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Realization of LBT for Co-existence of U-LTE with Wi-Fi using Cognitive Radio

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Abstract: *The advanced cellular network, Long Term Evolution (LTE) which presently operates in licensed spectrum has been extended to Unlicensed LTE (U-LTE) by Qualcomm and Ericsson to improve data rate and spectral efficiency by utilizing unlicensed spectrum. Carrier Aggregation of 3GPP LTE-A supports the aggregation of licensed and unlicensed spectrum in small and femto cells to provide better user experience. The recently evolved intelligent technology viz. Cognitive radio which supports the efficient spectrum utilization is applied in the proposed system model to detect the white spaces in unlicensed spectrum to accomplish Listen-Before-Talk (LBT) regulatory requirement of radio communication in U-LTE. Another major goal of U-LTE to co-existence along with WiFi users in a non-interference style is also accomplished by the use of Cognitive radio. Based on the above concepts, it is attempted to enhance the unlicensed spectrum utilization and to address the coexistence issues in U-LTE.*

Keywords: LTE, U-LTE, Cognitive Radio, Carrier Aggregation, Coexistence issues, Spectrum Utilization.

INTRODUCTION

Need for U-LTE

A rapid increase of mobile data usage and emergence of new applications such as Multimedia Online Gaming (MMOG), Mobile TV, Web 2.0 streaming contents have motivated the 3rd Generation Partnership Project (3GPP) to work on the LTE on the way towards fourth-generation (4G) mobile. 4G LTE is one of several competing 4G standards along with Ultra Mobile Broadband and WiMax (IEEE 802.16). The leading cellular providers have started deploying 4G technologies, with Verizon and AT&T launching 4G LTE networks and Sprint utilizing its new 4G WiMax network. The main goal of LTE is to provide a high data rate, low latency and packet optimized radio-access technology, supporting flexible bandwidth deployments. Same time its network architecture has been designed with the goal to support packet-switched traffic with seamless mobility and great quality of service. However, the supply of (licensed) frequency spectrum allocated to cellular operators is very limited; operators have been feeling the crunch.

Qualcomm, Huawei and Ericsson lobbied the 3GPP standards committee to allow LTE service to run on the 5 GHz band. That band is one of two unlicensed bands that are typically used by Wi-Fi service. 5 GHz is the U-NII (Unlicensed National Information Infrastructure) band and since it is relatively less congested, when compared the common 2.4 GHz ISM band and because new software has been developed to make the various signals play nice within a shared spectrum band, U-LTE in the 5GHz band is winning acceptance. 5 GHz band has a shorter communication range due to higher path loss but has wider available bandwidth. Fig. 1 shows the unlicensed spectrum layout in several different main regions at 5 GHz band [1].

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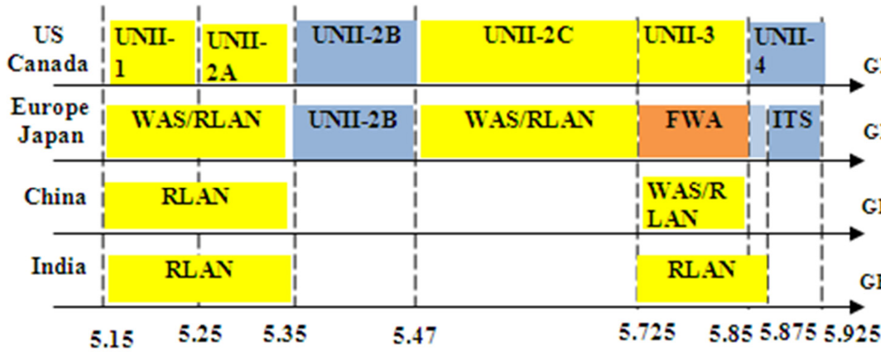

Fig. 1 Unlicensed Spectrum in different regions

Carrier Aggregation in U-LTE

The first design principle of U-LTE is the integration with licensed spectrum [2]. The integration between unlicensed and licensed carriers both operating LTE is the key operating mechanism. The Carrier Aggregation (CA) mechanisms defined in LTE Rel-10 to Rel-12 can serve this purpose in target scenarios. CA is a key feature of LTE-Advanced (LTE-A) that enables operators to create larger "virtual" carrier bandwidths for LTE services by combining separate spectrum allocations. CA is the primary feature deployed by operators with commercial LTE-Advanced service. The need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than those currently supported in LTE (up to 20 MHz) while at the same time ensuring backward compatibility with LTE. The benefits of this aggregation include higher peak data rates and increased average data rates for users. CA enables the combination of up to five LTE Release 8 (Rel-8) compatible carriers [3]. The licensed LTE carriers are Primary carriers and unlicensed carriers are Secondary carriers. Since the secondary carriers are under the control of primary in situations like load shifting and channel adaption the security and service QoS are ensured. Moreover, control plane messages are always transmitted on the licensed band and thus QoS is ensured. The user-plane data can be transmitted on either licensed or unlicensed carriers.

Coexistence Features

Due to non-exclusive usage nature of unlicensed spectrum by U-LTE, there are two main challenges. The foremost challenge of design of U-LTE is its coexistence with Wi-Fi systems on a fair and friendly basis. The Wi-Fi systems are the user deployed systems and they are the incumbent users or primary users of the unlicensed band. The PHY/MAC implementation differences between LTE transmissions and Wi-Fi, hinders the direct implementation of U-LTE transmissions as it can generate continuous interference to Wi-Fi systems. Second is the coexistence with different other U-LTE operators in the same unlicensed band. The operation in unlicensed band also needs to factor in the regulatory requirements of a given region. In some markets, like Europe and Japan, a specific waveform requirement on supporting LBT (Listen-Before-Talk) at milliseconds scale is required which would need changes in LTE air interface. In other markets, like US, Korea and China, there are no such requirements. In [4] without modifying PHY/MAC standards, three mechanisms are adopted to behave U-LTE as a good neighbor. Channel selection enables the small cells in U-LTE to select cleanest channel for SDL (Supplemental Downlink) carrier transmissions. In case of dense usage of Wi-Fi and U-LTE small cells, where no clean channel can be found, Carrier-Sensing Adaptive Transmission (CSAT) algorithm is used in Time Division Multiplexing (TDM) transmissions. Final alternative method is to restrict the use of unlicensed band for SDL transmissions in case of lightly loaded small cells.

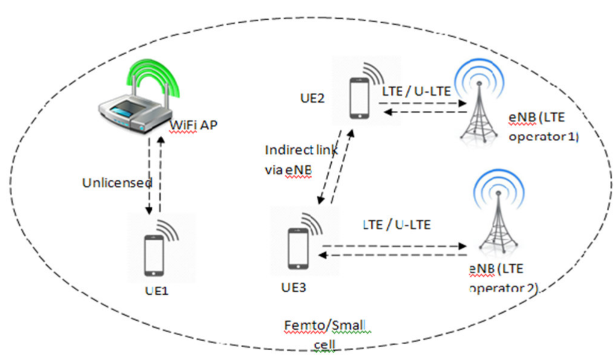

Fig. **2** Deployment Scenario of U-LTE with WiFi users

In Fig 2, the deployment scenario of U-LTE along with WiFi users is shown. User Equipments (UEs), by communicating with Wi-Fi Access Point (AP) using the unlicensed spectrum, form a *femto cell* and become primary users. During their communications with

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eNodeB (eNB), UEs form *a small cell* and try to utilize the unlicensed spectrum and become secondary users. As mentioned earlier, U-LTE operates in two modes: Supplemental Downlink (SDL) and Time Division Duplex (TDD). In SDL mode, the unlicensed spectrum is used only for downlink traffic, thereby eNB performs most of the necessary operations to ensure reliable communications, including checking whether the intended unlicensed channel is free from other use [5]. For TDD mode, the unlicensed spectrum is used for both uplink and downlink, resulting additional implementation complexity in UEs for LBT feature. Latest release of 3GPP LTE standard Rel.13 supports usage of unlicensed spectrum in both operating modes [6].

In summary, it may be arrived that besides Qualcomm and Huawei, the coexistence issue for U-LTE and Wi-Fi has not been addressed extensively by researchers. Hence, in this work the usage of Cognitive Radio (CR) in small cells is proposed. In this context, the following sections discuss the fundamentals of CR, the present usage of CR in LTE, and the proposed deployment of CR in U-LTE.

COGNITIVE RADIO NETWORKS

Features of CRN

The Federal Communication Commission (FCC) defined Cognitive radio (CR) as the radio that can change its transmission parameters based on interaction with the environment in which it operates [7]. The Wireless communication has been increased and requirement of high data rate has also been increased. The licensed spectrum space remains idle at most of the times [8] due to inefficient allocation of frequencies and the cellular bands are overloaded. To meet the spectrum demands and to utilize the spectrum, FCC revisited the problem of spectrum management [9]. This inventiveness focused on CR. The IEEE 802.22 is the standard for cognitive wireless regional area networks (WRANs). The main goal of CR is to identify the unused licensed spectrum for secondary users (SU) without causing interference to the Primary User (PU). This method of sharing is often called Dynamic Spectrum Access (DSA).

Sensing Techniques

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum, transmit power, interference, noise and radio's operating environment [10]. Spectrum sensing in Cognitive Radio Networks (CRN) is done for two purposes. One is to identify the spectrum opportunities (white spaces), other to detect the interference in the spectrum. White space detection is done by Non-cooperative approach (also known as Primary transmitter method) and Cooperative/collaborative approach. Non-cooperative approach includes match filter based detection, energy based detection, covariant based detection, cyclostationary based detection, waveform based detection, etc. In Cooperative/collaborative approach, information from multiple Cognitive radio users is incorporated for primary user detection. This approach includes either centralized access to the spectrum coordinated by a spectrum server or distributed approach [11]. Interference based sensing approaches includes (i) interference temperature detection where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users and (ii) primary receiver detection where the interference and/or spectrum opportunities are detected based on primary receiver's local oscillator leakage power.

Channel switching Techniques

In order to improve the spectrum occupancy and also to reduce the disruption rate to primary users the secondary users schedule their spectrum usage [12]. The mechanisms used for channel switching are predictive channel switching, random channel switching and optimal channel switching. Predictive channel switching mechanism calculates the remaining idle time of each channel and the channel with the largest remaining idle time is selected for switching. Random channel switching makes the selection in random manner when the interference occurs [13]. In optimal channel switching scheme the channel that is free and offers longer remaining idle time is selected for switching. The channel selection is made either in a reactive or proactive manner. In Reactive method the secondary user opts for channel switching only after collision with the primary user. In Proactive method secondary user predicts the collision and switches the channel before it occurs.

RELATED WORKS

In [14] authors have studied the Type 2 sensing (interference detection) for single-input single-output system of LTE-Advanced network. Cognitive radio technology is applied to sense the spectrum by using the conventional method of energy detection. In [15], the effect of distance between the macro user and femto cell on Signal-interference noise ratio(SINR), Path-loss(PL) and Throughput(THR) with changing bandwidth in LTE-A environment using Cognitive radio was analysed. In [16], the authors have focused on improving resource efficiency in LTE network by considering CR Device to Device (D2D) communication links. In [17, 18], the QoS (Quality of Service) maximization requirement for secondary users in CRN built upon 3GPP LTE platform was experimented.

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In summary, all the above works have focused only on LTE and LTE-A networks along with CR. However, no attempt is made in U-LTE with CR, despite CR's basic nature in exploiting white spaces efficiently. Hence, a detailed analysis has been made in this work for efficient spectrum unitization of unlicensed band for U-LTE using CR technique.

COGNITIVE RADIO IN U-LTE

System Model

The proposed system is so modelled to utilize the attributes of the CR to optimally operate U-LTE in U-NII band (5 GHz). As LBT feature is mandatory in regions like Europe, Japan and India, an efficient mechanism is to be devised to share the unlicensed spectrum with Wi-Fi, the primary users of the specified band in a non-interference basis. The extensive use of U-LTE by both primary and secondary users restricts the availability of clean channels and Qualcomm, by applying CSAT algorithm in TDM fashion, attempted to provide a solution for it. In this context, in this work, it is proposed to incorporate CR for effective spectrum sharing between U-LTE and Wi-Fi as well as between different U-LTE operators.

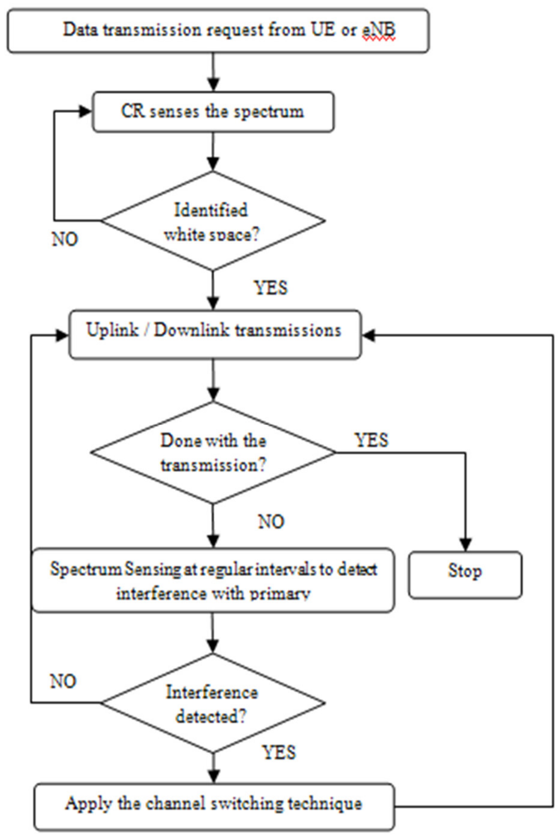

Fig. 3 System Model

Fig.3 depicts the system model of applying Cognitive radio features in U-LTE. The request of data transmission from either UE or eNB triggers the CR to sense the spectrum to identify the white space or the clean channel. Once the clean channel is identified, uplink or downlink transmissions will occur. To meet out the coexistence of U-LTE with Wi-Fi users in a non-interference basis, the CR senses the spectrum at regular intervals. Whenever the CR foresees the presence of Wi-Fi transmissions, channel switching is applied to switch the U-LTE transmissions to another clean channel. The deployment scenario of U-LTE shown in Fig.2 is enhanced with Cognitive radio devices only at eNBs for SDL mode and at UEs along with eNBs in TDD mode.

Spectrum Sharing

The major objective of the proposed work is to extend the capabilities of CR to identify the white space as well as to avoid interference with incumbent Wi-Fi users in a typical U-LTE. As stated in Section 2.2, various approaches, such as match filter based detection, energy based detection, covariant based detection, cyclostationary based detection, waveform based detection etc., can be used for white space detection by CR. Out of these techniques, it was observed by the authors that the cyclostationary methods yields better

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results through their previous work [19]. When CR foresees the requirement of the spectrum under usage by an incumbent user, it uses one of the channel switching mechanisms to shift the current transmission to some other clean channel. As discussed in Section 2.3, the channel switching mechanisms presently available are predictive channel switching, random channel switching and optimal switching and the selection of the switching mechanism is left to the nature of the application and the designer.

SIMULATION RESULTS

The system model is simulated incompliance to Rel. 10/11 3GPP LTE standards using Matlab 2012(b) showing the coexistence of LTE and Wi-Fi in 5 GHz band ranging from 5.0 to 5.3 GHz, 6 channels each with assumed bandwidth of 20MHz. The first phase of simulation is attempted without LBT feature i.e. without the application of CR. In the non-LBT feature, LTE occupies the available free channel and their transmissions will long last according to the usage. Since Wi-Fi systems adopt a contention based medium access control (MAC) protocol with random back off mechanism, it finds the medium busy most of the time, resulting in high back off rate. The above scenario is simulated with entries of multiple LTE and Wi-Fi systems into the spectrum in a random fashion and their occupancy in the available free channel. The success rate of LTE and Wi-Fi systems are studied for repeated iterations of simulation run. The simulation results prove the non-friendly and unfair sharing nature of LTE in the unlicensed band by occupying the spectrum most of the time, causing interference and denying the space for the incumbent Wi-Fi users. In Fig. 4, the performance graph shows the average success rate of LTE appears higher than Wi-Fi systems.

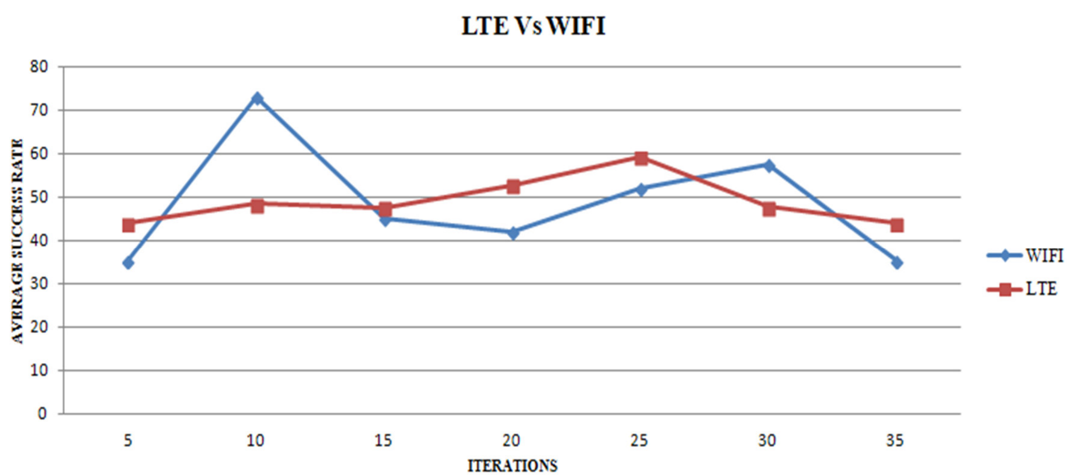

Fig. 4 Success rate of LTE and Wi-Fi systems

The second phase of simulation, inclusion of CR for the realization of LBT feature is under progress and yet to be completed.

CONCLUSION AND FUTURE WORK

The spectrum utilization of radio frequencies is gaining momentum due to the invasion of wireless equipments in every field of human life. In this regard, there is a change over from licensed LTE to U-LTE in view of the evident advantages of latter in terms of speed, cost etc. An improved method is proposed in this work to include CR in U-LTE for effective utilization of the white spaces in the radio spectrum. The basic attributes of channel searching and channel switching are utilized in this work to optimize the functionality of U-LTE in terms of clean channel searching and co-existence of secondary users with primary users. The Phase I simulation results of coexistence of U-LTE and Wi-Fi in unlicensed 5 GHz band in non-LBT fashion proved the unfair sharing of spectrum between them. The Phase II simulation with application of CR features to improve the effective spectrum sharing between U-LTE and Wi-Fi is under progress for the future publications.

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