Coexistence of LTE Networks Under LSA Paradigm in 2.6 GHz Band

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Abstract. This paper proposes a sharing scenario based on License Shared Access (LSA) framework with coexistence management between licensed Mobile Network Operator (MNO) and vertical MNOs. This allows the primary LSA license holder to lease the spectrum to the vertical operators when it is not used by the primary operator. We demonstrate the system in a real network consisting of two LTE-A base stations and core network, LSA Repository and LSA Controller. Furthermore, we implement the communication of the relevant network configuration parameters between the LSA Controllers in order to enable coexistence with interference-free conditions.

Keywords: Vertical spectrum sharing · LSA coexistence CBRS model · Field trials

1 Introduction

One may observe that the concept of advanced spectrum usage through spectrum sharing, dynamic spectrum access or flexible spectrum management, has

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become solid and mature in a broad sense [1,2]. It is nowadays well known that the static allocation of frequency resources among various stakeholders or technologies may lead to high resource underutilization, but at the same time, it seems to be the simplest and highly accurate way of protecting incumbent users from harmful interference. Therefore, exclusive use of spectrum bands is and will be still a dominant approach in the near future. Concurrently, unlicensed spectrum use such as Industrial, Scientific, and Medical (ISM) bands results to some extent in high spectrum utilization at the price of relatively high level of interference power observed in the allocated band. Flexible spectrum management is a tool that will try to solve the problem of ineffective spectrum usage while simultaneously lower the impact of interference phenomena. Moreover, it is now considered as a potential method or more effective approach for future applications by various stakeholders globally (such as Federal Communications Commission in USA (FCC), Conférence Eropéenne des administrations des Postes et des Télécommunications (CEPT) with European Telecommunications Standards Institute (ETSI) in Europe, Office of Communications (Ofcom) in UK, just to mention few).

Numerous researches, conducted experiments and even initial tests or trials in the field of spectrum sharing have paved the way for the currently observed trend in that domain [1,2]. Although it is currently not possible to guarantee accurately enough protection of the incumbent transmissions by relying on sole spectrum sensing and pure cognitive approach, the application of dedicated databases seems to be a pragmatic solution to this issue. It is widely suggested that such database-oriented solution should possess reasoning and learning capabilities on one hand side, and be supported by adjusted advanced monitoring and sensing functions on the other side [3–6] In this regard it is worth mentioning that ETSI is working on the implementation of the Licensed Shared Access (LSA) concept in the 2.3–2.4 GHz band [7,8]. Respectively, FCC created the foundations for dedicated solution for 3.5 GHz band, known as Citizen Broadband Radio Service (CBRS) [9]. Spectrum sharing has been also considered as an viable option for 5G networks [10–12], and from that perspective the application of LTE-A or New Radio (NR) base station operating in one of the two above mentioned regimes is of high interest.

LSA framework was introduced as a system allowing licensed and protected secondary use of spectrum for mobile network operators (MNO) by ETSI. The ETSI Reconfigurable Radio Systems, RRS, technical report [13] extends the concept by applying LSA for local and temporary licenses. The principal options for spectrum sharing between the operators and vertical sectors are the following: 1. first option - the spectrum users have different local or global priorities, 2. Second option, where the rule first-come-first-served is being applied, or 3. Last option - application of co-existence management, which tries to balance dynamically between demand and supply for spectrum.

In this demonstration we consider different priorities applied to coexisting operators (LSA licensees), which could be applied for example, when the mobile operator has a nation-wide license and it allows secondary use of the band locally by vertical sectors. The vertical sectors are private LTE operators in this demonstration. In short, in this paper we consider the implementation of the LSA model for simultaneous deployment of two LTE-A based networks operating in the frequency division duplexing (FDD) scheme, where one represents a national mobile operator and the other represents a local private LTE operator. To the extent of our knowledge, the proposed vertical sharing scheme where the coexistence of the LSA licensees is managed by the LSA Controller has not been demonstrated in the current literature related to LSA.

The paper is organized as follows. In Sect. 2 we briefly introduce the LSA and CBRS models. In Sect. 3, the system model and mechanisms to enable coexistence between the operators are described. Section 4 provides results of the field trials in a real LTE-A network. Section 5 concludes.

2 Foundations of LSA and CBRS Coexistence Model

So far, nearly all radio licenses for mobile broadband have been allocated with nationwide licenses. Mobile network operators have shared a specific frequency band in the frequency domain as block licenses. However, this approach makes it difficult for an operator to enter a new, possibly underutilized, area owned by another operator. This is especially difficult for smaller or virtual operators offering customized services for different use cases, who cannot compete in spectrum auctions with stronger operators. The high number of IMT bands and higher frequencies of the bands have initiated ideas of sharing mobile operator bands also geographically. The ideas include sub-leasing, neutral host operators, overlapping macro and small-cell networks, and local 5G licenses for industry verticals. In these proposals, two or more mobile operators potentially have adjacent geographical operating areas. In order to manage such a spectrum sharing schemes, two approaches are widely considered. These are briefly described for surveying purposes, as well as background introductory to the proposed modified LSA -based sharing system.

2.1 Licensed Shared Access - LSA

Licensed Shared Access (LSA) concept has been originally introduced by the Radio Spectrum Policy Group (RSPG) in its document [18] and was a response to the industry interests for new spectrum usage models. In principle, it aims at introducing new (additional) licensed users on spectrum bands currently assigned to other incumbent systems. By assumption, LSA concept assumes some level of volunteering, thus dedicated agreements between involved stakeholders are required. LSA model was a subject of intensive research, regulatory and standardization efforts, resulting in dedicated standards released by ETSI for 2.3–2.4 GHz band [7,8]. Ongoing regulatory activities are performed towards development of harmonized technical conditions, cross-border coordination, guidelines for the LSA sharing framework, incumbent usage, implementation examples, and technical sharing solutions specifically between the mobile broadband and incumbent PMSE service in the 2.3–2.4 GHz band [12]. As a result, a regulatory framework for LSA has been created, which assumes the presence of two dedicated entities operating on top of the existing network architectures. These are LSA Controller and LSA Repository (see Fig. 1). Whereas the former entity targets the assurance of the incumbent user protection (through calculation of the protection areas, analyzing from various perspectives various interference-related aspects etc.), the latter acts as the advanced repository for storage and updating the information about spectrum availability and usage. The summary of the spectrum sharing evolution towards LSA can be found in [19].

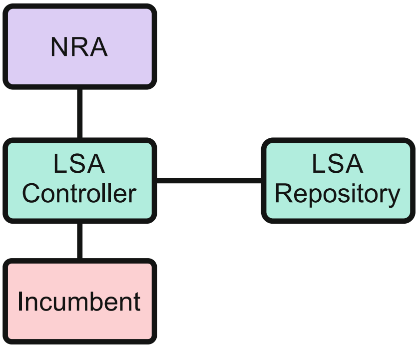

Fig. 1. LSA functional architecture

It is also worth mentioning that on February 2018 ETSI has released the feasibility study on temporary spectrum access for local high-quality wireless networks [13], which further strengthens the motivation for conducting the LSA-focused experiment with two coexisting MNOs operating in the 2.6 GHz. The considered scheme as well as the conducted experiment are described in the following sections.

2.2 Citizen Broadband Radio Service - CBRS

Citizen Broadband Radio Service (CBRS) with Spectrum Access System is the solution promoted recently by Federal Communications Commission (FCC) in the USA. It allows to utilize the contiguous 150 MHz width fragment of spectrum in the 3.5 GHz band, mainly between 3550 MHz and 3700 MHz. In general, this model foreseen simultaneous coexistence of multiple systems (also multiple wireless technologies) under specific circumstances, which guarantee the Quality-of-Service fulfilment of any protected user. In that context, three tiers solution has been created, which allows for hierarchical spectrum sharing (between the tiers) and vertical spectrum sharing (within the tier) [9,17].

In particular, the highest tier encompasses Incumbent Users (IU) which require full protection from harmful interference originated from lower layers (other systems coexisting in this band). The IUs include military and meteorological radar systems, as well as grandfathered Fixed Satellite Service and grandfathered Wireless Broadband. These systems may operate in the entire band considered for CBRS systems. No additional permission (beside the one obtained from the regulator) is required, and the IUs may start transmission any time it is necessary. The second tier consists of so called Prioritized Access License (PAL) users, which may utilize up to 70 MHz of band within the 3550–3650 MHz band (the remaining 50 MHz band is excluded from PAL usage). Each PAL base station may send requests for multiplication of 10 MHz band to Spectrum Access System (SAS), and SAS should allocate only contiguous fragment of the spectrum. SAS can be treated as a dedicated entity for spectrum and interference management in the CBRS model, but designated to control the second tier of users (PALs). Finally, the General Authorized Access (GAA) users are considered to constitute the lowest, third layer of the CBRS system, which must protect the upper tier users and must accept possible interference generated towards them. GAA devices may operate in the entire band. Figure 2 depicts the three tier model.

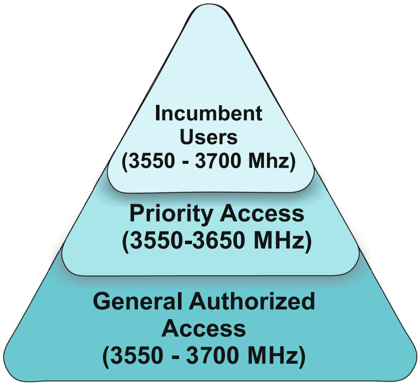

Fig. 2. Three tier CBRS model

Following the CBRS Alliance standard [16], a group of Citizens Broadband Radio Service Devices (CBSDs) may create a group (called Coexistence Group), where all the group members are abide to the same interference and spectrum managements policies. Dedicated logical entity, called Coexistence Manager will facilitate the operation of tier-3 users by management of all CBSDs within the group.

Although in this work we concentrate on the LSA applied to LTE networks with a similar coexistence functionality as introduced in the CBRS framework, let us note that major parts of the aforementioned CBRS model with a coexistence management has been tested recently on a real network in Poznan, Poland, described in [14].

3 LTE Coexistence - Vertical Spectrum Sharing Scheme for 2.6 GHz

An LSA sharing scenario is implemented where one eNodeB (eNB) acts as a primary mobile operator and has the highest priority, while the other eNB is a Private LTE operator and has a lower priority - see Fig. 3. The experiment has been conducted using OTE (one of the Greek network operators) premises and network equipment. All eNBs used in this experiment were part of the fully operational network with its own network management system deployed in Athens, Greece. The spectrum management system consisting of LSA Repository and Controller is implemented in Fairspectrum's server physically separated from the controlled LTE networks. Fairspectrum LSA Controllers can access the eNBs through remote access from a virtual machine located in OTE's facilities.

The 2.6 GHz FDD band 7 is considered with downlink frequencies 2620–2690 MHz and 10 MHz channel bandwidth (respectively, possible Evolved-UTRA Absolute Radio Frequency Numbers, EARFCN, for downlink transmission have been set to 2800–3400, and for uplink to 20800–21400). In the testbed in OTE premises, there are two 2.6 GHz FDD eNBs connected to core network. Although there are only two operators in the demonstration, the scheme can be generalized to account for multiple core networks and eNBs due to the distributed eNB Controllers.

3.1 Applied LSA Interference Protection Mechanism

In our demonstration, the LSA controller (C1 and C2) in Fig. 3 is a software implementation responsible of polling parameters from the eNBs, such as GPS coordinates, possible transmit power levels, current transmit channel, link status etc., committing the new operational parameters to the eNBs, and informing the Repository of the current parameters of each operator. Furthermore, the communication between LSA Repository and LSA Controller direction contains the operator priority class, used channel, transmit power, interference-to-noise-ratio criteria, bandwidth, noise figure, and adjacent channel leakage ratio (ACLR). These parameters are necessary for Controller to manage the coexistence.

The LSA Repository manages the timing of the necessary operations and assigns priority classes to the operators. The priority classes can be determined beforehand by the National Regulatory Authority (NRA) and input in the LSA Repository, or agreed through a mutual agreement between the operators. Furthermore, the Repository (LR) informs the operational parameters to the Controllers (LC) upon request.

The process flow consisting of information exchange and interference protection mechanisms is illustrated in Fig. 4, and described in the following:

1. Each Controller polls the parameter values from the eNBs every 60 s through a dedicated tool which is a part of the operator's Operations, administration and management system (OAM). The Controller chooses the best channel as

$$ch_{\max} = \arg\max_{i} \left\{\mathbf{eirp}(i)\right\}, \qquad i = 1 \dots M$$

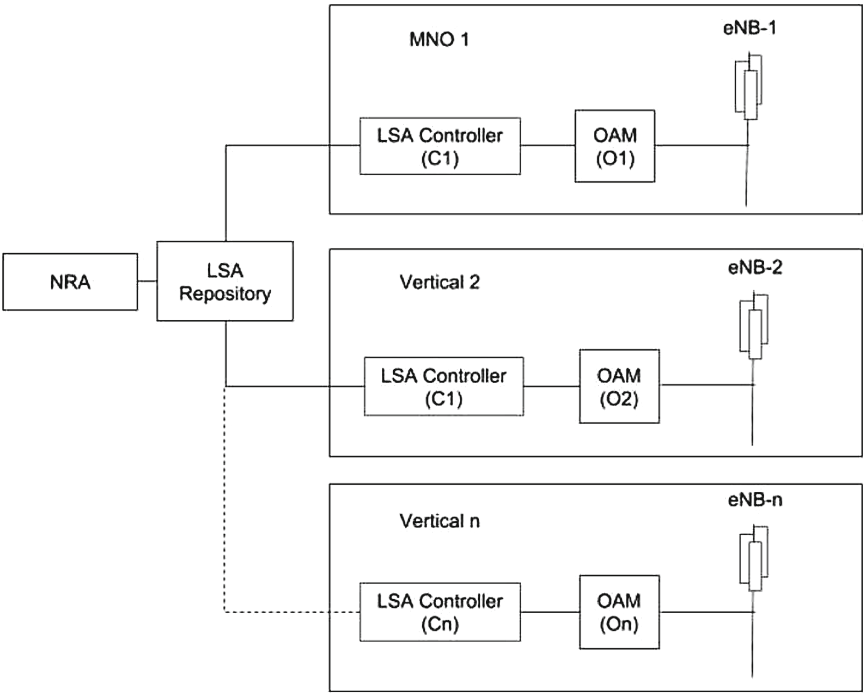

Fig. 3. Illustration of the experimentation system

where **eirp** is a vector containing the maximum EIRP values for each M 10 MHz channels for the eNB location, and the corresponding EIRP value, $eirp_{\max} = \mathbf{eirp}(ch_{\max})$. The EIRP values are based on path losses using the Extended Hata propagation [20] model between the interference source (eNB) and the protection contour of the other operator(s). Specifically, the EIRP value per channel is specified as:

$$\begin{aligned}\text{EIRP} \leq & -174 + 10\ log_{10}(BW) + NF + \frac{I}{N} \\ & + L_{eHata}(h_t, h_r, d, c) - G_t - G_r,\end{aligned} \quad (1)$$

where BW is the channel bandwidth in Hz, NF is the noise figure, $\frac{I}{N}$ is the interference to noise ratio, $L_{eHata}(h_t, h_r, d, c)$ is the path loss with a distance d between the eNB transmit antenna and the protection contour of the protected mobile network, c is the clutter type (urban, suburban, open) at the receiver location, h_t, h_r are the transmitter and receiver heights, and G_r, G_t are the transmit and receive antenna gains, respectively. The protection contour limit, γ, can be for example specified as the limit where the useful signal level of -80 dBm/10 MHz is observed.

2. The Repository provides the available licensee data to the Controller (in general, Repository also contains incumbent data which, however, in this

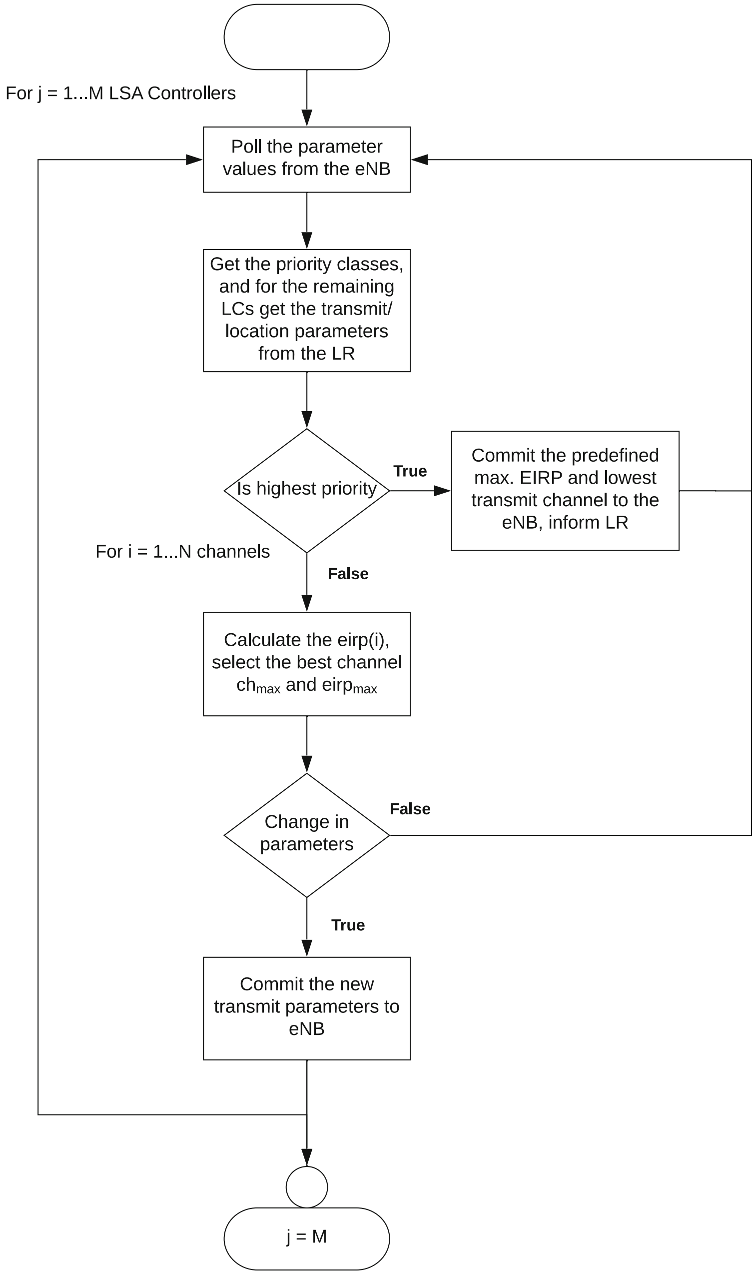

Fig. 4. Flow chart of the algorithm.

demonstration is not considerer). Since there are no other operators using the spectrum according to the provided data, the EIRP limit is set to predetermined maximum, i.e. 47 dBm for each channel. The controller then assigns the first available frequency (2620–2630 MHz) as the transmit channel with an appropriate EIRP for the eNB. The Controller commits the new transmit parameters to the eNB and informs this data also to the Repository.

3. Subsequently (or simultaneously), the Controller polls the values from the second eNB and synchronizes the licensees' data from the Repository. In this case, the protection contour of the first eNB is calculated and its transmit channel is taken into account in calculating the **eirp** vector if the priority class of the first operator is higher than that of the second operator. If the priority class of the second operator is higher than the priority class of the first operator the second Controller can assign the channel used by the lower priority operator to the higher priority operator. In this case, the second Controller bypasses all the lower priority protection contours in the calculation of the EIRP list for the second eNB. The controller then chooses the best channel for the second eNB, and notifies the Repository. The Repository further informs other Controller(s) to make a new calculation of the EIRP list based on the provided parameters and adjust their operational parameters.
4. Simultaneously, the Repository instructs each Controller to poll the parameter values from the eNBs every 60 s, and the process begins from the start (item 1 above). If there are no parameter changes, e.g. no priority class changes or location changes, or there are no new Controllers connected to the network, the system remains stable (no commits are made to the eNBs), and the eNBs continue to transmit on their current allocated channels and powers.

4 Field Trial Results

In the experiment, two LTE networks will operate dynamically within the 2.6 GHz band: the private network is of lower priority with regards to the MNO LTE network. The spectrum is monitored with Tektronix spectrum analyzer connected to a laptop. In the figures, 2600–2700 MHz band is shown (center frequency = 2650 MHz, span = 100 MHz, resolution bandwidth $rBW = 500$ KHz). The configuration parameters are presented in Table 1.

The demonstration begins by setting the lower priority Private LTE eNB on center frequency 2625 MHz with 10 MHz BW and transmit power P_t as 24 dBm (Fig. 5. The possible transmission power, P_t, for the eNBs are 17 to 24 dBm with one dB interval. The spectrum mask of the private LTE is shown on 2620–2630 MHz. On the right hand side of the spectrum at around 2670–2690 MHz band is unknown traffic not relevant to this demonstration. Next, as shown in Figs. 6 and 7, the higher priority MNO chooses the transmission channel currently operated by the private LTE. The private LTE is forced to choose another channel, and due to the adjacent channel leakage power the second best channel is at 2645 MHz (as shown in Fig. 8).

Table 1. Configuration parameters

Parameter	Value
N	-104 dBm
NF	4 dB
BW	10 MHz
ACLR	42 dB
h_t, h_r	10 m, 1.5 m
c	suburban
G_t	10 dB
G_r	0 dB
γ	-80 dBm/10 MHz
P_t	[17...24] dBm

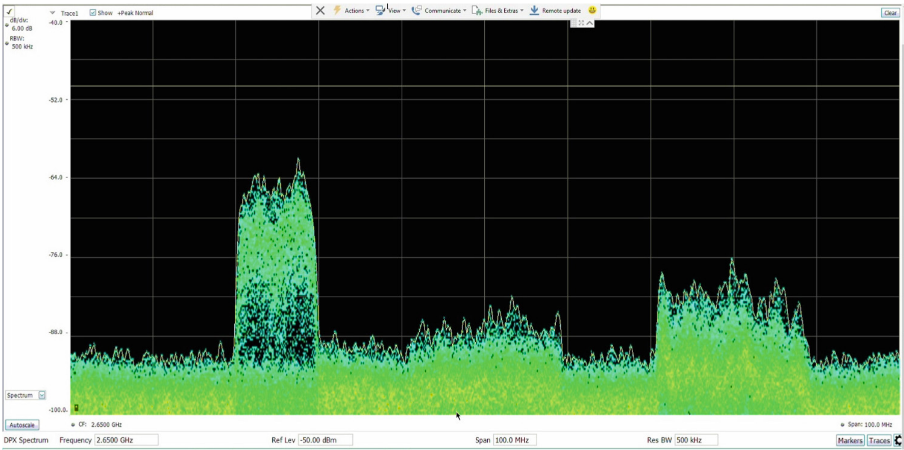

Fig. 5. Experimentation course, Phase 1 - private LTE network operates normally on $f_c = 2625$ MHz, the primary MNO has made a reservation on the same channel.

4.1 Lesson Learned

1. The delay of the Controller obtaining the configuration parameters of the other operator from the Repository depends on the selected polling interval, which in our tests was set to 60 s. However, since the commission of new parameters to the eNBs took nearly the same time, decreasing the interval does not drastically speed up the channel assignment. However, the commission time is device and network management system specific and cannot be generalized. Some eNBs and core network systems may response more rapidly and the polling interval would then offer more flexibility to control the response time. In total, the transmit channel change took around 3 min for the eNB to block the current transmission and switch to a different fre-

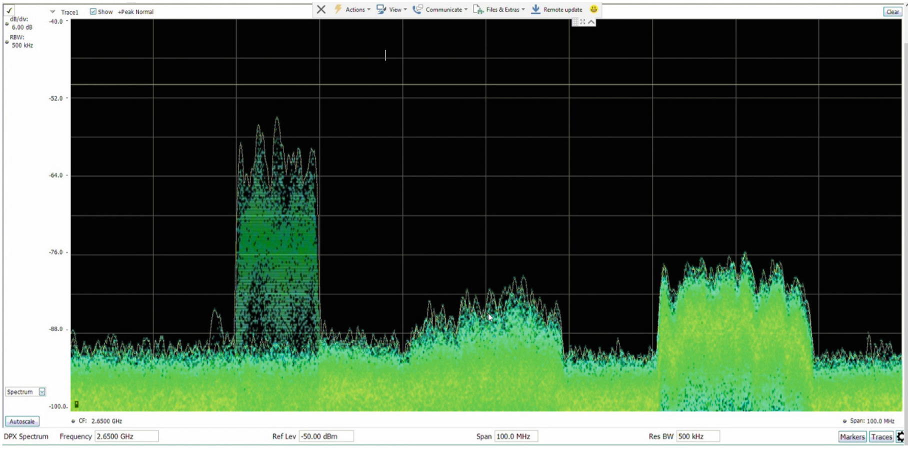

Fig. 6. Experimentation course, Phase 2 - private LTE network is forced to switch off the transmission and move to another channel.

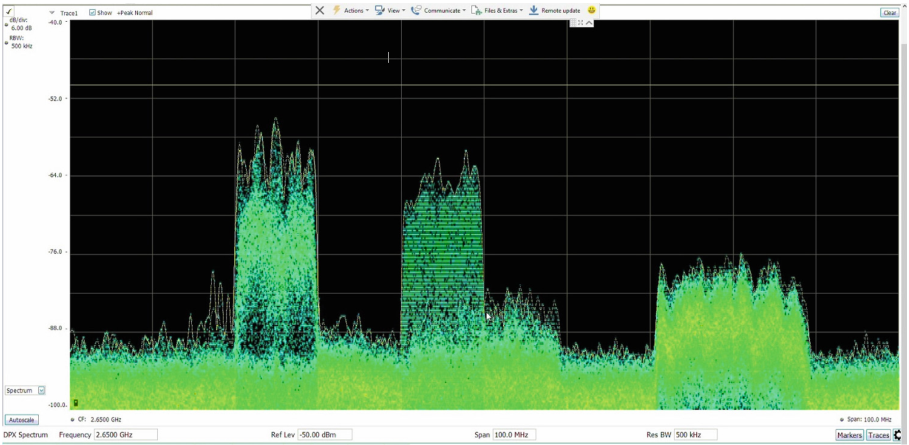

Fig. 7. Experimentation course, Phase 3 - private LTE starts transmission in the new channel.

quency band, which is adequate in a practical sharing scenario, where the channel reservation can be known hours or days beforehand.

2. Spectrum resources are scarce and expensive, thus spectrum sharing creates new opportunities for operators. Sharing decreases CAPEX and therefore it is beneficial from financial perspectives. It also provides the means to have a better utilization of the spectrum resources at periods of time with low network traffic. Furthermore, if operator decides to enter a new geographical area owned by another operator it will be much less costly to use the unused spectrum, while opening services to the end users can be started quickly. The

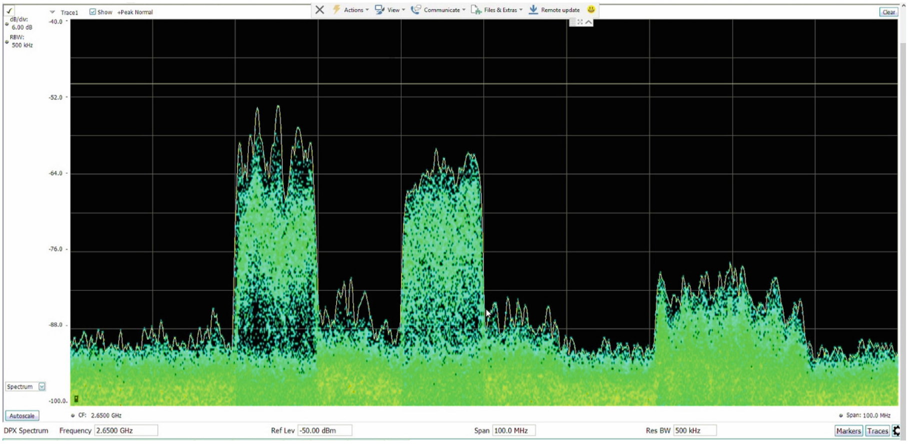

Fig. 8. Experimentation course, Phase 4 - both LTE networks operate simultaneously.

opportunities offered by spectrum sharing in a fashion demonstrated in this paper are based on CAPEX reduction, better resource utilization and low cost entry in a new band much quicker than waiting for regulatory license contests, which is an uncertain method of obtaining spectrum resources to many smaller, vertical or virtual operators.

3. To enable coexistence between the licensees the LSA framework could consider feedback from the LSA Controllers to the LSA Repositories (or a similar logical entity) regarding the licensees' network parameters, which in turn could provide the relevant information on network configuration parameters back to the Controllers. In our trials, we implemented successfully this information exchange, which enabled the Controllers to make the necessary protection calculations and assign the new frequency bands to the operators, thus avoiding interference conditions. It is clear that in order to implement this kind of feedback further studies would be needed, especially on the communication protocol, and exactly what parameters are possible to exchange in a large scale multi-operator environment. Moreover, in case that there are multiple vertical operators competing the primary licensees' spectrum, there should some kind of centralized reservation system where the vertical operators could make reservations of their spectrum use.

5 Conclusions

In this paper we presented briefly the LSA and CBRS systems, and proposed License Shared Access -based sharing scenario with a coexistence management between the licensees similar than that of the CBRS's. This allows the primary LSA license holder to lease the spectrum to the vertical operators when it is not used by the primary operator. We demonstrated the system successfully in a real network setting consisting of two LTE-A base stations, core network, LSA Repository and LSA Controller. Furthermore, we implemented the communication of the relevant network parameters between the LSA Controllers through the LSA Repository in order to enable coexistence without channel collision and harmful interference.

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