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Research study on dynamic spectrum-sharing mechanisms and establishment of experiment platform in Taiwan

Executive Summary

Telecom Technology Center

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Executive Summary

This document is the summary report from a research study on dynamic spectrum-sharing mechanisms and establishment of experiment platform in Taiwan, which the National Communications Commission (NCC) commissioned from Telecom Technology Center (TTC). The objectives of the research were to:

- understand recent regulatory concepts for spectrum sharing globally, and
- determine the key features of a regulatory framework that underpins and promotes such sharing mechanism in Taiwan.

I. Introduction

Radio spectrum is a scarce and precious resource that is significantly difficult to confront the proliferation of mobile devices and diverse mobile applications. It has been estimated that a capacity expansion by a factor of 1000 is needed by the year 2020 in order to satisfy future 5G communications demands.

According to international experiences, it is essential to improve the efficiency of spectrum use, for the spectrum is insufficient for the long-term requirement. However, most frequency bands below 6 GHz are already allocated to certain incumbents. Even when clearing spectrum is accepted by incumbents, re-farming the spectrum for commercial use takes time and requires significant investment. To resolve this problem, spectrum sharing has become an appealing solution to improve the spectrum efficiency as well as to increase extra available spectrum resources. Furthermore, the implementation of spectrum sharing will bring the new challenge since the related technologies and policies are still in an embryonic stage.

The research work of this project was conducted involving analyzing every spectrum sharing scheme, built on dynamic spectrum sharing techniques, such as licensed shared access (LSA), the three-tier model to support the Citizen's Broadband Radio Service (CBRS) in the US, TV white space (TVWS), and licensed assisted access (LAA) to unlicensed spectrum. Specifically, to figure out the required policies, supervisions, regulations, and technology management platforms (e.g. shared spectrum geolocation database), then, to draw up the suitable spectrum management strategies, spectrum sharing regulation, and technical specifications in Taiwan.

The structure of this project is as follows:

1. Chapter II presents an overview of recent spectrum sharing regulatory and research development in Europe, United States and other countries.
2. Chapter III is the comparative analysis concerning the spectrum sharing mechanisms.

3. Chapter IV presents a regulatory framework for spectrum sharing as part of the draft Telecommunication Administration Act.
4. Chapter V conducts the analysis of optimization for spectrum efficiency in spectrum sharing mechanism.
5. Chapter VI is to integrate the theoretical research into a design experiment, as well as the proof-of-concept demonstration for LSA and LAA.
6. Chapter VII summarizes the contents and key results.

Other routine that didn’t mention above, study group have to make a meeting once a month with NCC. Study group also held several discussion meetings to collect the opinions of stakeholders for our research.

II. Overview of recent spectrum sharing approaches in regulation and research

Spectrum sharing is a new tendency, and the corresponding technologies as well as policies energetically develop in Europe and America. In addition, to keep on the development of new types of spectrum sharing mechanism, part of them has been ready for the implementation of commercialization.

Spectrum sharing methods for mobile broadband services can be classified into sharing access in licensed and unlicensed bands. For the licensed frequency band, The European Commission in 2014 gave a mandate to the European Conference of Postal and Telecommunications Administrations (CEPT) to identify harmonised technical conditions for spectrum sharing in 2300-2400 MHz band. In response, the CEPT has developed a set of technical recommendations on the methodology, known as Licensed Shared Access (LSA) and the sharing conditions. In December 2015, the Federal Communications Commission (FCC) in U.S. called for proposals for future spectrum access system (SAS) administrators and environmental sensing capability (ESC) operators in the 3550-3700 MHz band. SAS and their associated ESC will function together to coordinate spectrum use and prevent interference in the 3.5 GHz Band.

For the unlicensed (license-exempt) frequency bands, LTE-WLAN aggregation (LWA), Licensed Assisted Access (LAA) and LTE-Unlicensed (LTE-U) have emerged as the mechanisms to allow LTE operating in unlicensed band currently used by Wi-Fi. These technologies are designed to offload the network traffic from mobile broadband spectrum to the unlicensed bands.

1. LSA

The process of developing a regulatory framework for spectrum sharing in European Union (EU) involved a joint effort of the European Commission (EC), the Electronic Communications Committee (ECC), the European Conference of Postal and Telecommunications Administrations (CEPT) and the European Telecommunications Standards Institute (ETSI). The first application of LSA is in the 2.3 GHz band, Band 40 in 3GPP. The incumbents in this band are Fixed Satellite Service (FSS), Radar, and PMSE. The ECC has studied sharing in the 2.3GHz where the ECC report 172 concluded that sharing between Broadband Wireless Systems (BWA) and other systems can be done. Currently CEPT is investigating the harmonised technical conditions for the use of the 2.3 GHz band and has issued Reports 55, 56 and 58.

Based on the ECC studies ETSI completed a technical report outlining a possible architecture and related function to enable a LSA system. ETSI continued with developing a technical specification on system requirements for operation of Mobile

Broadband Systems in the 2300- 2400 MHz band under LSA and the architecture including associated procedures and functionality of the related interfaces, as well as the specification defining the content of the LSA Spectrum Resource Availability Information (LSRAI) and the protocols on the interface between LSA Controller (LC) and LSA Repository (LR), the so-called LSA1.

The functionality can be summarized as:

a) LSA Repository (LR)

The LR supports the entry and storage of information describing Incumbent's usage and protection requirements. It is able to convey the related availability information to authorised LSA Controllers, and is also able to receive and store acknowledgement information received from the LSA Controllers. The LR also provides means for the NRA to monitor the operation of the LSA System, and to provide the LSA System with information on the Sharing Framework and the LSA Licensees. The LR ensures that the LSA system operates in conformance with the Sharing Framework and the licensing regime, and may in addition realize any non-regulatory details of the Sharing Arrangement.

b) LSA Controller (LC)

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

LSA could be a complementary solution for mobile network operators (MNO) for accessing spectrum for IMT-bands, within specified geographical, time or technical limits. LSA complements the traditional exclusive access based on individual authorisation when re-allocation / refarming of the spectrum is impracticable due to incumbent use. Thus, the purpose of LSA is not to replace the traditional exclusive access which is the preferred method. LSA would enable the sharing of spectrum with non MNOs incumbents based on national decision.

2. CBRS

In 2015, FCC authorized the use of the 3.5 GHz band (3550 MHz to 3700 MHz) for shared wireless access, opening up previously protected spectrum used by the US Navy and other DoD members.

To use CBRS spectrum, one must individually request and be assigned a band by a Spectrum Access System (SAS) programmatically. The SAS controls the interference environment, and enforces protection criteria and exclusion zones to protect higher priority users, and dynamically determines and enforces CBSDs' maximum power levels in space and time. Also, when the use of the spectrum is no longer required, the channel is freed up for use by other requesters.

The Spectrum Sharing Committee (SSC) of the Wireless Innovation Forum (WInnF) consisting of governmental, mobile broadband, wireless, Internet and defense ecosystems representatives serve as a standardization forum to support the development and advancement of CBRS spectrum-sharing technologies with initial focus on 3.5 GHz. The SSC has finalized the first stage standardization work, and defined operational and functional requirements, protocols for data and communications across the various open interfaces within the system to enable early trial implementations of interoperable systems. Furthermore, the 3GPP finalized the CBRS 3.5 GHz band 48 definition for LTE in the United States in December 2016.

FCC Rules Part 96 further defines three levels of priority access in descending order for assigning the use of the CBRS spectrum:

a) Incumbents

Existing users (e.g. US Naval Radar, DoD personnel) get permanent priority as well as site-specific protection for registered sites.

b) Priority Access Licenses (PAL)

Organizations can pay a fee to request up to four PALs in a limited geographic area for three years. Only the lower 100 MHz of the CBRS band will be auctioned off; with restrictions of a maximum of seven concurrent 10 MHz PALs allocated within the same region.

c) General Authorized Access (GAA)

The rest of the spectrum will be open to GAA use and coexistence issues will be determined by SAS providers for spectrum allocation.

The FCC revisited rules for CBRS in 2016, and introduced the light-touch leasing process to enable secondary markets for the spectrum use rights held by PAL licensees. Under the framework, no FCC oversight is required for partitioning and disaggregation, and PAL licensees are free to lease any portion of their spectrum or license outside of their PPA.

To protect FSS earth stations, the FCC has adopted a rule requiring satellite operators to register their stations annually. The protection of federal DoD incumbent users is implemented by utilizing the static exclusion zones (EZ) scattered in a large area of the country. In the second deployment phase, the ESC system enables the rest of the country, including major coastal areas, to become available, as the exclusion zones are converted into protection zones (PZ).

3. TVWS

TV White Space refers to the TV channels that are not used by any licensed services at a particular location and at a particular time. This spectrum resource is attractive to LTE deployment due to the availability of many vacant analog channels resulting from the Digital Switchover (DSO) process that is taking place in many countries across the world. This DSO process is to convert TV stations from analog to digital. With the development of the high efficient broadcasting technology for Digital TV in DSO, some previously occupied analog TV channels, including the radio spectrum used to avoid co-channel or adjacent channel interference between TV stations, and the unused broadcasting channels in a given geographic area or a given period of time indexed by the TVWS database, become vacant. Thus these frequency bands add to the existing portion of TVWS resources that have already been exploited for spectrum sharing by other wireless technologies.

In the US, the FCC introduced the regulatory and standardization framework for the TVWS concept in 2010. Currently in the US, the licence holders on this band from the broadcasting community have been granted the rights to re-sell their licenses in so-called incentive auctions. The European regulatory activities on TVWSs were initiated in the ECC of CEPT by addressing technical and operational requirements for the possible operation of cognitive radio systems in the WSs needed to ensure the protection of the incumbent radio services. The UK has been active in proposing the framework for TVWS operation. The UK regulator Ofcom has completed a series of trials of its TVWS framework in 2015. Based on the trials, Ofcom proposed some minor changes to the framework and is moving ahead towards commercial operation. In Asia, for example the regulatory authority of Singapore has developed a regulatory framework for TVWS operations in 2014, as well as technical standard for white space devices in 2016.

The availability of vacant TV channels for spectrum sharing by unlicensed devices varies with location, time, and usage characteristics specified in spectrum access management rules.

4. LTE spectrum sharing in 5 GHz unlicensed bands

Data offloading to unlicensed spectrum in existing 802.11 WLAN infrastructure, e.g. Wi-Fi, is the conventional method used by wireless network operators to increase system capacity for their subscribers.

For LTE deployment in 5 GHz U-NII bands, besides the traditional WLAN data offloading method, more sophisticated spectrum sharing mechanisms have been studied for achieving improved throughput, including LTE-WLAN aggregation (LWA), Licensed Assisted Access (LAA), and other emerging multi-connectivity/aggregation options like LTE-Unlicensed (LTE-U). As to co-existence mechanism, Listen-Before-Talk (LBT) and Carrier Sense Adaptive Transmission (CSAT) protocols are adopted respectively for LAA and LTE-U to prevent the co-channel interference. In summary, sharing access in unlicensed bands is an arduous effort because of the technical barriers such as prevention of wireless interference and coexistence of heterogeneous systems, while the deliberate management system is necessary for sharing access in licensed bands since the reliable and secure communications for the incumbents are demanded.

To take advantage of the well-developed network management technologies in LTE, LWA at the radio access network (RAN) is proposed as an alternative to Wi-Fi offloading, and it has been included in a 3GPP Release 13. While DL traffic can be transmitted through both LTE and Wi-Fi links, UL is only through LTE.

Another spectrum sharing mechanism included in 3GPP Release 13 is Licensed Assisted Access (LAA). Under LAA, the unlicensed carrier can be used as a Secondary Component Carrier in the LTE Carrier Aggregation framework. Instead of switching packet transmission to WLAN as implemented in Wi-Fi offloading, LAA deploys LTE itself in the unlicensed spectrum to provide enhanced Quality of Service (QoS). In line to planned 3GPP Release 14 specifications, Enhanced LAA (eLAA) is defined as an enhancement to LAA. While LAA only supports DL, eLAA uses carrier aggregation in both UL and DL to collate licensed and unlicensed bands and thereby can support UL and DL LTE operations in the unlicensed spectrum.

LAA and LTE-U are going through a series of field trials to prove their transmission qualities and fair sharing (i.e., coexistence) of the unlicensed spectrum with the existing Wi-Fi systems. Preliminary results, although, have shown that presence of LAA does not hamper the performance of Wi-Fi, more rigorous trials are still needed.

While LWA integrates the WLAN radio link as part of the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) without imposing any modification request on the core network, LAA needs to adjust the channel contention scheme and the transmit power control accordingly. This kind of modification is applied to ensure fairness for other technologies in the worldwide usage of the 5 GHz unlicensed bands, in addition to the overall throughput enhancement in the network.

III. Comparative analysis of spectrum sharing mechanisms

The most prominent spectrum sharing concepts in licensed band are Licensed Shared Access (LSA) from Europe and Citizens Broadband Radio Service (CBRS) from U.S. In both sharing concepts, incumbent users have the highest priority in terms of spectrum access and protection against interference from other users at any location and time. While the LSA leverages existing assets and capabilities of the mobile network operator domain, the CBRS extends the business model dynamics from connectivity to content, context and commerce.

The LSA concept allows two-tiered sharing between an incumbent and a share user with LSA licensee both having exclusive individual access to a portion of spectrum at a given circumstance through two key elements, LSA Controller and LSA Repository. Compared to LSA, CBRS is a three-tiered access model which comprised of federal and non-federal incumbents, including the general authorized access (GAA) tier, to facilitate opportunistic spectrum use. Priority access (PA) users are allocated to exclusive channels and protected from other PA and GAA users. In the GAA tier, multiple users can use a given channel, and thus there is no interference protection.

The main difference between these two concepts is the degrees of permission. The LSA approach envisages exclusive shared use of the spectrum in time, location and frequency with the incumbent who uses its spectrum allocation infrequently or less extensively. The associated technical conditions allow spectrum sharing in such a band so that on one hand the incumbents could be protected from unwanted interference from the 'licensed' users and on the other hand, the licensed user could have a guaranteed conditional access to the spectrum to ensure predictable quality of service in the shared band. On the contrary, GAA users could dynamically access the shared spectrum through a simple register process to SAS system.

In addition, incumbents in LSA mode are required to notify the LSA repository of usage information for interference prevention, whereas this procedure is not applicable in SAS mode since the associated incumbents are U.S. Department of Defense. To meet the mission critical requirements of military incumbent users, the corresponding interference prevention has to be entirely determined by sensing the application area or demarcating the exclusion or protection zones. Confidentiality of the sensitive military incumbent user information is ensured through strict operational security requirements and corresponding certification of the sensing elements, as well as with operator authorization.

Furthermore, an LSA license is assigned to one mobile network operator (MNO) or LSA licensee across an entire country or a large geographic area. It implies that the complex interference mitigation is not required for LSA. This is in contrast to CBRS because the wireless spectrum is assigned to PALs in a single Census Tract, which is not based on the area of the region but the population density of the region. The GAA users also need to be actively managed to prevent interference to the PAL users.

IV. The suggestions to achieve the spectrum sharing schemes

In Taiwan, there are 590 MHz of licensed spectrum for 4G mobile communications at the end of 2017. By releasing more licensed spectrum for mobile broadband, the available bandwidth will reach 1,140 MHz in 2020, respectively. The volume of spectrum resources in the short term is adequate for the MNOs' need. It implies that supplying with huge and extra spectrum resources at the present stage may cause the glut of spectrum on Taiwan's communication markets. Consequently, the spectrum efficiency is difficult to be further improved.

However, in the long term, the demand for radio spectrum is increasing since 5G wireless systems and innovative communication services are developing. Spectrum sharing is still an important and critical approach for future innovative applications. Therefore, enough supply of spectrum resources at the present stage could be treated as an advantage. The extra spectrum might be adapted for the shared spectrum with lower cost licenses. The MNOs have adequate licensed bands are unlikely to compete for these shared spectrums. Thus the characteristic of low cost on these shared spectrums will gives incentives for new innovative operators to devote their full efforts into the future communication markets.

On the other hand, spectrum management is the process of regulating the use of radio frequencies to promote efficient use, prevent interference, and gain a net social benefit. The corresponding regulations or administration laws are always the powerful approaches to manage the wireless spectrum in the most countries of the world. In other words, spectrum sharing must comply with the related regulations. The policies and regulations are not only the key triggers for spectrum innovations, but also the crucial factors to the development of spectrum sharing.

On the legal and policy aspects, currently, the spectrum usage rights are included in the license of telecommunication service in Taiwan. The spectrum bandwidth is predefined and allocated to the corresponding telecommunication business. In other words, there are strict limits on spectrum usage so that sharing or rental of spectrum is not allowed. As a result, it is necessary to legislate an administrative regulations for spectrum sharing.

Fortunately, the draft Telecommunications Management Act that NCC proposed recently is comprised the relative rules for the development of new spectrum access technologies, as a foundation for the establishment of a framework of spectrum sharing and the administration of unlicensed spectrum, to assure sufficient spectrum resources for the long-term development of mobile broadband technologies. It is expected that these measures could promote the efficiency of the spectrum utilization, ensure the development of wireless technologies, and encourage the innovation of new technologies and services in communications.

As above-indicated, for fulfilling the improvement on spectrum efficiency, spectrum sharing is still likely the necessary method. How to take this opportunity to realize the spectrum sharing schemes is an important issue. With a focus on Taiwan, the suggestion to achieve the spectrum sharing schemes is proposed.

a) Legislate new administrative regulations for spectrum sharing

Due to lack of administration for spectrum sharing in licensed bands in Taiwan, it is necessary to make new administrative rules to specify the shared conditions, scenarios, and technical standards. On the other hand, sharing in the licensed spectrum relies on the database management system to protect the incumbents. The corresponding regulations for governing database systems are also required so that the operators could make arrangement for database administration.

In the meantime, planning the suitable spectrum and area for field testing is also important. The operators in telecom and wireless communication industries will be invited to participate in the experiment platform. It is expected that the operators and industries will provide a more detailed assessment for spectrum utilization environment and improving the national spectrum sharing mechanism.

b) Expand the sharing scheme into more types of applications

After the experiment results are steady, that is, the first step is to ensure that the primary users are undisturbed and the secondary users are able to provide their services in certain quality, and then to expect opening up a wider range of areas with more types of users to make full use of radio frequency resources, which including scientific researches and nonprofit organization services. As the diversity of shared users is increasing, the innovative services and applications can be further developed.

V. The analysis of optimization for spectrum efficiency

To increase the resolution of spectrum availability and utilization, there is a need to augment the spectrum database content with real-time sensing results. Advanced spectrum sensing techniques are needed to quickly and accurately identify transmission opportunities over a very wide spectrum pool that may host a large number of different wireless services. However, designing a framework that enables the marriage of database-driven and sensing-driven spectrum sharing approaches remains an open problem. Furthermore, sharing between users with different access-priorities confront novel challenges that demand study of new access paradigms and protocols, dynamic and flexible incumbent protection zones, and adaptive models for spectrum allocation and assignment. Consequently, database administrators of the shared spectrum have to identify the status of spectrum usage precisely, and match shared users up with the idle band efficiently. Sensing capability and radio environment map should be implemented and integrated with database for optimal spectrum sharing.

Since intelligent mobile users such as smartphones and tablets can sense the wireless spectrum, channel sensing tasks can be assigned to these mobile users. This is referred to as the crowdsourcing method. However, there may be some malicious mobile users that send false sensing reports deliberately, for their own purposes. False sensing reports will influence decisions about channel state. Therefore, it is necessary to classify mobile users in order to distinguish malicious users. We assign a reputation value to achieve this goal. Meanwhile, to cast the optimization problem, we also propose a self-adaptive algorithm in order to obtain bounded close-to-optimal solutions, and analyses the approximation ratio of the proposed algorithm.

VI. The establishment of the experiment platform

Demands for spectrum have been a great challenge to wireless communications such as Internet of Things (IoT) and 5G or beyond. Dynamic spectrum sharing and access (DSS/DSA) has been a trend for mitigating spectrum deficiency. Trials of DSS/DSA have taken place in the United States, European Union and Asia-pacific countries such as Singapore. With the deployments and technological advancements of LTE-based, IoT and 5G networks, the academia, industry and regulators have been conducting research and developments on how next generation network services may expand in capacity and diversity and raise socio-economic values via DSS/DSA.

Specifically, Licensed Shared Access (LSA) and Unlicensed/General Authorized Access (GAA) have been two prominent and emerging regulatory modes for DSS/DSA in the very valuable sub-giga hertz bands. LSA facilitates shared access with quality of services (QoS). The Finish CORE++ project and the Italian LSA pilot have setup LSA testbeds and performed various evaluations.

There are many questions yet to be answered by further research, experiment and demonstration regarding LSA technologies, architectures, operation models, and associated regulatory policies. Three research objectives to achieve are as follows:

a) to help ICT industry to grasp technology, system and service developments of

LSA;

b) to provide scientific and technological support and recommendations to both LTE service operators and regulators regarding LSA by LTE services; and

c) to develop foresights about spectrum sharing technologies and operation model developments.

To achieve these objectives via proof-of-concept (PoC) demonstrations and experiments, a Virtually Shared Spectrum Access (ViSSA) platform is developed via the DSA Lab of NTU, the LTE small cell networks in Mobile Broadband Network Lab, NSYSU, the Information and Communications Research Laboratories, Industrial Technology Research Institute, and the monitoring display system of Radio Spectrum Lab, TTC.

The ViSSA platform (Figure 1) consists of five parts:

a) a monitoring and management center (Figure 2) with a geolocation database/spectrum repository (GLDB/SR);

b) incumbents that may register to GLDB/SR and an incumbent signal generator that directly accesses spectrum;

c) a few secondary mobile networks of LTE small cells, each having a LSA controller (Figure 3) to communicate between GLDB/SR and its own network management;

d) feature-based sensing of incumbent signals; and

e) integration links among distributed *a) – d)* via Internet.

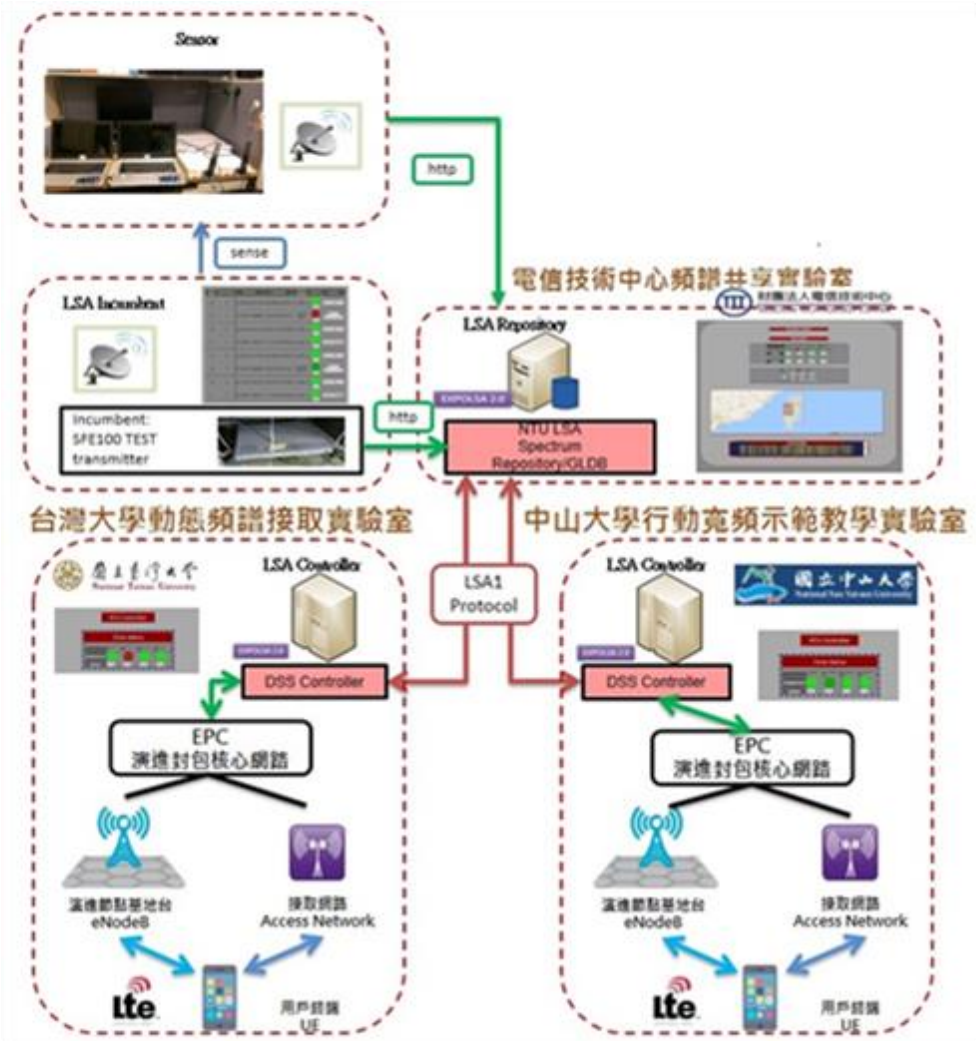

Figure 1: ViSSA architecture

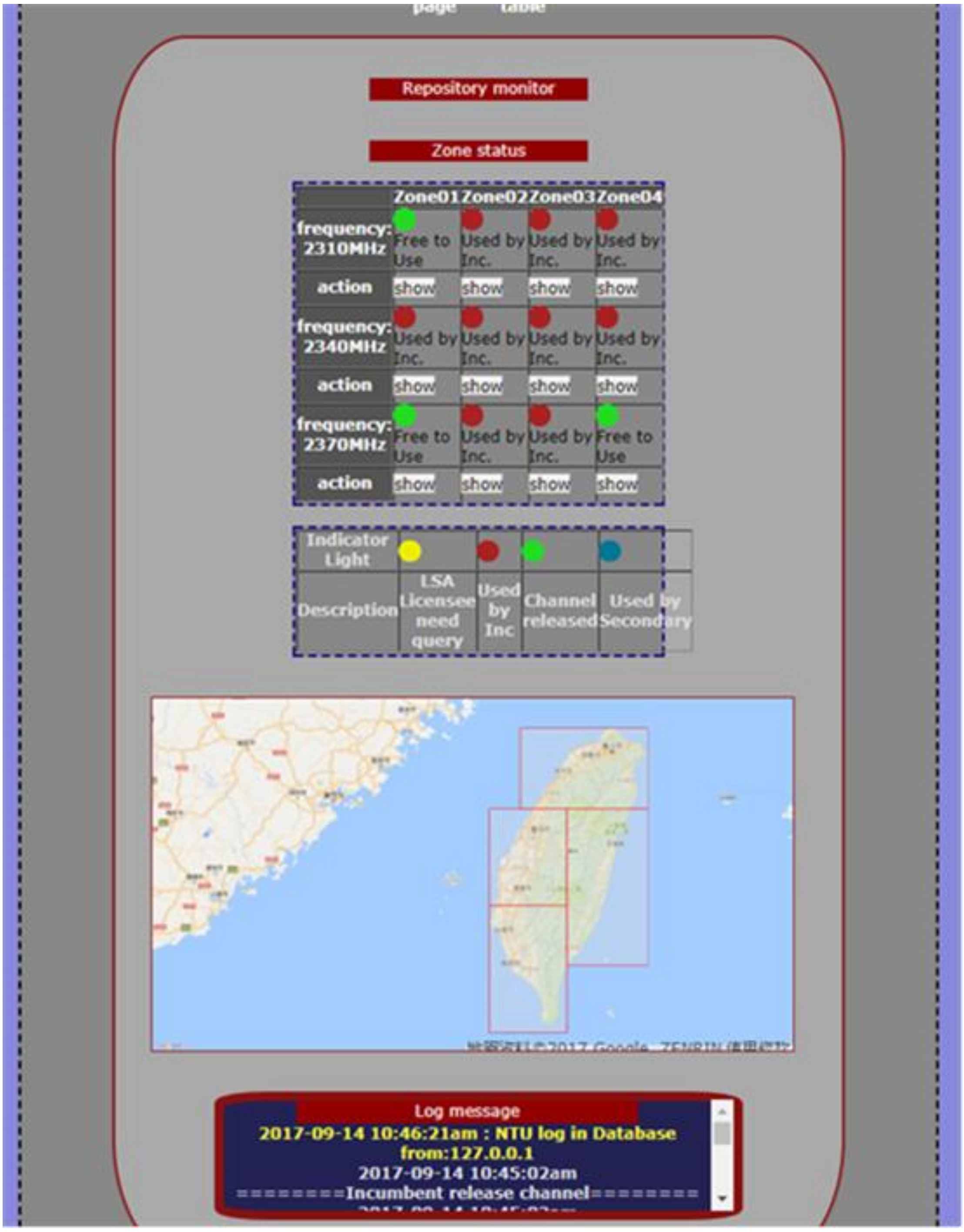

Figure 2: Monitoring and Management Display

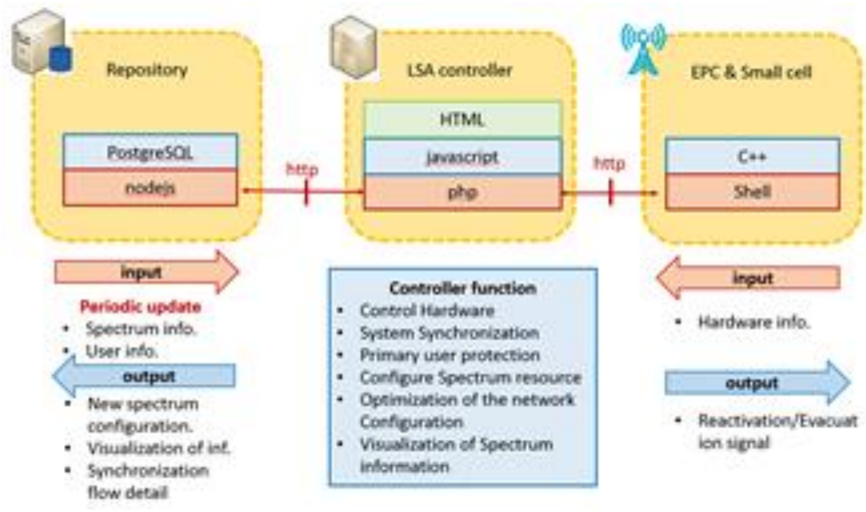

Figure 3: Controller integration with GLDB/SR and EPC

Key to the integration are firstly periodic synchronization between GLDB/SR and LSA controller, which follows TS 103.379 (LSRAI) protocol, secondly the interface between LSA controller and EPCs, and lastly the HTTP-based interface between GLDB/SR and the monitoring system.

We have conducted two on-site demonstrations of LSA management of database-guided (Figure 4) and sensing-based (Figure 5) evacuations yielding to the incumbent and re-activation in other available spectrum bands by the secondary networks. On the sequences of database guided evacuation and re-activation, when an incumbent registers on LSA spectrum repository (SR), the SR notifies the LSA controller and the controller sends evacuation and re-activation commands to the network management (OA&M) according to LSA1 interface protocol. The LTE EPC receives and forwards the commands to LTE eNodeB for execution. Finally the confirmation follows the reverse path. The associated state changes will be displayed on the monitoring center accordingly, and such demonstrations will finish in no more than 70 seconds.

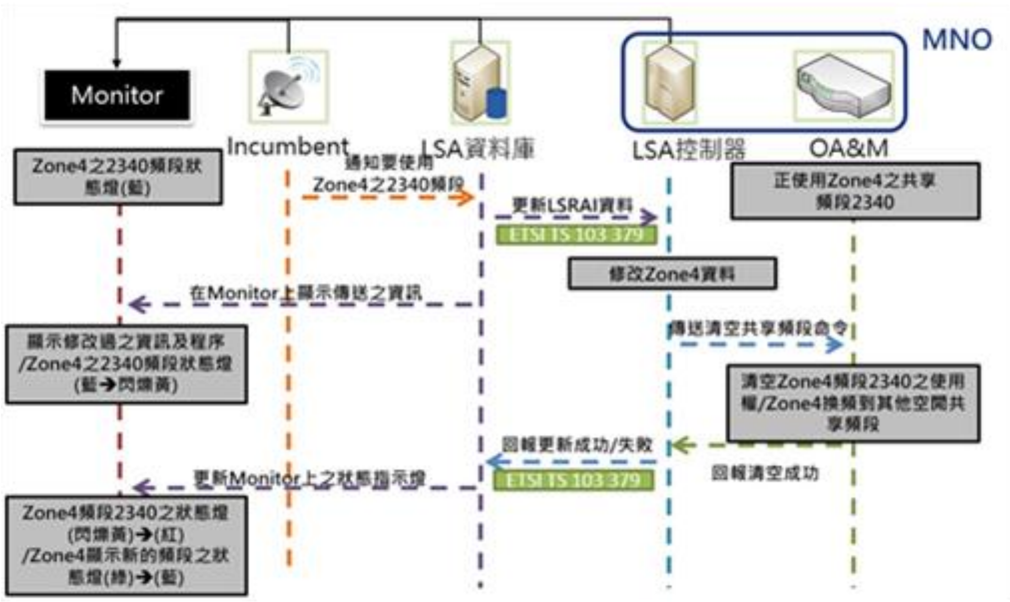

Figure 4: Database guided evacuation and re-activation

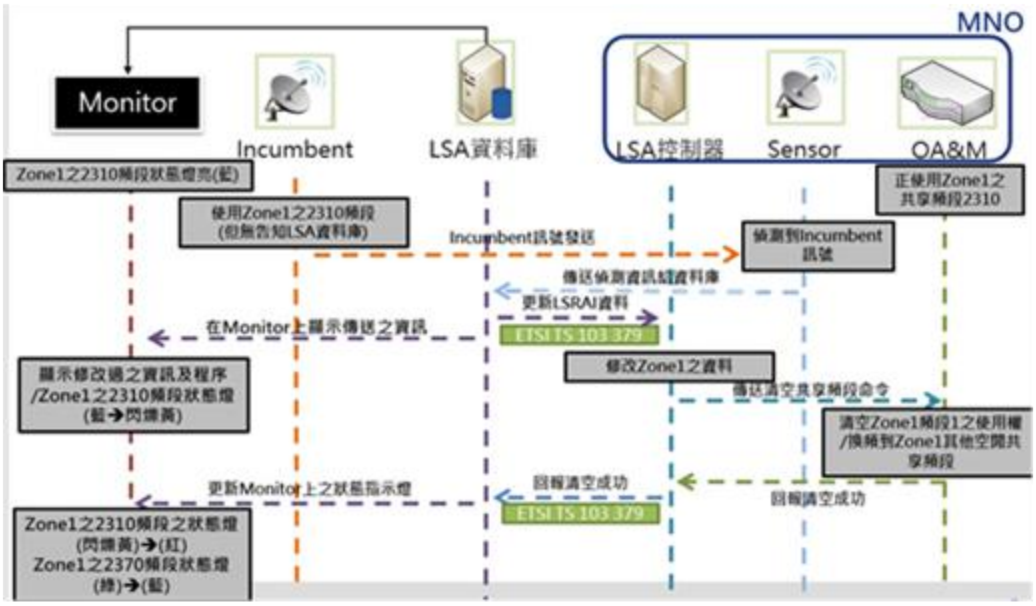

Figure 5: Sensing-based evacuation and re-activation

As wireless usage increases on expensive licensed bands, the mobile wireless industry is looking at offloads onto unlicensed bands. One of the approaches currently under investigation is the carrier aggregation of LTE in licensed and unlicensed spectrum, which led 3GPP to include in the last Release the specification of Licensed Assisted Access (LAA) extensions to allow the licensed bands to be augmented by carriers located in unlicensed 5GHz bands, through the principle of carrier aggregation. However, for LTE to fairly coexist with Wi-Fi, many open issues still require investigation, as there is not yet a clear consensus on the actual impact that each network can have on the performance of the other.

The use of LTE in unlicensed spectrum generates multiple challenges, since LTE physical channels have been designed on the basis of uninterrupted and synchronous operation, while existing systems in the unlicensed bands operate in a decentralized, asynchronous manner employing protocols to promote fair usage of the spectrum. Therefore, a LBT (Listen-Before-Talk) function for clear channel assessment before accessing the channel is required, for the design is that LTE coexists with other technologies like Wi-Fi in a “fair” and “friendly” basis.

While different contributions in literature propose approaches to fairly share the spectrum, a key challenge to perform research on this topic is that despite the large body of simulation results in the literature, the simulators are not publicly available. The obtained results are not easily reproducible, and system performance metrics are presented without much detail revealed about the underlying models and assumptions. The coexistence performance is affected by different aspects and LAA parameters, and we have studied the impact of many of them.

VII. Overall conclusions and potential next steps

The radio spectrum is an essential for wireless communications, whereas the demands are always increasing. According to the spectrum sharing concepts, the usage efficiency of licensed spectrum could be improved by utilizing the idle bands with incumbent protection, while the Quality of Service (QoS) for mobile broadband communications could be progressed through offloading the network data traffic onto the shared spectrum bands.

Such the new types of sharing framework are novel spectrum coordination schemes beyond the current "licensed exclusive use" and "unlicensed open access". These new schemes provide effective interference preventing mechanism in spectrum sharing, to guarantee that the primary users (incumbents) could not be influenced by the transmission of the secondary users. Therefore, we can re-examine the use of wireless spectrum in Taiwan, and also seek out more feasible solutions for improving efficiency of spectrum use, and promote more applications for wireless spectrum. Our results show that current implementations of the spectrum sharing inference scheme may not be limited to the TV bands, but based on the international trends will figure out more favorable bands.

This project has provided a comprehensive review of important trends, regulatory reform initiatives, and research challenges that are part of the ongoing systematic efforts to bring about fundamental changes to how we manage and utilize radio spectrum. We propose a favorable framework, by observing and studying international experiences. In the meantime, the experiment platform for spectrum sharing has been established in parallel to execute the proof of concept and to ensure the feasibility. According to the experiment results, the corresponding regulations will be revised.

The current utilization of the spectrum is quite inefficient, consequently, if properly used, there is no shortage of the spectrum that is presently available. Therefore, it is anticipated that more flexible use of spectrum and spectrum sharing between radio systems will be key enablers to facilitate the successful implementation of future systems. However, it is a multidisciplinary challenge that requires a joint engagement of technical, economic and policy perspectives. Further research is needed to develop and advance our ability to quantify spectrum efficiency, harmful interference, spectrum value and fair access to the spectrum.