FIELD TRIAL OF LICENSED SHARED ACCESS (LSA) WITH ENHANCED LSA CONTROLLER POWER CONTROL CONCEPT ALGORITHMS

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ABSTRACT

This paper presents the results from an end-to-end ecosystem trial of the Licensed Shared Access (LSA) concept using over the air TD-LTE network in the third Generation Partnership Project (3GPP) spectrum band 40 (2.3-2.4 GHz) in Finland. In the field trial, the LTE network shared the spectrum with Program Making and Special Events (PMSE) Incumbent wireless cameras. New LSA concept elements, LSA Repository for Incumbent protection information and LSA Controller for controlling the mobile broadband network in the same spectrum band were implemented in the trial environment. The trial utilized commercially available network elements like multimode multiband terminals, LTE base stations, core network and network management system. Incumbent spectrum usage data was collected to the LSA repository, which further converts it to spectrum availability information for the LSA controller. The trial goes beyond previous LSA demonstrations by presenting enhanced LSA controller power control concept algorithm that instead of maximizing the number of transmitting base stations as in the Protection Zone Optimization (PZO), formulate the optimization objective as a function of BS transmit power. An advantage of this procedure in contrast to the PZO is that adjusting the transmit power level do not result in abrupt changes in the received signal quality; therefore it is possible to reach better overall throughput. Furthermore, enhanced Incumbent protection is provided with algorithms considering aggregate interference from the LTE network to the Incumbent. The developed LSA controller was implemented as Self Organizing Network solution integrated into commercial Operational Support System. Incumbent users' rights were protected by evacuating and or reconfiguring the overlay LSA TD-LTE band and handing users over to coverage FDD LTE network if required when requested by the Incumbent spectrum user. Numerical results are presented to quantify the duration of the LSA procedure flow. The trial showed that the LSA concept can be implemented with commercial available network elements and a minimum amount of new software and hardware components. The performance results on the LSA system workflow indicated that in the PMSE use case the usage of the LSA band can be managed timely manner and the Incumbents' rights can be protected. Furthermore, developed approach could be expanded to be utilized in the LSA evolution towards satellite converge in 3.6 – 4.2 GHz band and more dynamic the US 3 tier Citizens Broadband Radio Service (CBRS) system.

1. INTRODUCTION

We have witnessed the exponential growth of wireless services to access information, consume and produce content, and conduct commerce from variety of mobile devices anywhere, anytime in our digitalizing information economy [1]. Spectrum is becoming one of the most in-demand resources in the wireless industry. In addition to traditional exclusive spectrum with long term licenses utilized by mobile broadband (MBB) industry, there are globally allocated exclusive International Mobile Telecommunications (IMT) spectrum bands that are currently restricted by the Incumbent use, but are mostly unused in time and or space. This underutilized spectrum resource have recently been considered as an opportunity by research community, regulatory and standardization bodies, and industry in finding sufficient supply of spectrum resource to meet the growing demand of the MBB communication on time. The recent spectrum sharing concepts under study in the regulation, technology and business are the 3 tier Citizens Broadband Radio Service (CBRS) from the US [2], [3] and the Licensed Shared Access (LSA) [4] from Europe.

The novel LSA spectrum sharing concept introduces sharing between a Mobile Network Operator (MNO) and Incumbent spectrum user from other industry domain. The European regulatory and standardization bodies have shown growing interest in the LSA approach for coordinating the spectrum access of both the Incumbent and the MNO in the same the third Generation Partnership Project (3GPP) spectrum band 40 (2.3-2.4 GHz). The European Commission outlines LSA as [5], "*a regulatory approach aiming to facilitate the introduction of radio communication 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 authorized 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 authorized users, including Incumbents, to provide a certain QoS*".

The LSA framework allows an Incumbent spectrum user and a Licensee to share spectrum resource in a binary way so that both have exclusive individual access to a spectrum at a given time and space [5] and [4]. As a starting point the National Regulatory Authority (NRA) is responsible for identifying LSA spectrum, defining the *sharing framework* consisting of rules and conditions for sharing, as well as granting the license to the LSA Licensee. Next, based on this national spectrum sharing framework and under the permission and governance of the NRA, the Incumbent and the LSA Licensee agree on the private commercial *sharing agreement.* In these binary and voluntary LSA agreements, the Incumbent spectrum user defines the part of owned spectrum that can be used for licensed sharing, the license duration and geographical area.

This paper focuses on validating the LSA concept and measuring key performance parameters for sharing between an MNO Licensee and another type of Incumbent, in particular Program Making and Special Events (PMSE) spectrum user in the typical European and Finnish LSA use case.

The LSA concept has been over the air trialed the first time in Finland by the Cognitive Radio Trial Environment (CORE) project consortium in April 2013 [6] followed by iteratively updated features demonstrated in April 2014 [7], December 2014 [8] and September 2015 [9]. Recently, field trial with similar LSA functionally based on the latest European Telecommunications Standards Institute (ETSI) LSA standards, Italian national regulatory framework and Incumbent types has been conducted in Italy [10]. This paper enhances LSA concept validation and the trial environments by introducing LSA controller implemented as a part of Self Organizing Network (SON) solution first time with enhanced power control concept algorithms that optimize protection zones to protect the Incumbent's business, while maximizing availability for the Licensee and overall throughput to end users.

The paper is organized as follows. The Finnish LSA trial environment, key elements and developed algorithms are introduced in Section 2. Section 3 presents field trial set up, process and operations. Performance evaluation and results from the LSA trial using live commercial LTE network in the 2.3 GHz band are summarized in Section 4. Finally, conclusions are drawn and the acknowledgement closes the article.

2. LSA FIELD TRIAL ENVIRONMENT

The LSA concept complements radio access network architecture with two new functional elements, LSA Controller (LC) and LSA Repository (LR) [11], [12] and [13]. The LSA functional architecture and the trial environment is comprised of the following key elements as shown in Fig. 1:

- PMSE Incumbent with the LR,
- Heterogeneous LTE network of TDD and FD LTE macro and small cell Evolved Node B (ENB) Base Stations (BSs), Evolved Packet Core (EPC) core network, network management system (NMS) and end user equipments (UEs),
- LC utilizing commercially available OSS NMS, SON platforms and interfaces with Incumbent protection algorithms and SON features.

The stakeholder roles, individual system elements, their operations and connections are discussed in more detail in the following sub-sections.

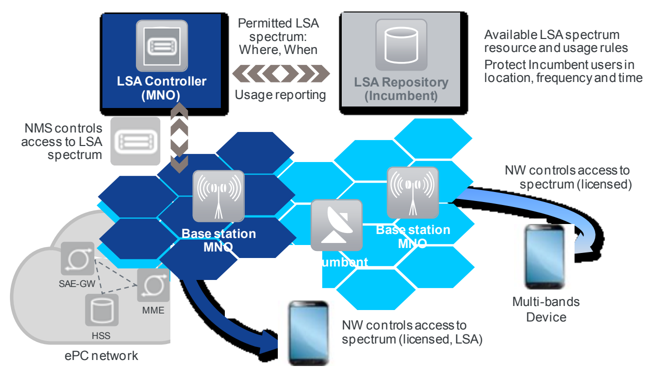

Figure 1. Technical functions of the Licensed Shared Access architecture

2.1. Incumbent spectrum manager and LSA repository

Incumbent in the trial is selected according to the typical European, and in particular national Finnish LSA use case to be an employee of a media or broadcasting company using PMSE services in program making on the 3GPP band 40 (2.3-2.4 GHz), as defined in [14] and [15].

The Incumbent Manager (IM) tools and the LR were initially developed in the Tekes Trial White space test environment for broadcast frequencies (WISE2) project [16]. The LR is a database with the following key functions [13]:

- the entry and storage of information determining Incumbent's usage and protection requirements,
- communicate with several LCs and conveys availability information to authorized LCs,
- receive and store acknowledgement information received from the LCs,
- provide means for NRA to monitor operation, and to provide the system with information on the sharing framework and the LSA Licensees and
- ensure that the LSA system operates in conformance with the sharing framework, and any non-regulatory details of the sharing arrangement
- separate non-LSA Licensee domain and LSA Licensee domain to maintain the assets privacy

Based on LR information, protected areas are defined based on the underlying regulatory sharing framework and sharing agreement requirements. Protected areas can be divided into three categories: *Exclusion zones* (EZ) within which LSA Licensees are not allowed to have active radio transmitters, *protection zones* (PZ) where Incumbent receivers will not be subject to harmful interference caused by LSA Licensees' transmissions and *restriction zones* (RZ), where LSA Licensees are allowed to operate radio transmitters, under certain restrictive conditions e.g. maximum effective isotropic radiated power (EIRP) limits and or constraints on antenna parameters [12]. This allows that LSA Spectrum Resource (LSR) usage by an Incumbent is protected, i.e. Incumbent doesn't necessarily have to provide details on the LSR usage to the LSA Licensee [12].

LSA *spectrum resource availability information* (LSRAI) is provided to a Licensee, which conveys the LSA spectrum resource that may be used by the Licensee, and the respective operational conditions or restrictions that the Licensee shall apply. Incumbent user is requested to make a specific LSRAI *Notification* to enable the LR to send LSA spectrum resource availability information to the LC. It can be used to send either specific immediate notifications, periodic updates of the overall LSRAI related to this LC, or scheduled action. In addition Licensee could send the LSRAI *Request* to make a request for LSRAI, which can be used to initiate LSA operation, or to synchronize information between LR and LC during LSA operation.

It is essential that these procedures do not increase Incumbent user's operational load while ensuring Quality of Service (QoS), security, robustness, reliability and fault management functional requirements. Two novel tools utilized were developed in the WISE2 project to automate and optimize Incumbent reservation collection: The *LSA Incumbent Manager* and the PMSE Location Mobile application. The tools are described in details in [17].

In the trial, the LC located within the LSA MNO Licensee's domain has the main responsibility of computing the protection criteria and implementing the terms of the sharing agreement between the Licensee and the Incumbent. Based on the availability information, reservations and possible Incumbent movement, the LSA Licensee should act upon, and decide whether and how it can use LSA base station radio resources at certain location or not.

Regulators may monitor the LSA system spectrum usage via the LR for possible exception situations such as the unavailability of LC or unconfirmed protection request. Notification will be sent to the regulator immediately if failure occurs. The LR sends a Connectivity Check Notification message to the LC and the LC responses back to the LR with a Connectivity Check Notification Ack message. If no pongs received the LR closes the connection to the LC and the LC shut downs the LSA network if not already done so.

2.2. LSA controller

The LC developed in the Cognitive Radio to Business (CRB) and Local Area Spectrum Sharing (LASS) projects by the Nokia in collaboration with the CORE consortium [18] provides the MNO LSA Licensee with means to access the LSA spectrum, to react on the Incumbent user activity and to optimize usage of the LSA spectrum resources within the LSA Licensee's domain. The LC enables the LSA Licensee to:

- obtain spectrum resource availability information from the LR
- provide acknowledgment information to the LR
- interact with the Licensee's mobile network in order to dynamically support the mapping and deployment of availability information into appropriate radio transmitter configurations and to receive the respective confirmations from the mobile network
- optimal radio configuration plans tailored to the result of LSA protection algorithms and current operational status of the radio network.

In this trial, the LSA Licensee is able to receive de-activation and activation requests from the LR based on Incumbent's frequency reservation reports. The Incumbent's reservations include *location, frequency bands, time range, and PMSE protection type; transmit power threshold and the emergency evacuation*.

2.2.1. LC User Interface

In the trial set up, the MNO LSA Licensee's LC User Interface (UI) consists of three main sections: radio network status, LSA network control and protection algorithms. The LC gathers information on BS cells and their operational *statuses* through the NMS and depicts it in the map view as shown in Fig. 4. The five LSA macro cells and one small cell with their statuses in the trial are shown with different colors;

green cell is active, yellow cell is being evacuated or reconfigured (power control) and grey cell has been evacuated and disabled. The LSA spectrum resource information and possible existence of Incumbent(s) is also collected, and presented in the same UI. In the example, there is a single Incumbent in an active mode and operating in the same band and area as the Licensee, so LSA spectrum resource reconfiguration process has reduced the transmit power of the impacted macro cells.

In the *network control UI* shown in the Fig. 2 the MNO Licensee's is able to control set of features with respect of the LSA network, its usage, and the Incumbents' protection. In the *LSA network enabled* selection, MNO can prevent the usage of the LSA BSs regardless of the spectrum resource availability. Similar manner, if the LSA network is currently in use and the MNO Licensee un-checks this option, the LC will deactivate automatically the respective BSs. The *graceful shutdown (GS)* option enables BS transmitters to lower its power level step-by-step during the selected time period before disabling the air interface instead of shutting down abruptly the transmitter in the cell down during de-activation. This allows terminals to detect another network layer and carry out a seamless handover avoiding a cell reselection, thus causing potentially a connection break to the ongoing session. In this trial FDD LTE radio network on band 1 (2.1 GHz) is used for back off and load balancing with LSA TD LTE resources. The *emergency evacuation* enables locking all the LSA network BS cells, according to pre-defined emergency plan with automatic plan activation operation for the whole network as in the case of public safety access class barring NMS feature [19], in order to achieve fastest possible evacuation time using OSS NMS functionalities only. In this paper, we introduce novel LC power control concept algorithms that instead of maximizing the number of transmitting BS cells, formulate the optimization objective as a function of BS transmit power. Adjusting the transmit power level do not result in abrupt changes in the received signal quality; therefore it is possible to avoid radio link failures and reach better overall throughput.

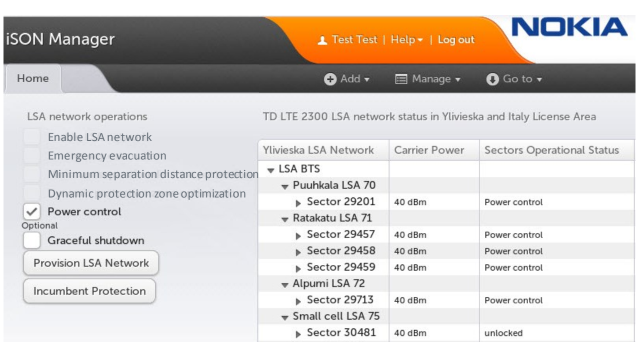

Figure 2. Mobile network operator's LC network control UI for selecting the trial features and controlling the LSA network use.

2.2.2. LC algorithms

A criterion which guarantees an interference-free operation of the LSA Licensee and the Incumbent transmissions is fundamental for allowing the coexistence between the LSA network and the Incumbent. In this trial set up the use of LSA spectrum resource can be based on three algorithms. The *Minimum Separation Distance* (MSD) protection algorithm calculates the minimum required distance between the Incumbent and the LSA BS transmitter taking into account both the Incumbent and Licensee radio transmission parameters, such as transmission power and antenna directivity to calculate the MSDs to specific geographical directions. The Incumbent protection MSDs are consistent with the methodology presented in [15] corresponding to the worst case scenarios.

However, as the MBB network (MN) is an interference-limited system where multiple spatially separated BS cells have radio frequency (RF) transmissions simultaneously on the same frequency band, the aggregated field strength created by the MN at the Incumbent receiver can result in unbearable interference conditions. The second protection algorithm, the *Protection Zone Optimization* (PZO) method tackles this through computing the aggregate cumulative interference created by all the cells in the MN. Even if the MSDs of all individual BSs are satisfied the interference created by the MN can be higher than allowed, resulting in MSD longer than MSD of any single LSA transmitter, that is, the aggregate interference from all BSs of the network can exceed the Protection zone limit even if none of the BSs exceeds it alone. This limit is defined by the Incumbent receiver sensitivity, noise floor, and additional interference margin. In the PZO method, linear optimization and accurate propagation modeling is used to determine the individual cells which are required to be switched off so that the resulting aggregate field strength at the Incumbent receiver remains below the protection zone limit [17].

The third LSA controller algorithm is *power control optimization* (PWR), a novel Incumbent protection method developed for the LSA testing platform presented in this paper, and which is not previously studied in the context of LSA [20]. Instead of maximizing the number of transmitting BS cells as in the PZO, the optimization objective can be formulated as function of the cell transmit power. An advantage of this procedure in contrast to the PZO is that adjusting the transmit power level do not result in abrupt changes in the received signal quality, therefore it is possible to reach better overall throughput and avoid radio link failures for the end users. Particularly, the objective is to maximize, for example, the average received signal power in the MNO network located outside the PZ given the constraint on the allowed interference level inside the Incumbent's PZ, and the constraints on the feasible values of the transmit power levels.

The optimization is performed to all MNO BSs which are effectively contributing to the aggregate interference field, and where the adjustment of the transmit power levels practicable. Once the optimal values are found, the power control algorithm forwards these parameters to the LSA controller, which modifies the MNO BS transmit power levels accordingly, in order to protect the simultaneous Incumbent transmission. The PWR allows the MNO Licensee to operate its network at full viable capacity while satisfying the criteria for interference-free operation of the co-existing Incumbent. Example of the calculated aggregate field strength of the CORE++ trial network when cells are transmitting first at the maximum power level and second after applying the power control algorithm are shown in the heat maps on Fig. 3. Fig. 4 illustrates the situation in the LC UI view showing the reduced power of the cells.

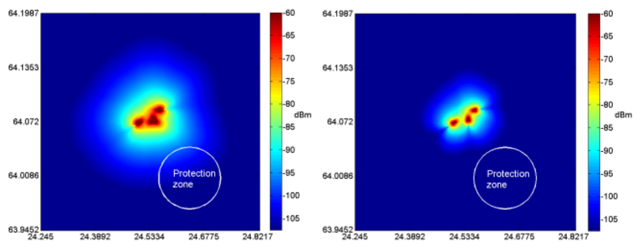

Figure 3. Calculated aggregate field strength of the trial network when cells are transmitting first at the maximum power level and second after applying the power control algorithm

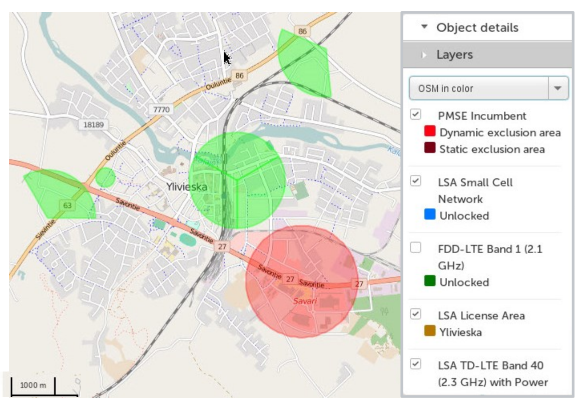

Figure 4. LSA Incumbent power control protection in the LC UI map view.

The LC algorithm outputs four lists: 1) BS cells which cause interference and should be evacuated if sectors are active, 2) BS cells which cause interference with current transmit power but could continue operation with lower power level, 3) the respective optimal transmission power levels for the BS cells, and 4) cells that are not interfering with at least one of the Incumbent users and are possible candidates for activation. However, a cell can be activated only if the same cell is not included to the other Incumbents' lists and the cell is currently off air.

The *Load balancing* [21] is an additional SON feature of the trial system, allowing monitored and controlled terminals to switch between the FDD-LTE coverage and back off layer and the LSA TD-LTE networks on demand. The load balancing is LTE SON self-optimization feature that aims to even out the load generated across the network by moving users from one cell to another [22]. LSA enabled BSs can be used as an additional capacity layer, balancing the load and optimizing connectivity experience for users. The nature of LSA spectrum availability leads to considerations on which users groups can be best served and are least affected by possible evacuation.

2.2.3. LC architecture

The LC used in the trials is developed in the Tekes Trial CRB and Tekes 5G LASS projects. Demo controller fully utilizes commercially available OSS solutions and related *Intelligent Integrated SON* (iSON) architecture and interfaces. iSON Manager is a tool to control SON function and MNO's network operations by providing closed loop automation and orchestration while enabling experts to maintain control and visibility on the network. iSON provides content packs for self-configuration, self-optimization and self-healing. Each content pack includes support for specific end-to-end process for SON.

Radio access networks comprise complex combinations of cells, frequencies, technologies and layers that require smart optimization and network management. By automating the management of Heterogeneous Networks (HetNets), iSON enhances their interworking and mobility. With tools to manage and interoperate multiple layers and technologies, iSON ensures small cells interwork with the macro layer, even in a multivendor environment. Other key SON functions are traffic steering and mobility management [23]. *Traffic steering* directs traffic to a particular radio access technology or layer to enable operators to optimize their resources, improve the way users experience services and minimize power consumption. Traffic steering works hand-in-hand with *mobility management* to ensure a reasonable number of handovers and eliminate radio link failures. It also considers other factors such as the capabilities of the terminals and network and the load in different technologies and layers. Process integrated SON enables SON support for operator process features like *site creation* and LSA deployment [24].

In the trial, LSA1 interface between the LR and the LC is utilizing existing Protocol to Access White-Space (PAWS) protocol [25] and JSON data Websocket connection interface as shown in the Fig. 5. The LSA_OAM interface uses available Nokia proprietary Configuration Manager (CM) open application programming interface (Open API) based on Web Services within the OSS interoperability initiative (OSSii) between different OSS vendor's equipment [26]. The 3GPP Service and System Aspects Telecom Management working group (SA5) standardization work has just started with a 3GPP Work Item study on operations, administration and management (OAM) support for the LSA [27].

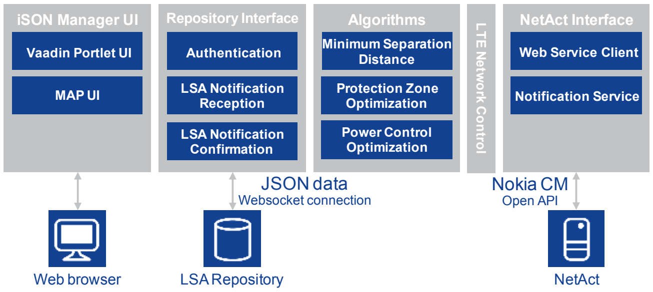

Figure 5. LC architecture built on top of iSON Manager.

2.2. LTE network

The LTE trial network environment consists of commercially available 3GPP Release 8+ compliant radio accesses and core network as shown in the Fig. 6. Nokia's commercially available LTE-Advanced capable Flexi Multiradio 10 macro and FlexiZone small cell BSs are used. Three macro TD-LTE base stations and six small cell at 3GPP band 40 (2.3-2.4 GHz) are located in the vicinity of the city and Centria University of Applied Sciences campus area in Ylivieska, Finland. In addition two FDD-LTE macro Flexi Multiradio 10 Base Stations provide primary LTE coverage layer to the same area in the IMT band 1 (2.1 GHz) and remains available as back off layer, should the LSA spectrum resource become temporarily unavailable.

All the LTE BSs are connected to LTE EPC core network at Nokia Oulu and are managed from a single point by the multi-technology, multi-vendor NetAct OSS NMS platform located in Tampere. The SON LSA demo controller discussed above runs in Nokia Espoo and interfaces with the NetAct NMS in order to exchange network information and to execute configuration management operations.

Commercial LTE multi-mode (FDD and TD) multi-band (band 1 and 40) UEs are used supported by major chip set vendors. In the trials Samsung S4 terminals supporting seamless TD-FDD handover are used.

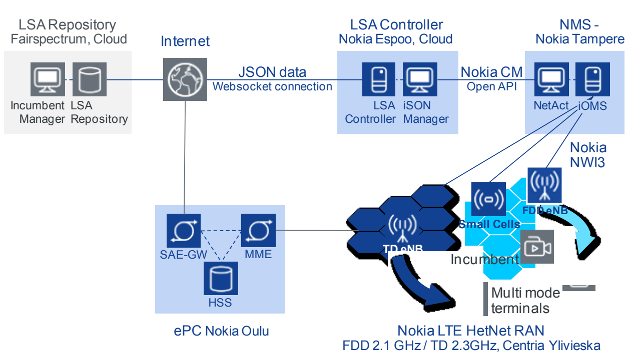

Figure 6. CORE++ field trial environment for LSA [17].

3. LSA FIELD TRIAL SET UP

The first LSA field trial using commercially available over-the-air LTE network in the 2.3GHz IMT band 40 was shown in the CORE+ trial environment in Finland April 2013 documented in [6] followed by iteratively enhanced trials utilizing research LSA controller developed by Finnish National Research Center VTT [22], [8] and [28]. SON LSA controller was first demonstrated in Finland together with CORE++ consortium in May 2015 using the trial environment described in Section 2. and documented in [17]. A new enhanced trial discussed in this paper with novel power control algorithm was demonstrated in September 2015 in the DySpan 2015 conference.

3.1. Key features

The LSA trial includes the following key elements and features:

- IM tools to track Incumbent spectrum data and store into LR
- LR storing Incumbent spectrum user's data
- Commercial FDD and TD LTE BSs at 3GPP bands 1 and 40.
- Commercial EPC core network and OSS NMS with advanced SON features
- MSD, PZO and PWR protection algorithms to maximize and optimize the LSA spectrum resource usage while ensuring agreed Incumbent protection.
- SON LC to manage TD-LTE BSs via the NMS according to LR's LSRAI.
- SON LC emergency evacuation feature to evacuate LSA band on demand.

This trial goes beyond [28] and [9] by introducing novel power control protection algorithms implemented into SON LSA controller integrated with the commercial NMS.

3.2. Trial workflow

The overall process flow of the LSA procedures and the trial specific demonstration workflow are discussed next. Based on the LSA system architecture [13] we have divided LSA operative flow into the three main phases: LSA provisioning, LSA operations and LSA release phase.

In the *provisioning* phase, the sharing framework, sharing agreement and licensing will take place between the regulator, the Incumbent and the Licensee. In the trial Finnish NRA FICORA has granted the trial license to use the 2.36 – 2.40 GHz band in the trial test license area in Ylivieska, Finland. Based on this information the MNO LSA Licensee identifies, configure and optimize radio network for the LSA spectrum resources.

In the second *operations* phase, the Incumbent spectrum user starts *activation* by informing the LSA band availability to the Licensee via the LR. The LSA Licensee activates and configures BSs to use vacant band based on the LSRAI and reports on LSA band usage. During the LSA operation the Licensee estimate interference, optimize LSA spectrum resource usage and maintain QoS and Quality of Experience (QoE). If requested by the Incumbent, the Licensee needs to *de-activate* spectrum resources and return it to the Incumbent. Actions include cell re-configuration or de-activation, interference estimation, maintaining QoS and QoE and confirming usage to LR. Now the Incumbent can re-start to use the band and inform the LR when the LSA spectrum resource could be handed back for the Licensee.

In the final *release* phase, the Licensee fully releases the LSA spectrum resource when the LSA license expires and the Incumbent can start to use it for its own purposes. The technical LSA trial in this paper is focused on validating performance of the second operations phase. The components of the trial was discussed in the section 2 and shown in Fig. 1 and Fig. 6. The trial flow in which the Incumbent updates usage and protection requirements via LR notification of new LSRAI have the following steps [13]:

- LR activation
- LC registers with LR
- LR configures itself with up to date set of Incumbent requirements
- Incumbent modifies the usage and protection requirements and inputs them to the LR
- LR checks compliancy with the Sharing Framework and Sharing Arrangement
- LR processes the changes taking into account other possible Incumbent's requirements
- LR informs the LC about the updates
- LC acknowledges (ACK) modified LSRAI after LC has processed the changes and requested the NMS to update the cells configuration(s).
- Once the changes have been applied by the NMS network LC ACK the updated LSA spectrum resources availability information to LR
- LC has up to date set of LSA spectrum resources availability information from the Incumbent
- MBB network operates on the available LSA spectrum resources accordingly

The exchange of data between the LR and the LC is supported by a procedure at LSA1 interface as shown in the Fig. 7. In this trial use case, as soon as new LSRAI is configured in the LR, the LR notify immediately the LC.

- The LR sends a LSRAI notification message to the LC, containing new or updated LSRAI.
- Upon reception of the LSRAI notification message the LC will check the consistency of the information provided.
- If consistency check is successful, the LC will respond with a LSRAI notification ACK message to confirm the reception of new LSRAI.
- Upon successful configuration of the LSA Spectrum Resources, the LC sends a LSA Spectrum Resource Confirmation message to the LR to confirm execution of changes.
- Upon reception of the LSA Spectrum Resource Confirmation Request message, LR acknowledges the reception of the confirmation by sending a LSA Spectrum Resource Confirmation Request Response message to the LC.

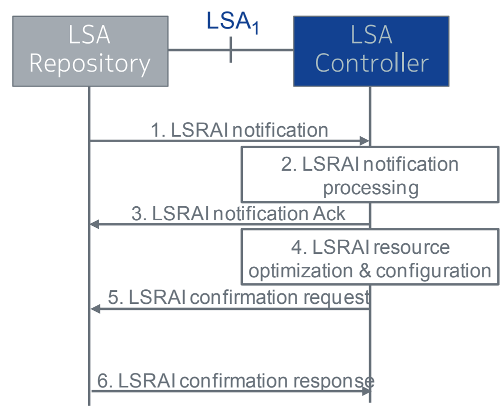

Figure 7. LSA message flow for the LR notification of new LSRAI

4. PERFORMANCE VALIDATION

The most important performance indicator is the evacuation time from the Incumbent de-activation request to the time the affected LSA BS cells are disabled and off-the air or reconfigured. Additionally important is the increased delay caused by introduced power control algorithm and needed NMS operations.

4.1. Measurement system

The LSA procedures and functions of the system elements described above can be presented as the different phases of the LSA spectrum resource de-activation and BS cell reconfiguration process for the trial performance validation measurements as follows:

1) The LSA process starts as the Incumbent spectrum user makes a de-activation request to the LSA IM. The IM submits the information to the LR which forwards the information to the LC.
2) The LC receives Incumbent information from LR. Based on the Incumbent user information, the LC calculates which BSs or cells on the LSA network are impacted and submit de-activation or power reconfiguration commands to the NMS accordingly.
3) The NMS receives the de-activation and or reconfiguration commands from LC and executes

new radio plan for the affected BS cells on the LSA network. Two radio plans are used. In urgency, the MBB network *locks* i.e. turns off transmitters of the impacted BS cells and UEs will automatically start a cell re-selection procedure. Alternatively, when evacuation is known in advance, the GS enables the power of the LSA BSs or cells to be decreased gradually so that UEs will do a seamless handover when the signal level at the serving cell drops below the signal level of the available FDD cell.

4) A BS or cell in the LSA network is de-activated or reconfigured followed by the no or reduced LTE signal detected in the LSA spectrum. The NMS finishes the radio plan execution, begins the LSA cell status check and sends cell off-the-air or reduced power level status update to the LC.
5) As soon as all needed LSA cells have reached updated status confirmation from the NMS, the LC ends evacuation or reconfiguration and submits completed status information to LR.
6) Incumbent user receives a confirmation on the new state to the LSA IM.

In the case of GS, the time for the shutdown as well as the step size for the BS cell power decrease can be specified. In the PWR method, the GS is followed by BS cell transmit power reconfiguration and radio transmission enabling. These execution times will be added to the basic band evacuation case total time. The Anite's Nemo Outdoor drive test tool was used to record LTE signaling information from the UE in order to record the time stamp for the BS off-the-air or transmit power change.

4.2. Measurement results and discussion

Described LSA band evacuation and reconfiguration process utilizing the enhanced SON LC was implemented into the Finnish CORE++ LSA trial environment and initial performance measurement studies have been conducted to evaluate the involved time scales. Corresponding time stamps are reported in Tables 1 and 2.

The evacuation performance measurement results in the Table 1 indicate that, in the case of the evacuation of the first cell, it takes in average 21 seconds from making the evacuation request until the LSA band has been cleared, and additional 13 seconds until the confirmation of the evacuation of all the cells is visible to the Incumbent in the LSA IM. As discussed in the section 2 the trial environment consists of both commercial network elements and specific demo elements developed for the LSA trials. In the table 2 the measurement results have been divided accordingly into a LSA SON Demo Controller platform and commercial LTE NMS delays. The LTE NMS operations took in average 34s for both the MSD and PZO algorithm cases, while PWR took 30s. In the PWR tests, we included the GS option with took additional 33s as configuration time and 30s for the actual power reduction phase. The NMS configuration plan provisioning time was minimized by utilizing pre-validated radio plans in which case the execution time of provision operation is shorter and not linearly dependent on the LSA network size. In the trial provisioning, a multi-site de-activation radio plan takes only about three seconds more to complete than a single site indicating promising results for larger LSA network management.

The LSA system demo platform execution time consists of the LR and the LC delays. The LR delay was approximately 0,5 - 0,8 s depending on to cloud service variations while LC was 1,4 s for the MSD and 4,2 s for the PZO algorithm due to difference in computational complexity. Measured LC component delay of the PWR method was 32 s including GS period of approximately 30s. In the trial, the e2e evacuation delay in the basic MSD case was reduced by 31% compared to [17] due to NetAct 15.2 version improvements. Novel PWR method delays were within the same range when excluding the additional delays of optional GS control and power down process steps. In the power control e2e measurement results the additional 368s delay was caused by mandatory ENB rebooting after the power reconfiguration in the used BS model.

The results presented in Tables 1 and 2 reveal that the developed concept works in realistic scenarios with live network. The average evacuation time of 24 seconds for the PZO and graceful power reconfiguration time of 58 seconds to no interference is an adequate result for most Incumbents and particularly for the PMSE use case. On the other hand, enabling or disenabling large live networks may activate wide load balancing and self-optimization routines [23] which could take hours before mobility and cell selections are again fully optimized in the adjacent cells. This process as well could be speed up by pre planning LSA use cases as a part of initial network planning.

The future research includes studies and trials how to ensure consistent QoS and QoE for the end users when LSA spectrum resource availability changes abruptly. In this trial the tests were made in optimal conditions without e.g. the real network congestion, which could slow down the evacuation process considerably. In order to reduce the number of radio link failures (RLF), the shutdown or the modification of the transmit power and or antenna downtilt could be done during a certain GS period, allowing users to be handed over to other cells. Particularly, the time used in consecutive NMS operational steps and ENB rebooting could be radically reduced from minutes to seconds by modifying the GS NMS feature to the *graceful power control* feature by changing transmit power smoothly from initial level to LC commanded one without going thru the locked state and rebooting phases. The third thing to consider is which alternative network to use for the back off handovers. For example, the alternative network could be of lower capacity or it could be congested, leading to lowered QoS for the end users after the LSA evacuation process. This is an active research topic for carrier aggregation, load balancing, traffic steering and handover optimizations in a HetNet network management.

Table 1. LSA band reconfiguration measurement results

	Meas point	MSD (s)		PZO (s)		PWR (s)	
		Time	SD	Time	SD	Time	SD
1. Incumbent request via IM	LSA IM	0		0		0	
2. LC receives Incumbent info from LR	LC	0,27	0,03	0,32	0,03	0,41	0,03
3. NMS starts re-configuration command	NMS	0,98	0,08	4,10	0,75	4,48	0,92
4. BS / cell on LSA band is re-configured	LSA band	20,75	1,56	23,48	1,30	58,02	1,49
5. NMS starts PWR conf.	NMS					64,82	0,89
6. NMS notify LC plan commission completed	LC	34,47	1,08	37,72	1,25	95,26	1,71
7. Incumbent user receives confirmation to IM	LSA IM	35,49	1,02	38,64	1,22	96,19	1,48
8. ENB reboot	eNB					463,9	0,46

Table 2. Total measured execution times of system element

Execution time [s]	e2e			component		
	MSD	PZO	PWR	MSD	PZO	PWR
NMS (GS)			33,42			33,42
NMS (reconfig.)	33,54	33,77	63,77	33,54	33,77	30,35
LC	34,94	37,98	95,40	1,40	4,21	31,63
LR	35,49	38,64	96,19	0,54	0,66	0,78
eNB rebooting			463,9			367,7
Algorithm calculation				0,29	0,31	0,34

5. CONLUSIONS

The paper has presented a field trial demonstration of the novel LSA concept that allows a mobile network operator to share spectrum resource from other type of Incumbent spectrum users with a predictable QoS where and when it is not used by the Incumbent. The LSA complements the traditional exclusive access based on individual authorization when re-allocation of spectrum is impracticable due to the Incumbent use. The LSA is a complementary spectrum management concept on voluntary basis that fits under an individual licensing regime in which the LSA Licensee has exclusive spectrum rights of use when entitled to use the spectrum.

The trial successfully demonstrated that a TD-LTE network Licensee can take the 3GPP band 40 (2.3-2.4 GHz) into the LSA use and vacate it when requested by the Incumbent spectrum user. The load between bands were balanced utilizing the load balancing method, and in the case of evacuation end users, proactively did hand over to the FDD LTE networks to maintain their connection, enabled by the graceful shut down feature. The trial showed that the dynamic availability of the LSA spectrum can be managed with commercially available network elements and a minimum number of additional functional components, the LSA Repository and the LSA Controller. Furthermore, the trial demonstrated first time the LSA controller developed as a SON module with the novel power control concept algorithms. Advanced protection algorithms were tested and compared to maximize LSA spectrum resource availability for the Licensee while ensuring Incumbent protection.

Performance validation was conducted by measuring the duration of the spectrum evacuation and the BS cell reconfiguration workflow steps in the LSA band due to the Incumbent's immediate LSA spectrum resource availability notification. The measurement results revealed that both the emergency evacuation and the BS cell reconfigure operation can be done in a way that fulfills typical PMSE service Incumbent's requirements in the Finnish use case and wider in a static and a semi-static LSA use cases. Comparing results to the previous LSA trials, the NMS integrated LSA controller reduced overall operations delay approximately 31% in evacuation cases and increased delay by 88% when graceful shutdown + power control was utilized.

In the future, the SON LSA Controller will be enhanced by exploiting features from LTE Advanced and self-organizing networks, e.g. more sophisticated Load Balancing and Traffic Steering. In particular, to further improve the deployment of the dynamic power control protection method to maximize LSA resource availability on the border area between radio systems, the novel graceful power control NMS feature should be studied and developed. Interference measurements will be conducted to measure real interference levels in the trial environment to develop algorithms and to help regulation and standardization in defining the actual rules and conditions for sharing framework and arrangements. Furthermore the CORE++ trial environment will be extended to cover 3.5 GHz spectrum band to study the LSA concept's evolution paths towards the satellite convergence bands, the US 3 tier Citizens Broadband Radio Service (CBRS) and the 5G.

6. APPENDIX

A list of the key Licensed Shared Access abbreviations used in this paper:

3GPP	Third Generation Partnership Project
CM	Configuration Manager
EIRP	Effective Isotropic Radiated Power
eNB	Evolved Node B
EPC	Evolved Packet Core
EZ	Exclusion Zone
HetNet	Heterogeneous Network
BS	Base Station
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex technology
GS	Graceful Shutdown
IM	Incumbent Manager Tool
IMT	International Mobile Telecommunications
LC	Licensed Shared Access Controller
LSA	Licensed Shared Access
LSA1	Interface between LSA Repository and LSA Controller
LSR	LSA Spectrum Resource
LSR	LSA Spectrum Resource Availability Information
LR	Licensed Shared Access Repository
LTE-A	Long Term Evolution Advanced
MBB	Mobile Broadband
MN	Mobile Broadband Network
MNO	Mobile Network Operator
MSD	Minimum Separation Distance algorithm
NMS	Network Management System
NRA	National Regulatory Authority
PMSE	Program Making and Special Events
OAM	Operation, Administration and Management
OSS	Operational Support System
PAWS	Protocol to Access White-Space
PWR	Power Control Optimization algorithm
PZ	Protection Zone
PZO	Protection Zone Optimization algorithm
QoE	Quality of Experience
QoS	Quality of Service
RLF	Radio Link Failure
RF	Radio Frequency
RZ	Restriction Zone
SON	Self Organizing Network
TD	Time Division Duplex technology
UE	User Equipment

6. ACKNOWLEDGMENT

This work has been done in the CRB, LASS, CORE and WISE2 research projects within the Trial and 5G programs of Tekes - the Finnish Funding Agency for Technology and Innovation. The authors would like to acknowledge the project consortium members.

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