MS. Dissertation in Engineering

Application of a Channel Selection Algorithm for Unlicensed Spectrum

- Frequency Sharing of Wi-Fi/LTE-U -

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이 논문을 공학석사학위 논문으로 제출함

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Abstract

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A spectrum-sharing policy is yet to be established for unlicensed bands. There are several controversies related to providing 5-GHz (5G) band service with the coexistence of Wi-Fi and LTE–LAA (License Assisted Access). LTE–LAA is a technical and political scheme for sharing spectrum bands. Using this technique, the channel can be evaluated, and a proper channel can be selected before data transmission. This mechanism is called "listen before talk" (LBT), and the channel selection procedure is called "clear channel assessment" (CCA). LTE service providers suggest standardizing this technology using an unlicensed band. However, existing Wi-Fi users are skeptical about the sharing process. In this paper, we describe proper spectrum-sharing mechanisms based on policy-based channel selection algorithms. Based on the results, proper regulation of the 5G LTE-U is required to avoid conflicts among service providers. This work uses a policy-based mechanism to understand the role of the government in managing these bands. The main idea is that stricter sharing-policy regulations and higher thresholds must be implemented to protect the rights of existing users.

Key Words: 5G, LTE-U, LAA, Unlicensed band, Listen Before Talk, Clear Channel Assessment

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1. Introduction

1.1 Research Background

According to the Wi-Fi Alliance, internet users may face spectrum shortage between 2020 and 2025. In this regard, mobile operators and Wi-Fi operators need to develop spectrum-sharing strategies for today's connected society all over the world. (S. Methley, 2020)

Qualcomm Technology annually updates 5G spectrum usage information. As of 2020, over 45 operators, 40 OEMs, 340 operators have invested in 5G technologies. 5G is being designed for diverse spectrum types and bands. In addition, the FCC is driving key spectrum initiatives to enable 5G. (Qualcomm, 2020)

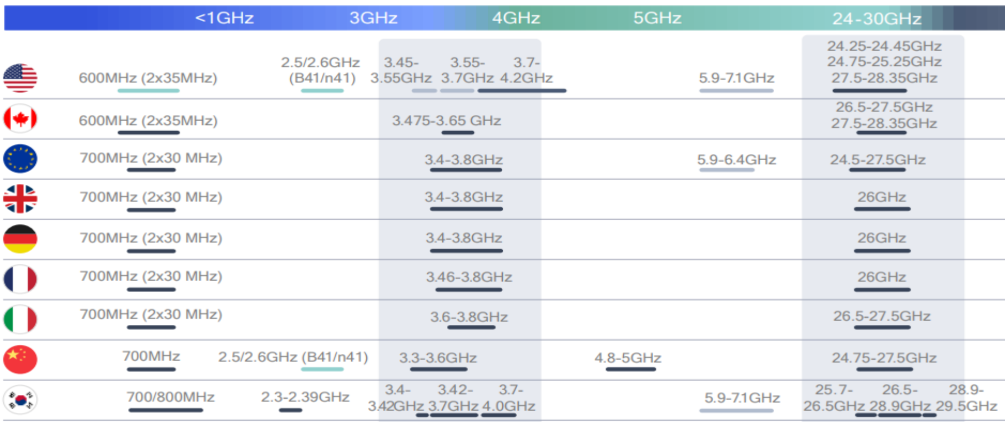


Figure 1. Global snapshot of the allocated 5G Spectrum

Recently, the use of unlicensed spectrum above 6 GHz has attracted the attention of the industry and regulation and standardization bodies. 3rd Generation Partnership Project (3GPP), in Release 16, has focused on a study item on New Radio (NR). South Korea's Ministry of Science and ICT issued a proposal for using 6 GHz Wi-Fi nation. (MSICT, 2020)

When an LTE system shares the same unlicensed band with a legacy Wi-Fi system, it is challenging to prevent the Wi-Fi system from severe performance degradation while maximizing LTE throughput. The carrier sense multiple access with collision avoidance (CSMA/CA) protocol employed by Wi-Fi systems requires that Wi-Fi access points (APs) and users need to listen before transmissions and access the channel only when it is idle (Tan, 2020)

This paper considers an LTE system to share the same unlicensed band with a Wi-Fi system in the absence of signaling exchange. The design objective was to maximize LTE network capacity and simultaneously protect the Wi-Fi system.

1.2 Problem Description

1.2.1 Controversies on Wi-Fi and LTE-U Coexistence

From the perspective of policymaking, regulators should understand each agent's situation and objectively enact unlicensed band law. The purpose of developing an industrial, scientific, and medical (ISM) band is to broaden opportunities for various users in terms of efficient slot allocation and enhance technologies through using this band. It is improper to give rights to few service providers, which monopolize band use. Thus, regulations should promote mutual operation of various service providers.

One of the primary differences is the MAC layer between Wi-Fi and LTE channel access work. In Wi-Fi, all station communicates through the access point. The biggest challenge of band sharing is unlicensed bands that are not interfering with existing Wi-Fi users and LTE service providers. Currently, most of the spectrum sharing mechanism is to limit the emission power, but sharing policies and regulations have not been settled down (Hwang, 2014). While LTE operators insist unlicensed spectrum for increased network capacity and higher data rates, some Wi-Fi service providers blame LTE service providers since they introduced the possibility of spectrum sharing of 5 GHz for an unlicensed band (3GPP). To solve this problem, this paper examines the technological feasibility and policy requirements of unlicensed 5G band applications. In my opinion, the technical standards should be stricter than what LTE–LAA service providers suggested.

However, LTE service providers need to find new spectrum bands to improve service quality. The ISM band is a low-cost band that is compelling to carriers as network traffic increases due to the increase in mobile connectivity, transitioning from licensed to unlicensed frequencies in 2020. Hotspot 2.0 features in enterprise Wi-Fi infrastructures to transition traffic between networks, yet the promise of unlicensed LTE has intrigued many to consider indoor small cells.

From the perspective of telecom service providers, opening for an unlicensed band is a threat to their business model. However, global trends, such as in Germany and Japan, unlicensed band is open to Wi-Fi and Bluetooth users. The efficiency of use of the 6-GHz 3GPP has been studied for 3GPP NR-U (New Radio-Unlicensed). (Electronical News, 2020)

1.3 Research Question

The purpose of this work was is to simulate the specific regulatory environment for channel selection algorithms. Each parameter was obtained from the current technical reports from the LTE-U forum. The main objective of this research was to develop a channel selection algorithm of environments where LTE–LAA and Wi-Fi coexist from the perspective of the LTE service provider because Clear Channel Assessment (CCA) has been developed by the LTE–LAA service provider, and they have strong viewpoints on enacting this technological standard. For the policymaker, it is important to keep neutrality and specify the regulation to minimize the interference.

1.3.1. Fairness and Efficiency of Sharing Policy

Spectrum-sharing policy should fulfill the needs of various users. Thus, the regulator's role is important to decide whether to open an unlicensed band. However, this study was originated from the purpose of opening unlicensed spectrum for the public. Unlike Wi-Fi users, mobile operators are already designated for their own spectrum.

The main political question is, why LTE-U users are required to share unlicensed spectrum.

1.3.2. Evaluation and Simulation of Sharing Technology

Many articles on spectrum sharing and Wi-Fi/LTE-U coexistence have been published. Some studies reported on the degradation of Wi-Fi quality, while Qualcomm insists that Wi-Fi performance is not affected. This paper applies LBT schemes to evaluate the random energy detection scenario to find out the proper level of noise so that regulators can enact unlicensed spectrum.

1.4 Contribution

1.4.1 This work contributes to the development of policy-based spectrum-sharing mechanism for Wi-Fi and LTE–LAA coexistence.

1.4.2 This research helps to develop a discussion of Wi-Fi and LTE–LAA use. If this paper finds proper mechanism or regulation, policymaker will consider for the result of this research.

1.4.3 While previous work mainly focuses on only one aspect, such as technological performance or policy development, this paper offers the combination of both perspectives to evaluate the feasibility of spectrum-sharing techniques.

1.4.4 To protect the existing users and minimize interference, this work proposes stricter regulations on unlicensed band.

2. Literature Review

2.1 Spectrum-Sharing Policy

Global regulators should incentivize band sharing. Regulators must decide which bands are suitable for sharing and select the right sharing framework to ensure innovative and affordable mobile services. Firstly, the proposed band should provide a sufficient spectrum in areas where mobile operators see a growing demand. Secondly, the sharing framework should be understandable, usable, and tailored to the needs of the users. (GSMA, 2019)

Light licensing policy or flexible licensing has been recently suggested for the 5GHz band of 5G LTE-U. In reality, the total regulation-free spectrum has limitations and is difficult to be implemented. A smoother regulation act that reduces the regulation step is essential for the players of the spectrum market. For regulators, strict regulation might be easier to manage the spectrum, while it might cause LTE service providers to lose their competitiveness.

Table 1. Traditional unlicensed band-sharing policy (Hwang, 2014)

	Licensed sharing	**Unlicensed sharing**
Technological efficiency	Unused space exists	Maximum use of space

Allocation efficiency	Based on the market mechanism, the most demanding user is allocated	No protection for individual users
Investment	Guaranteed and clear demand triggers investment	Not many triggers for investment
International telecommunication policy	Easy to grasp spectrum usage status; thus, easy to control rights	Difficult to grasp usage status; thus, difficult to grasp rights
Spectrum sharing cost	No additional management cost is needed	Minimum technological requirements

The first version of unlicensed LTE is called LTE-U developed by the LTE-U forum to work with the existing 3GPP Releases 10/11/12. LTE-U was designed for quick launch in countries, such as the United States and China, which do not mandate implementing the listen before talk (LBT) technique. LTE-U would allow cellphone carriers to boost coverage in their cellular networks by using unlicensed 5-GHz band already supported by Wi-Fi devices. (Qualcomm, 2016)

Therefore, a critical requirement for the design of unlicensed LTE is that it must coexist with other technologies, like Wi-Fi. In some markets, like Europe and Japan, an LBT feature for CCA before accessing the 5-GHz unlicensed channel is required, while in others, such as the USA, China, India, and Korea, there is no such requirement.

For markets that do not require LBT, the industrial consortium LTE Unlicensed (LTE-U) Forum specified a proprietary solution for unlicensed LTE based on Release 12, which is referred to as LTE-U.

LTE-U is intended to let cell networks boost data speeds over short distances without requiring the user to use a separate Wi-Fi network as they normally would. It differs from Wi-Fi calling in the sense that there remains a control channel using LTE, but all data (not just phone calls) flows over the unlicensed 5-GHz band, instead of the carrier's frequencies.

In 2014, the LTE-U forum was created by Verizon in conjunction with Alcatel-Lucent, Ericsson, Qualcomm, and Samsung as members. The forum collaborates and creates technical specifications for base stations and consumer devices passing LTE-U on the unlicensed 5-GHz band, as well as coexistence specs to handle traffic contention with existing Wi-Fi devices. T-Mobile and Verizon Wireless have indicated early interest in deploying such a system as soon as 2016. While cell providers ordinarily rely on the radio spectrum, LTE-U would share space with Wi-Fi equipment already inhabiting that band, such as smartphones, laptops, and tablets connecting to home broadband networks and free hotspots provided by businesses.

2.1.2 Case of South Korea

South Korea could become the first country in Asia to release the 6-GHz band to Wi-

Fi. South Korea's Ministry of Science and ICT issued a proposed "amendment of technical standards," which could lead to Korean 6-GHz Wi-Fi adoption in 2020. This means that South Korea is now leading the race on the adoption of 6-GHz Wi-Fi. (Claus, 2020)

Table 2. Korean spectrum allocation plan for public use (MSICT, 2020)

Purpose of Use	**Agency**	**Frequency Band**	**Allocation Plan**
Reserve for Nation Disaster	Fire Administration Police Administration	5 GHz	82 MHz
Prevention of Marine Vessel Accidents	Ministry of Maritime Affairs and Fisheries	4 MHz 9 GHz	104 MHz
GPS/Satellite Communication	Korea Aerospace Research Institute	1, 2, 6, 9 GHz	319 MHz

6 GHz (5925–7125 MHz, 1.2 GHz) will be provided to the unlicensed band. 3GPP 410–7125 MHz unlicensed bands for Wi-Fi and cellular networks play equally critical roles, with Wi-Fi being the preferred connection, and at other times, cellular. Until now, the FCC has allocated comparable amounts of spectrum for each, but with the current Notice of Proposed Rulemaking (NPRM) for 6 GHz, the FCC is contemplating a huge additional 1.2-GHz allocation for unlicensed spectrum only. MSICT has completed 5G spectrum auction in June 2018 for both sub-7mmWave, including 3.42–3.7 GHz and 26.5–28.9 GHz. The

world’s first commercial 5G smartphone for sub-7 was launched in April 2019. South Korea has achieved over 3 million 5G subscribers as of September 2019.

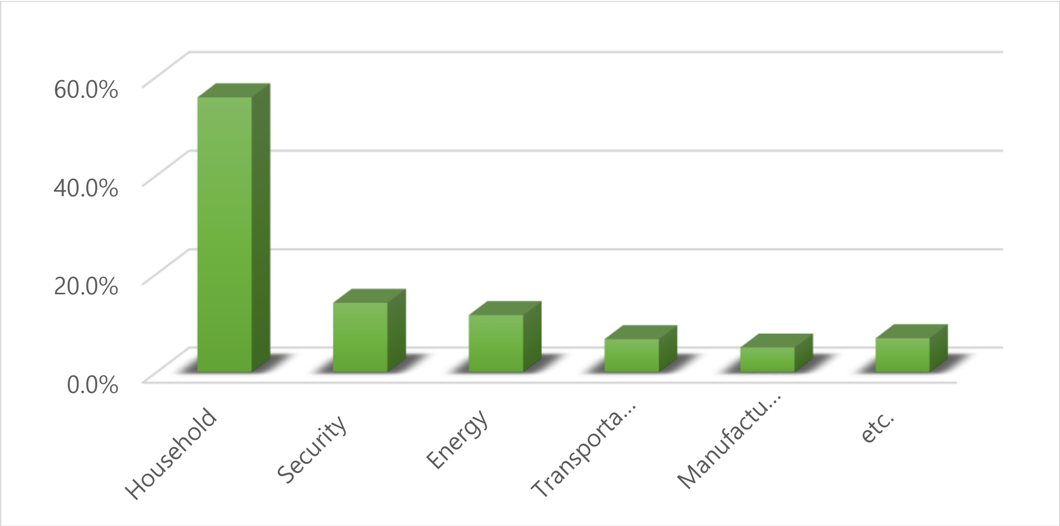


Figure 2. Types of unlicensed band service users in South Korea (RAPA, 2020)

Figure 2. Illustrates the status of unlicensed band users. Household use constitutes 55.8% of the total unlicensed band use.

2.2 Spectrum-Sharing Technologies

1) Underlay: Underlay technologies are used for other licensed or license-exempt spectrum use but at extremely low power levels. This allows the underlay use to share or collectively use the spectrum. Underlay use is not licensed. Ultra-Wide Band is an example of an underlay technology (Haykein, 2005).

2) Overlay: An overlay approach permits higher powers that could cause interference to existing users but overcomes this risk by only permitting transmissions at times or

locations where the spectrum is not currently in use. This can be achieved either using technology (e.g., cognitive radio) or by regulatory means (e.g., only permitting use in certain regions). In this work, we are concerned with overlay use that is not licensed (Haykein, 2005).

2.2.1 Licensed Assisted Access (LAA)

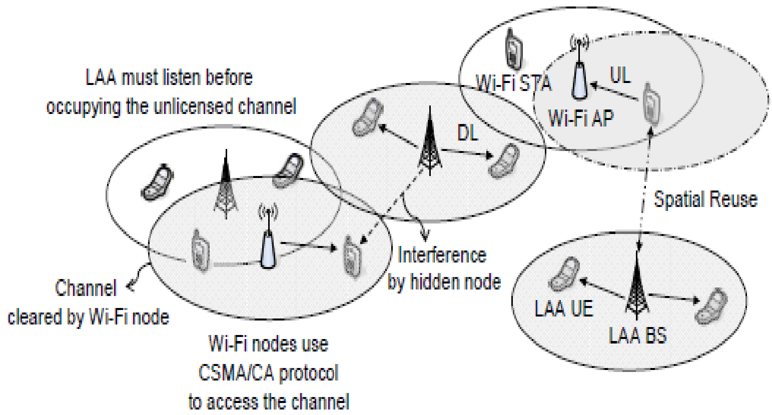


Figure 3. License Assisted Access (LAA) System Architecture (Ahmed, 2016)

Recently, the Third Generation Partnership Project (3GPP) has initiated standardization for LTE services in unlicensed band ex) aggregation of LTE on licensed and unlicensed spectrum known as "License-Assisted Access using LTE" (Chung K. Kim). The key mechanism of LAA is the carrier aggregation (CA) in which the unlicensed carriers are operated for a collocated secondary cell to opportunistically boost data rate while using the licensed LTE carrier for a primary cell to deliver critical information and guaranteed Quality of Service (QoS).

The secondary cell on unlicensed spectrum can be used for supplemental downlink capacity only, or it can be used for both supplemental downlink and uplink capacity. As there are regional regulations for coexistence of these heterogeneous systems, the coexistence with other systems has been mainly studied in LAA standardization. Meaningful coexistence is enabled by the LBT mechanism, which allows two different systems, Wi-Fi and LAA systems, to share the unlicensed band with contention-oriented access while maintaining the performance of the individual system.

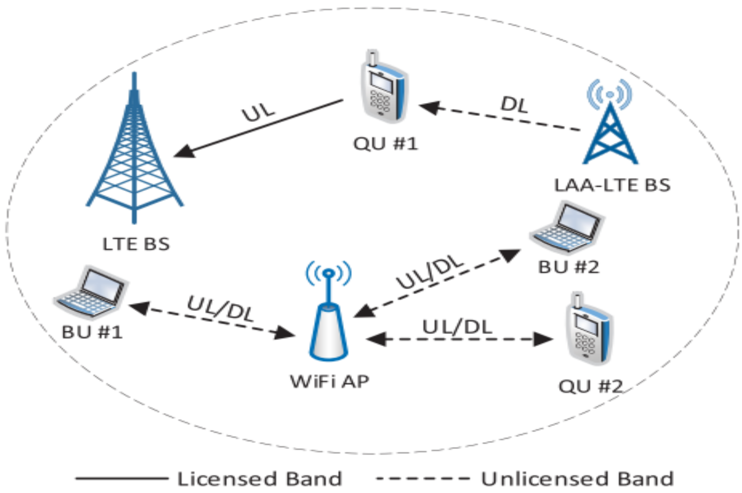


Figure 3. LAA–LTE/Wi-Fi coexistence system (Tan, 2019)

Figure 5 shows the model of the LAA–LTE/Wi-Fi coexistence system considered in this paper. The LTE base station operates on a licensed band, while the Wi-Fi AP and LAA–LTE base stations share the same unlicensed band. This paper consider the supplemental downlink (SDL) deployment of LAA–LTE where the LAA–LTE base station only utilizes the unlicensed band for downlink (DL) operation, while the control and uplink (UL) signals are transmitted by the LTE base stations (BS) via licensed bands. Thus, the LAA–LTE and LTE BS are connected via optical fiber networks. The design objective for the coexistence system is to maximize the number of primary users accessing the LAA–LTE network and maintain an acceptable level of QoS for Wi-Fi services.

2.2.2 Listen Before Talk (LBT)

The LBT procedure is based on the ED method to determine whether the channel is free to use. The ED method is a CCA. The mechanism attempts to determine if the medium is busy by measuring the total energy a device receives. If the received energy is above a certain *ED threshold*, the medium is considered busy. (Bilijana,2019) Because of this, the ED threshold is one of the most critical parameters to be set for fair coexistence. The maximum configurable ED threshold is denied by the regulations for each region. According to 3GPP agreements, the established ED threshold for LAA should be −72 dBm for 20 MHz channel. The ED threshold should be adaptive based on the mechanism in use. (3GPP, 2018)

LBT is a procedure that uses CCA. It determines the energy level on a channel before attempting to transmit it through a time-sharing mechanism (Ananth, 2016).

2.2.2.1 Qualcomm Evaluation

Qualcomm suggested a channel selection algorithm in 2014. Qualcomm reports showed that significant throughput gain can be achieved by aggregating LTE across licensed and unlicensed spectrum bands. Such gains do not come at the expense of degraded Wi-Fi performance. Both technologies can fairly share the unlicensed spectrum. (Qualcomm, 2014)

<Channel Selection Process>

Choose the cleanest channel in general → If possible, avoid primary channels of Wi-Fi → If possible, avoid channels occupied by other LTE-U operators, and choose channel occupied by the same LTE-U operator.

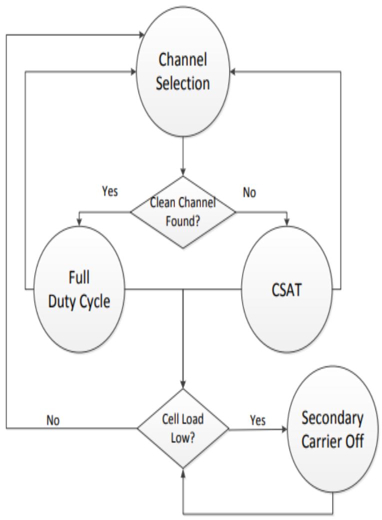


Figure 6. Qualcomm Channel Selection Algorithm (Qualcomm, 2014)

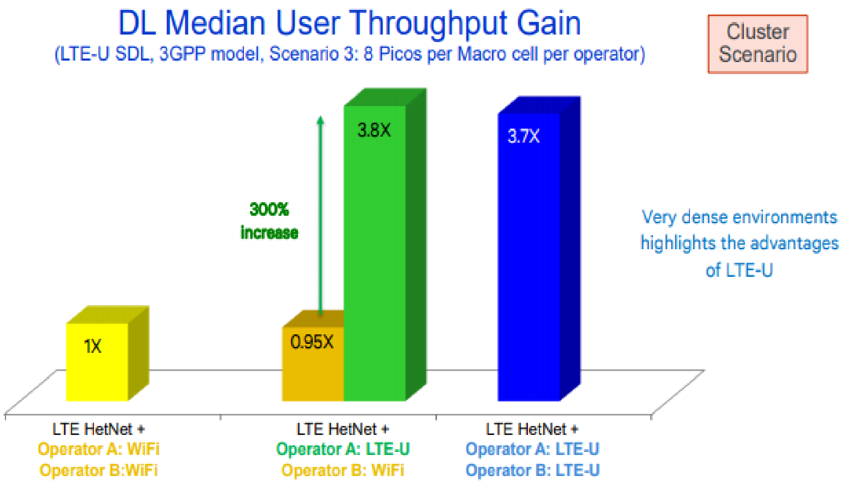


Figure 3-4 Downlink median user throughput gain for 8 clustered Picocells per macro per operator scenario

Figure 7. Performance Result by Qualcomm

2.2.2.2 3GPP Evaluation

Multiple sources identified that the Wi-Fi performance can be significantly degraded when it coexists with LAA. These observations were the main motivation behind the adoption of the LBT algorithm based on the exponential back-off in Wi-Fi. The simulation results that have been agreed upon are summarized here. (Kwon, 2016)

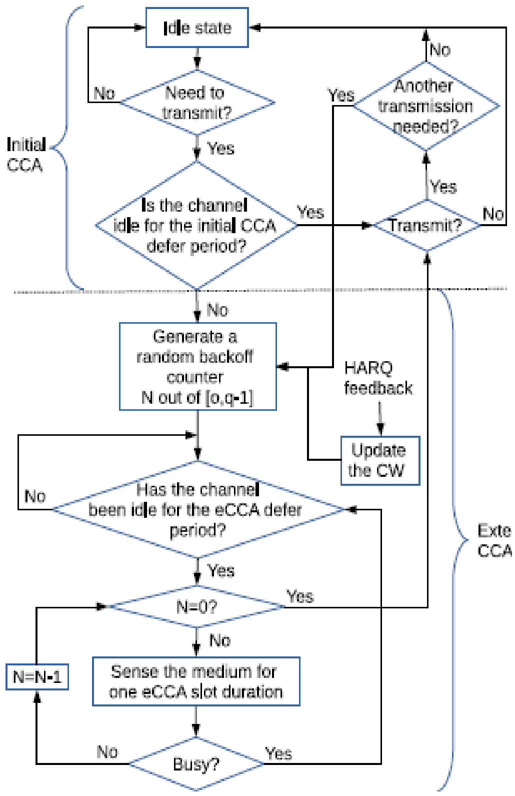


Figure 8. 3GPP channel selection algorithm

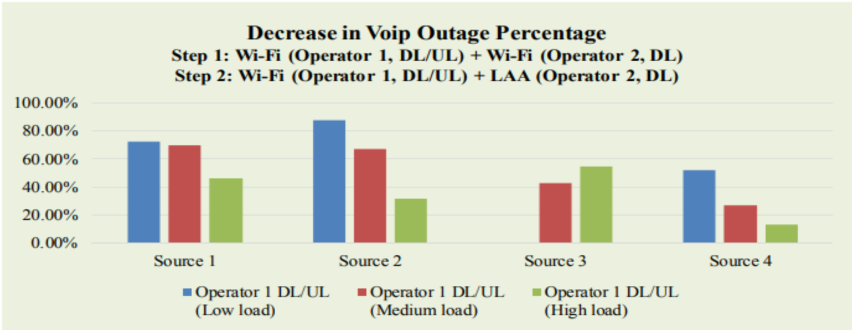


Fig.5. Decrease in VoIP outage for the DL/UL Wi-Fi network (Sources 1-4 are from 3GPP contributions R1-152326, R1-152642, R1-152937, and R1-153343, respectively.)

Figure 9. 3GPP evaluation results

During the discussion in 3GPP, it was identified that ensuring coexistence for indoor scenarios is more difficult than that for outdoor scenarios due to the proximity between LAA eNBs and Wi-Fi access points (APs)/stations (STAs).

2.3 Comparison with Previous Work

Based on the previous work, I added the concept of license-type evaluation and different thresholds compared to the original CCA work. Most of the previous papers detailed the technical aspects of the frequency sharing scheme. This paper insists that approaching the spectrum reuse problem is necessary for government intervention and regulation of unlicensed band. It is a low-cost band, so many users will attempt to utilize this band. Therefore, regulations should be enacted to prohibit the selfish behavior of corporate service providers. Nonetheless, the purpose of the unlicensed band is to provide efficient use and better opportunities for small- and medium-sized companies, thereby protecting existing users. Many users can utilize slots in a friendly manner, and they can share basic user information.

Table 3. Comparison with previous work

Researcher	**Qualcomm (2014)**	**3GPP (2018)**	**Boyoon Choi (2020)**	**Boyoon Choi (2020)**
How to evaluate the channel	Choose the cleanest channel in general	Choose the lowest energy channel	Choose the unlicensed type of channel	Choose the unlicensed type of channel
Primary condition for choosing the channel	If possible, avoid primary channel	If possible, avoid primary channel	Avoid licensed band	Avoid licensed band
Different traits of license type			Licensed slots require longer guard interval	Licensed slots require higher threshold

Ensuring coexistence for indoor scenarios is more difficult than that for outdoor scenarios due to the proximity between LAA eNBs and Wi-Fi access points (APs)/stations (STAs). It is also apparent that restricting LAA eNB to transmit data only in the unlicensed carrier is more challenging to prove fair coexistence because the licensed carrier given to LAA eNB is an additional resource that can be exploited to alleviate the transmission demand on unlicensed spectrum in Step 2, resulting in a more friendly environment for fair coexistence.

The results captured in this section from [1] are thus focused on the most demanding scenarios in proving the fair coexistence. The IEEE 802.11ac technology is assumed for Wi-Fi networks.

The user-perceived throughput (UPT) considered by 3GPP is as an important performance measure for network serving an unfilled buffer traffic. The UPT is defined as the amount of data over the actual time spent for downloading, excluding the idle time for waiting files to arrive. Figure 4 shows the improvement in the UPT for the non-replaced DL only Wi-Fi network in Step 2 compared to Step 1 with different loading conditions. Buffer occupant time of 15%–30%, 35%–50%, and 60%–80% averaged over APs of the nonFig.5. Decrease in VoIP outage for the DL/UL Wi-Fi network (Sources 1–4 are from 3GPP contributions R1-152326, R1-152642, R1-152937, and R1-153343, respectively.) 0.00% 20.00% 40.00% 60.00% 80.00% 100.00% Source 1 Source 2 Source 3 Source 4 Decrease in VoIP Outage Percentage Step 1: Wi-Fi (Operator 1, DL/UL) + Wi-Fi (Operator 2, DL) Step 2: Wi-Fi (Operator 1, DL/UL) + LAA (Operator 2, DL) Operator 1 DL/UL (Low load) Operator 1 DL/UL (Medium load) Operator 1 DL/UL (High load) Fig. 4. Improvement in the UPT for the DL only Wi-Fi network (Sources 1–7 are from 3GPP contributions R1-150694, R1-152732, R1-151821, R1-152863, R1-153384, R1-153426, and R1-153629, respectively.) 0.00% 20.00% 40.00% 60.00% 80.00% 100.00% 120.00% 140.00% Source 1 Source 2 Source 3 Source 4 Source 5 Source 6 Source 7 Improvement in UPT Performance when Wi-Fi coexists with LAA Step 1: Wi-Fi (Operator 1, DL) + Wi-Fi (Operator 2, DL) Step 2:

Wi-Fi (Operator 1, DL) + LAA (Operator 2, DL) Operator 1 DL (Low load) Operator 1 DL (Medium load) Operator 1 DL (High load) A revised manuscript to IEEE Communications Magazine on LTE Evolution on Apr. 25, 2016 (initially submitted on Nov. 30, 2015) 10 replaced Wi-Fi network in Step 1 is considered as low, medium, and high load, respectively. From Fig. 4, it can be observed that the Wi-Fi UPT performance is improved when the Wi-Fi network coexists with an LAA network rather than another Wi-Fi network. This is mainly because LTE has a higher spectral efficiency than Wi-Fi due to the better link adaptation based on explicit CSI feedback, while the control messages such as CSI feedback can go through the licensed carrier. Consequently, the interference from Operator 2 to Operator 1 is reduced in Step 2, thereby improving the Wi-Fi performance in Step 2. Fig. 5 shows the coexistence performance when Operator 1's Wi-Fi network serves bidirectional (i.e., both DL and UL mixed FTP and VoIP traffic). From the figure, it is shown that VoIP outage for non-replaced Wi-Fi networks can be reduced significantly when it coexists with the LAA network. Therefore, 3GPP LAA design can indeed ensure the coexistence with incumbent Wi-Fi networks for both non-real-time and real-time traffic.

3. Modeling

The purpose of developing this model was to simulate the LAA usage time depending on the different channel selection algorithm (license type evaluation and energy detection evaluation). The cellular network is operated in an unlicensed spectrum assuming there are Wi-Fi (802.11 ac) users along with LTE (5G LTE–LAA) users. LAA BSs and Wi-Fi access points (APs) coexist for sharing the same unlicensed band. We assumed that LTE service providers have their own licensed band but in case a sudden high data demand is requested, LTE–LAA users will assess the channel and transmit the data to the best possible channel (in the case of many LAA slots). In this scenario, the cognitive radio multi-hop network has been used for the wireless network adopting multi-hop wireless technology without the deployment of wired backhaul links. Each of Wi-Fi nodes, AP, or station, selects one of the multiple 20-MHz channels in the 5-GHz ISM band, which will be shared with the downlink of LAA BSs.

More specifically, we consider only the downlink traffic version of the LTE–LAA system in the current design, while its uplink traffic can be also shared over one of the other channels. 3GPP simulation design using the LBT model and parameter was used. This paper adopted the case of two operators with nodes deployed in the same room inside of a building. Both operators share the unlicensed carrier. One operator is fixed as a Wi-Fi operator, whereas the second operator is LTE- LAA.

There are two ways of selecting the channel: one is fixed frame-based, and the other is load-based. In this model, each methodology is adopted for an enhanced LBT scheme, which applies a flexible licensing scheme to protect the existing user.

Before a transmission or a burst of transmissions on an operating channel, the equipment shall perform a CCA check. If the equipment finds the channel clear, it may transmit immediately and occupy the channel for the channel occupancy time. For the FBE based total maximum fixed time 10 ms. During CCA check, if the 20-μs band is empty, then just transmit the data. For my model, the head channel contains various information, such as license type, occupancy type, and CCA threshold information and decides which channel will be the best choice for LTE. Maximum time usage is the same as 10 ms but finds the best available channel based on the license type.

The purpose of developing this model was to compare the performance and efficiency levels depending on license policy. Some countries regulate their transmission power for unlicensed band. If the measured energy level exceeds the fixed threshold, the corresponding channel is declared as occupied by other nodes; otherwise, the channel is idle.

3.1 General Assumption

Primary and secondary users are distinguished based on their requirement for the QoS. When the service quality is guaranteed, the user is regarded as the primary user and if not, it is considered as the secondary user. Based on Qualcomm white paper, they suggested friendly cooperation over the use of Wi-Fi, and not making interference on both primary and secondary users. However, many Wi-Fi service providers are skeptical about their technologies. We assumed that the Wi-Fi user is a primary user to find out how Wi-Fi users can be offered guaranteed service.

We assumed that LTE users will utilize this spectrum band for various purposes, such as IoT (Internet of Things) service or Wi-Fi hotspot. Due to the faster speed (1.6X) and safer privacy, there will higher demand from the future generation. This model is designed to retain the QoS of Wi-Fi and enhance the LTE-U speed for efficient use of the scared spectrum.

3.2 Flow Chart

3.2.1 License Type Evaluation (Guard Interval Evaluation)

Guard interval evaluation was adopted from the FBE process. Evaluating the head channel will give information on the license type and occupancy rate. According to the license type, LTE–LAA users will assess the availability of the time slot of the channel. LTE–LAA users can choose the best option for the channel based on this evaluation methodology. This mechanism offers stricter regulation than the LBT-FBE mechanism since it adds the concept of license type. The reason for developing this model is to protect the existing users. Depending on the license type, LTE–LAA will evaluate the channel. This methodology does not consider the energy level and is based on regulation control. Here the usage information should be available to secondary users to intrude the unlicensed band. If this database information is available to all users, this might be the best case for managing the channel efficiently. However, knowing all usage information from all users is almost impossible. This methodology will highly depend on the “Guard interval amount” and “occupancy rate.”

▶ Channel Evaluation Procedure

1) If the 20-μs empty slots are found → transmit data
2) If not, perform license type check
3) Check for the license type of previous and next channel
4) If there is an occupied licensed slot → Non-Pass
5) If there is an empty licensed slot → Pass
6) If there is an empty or occupied unlicensed slot →Pass
7) Compare and select the best channel based on the LAA-available slot

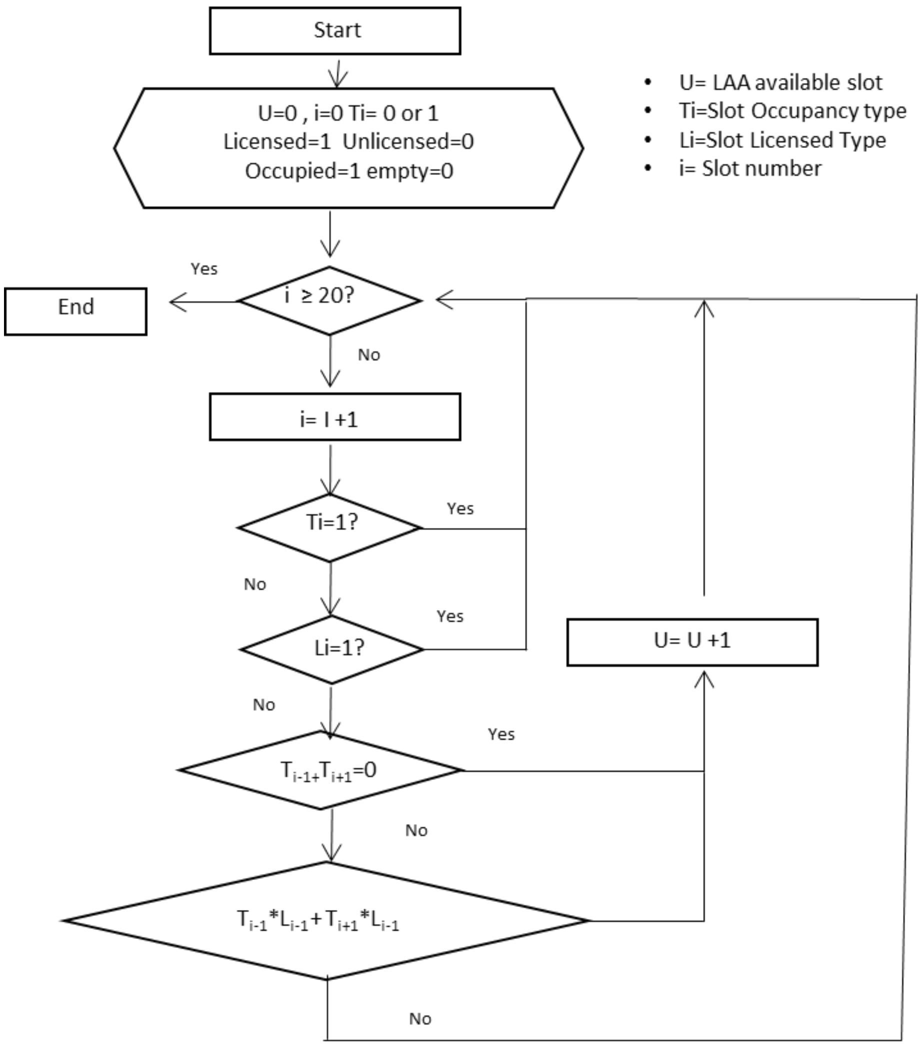


Figure 9. Flow chart of the guard interval evaluation algorithm

3.2.2 Energy Detection Evaluation

Energy detection is the most popular method of signal detection that can be deployed in all wireless networks requiring knowledge of the type of underlying modulation scheme employed at the physical layer. The main advantage of energy detection is its simplicity. Equally important is the fact that it does not need to keep running constantly and can be turned on when the MAC layer requests the PHY layer for CCA, thus allowing device sleep, which is convenient for power-constrained devices. The drawback is that since ED does not take advantage of the processing gain inherent in signals, it suffers from a poor signal-to-noise ratio, leading to unreliable channel state detections. It defines the ability of Wi-Fi to be detected non-Wi-Fi (in this case, LTE) energy in the operating channel and back off the data transmission. If the in-band signal energy crosses a certain threshold, the channel is detected as busy (no LTE transmission) until the channel energy is below the threshold. (Yuan Li,2015) From the regulator's perspective, this is a technology-driven energy detection mechanism. Thus, we adopted different threshold levels to licensed users. This will protect better performance for primary users. On the other hand, it is important to balance between protecting primary users and allocating efficient time slots to users. Originally LBE processing has a channel back-off mechanism, but in this procedure, we excluded it since we wanted to focus more on the regulation perspective rather than the technological aspects. −62 dBm is designated ED-CCA threshold from the European Standard, and for unlicensed giving, higher threshold is the main concept for the mechanism.

▶ Channel Evaluation Procedure

1) If the 20-µs empty slots are founded → transmit data
2) If not find an empty slot
3) Perform CCA check
4) Check for the previous and next channel for license type
5) If there is a licensed occupied slot → Threshold = −52 dBm
6) If there is a licensed unoccupied slot →Threshold = −62 dBm
7) If there is either empty or occupied unlicensed slot → Threshold = −62 dbm
8) Compare and select the best channel based on the LAA-available slot

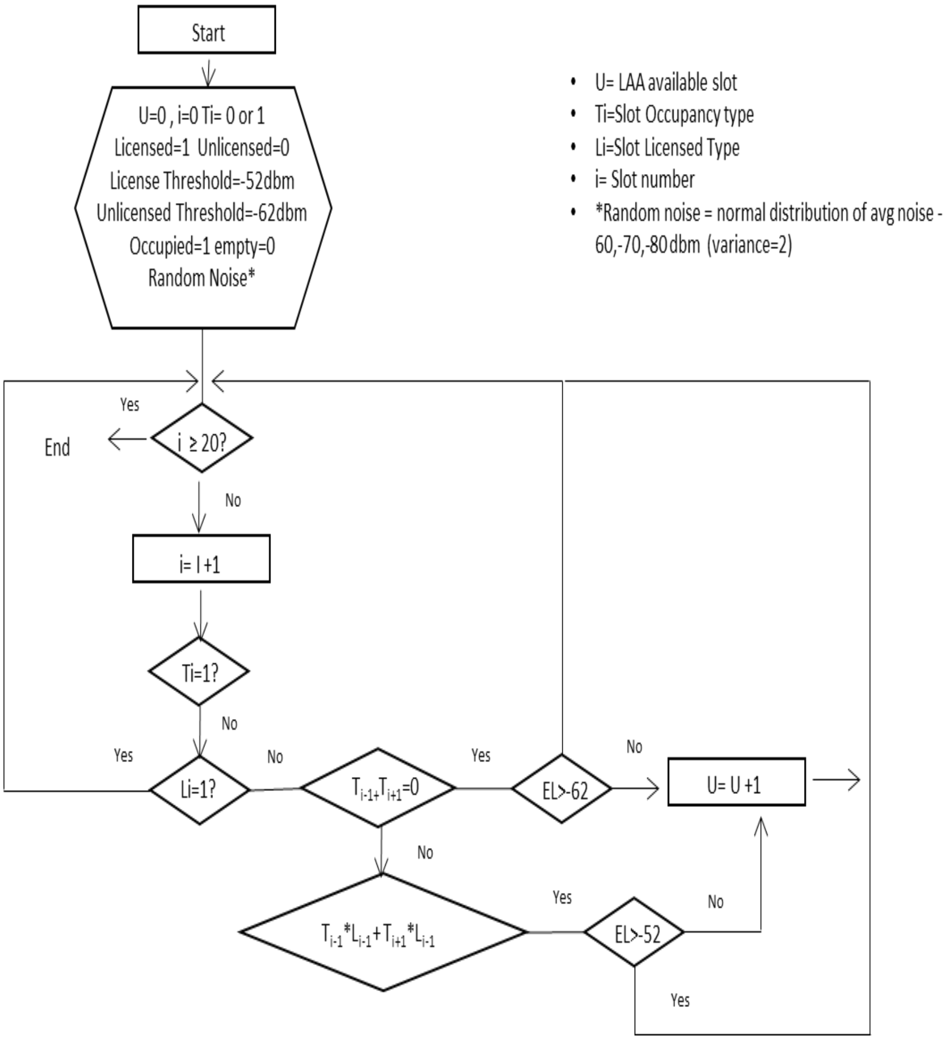


Figure 10. Flow chart of the energy detection algorithm

4. Simulation

4.1 Parameter setting

The technical standardization and specific regulation 5G unlicensed band have not been settled down yet, and few technical reports have been performed to establish the parameters. Thus, we attempted to reflect standardized parameters for spectrum sharing. There are previous technical reports on the feasibility of technical standardization. Here we focus on the policymaker's perspective for coming up with necessary regulations. This paper considers various situations to make the radio regulation law for the future 5G unlicensed band.

Wi-Fi users have been already allocated for the given time slots. We consider three cases: users allocated 20% (Low Occupancy Rate), 50% (Medium Occupancy Rate), and 80% (High Occupancy Rate). LTE–LAA users will check for the available slots to evaluate the channel. They will check for a total of 100μs. The energy level was generated randomly using a MATLAB function simulating each energy level scenario. We investigated different license portions and evaluation schemes to select the channel. CCA-ED threshold level is designated from the technical parameter. By using this threshold, we see how this will operate when LTE–LAA will select the channel for different licensed slot portions.

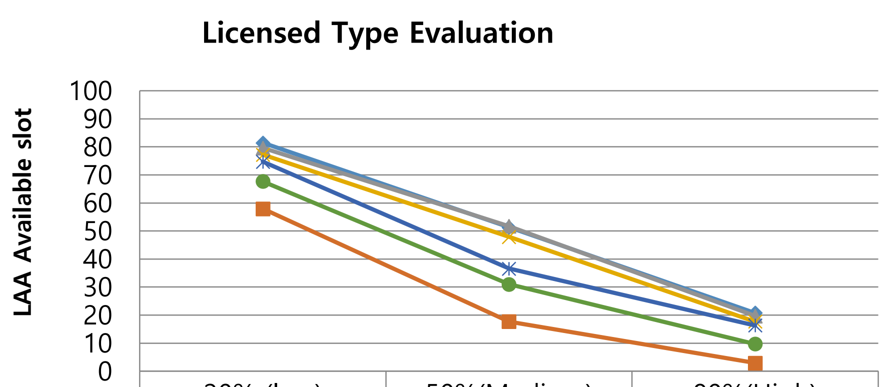
Table 4 . Simulation parameter

Parameters	LAA (SU)	Wi-Fi (PU)	Wi-Fi___33(SU)
	-	802.11 ac	802. 11ac
Frequency Band	5GHz band for unlicensed band		
Total Slot Checking	100 μs		
Bandwidth	20 MHz	20 MHz	20 MHz
CCA-ED Threshold	Not Considered	−52 dBm	−62 dBm
Average Energy Level	Not Considered		−60 /−70/−80/−90/−110 dBm (Random Normal distribution variance = 2
Channel Occupancy Rate	Not considered		20% (low) 50% (Medium) 80% (High)
Licensed type	Unlicensed	Licensed	Unlicensed

To see different environmental situations, the average energy level has been differentiated. An energy level higher than −60dBm indicates a presumably high level of energy. If the energy level is higher than the threshold, the slot is not available to the LTE–LAA users. LTE–LAA users can only be unlicensed or secondary users. This is because they use this band for supplementary purposes. Usually, LTE–LAA users with high data demand are allocated for the slot acquired by auction.

4.2 Simulation Result

4.2.1 Licensed Type Evaluation (Guard Interval Evaluation)



	20% (low)	50%(Medium)	80%(High)
Unlicensed	81.4	51.3	20.8
10% Licensed	79.6	51.7	19.7
30% Licensed	77.2	47.9	17.7
50% Licensed	74.7	36.6	16.3
70% Licensed	67.7	31	9.7
90% Licensed	57.9	17.7	2.9

Figure 10. License type evaluation simulation overall results

In this scenario, the guard interval is fixed to 1 μs when evaluating the channel. This means when evaluating 100-μs channel to check for available slots, if there is a licensed user and occupied, then the adjacent to 1-μs slot is considered not available. However, the regulators can adjust the guard interval amount when this methodology is implemented. It is obvious that when the occupancy rate is low, it has higher chances to find the available slots. In the case of the whole band licensed to Wi-Fi users, LAA-available slots are still more than half (57.9%) of the slots when the channel occupancy rate is low (20%). This means that regulators can be flexible to give license to many users when the channel occupancy rate is low. However, when the channel is half-occupied, the LAA-available slots sharply decrease. When the channel occupancy rate increases by 150%, then the LAA-available slots will decrease by 69.74%. When the channel is half-occupied, 30% of the license slot will give 47.9% of the licensed slot. The last case (High Occupancy Rate) most likely happens at which 5 GHz is expected to be used by many users. The original purpose of the ISM band is to make it available to many users to give a flexible license policy. Since the band is available to more users, regulators will be convinced to utilize the band. If the band is already occupied for many unlicensed users, further providing license is unlikely. Depending on the LTE–LAA required available slots, the regulators will find the best portion of licensed slots for each occupancy rate.

4.2.2 Energy Detection Evaluation

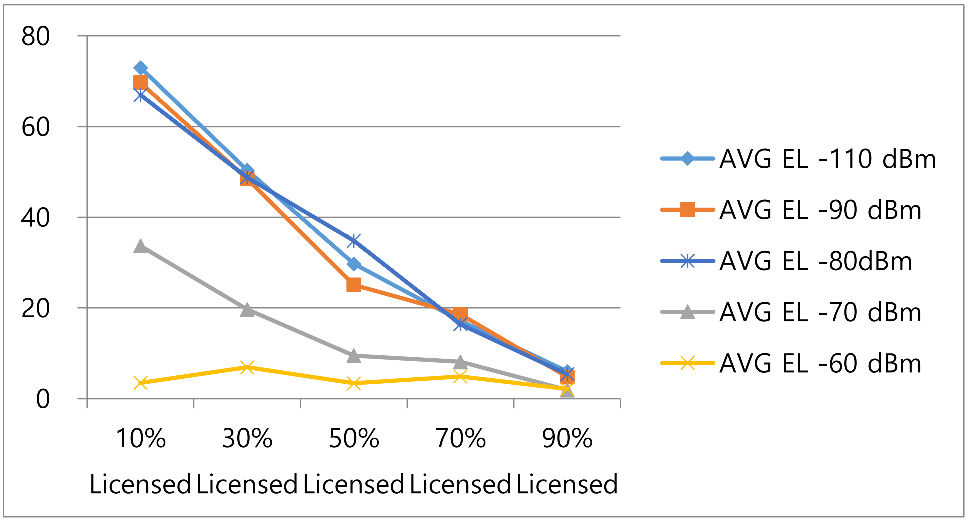


Figure 11. Energy detection evaluation simulation results

Results from the energy detection evaluation methodology show significant sensitivity to the given average energy level environments. According to the LTE-U forum technical reports, the channel selection algorithm for energy detection is fixed to −62 dBm. The low-energy level, which might be the case for the indoor environment, is not sensitive to energy level regulation. The variable of “LAA-available slot” is inelastic to the ED-CCA threshold. However, the average energy level near or higher than −70dBm is elastic to the change in energy level threshold. According to this viewpoint, policymakers should enact different regulations for indoor and outdoor environments. When LTE service providers develop equipment operating in low-energy level, it is more likely to have LAA-available slots and diverse options to select the channel.

Energy detection evaluation methodology has a lower chance to find the LAA-available slots, and it decreased sharply as the licensed portion increased compared to the license type evaluation. If this methodology is applied, LTE–LAA might have to develop equipment at low power.

License type evaluation might be considered as policy-based regulation, and energy detection evaluation is more likely a technological scheme to share the slot. Licensed-type evaluation is a simple concept, and the result showed an occupancy rate higher than the energy detection evaluation. Energy detection evaluation is a stricter concept of assessing available slots. When the random noise level is below −70 dBm, the LAA-available slot is highly dependent on the regulation and occupancy type. However, as the noise level goes up to −60 dBm, its evaluation is independent of the occupancy rate and portion of licensed slots. It shows that depending on the noise level, the available LAA slots dramatically decrease. Especially, the noise level from −80 to −70 dBm is drastically reduced.

When every slot is unlicensed or licensed, the occupancy rate is inelastic to the LAA-available slots. In the case of many slots already allocated to users, the energy detection level will show LAA-available slots and provide more efficient use of the spectrum.

Table 5. Comparison of license type evaluation and energy detection evaluation

License Type Evaluation	Energy Detection Evaluation
If Licensed? Giving guard Interval	If Licensed? Giving high CCA ED-Threshold

(Time difference)	
Needs Database Usage to get information	Needs real-time Sensing to get information
Low cost	High cost
Interference depends on the Guard intervals ✓ higher guard interval will result in stricter regulation	Low Interference (Stricter regulation than the CCA)
Policy-Based Regulation	Policy-Based Regulation + Technical Scheme

When comparing both algorithms, they are different from the guarantee of guard interval time or the limits on the neighboring channel slot's energy level depending on their license type. License type evaluation should share usage information with unlicensed band users. It does not require special sensing technologies, but a negotiation between users will be necessary to share the band. However, this might be an inefficient way of using spectrum, because even when the time slot is empty, LTE–LAA cannot transmit their data to obey the regulation. Detection of energy level requires stricter regulation and might reduce interference, but this needs high-cost technology which might have to sense real-time to find out usage information and check each time slot's energy level. It costs building huge infrastructure and consumes lots of energy. When adopting this channel selection mechanism, based on each country's situation, proper mechanism should be selected after performing further studies and investigations.

5. Conclusion

5.1 Overall Implication

While spectrum sharing holds potential, it cannot outperform exclusively licensed mobile spectrum. The global success of mobile services has been built on a foundation of the exclusively licensed spectrum as it supports widespread services and certainty needed for long-term heavy network investment and high-quality service. However, sharing can play a complementary role in traditional spectrum licensing by allowing mobile services to access new bands where there are no other reasonable alternatives.

Unlicensed band for the sharing policy and radio regulation should be enacted, and their neutrality must be sustained based on the environment. If the LBT scheme could smoothly operate, the scarcity problem of frequency band might be the key solution. This paper simulates the operation of an unlicensed band to help develop proper regulations. Policymakers should consider which algorithm will improve the efficient use of spectrum and higher performance. Furthermore, they also need to consider which party will take advantage of enacting this regulation. This scheme could provide easier access to the spectrum and allow many small- and medium-sized companies to use the unlicensed band, thereby contributing to the society in the long-term.

Regulators can enable sharing by giving incumbent users the right to share their spectrum voluntarily through commercial agreements or by awarding rights to use the spectrum in areas and/or at times when the incumbent is not using it. However, where sharing is not voluntary, secondary usage rights should be set out for small- and medium-sized companies against the primary spectrum license. This way, incumbent license holders are aware that sharing is possible and under what conditions. So, they can acquire a license, which can be factored into their business plan. Spectrum sharing will also impose opportunity costs on incumbents, so remuneration would be provided.

Mobile operators should also be permitted to voluntarily establish commercial agreements to lease spectrum to other types of operators in areas where it is not currently in use.

5.2 Limitation

This is a simulation-based model, which contains various assumptions, so it cannot predict future events. It might differ from the real applications. Given that technical and noise environments might vary depending on different situations, I adopted an average energy level to predict the limitations of the unlicensed 5G band.

5.3 Further study

This work did not address the economic cost or assess each party's benefits and disadvantages. In addition, overall social welfare was not considered in this research paper. For further study, I will include how each agent of the telecommunication ecosystem will react to this regulation and technology. An unlicensed band causes privacy concerns for both licensed and unlicensed users. In addition, security issues of unlicensed bands must be further studied.

Appendix

<License Type Evaluation Code>

```
Clear all

N=100;

Iter=1;

Tprob=0.8;

Lprob=0.2;

for KK=1:Iter

TiArry=rand(1,N);

LiArry=rand(1,N);

for K=1:length(TiArry)

  if (TiArry(K)>Tprob)

     TiArry_i(K)=0;

  else

     TiArry_i(K)=1;

  end

end

for K=1:length(LiArry)

  if (LiArry(K)>Lprob)
```

```
    LiArry_i(K)=0;
  else
    LiArry_i(K)=1;
  end
end

u=0;
for K=1:N

  if (TiArry(K)==0)
    if (LiArry(K)==0)
        u=u+1;
    else
        if(K==1)
          prev=0;
          next=TiArry(K+1);
          prev_l=0;
          next_l=LiArry(K+1);
        elseif(K==N)
          prev=TiArry(K-1);
```

```
      next=0;
      prev_l=LiArry(K-1);
      next_l=0;
    else
      prev=TiArry(K-1);
      next=TiArry(K+1);
      prev_l=LiArry(K-1);
      next_l=LiArry(K+1);
    end
    sum=prev+next;
    tl= prev_l*prev+next_l*next;
    if (sum==0)
     u=u+1;
    else
      if(tl==0)
        u=u+1;
      end
    end
  end
end
```

```
end
NzTi(KK)=length(find(TiArry_i>0))
NzLi(KK)=length(find(LiArry_i>0))
end
```

< Energy Detection Evaluation >

```
clear all;
N=100;
Iter=10;
Tprob=0.2;
Lprob=0.1;
for KK=1:Iter
TiArry=rand(1,N);
LiArry=rand(1,N);
       for KK=1:Iter
       TiArry=rand(1,N);
       LiArry=rand(1,N);
       NL=-80;
       variance= (0.001*10^(NL/10));
       %variance=2;
       %variance = 1/(Ts*(10^(SNRdb/10)));
```

```
W = sqrt(variance).*randn(1,N); %Gaussian white noise W
W_dbm= 10*log10((W.^2)/0.001);
for K=1:length(TiArry)
  if (TiArry(K)>Tprob)
     TiArry_i(K)=0;
  else
     TiArry_i(K)=1;
  end
end
for K=1:length(LiArry)
  if (LiArry(K)>Lprob)
     LiArry_i(K)=0;
  else
     LiArry_i(K)=1;
  end
end
u=0;
for K=1:N

  if (TiArry_i(K)==0)
```

```
if (LiArry_i(K)==0)
    if(K==1)
      prev=0; %T(i-1)
      next=TiArry_i(K+1);%T(i+1)
      prev_l=0;%L(i-1)
      next_l=LiArry_i(K+1);%L(i+1)
    elseif(K==N)
      prev=TiArry_i(K-1);
      next=0;
      prev_l=LiArry_i(K-1);
      next_l=0;
    else
      prev=TiArry_i(K-1);
      next=TiArry_i(K+1);
      prev_l=LiArry_i(K-1);
      next_l=LiArry_i(K+1);
    end
    sum=prev+next;
    tl= prev_l*prev+next_l*next;
    if (sum==0)
```

```
            if(W_dbm < -62)
                u=u+1;
            end
        else
          if(tl==0)
            if(W_dbm < -52)
                u=u+1;
            end
          end
        end
    end
  end
  us(K)=u;
end
ua(KK)=u;
NzTi(KK)=length(find(TiArry_i>0));
NzLi(KK)=length(find(LiArry_i>0));
KK
end
u_avg=mean(ua)
```

```
        mean(NzTi);

        mean(NzLi);

end
```

Bibliography

3GPP TSG-RAN Meeting (2014). Summary of a workshop on LTE in unlicensed spectrum

3GPP (2015) Study on Licensed-Assisted Access to Unlicensed Spectrum

3GPP (2018) LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical

Layer Procedures, document TS 36.213 V14.7.0, Release 14, 3GPP,

Ahmed K. sadek, Tamer Kadous, Qualcomm Technology Inc (2016) IEEE ICC 2015-workshop on LTE in Unlicensed bands: potentials and challenges

Ananth V. Kini, L. Canonne-velasquez, Mohesen Hosseinian, (2016) Annual conference on Information Science and System (CISS)

Anwer Al-Dulaimi, Saba Al-Rubaye " Pursuit of more capacity triggers LTE in Unlicensed band"

Best, Jo (2013) "The race to 5G: Inside the fight for the future of mobile as we know it"

Chung K. Kim, Chan S. Yong (2016) "Adaptive Listen-Before Talk (LBT) scheme for LTE and Wi-fi Systems Coexisting in Unlicensed Band 13th IEEE Annual Consumer Communications & Networking conference (CCNC)"

Claus Hetting (June 27, 2020) "South Korea could become Asia's first 6 GHz Wi-Fi nation"

Electronic Communication Committee (2009) Light Licensing, License Exempt and Commons: ECC Report 132

Electronical News (2020) "비면허 5G'에 6㎓ 대역서 최대 1.2㎓ 폭 공급

ETSI EN 301.893 v1.7.1, "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN," 2012.

Grubel, H. G. & Lloyd, P. J. (1975). Intra-industry Trade. London: Macmillan Press.

GSMA (2019) Spectrum Sharing Public Policy Position

Henderson, J. M. & Quandt, R. E. (1987). Financing structure. American Economic Review, 39(1), 123–145.

Hwang Seung Hoon (2014) LTE technology using Unlicensed band

International Telecommunication Union (2009) spectrum sharing ICT regulation toolkit

Joey Jackson (2015). "CES 2015: Qualcomm takes on Wi-Fi with LTE-U." RCR Wireless News.

Jon M. Peha (2008). Sharing spectrum through spectrum policy reform and Cognitive Radio. Carnegie Mellon University: Department of Engineering and public policy.

Jung sun Shim (06.25. 2020) 5G Quality of Wi-Fi will be accessible soon.

Kwon Hyun Joon(2016) Licensed-Assisted Access to Unlicensed Spectrum in LTE Release 13

Maziar Nekovee (2010) Final Report on regulatory feasibility assessment *Quantative Assessment of Secondary Spectrum Assessment*

O.S Park (2016) Trend of 5G massive IoT Electrics and Telecommunication Trends

Qualcomm Technologies (2014). Qualcomm Research LTE in Unlicensed spectrum: Harmonious coexistence with Wi-Fi

Richard Thanki (2014) "Jury Still Out on LTE-Unlicensed"

S. Haykein (2005) cognitive Radio: Brain-empowered wireless communications IEEE JSAC, Vol 23, No.2 pp.201-20

Shweta Sagari (2015) Coordinated dynamic spectrum management of LTE-U and wifi networks: IEEE international symposium on dynamic spectrum Access networks (Dyspan)

Shweta Sagari (2015) Coordinated dynamic spectrum management of LTE-U and wifi networks: IEEE international symposium on dynamic spectrum Access networks (Dyspan)

Sungman Oh (2012) A study on the introducing light-licensing as collective spectrum usage. 오성만 (2012) 주파수 공유와 간소화된 면허제도 도입에 관한 연구

PETER RYSAVY (Mar.19.2020) 6GHz should be allocated for both licensed and unlicensed applications Column

TTA (2013) Prospect of spectrum sharing policy of super wifi. Special Report 6 주파수 공유정책 측면의 슈퍼와이파이 활성화 전망.

Junjie Tan (2019) QoS-Aware User Association and Resource Allocation in LAA-LTE/WiFi Coexistence Systems

Junjie Tan (2020) Intelligent Sharing for LTE and WiFi Systems in Unlicensed Bands: A Deep Reinforcement Learning Approach

Zecheng Xie, Rongtao Xu (2016) A study of Clear Channel Assessment Performance for Low Power Wide Area Networks

Abstract (Korean)

5세대(5G) 이동통신 확산을 위하여 정부는 '비면허 5G' 주파수 대역인 6GHz 대역폭에 최대 1.2㎓ 폭을 공급할 예정이다. 4차 산업에 대응하여 기업이 스마트 공장에 적합한 맞춤형 5G망을 구축하기 위한 목적이다. 과학기술정보통신부(MSIT)는 6㎓ 대역 대상으로 비면허 주파수 대역의 5G 연구반을 가동, 주파수 분배 방안 수립과 기술기준 제정에 착수한 것으로 확인됐다. 비면허 5G(NR-U)는 정부가 개방한 비면허 주파수 대역에 5G 코어망과 기지국 등 표준 기술을 적용해 초저지연초고속 성능을 구현하는 기술로, 6월 국제민간표준화기구(3GPP) 상용화를 앞두고 있다. 그러나 5/6GHz 대역의 주파수는 와이파이와 LTE-LAA가 공존하게 될 영역으로 이해관계자들의 주장이 엇갈리고 있다. LBT (Listen-Before-Talk)는 비면허 주파수를 공유하는 방법으로 기술적/행정적 방안으로, 채널을 분석하여 데이터를 전송하기 가장 적절한 주파수대역을 선출하는 방법중에 하나이다. 이 대역을 선출하기 위한 기술 방법은 CCA (Clear Channel Assessment)라고 한다. 이 기술은 LTE 통신사업자들이 개발한 기술로 구체화된 기술표준을 요구하고 있다. 하지만, 이 기술을 와이파이 사업자 입장에서는 이 기술의 실제 실용가능 여부에 대해 의구심을 갖고 있다. 그 이유는 해당 기술이 지나치게 LTE 통신사업자들에게 유리하게 개발된 기술이라는 논쟁이 있기 때문이다. 이에 통신기술정책 결정자는 양측이 공존할 수 있는 법 제정방안을 강구해야 하며, 이 논문에서는 기존 와이파이 사용자들을 보호하며 통신 사업자들 역시 주파수를 공유할 수 있는 제도정책의 방법을 정책자 입장에서 연구해보자 한다. 비면허 주파수를 개방하게 되었을 때 채널 사용자 비율과 라이선스 배부 비율 사이의 효율성에 대해 연구하였다. 그리

고, 사용 가능한 채널을 비교하는 방법을 기존연구를 통해 비교하고 새로운 모델을 개발 했다. 또 기술 표준으로 이미 제정 된 노이즈 한계치가 실제 공유가 됐을 때 어떤식으로 작용되는 지를 알아보기 위해 시뮬레이션 분석을 통해 예측해 보았다.

주요어 : 비면허 주파수, 5G , LTE-U, Listen-Before-Talk, Clear Channel Assessment, **시뮬레이션 기법.**

학번 : 2014-22666