular Communications*

In this scenario, the LSA licensee is a macro cellular LTE network that covers a relatively wide area and aims at capacity extension. Lower user mobility is expected compared to the railway scenario, but higher user mobility compared to the small cell scenario. However, it is obvious that the user mobility will be less predictable than in the railway scenario where users move along the well-defined trajectories and according to a priori known schedules of trains.

Note that part or all of the extra bandwidth / capacity will not be available at all areas / times. Of course, the timescale of the spectrum access model will play a significant role in the nature of the fluctuation of available capacity and the design of QoS provisioning mechanisms. There are two cases in which the QoS of an ongoing connection can suffer in this scenario:

- When a moving user equipment (UE) leaves an area where the extra LSA capacity is available and enters an area where it is not.
- When the incumbent user of the band wants to use the band and as a result the LSA licensee needs to vacate the band in the middle of an ongoing call / session.

The service provided by the LSA licensee may be limited in coverage and might offer a lower QoS compared to existing LTE networks. This will need to be balanced by lower prices in order to compete with incumbent LTE operators occupying other bands. However, the business case might be feasible due to the relatively low capital and operational expenditure (CapEx/OpEx) associated with the new LSA licensee network.

C. *Scenario 3 – Small cell Communications*

In this scenario, we consider a small cells environment. This is a local area/low mobility scenario, where a high traffic is expected and users do not move much. We assume that the small cells are in practice indoor, plug and play base stations using LTE radio access technology (in 3GPP terminology these base stations are called 'Home evolved Node B's - HeNBs) which, however, also provide outdoor access. LSA frequencies are allocated to the small cells, while operator's spectrum is allocated to the macro network.

Under the resulting heterogeneous network (HetNet) setup there are several issues that have to be addressed, e.g., interference mitigation, uncoordinated deployment of HeNBs, self-organizing requirements of HeNBs etc.

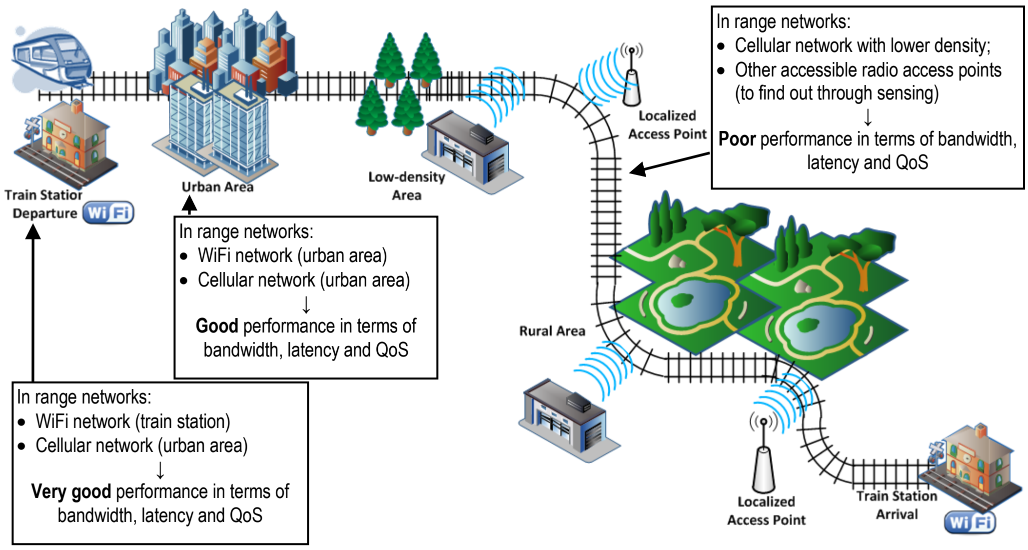

Fig. 1. Railway scenario, from the end-user perspective

V. ADEL Network Architecture

A. *Functional network description*

In ADEL the LSA players interact with each other using the functional LSA network depicted in Fig. 2. We have come up with this architecture in order to balance 1) The QoS guarantees offered to incumbent and licensee users, as per the LSA principle and 2) better overall spectrum utilization and control, made available through advanced RRM and sensing reasoning. The functional modules of the ADEL LSA-based system architecture are described below.

- LSA Repository: This is a database that stores (and possibly updates) incumbent-specific information, that is, it stores information about:
    - carrier frequency and bandwidth;
    - location and coverage area;
    - hardware characteristics of the transmitter (e.g., maximum transmission power level, antenna height etc.).

  Radio Coverage Map (RCM): This is a representation of the current situation of the radio environment that is under the control of the LSA controller. The information on the coverage map may originate from (i) propagation calculations performed using terrain databases and inputs from the incumbents/LSA licensees and (ii) measurements performed / decision taken by the collaborative spectrum sensing networks. As the main objective of the coverage map is to assist the LSA controller to perform RRM tasks, it sends to it a subset of the information it contains when requested. The coverage map is also responsible for updating itself when necessary
- LSA Spectrum Usage Rules: This module is a database under the responsibility of the NRA that stores the rules that define the Sharing Agreement (e.g., LSA band, radio service of the incumbent/LSA licensee, number of incumbents/LSA licensees, spectrum access type etc.).
- LSA Controller: This is the entity that implements the resource allocation procedures and it is key to the guarantee of QoS to all players. It is divided into two different functional sub-modules: the LSA Request manager and the LSA RRM module. The LSA Request manager, requests the authentication of the LSA licensee and performs priority management according to the LSA Spectrum Usage Rules. The LSA RRM performs the computation of available resources to assign to the LSA licensee based on LSA Spectrum Usage Rules and Radio Coverage Map. After this has been determined, it implements admission control of the LSA licensee spectrum requests. If there are resources available, the LSA RRM then computes what are the most appropriate resources (e.g. carrier frequency and Tx power) to assign to this LSA licensee and sends the information about the selected resources to the LSA licensee in question. The LSA licensee may accept or refuse the assignment. When the LSA licensee accepts the assigned resources, the LSA Controller sends information about the assigned resources to the Radio Coverage Map, so the latter can update itself. Periodically, the LSA Controller analyses the Radio Coverage Map to detect potential policy violations. In this case, it informs the LSA licensee.
- LSA Authentication Server: This is a module, under the responsibility of the NRA, used to store information and perform tasks related to the authentication of all the functional modules.
- LSA Billing: This module is responsible for the financial accounting tasks.
- Spectrum Sensing Reasoning: The functions under the responsibility of this module are: a) define sensing requirements for each sensing network; b) detect faulty measurements; c) compute sensing map (same format as RCM); d) update map (i.e., decide which pixels of RCM should be updated with sensing results); e) determine which zones of the map need additional sensing. This module is connected to the Radio Coverage Map and also assists the policy protection mechanisms.

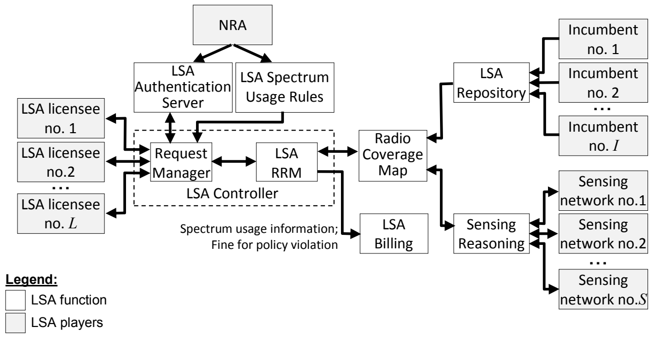

Fig. 2. ADEL functional network architecture

B. Network virtualization

The implementation of the network architecture described above can also support Cloud-RAN (Radio Access Network) [18] topologies, where several remote radio heads (RRH) are connected through optical fibers to a centralized virtual base-band units (vBBUs) pool. The rationale is to perform both spectrum sharing via LSA and infrastructure/processing resources sharing via virtualization.

Cloud-RAN also allows the effective deployment of Massive MIMO techniques. In a conventional Massive MIMO system, spatial correlation reduces the effective degrees of freedom (DoF). This problem can be resolved if, instead of having many antennas at a single place, they are distributed and coordinated by the centralized virtual BBUs. Such a Massive Distributed MIMO (MD MIMO) antenna system offers throughput gains and power savings, but at the same time imposes significant research challenges in terms of scalability.

VI. Conclusions

LSA is a licensing paradigm that allows spectrum sharing between incumbents and LSA licensees while protecting the former from harmful interference and, at the same time, providing QoS guarantees to the latter. It is seen as a viable solution for allocating additional spectrum to MBB in order to meet future wireless capacity demands. While current LSA regulations are conservative, in ADEL we propose a more flexible and dynamic LSA system which incorporates dynamic RRM and database-assisted collaborative spectrum sensing, thus improving the overall efficiency of spectrum utilization. In this paper, we presented the core architecture of the envisioned enhanced LSA system and described some relevant scenarios of practical importance.

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