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Enhancing 4G Co-existence with Wi-Fi/IoT using cognitive radio

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Abstract
The advanced cellular network, long term evolution (LTE) that presently operates in licensed spectrum has been extended to unlicensed LTE (U-LTE) to improve data rate and spectral efficiency by utilizing unlicensed spectrum. Carrier aggregation of 3GPPLTE-A supports the aggregation of licensed and unlicensed spectrum in small and femto cells to provide better user experience. The proposed work consists of two objectives, first to accomplish the listen-before-talk (LBT) regulatory requirement of radio communication in U-LTE and the second to enhance their co-existence with Wi-Fi/IoT users in a non-interference style by reducing the back-off rate of Wi-Fi. The importance of spectrum utilization by the incumbent users of unlicensed band for the upcoming Internet of Things communications is also a key consideration in this work. The recently evolved intelligent technology viz. Cognitive radio (CR) is applied in the proposed system model to meet the objectives. A ground research is done in a simulation environment of LTE signals and 5 GHz band to evaluate the back-off rate of Wi-Fi. A comparative performance analysis between proposed and existing systems are also done and presented in this paper.

Keywords LTE · U-LTE · Cognitive radio · Carrier aggregation · Coexistence issues · IoT communications-5 GHz band

1 Introduction

LTE networks are carrying increasing amount of data. Reducing the cell size to meet the data demand is not the complete solution and the need for more spectrums still exists. The usage of unlicensed spectrum alongside licensed bands provides an attractive opportunity for LTE operators to satisfy their subscribers' data demand. Unlicensed LTE (U-LTE) is most interested in enabling its access in 5GHz ISM unlicensed band. The reason is quite simple as several hundred MHz of spectrum bandwidth is available in 5GHz. One main constraint for accessing these frequencies is being able to coexist with other Wi-Fi/IoT users i.e. listen before talk (LBT) is required. In this paper, the proposed work realizes the LBT requirement of U-LTE with the usage of cognitive radio (CR).

The remaining sections of this paper are organized as follows: Sect. 2 gives the overview of U-LTE, its evolution and open issues in co-existence with 5GHz band. Section 3 describes the features of Cognitive Radio Networks, its compliance with 5GHz band and spectrum sensing techniques. Section 4 summarizes the existing related works of proposed system. Section 5 presents the formulated proposed system and followed by simulation architecture and results in Sect. 6. The outcome of proposed work is concluded in Sect. 7.

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2 Unlicensed- LTE (U-LTE)

2.1 Need for U-LTE

The 3rd Generation Partnership Project (3GPP) [1] got inspired to function on fourth-generation (4G) mobile namely

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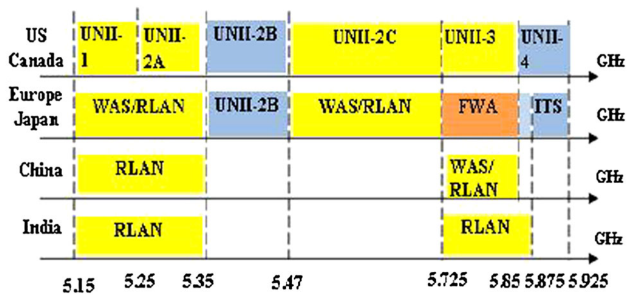

Fig. 1 Unlicensed spectrum in different regions

LTE to meet the very high data usage by recently evolved multimedia applications. 3GPP releases R13 and R14 [2,3] includes LTE-Advanced (LTE-A) and narrow band-IoT (NB-IoT). Also 3GPP release 15 concentrates on LTE-Advanced Pro with a data rate of 3Gbps and bandwidth of 640MHz [4]. Besides ultra mobile broadband and WiMax (IEEE 802.16), LTE competes with several other 4G standards. Followed by the US government approval of the first "LTE-U" devices, T-Mobile USA is ready to deploy over 5GHz frequencies [5]. High data rate, low latency, packet optimized radio-access technology and flexible bandwidth are the main goals of LTE. Also, its network architecture too supports packet-switched traffic with persistent mobility and high quality of service. Anyhow, the cellular operators are limited by the allocation of licensed frequency spectrum.

Qualcomm, Huawei and Ericsson influenced the 3GPP standards committee to allow LTE service to run on the 5 GHz band. This 5 GHz band is one of two unlicensed bands that are typically used by Wi-Fi service. 5 GHz is the Unlicensed National Information Infrastructure (U-NII) band and since it is relatively less congested, when compared to 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. Figure 1 shows the unlicensed spectrum layout in several different main regions at 5 GHz band [1].

2.2 Carrier aggregation in U-LTE

The first design principle of U-LTE is the integration with licensed spectrum [6]. 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. Several spectrums are aggregated to create large "virtual" career bandwidths to support LTE services, which is the key feature of LTE-Advanced (LTE-A). For commercial purpose, operators deploy CA as the prime feature of LTE-A. The current bandwidth (up to 20 MHz) of LTE got enhanced by this CA and as well as it ensures the backward compatibility. The users also get benefits in terms of high data rates and increased average data rates. CA enables the combination of up to five LTE Release 8 (Rel-8) compatible carriers [7]. 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.

2.3 5 GHz band and Wi-Fi/IoT usage

The internet of things (IoT) or machine-to-machine (M2M) communications is one of the most exciting and fastest growing technologies across the globe today. It employs the embedded technology with sensors and actuators, connects to other devices or to cloud, and automatically transmits information. Wi-Fi, Bluetooth, ZigBee, Active RFID, loWPAN, EtherCAT, NFC, RFID, etc. are the standards and proprietary solutions used by the devices to connect among themselves as well as with cloud [8]. Based on the physical characteristics of the environment and presence of obstacles like wood, concrete, metal, etc. the volume of sensors, their range and data rates, the technology used to connect the devices will be chosen. Wi-Fi has been the most successful among these technologies listed above due its adaptability, scalability, ease of use and cost. In view of its advantages, Wi-Fi has become a ubiquitous standard of connectivity and is used in the residential building, commercial enterprises, educational institutions, hospitals, airports etc.

As the 2.4GHz band is meant for unlicensed users, it is presently heavily crowded and hence, the IoT device communication and Wi-Fi are shifting to less crowded 5 GHz band. Therefore, it is necessary to safe guard the 5 GHz band for its incumbent users viz. IoT and Wi-Fi. In this perspective, the proposed work addresses the importance of saving 5 GHz band for the next generation wireless communications.

2.4 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/IoT systems on a fair and friendly basis. The Wi-Fi/IoT 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/IoT, hinders the direct implementation of U-LTE transmissions as it can generate continuous interference to Wi-Fi/IoT systems. Second is the coexistence of two or more different 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, Japan and India, a specific waveform requirement on supporting listen-before-talk (LBT) 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 these countries, with carefully designed coexistence mechanisms realizable by software to ensure peaceful coexistence with Wi-Fi/IoT, operators can deploy LTE in unlicensed bands that are compatible with Rel. 10/11 3GPP LTE standards. In markets where LBT is required, LTE in unlicensed operation can be further optimized through air interface enhancement with the introduction of LBT feature potentially in 3GPP Release 13 [9,10].

Number of PHY/MAC modifications is required to meet regulatory requirements in LBT regions. The required modifications are defined in LTE release 13 and beyond, providing a standard LBT mechanism for LTE to coexist with Wi-Fi/IoT and other access technologies within the unlicensed bands. Especially, LTE PHY/MAC enhancements are required to meet the functionalities such as clear channel assessment, discontinuous transmission (DTX) with limited maximum transmission duration, UE support for carrier selection and modified HARQ protocol to enable LBT.

In summary, it may be arrived that besides Qualcomm, Nokia and Huawei, researchers have not addressed the coexistence issue for U-LTE and Wi-Fi/IoT extensively.

3 Cognitive radio networks

3.1 Features of CRN

CR is defined by the Federal Communication Commission (FCC) as the radio that is capable of changing its transmission parameters as it interact with the environment that it operates on [11]. Increase in high data rate requirements has results in increase in wireless communications. The inefficacious allocation of frequencies in licensed band leaves white spaces in the spectrum while the cellular bands are overloaded [12]. For effective utilization of spectrum and also to meet the spectrum demands, FCC revisited the problem of spectrum management [13] and this leads to CR invention. 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 interfering Primary Users (PU) and this method of sharing is often called as Dynamic Spectrum Access (DSA).

3.2 Cognitive radio in 5GHz band

Cognitive radio is the key technology that can enhance the convergence of next-generation wireless devices those operate in IEEE 802.11 and IEEE 802.16 standards. The flexibility in the hardware and its feasibility to program for a band or mode enables CR to adapt over to an ISM band or up to an IEEE band and even to unlicensed 5GHz bands. In 5GHz band, two types of networks are considered to be operating, primary and secondary or cognitive radio networks (CRN). The incumbent users of 5GHz such as regular Wi-Fi users and IoT communications operate the primary network. The cognitive radio networks only access the spectral band not used by the primary band. Each CRN can be made to use multiple channels for better performance by adopting modulation schemes using software defined radio (SDR) devices such as Universal Software Defined Radio Peripheral (USRP). Therefore, CR dynamically monitors certain bands of the 5GHz unlicensed spectrum to identify the idle spectrum and uses them as needed [14].

3.3 Future of CR

In future of internet of things (IoT), the fact is that billions of objects are expected to be interconnected through wireless results in huge volume of traffic with high demand in spectrum [15,16]. The spectrum is finite in nature and becoming rare and expensive. As a result of it, the IoT paradigm requires the innovative CR paradigm to go hand in hand to meet the demands of spectrum.

Also, based on the approaches of the dynamic use of frequencies pursued to provide high spectral efficiency, CR fits itself to support 5G networks. CR principles can be incorporated to enable the spectral coexistence of two or more than two heterogeneous wireless networks in different dimensions such as time, frequency, spatial, polarization, and geographical space through cognitive beam forming, cognitive interference alignment, adaptive power control, carrier aggregation, dynamic carrier/bandwidth allocation.

3.4 Sensing techniques

The various parameters of spectrum such as radio channel characteristics, white spaces, transmit power; interference, noise and operating environment are sensed and measured by the spectrum [17]. 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, a primary user is detected based on collective information from multiple cognitive radio users. This approach includes either centralized access to the spectrum coordinated by a spectrum server or distributed approach [18]. Interference temperature detection and primary receiver detection are the other interference based sensing approaches. In former method, secondary users are allowed to coexist with primary with low transmission power and monitored by the interference temperature level. The second method detects the interference based on the primary receiver's local oscillator leakage power.

4 Related works

Extensive research has proved that CR is the promising technology to improve the spectrum utilization/sharing in an opportunistic manner. Few researches have adopted CR to enhance the spectrum sharing in femto cells of LTE/LTE-A networks [19,20]. In such research works femto cells are made cognitive to improve the QoS parameters. In [21] authors have studied the Type 2 sensing (interference detection) for single-input single-output system of LTE-Advanced network. They use conventional energy detection method to sense the spectrum in cognitive radio technology and no innovative methods are introduced. Alternative methods to sense spectrum is still an open issue for research.

The authors in [22] analyses the throughput (THR) with changing bandwidth in LTE-A environment, Path-loss (PL), the effect of distance between the macro user and femto cell on Signal-interference noise ratio (SINR) using cognitive radio. In [23], the authors have focused on improving resource efficiency in LTE network by considering CR device to device (D2D) communication links. In [24,25], the quality of service (QoS) maximization requirement for secondary users in CRN built upon 3GPP LTE platform was experimented. All these research works have tried to cognitize the LTE/LTE-A femto cell to improve their efficiency in terms of throughput, spectrum sharing, spectrum utilizations, etc. and however no attempt was made to apply CR in U-LTE.

Co-existence of U-LTE/LTE-A networks with existing wireless networks is regarded as the latest paradigms. A considerable research has done to reduce the interference level of U-LTE/LTE-A to Wi-Fi users. In early U-LTE with non-LBT feature, Qualcomm [9] proposed Carrier Sensing Adaptive Transmission (CSAT) with TDM cycle sharing mechanism for coexistence of U-LTE signals with other existing wireless technologies. This method resulted in increased delay perceived by U-LTE users. Qualcomm has also done the design modifications to meet LBT requirements using Clear Channel Assessment (CCA) method and has proven better results.

In our previous work [26], the coexistence of U-LTE with Wi-Fi in unlicensed 5 GHz band in non-LBT fashion was studied. The simulation results proved the unfair sharing of spectrum between them. Hence, in this proposed work, considering the Indian market scenario, where LBT requirement is mandatory for coexistence of U-LTE with Wi-Fi/IoT, the basic feature of CCA is combined with CR for effective protection of incumbent Wi-Fi user's performance and presented in the proceeding sections. The Wi-Fi/IoT communications are considered as primary network. The U-LTE is the secondary or CRN, which access the idle spectrum of 5GHz when not used by Wi-Fi/IoT users.

Yet another open issue is the Co-existence of several U-LTE operators named as inter-operator spectrum sharing. In this scenario the unlicensed spectrum need to be shared among inter operators as well as with incumbent users of unlicensed band. However, such is issue is beyond the scope of this paper and presented only to serve the purpose of literature review.

5 Cognitive radio in U-LTE

5.1 System model

The proposed system is so modeled that it utilizes 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 and also paving the way for the currently evolving IoT or Machine-to-Machine (M2M) communications.

In Fig. 2, the deployment scenario of U-LTE along with Wi-Fi/IoT users is shown. User equipment (UEs) and IoT devices, by communicating with Wi-Fi access point (AP) using the unlicensed spectrum, form a femto cell and become primary users. During their communications with 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. Operations such as ensuring reliable communications, checking availability of intended unlicensed channel are performed by eNB node [27].

For TDD mode, the unlicensed spectrum is used for 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 [10]. In this work, SDL mode is considered and the eNB is equipped with CR for the purposes of

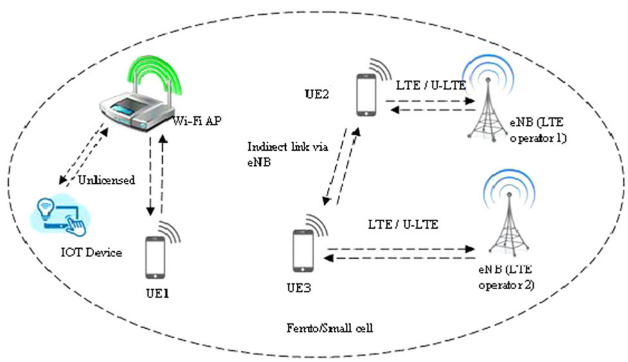

Fig. 2 Deployment scenario of U-LTE with Wi-Fi/IoT users

detecting idle spectrum and communicating without causing interferences to primary users.

The proposed method of applying CR features in U-LTE for effective utilization of 5 GHz band is given in Fig. 3. The request for data transmission from eNB triggers the CR to identify the white space or the clean channel by sensing the spectrum. Upon the successful identification of the clean channel, downlink transmissions take place between the terminal devices. The channel can be occupied for a fixed time named as Channel Occupancy Time (CCT) for 10 ms as stated by ETSI standards [28]. To comply with the demands of U-LTE and to facilitate the coexistence of them with incumbent users in a non-interference basis, CR senses the spectrum at regular intervals to cater their needs by allocating idle spectrum until the end of their transmissions. The usage pattern by U-LTE users varies from few milliseconds, hours or days in multiples of CCT slots and considered as long lasting opportunities. However, there are also short-lasting opportunities where spectral idleness will expire before the usage by the U-LTE. But this study focuses only on spectrum opportunities lasting at least for few seconds.

5.2 Channel and traffic model

Considering DSA network of CR, the following are the assumptions made to formulate the channel and traffic model [29].

1. The U-NII band spectrum is divided into C identical channels shared by primary and secondary users. The channels are assumed to be perfect i.e. they are either busy or free.
2. Newly arriving requests from primary or secondary will be allocated a free channel, if available. If they do not find a free channel, they back off.
3. For a primary/secondary user i, the channel is occupied for a period and available for a period $T^{(i)}_{Busy}$ and available for a period $T^{(i)}_{free}$.

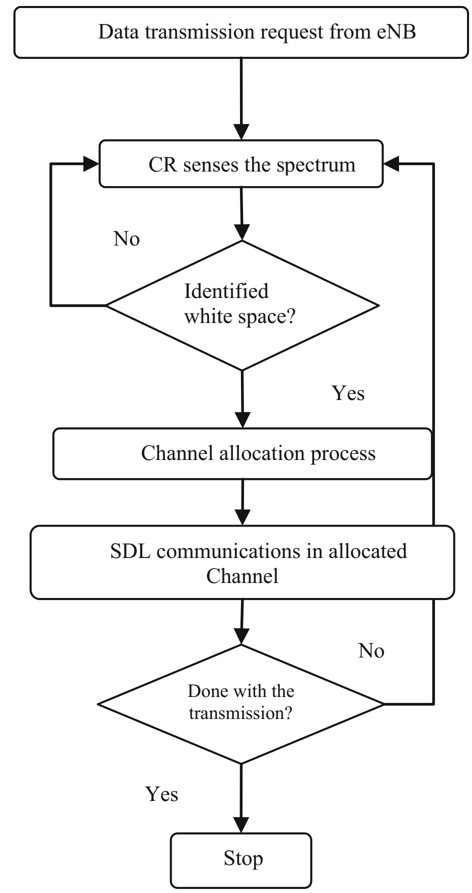

Fig. 3 System model

4. Primary and secondary users make requests for channel according to Poisson process with arrival rate λ p and λsand they hold the channel for a time, which is exponentially distributed with mean 1/µp and 1/ µs respectively.
5. p is the number of primary users with transmission time µp. s is the number of secondary users with transmission time µs. Their transition rate is defined as pµp and s µs.
6. At any instant of time t, let s (t) and p (t) be the number of channels occupied by secondary and primary.
7. When primary and secondary users occupy p and s channels, a new arrival of primary request can occupy any one of the (C-p-s) channels.
8. When primary and secondary users occupy p and s channels, a new arrival of secondary request can occupy any one of the (C-p-s) channels.

The probability that user i (primary / secondary) occupy the channel is given by

$$T_i = \frac{T^{(i)}_{Busy}}{T^{(i)}_{Busy} - T^{(i)}_{free}} \tag{1}$$

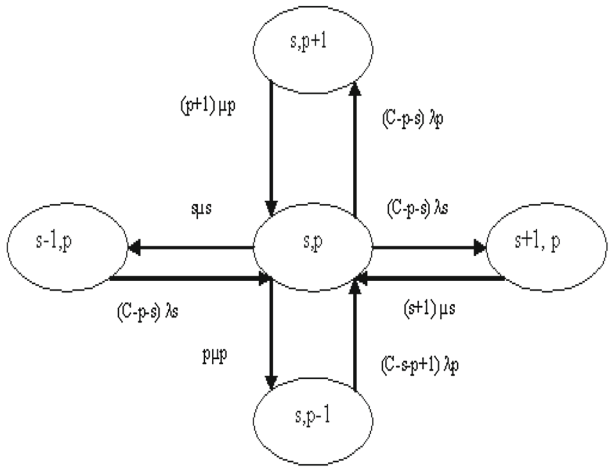

Fig. 4 Channel occupancy state transition for s + p < C

The channel occupancy in the U-NII spectrum can be modeled using Markov chain. Let Φ denotes the set of feasible states where $\Phi = \{(s, p)|s \geq 0, p \geq 0 \text{ and } s+ \leq C\}$, $\phi(s, p) = 1$, if (s, p) ε Φ and $\phi(s, p) = 0$ otherwise. The steady state probability of the channel occupancy is given by

$$P(s, p) = \lim_{t\to\infty} \Pr\{s(t) = s, p(t) = p\} \quad (2)$$

The balance equation for the channel occupancy state transitions as shown in Fig. 4 can be formulated as

$$\begin{aligned}&[p\mu_p + s\,\mu_s + (C\text{-}p\text{-}s)\,\lambda_p + (C\text{-}p\text{-}s)\,\lambda_s]P(s,p)\,\phi(s, p)\\&= (p+1)\,\mu_p\,P(s,p+1)\,\phi(s, p+1)\\&\quad + (s+1)\,\mu_s\,P(s+1, p)\,\phi(s+1, p)\\&\quad + (C\text{-}s\text{-}p+1)\,\lambda_p\,P(s, p\text{-}1)\,\phi(s, p\text{-}1)\\&\quad + (C\text{-}s\text{-}p)\,\lambda_s\,P(s\text{-}1, p)\,\phi(s\text{-}1, p)\end{aligned} \quad (3)$$

P(s,p) also satisfies the normalization condition,

$$\sum\nolimits_{p=0}^{C} \sum\nolimits_{s=0}^{C} P(s, p)\phi(s, p) = 1 \quad (4)$$

Thus P(s,p) can be obtained, $\forall(s, p) \in \phi$. The probability that a newly arriving primary or secondary is blocked is the probability that all the C channels are occupied. Thus the back off probability P back off is given by

$$P_{backoff} = \sum_{p=0}^{C} \sum_{s=0}^{C} P(s, p)\Psi(s + p = c) \quad (5)$$

Where $\psi(f(s, p))$is an indicator function i.e. $\psi(f(s, p)) =$ 1if $f(s, p)$ holds and $\psi(f(s, p)) = 0$ otherwise.

Table 1 Simulation parameters

Parameters	Values
No. of channels (C)	23
λ p,λ s	2/s
1 / μp	100 ms
1 / μs	100 ms (non-LBT)
No. of users	10–500
Energy of Wi-Fi signal	– 60 to – 30 dBm
Energy of LTE signal	– 80 to – 65 dBm
CCA threshold	20 μs and < – 80dbm
Channel occupancy time of LTE in LBT 1 / μs	10 ms

6 Simulation

The system model is simulated in compliance to Rel. 13 3GPP LTE standards using Mat Lab showing the coexistence of U-LTE and Wi-Fi/IoT in 5 GHz band ranging from 5.0 to 5.3 GHz, 23 channels each with assumed bandwidth of 20MHz. For comparison purpose, the coexistence of U-LTE and Wi-Fi/IoT in 5 GHz band without LBT feature is also simulated and shown. The following sections describe the simulation models for both coexistence mechanisms without LBT and with LBT along with their simulation results and comparison.

A real-time Wi-Fi user traffic was collected and used as input data set. On observing real-time LTE traffic, LTE signals were generated to match their energy level. Both LTE and Wi-Fi signals are fed into the system in a random fashion to enact the real-time environment.

The network scenario shown in Fig. 2 with SDL mode is considered. The network is assumed with macro cells of eNB nodes and picocells with Wi-Fi access points (APs). The system under test is evaluated with increase in number of users for both Wi-Fi and LTE.

The values of the parameters considered to obtain the simulation results are listed in Table 1.

6.1 Coexistence of LTE with Wi-Fi / IoT without LBT

The block diagram for simulating the coexistence of U-LTE with Wi-Fi/IoT without LBT is shown in Fig. 5. Two separate sources, one for LTE and other for Wi-Fi/IoT generates multiple signals in random fashion with respective energy and transmission time. The Channel allocation system allocates the available free channels for the successful transmission between respective source and sink. The U-LTE and Wi-Fi/IoT systems occupies the available free channel, transmits for its respective time duration and leaves the channel free making it available for other contenting LTE or Wi-Fi/IoT sources. But, LTE systems, being high demand in nature, and

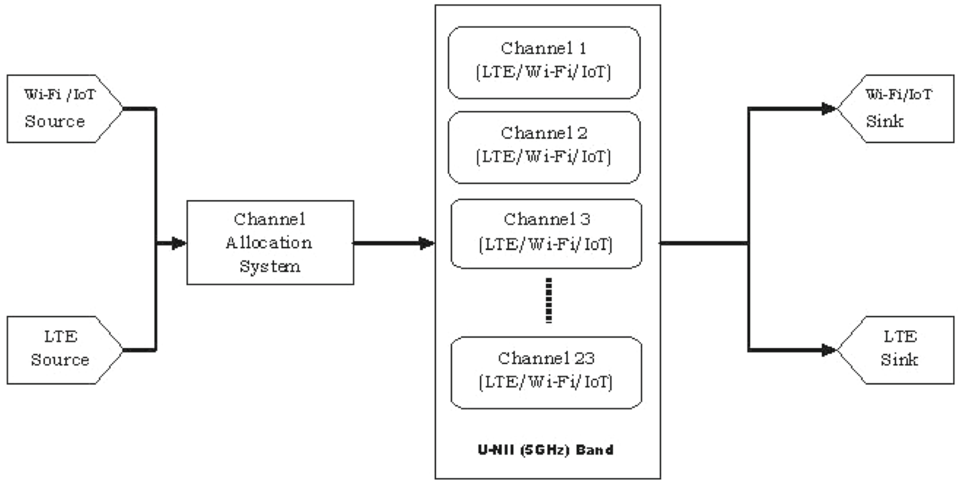

Fig. 5 Block diagram of channel allocation in non-LBT scenario without cognitive radio

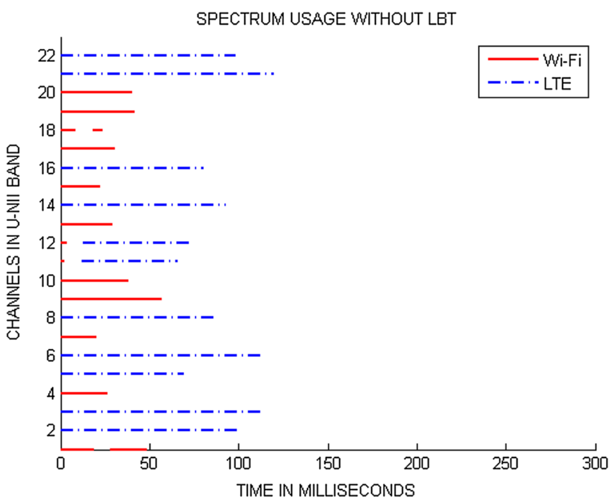

Fig. 6 Scenario 1: initial channel occupancy status between Wi-Fi and U_LTE signals in Non-LBT

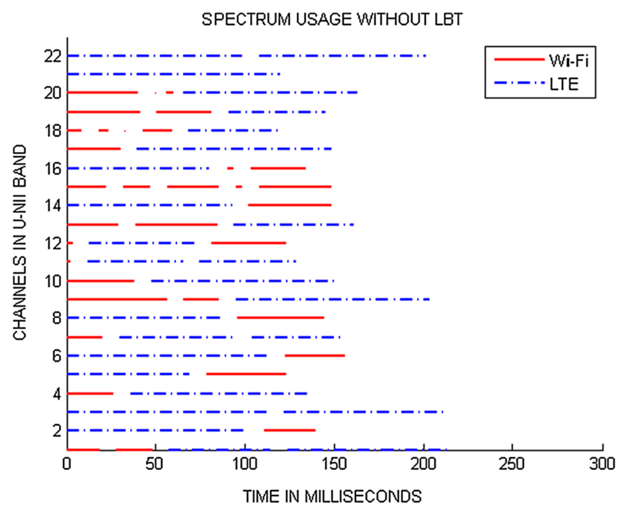

Fig. 7 Scenario 2: Channel occupancy status with increased number of U-LTE signals in Non-LBT

with long communication duration, occupies the channels and seldom leaves. 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.

Considering a smallcell / femtocell, the number of users assumed to be minimum of 10 and maximum of 500. The two scenarios depicting coexistence of U-LTE with Wi-Fi/IoT without LBT at different continuous instances of time for 100 users are shown in Figs. 6 and 7. In Fig. 6, the channel occupancy status during the initial time span of 100 ms is shown. During that time, 13 channels out of 23 are occupied by Wi-Fi/IoT signals and the remaining 10 channels are occupied by U-LTE signals. Therefore, channels of U-NII band have been occupied almost fairly by U-LTE and Wi-Fi/IoT systems during the initial phase of channel allocation.

Figure 7 depicts the channel occupancy status at later time after 200 ms. Here, only eight channels are occupied by Wi-Fi/IoT signals whereas remaining 15 are occupied by U-LTE signals. Due to high demand nature of LTE, the channels are occupied by them leaves no space for Wi-Fi systems and hence they results in high back off rate.

The simulation was studied with different number of users ranging from 10, 20, and 30 up to 500 in order to analyze the back off rate of Wi-Fi/IoT signals. The average back off rate of Wi-Fi/IoT signals is almost 50% higher than LTE with increase in number of users and is shown in Fig. 8.

6.2 Coexistence of U-LTE with Wi-Fi / IoT with LBT using CR system

The block diagram for simulating the coexistence of U-LTE with Wi-Fi/IoT with LBT using CR is shown in Fig. 9. As similar to non-LBT simulation system, there are two separate sources, one for LTE and other for Wi-Fi/IoT gen-

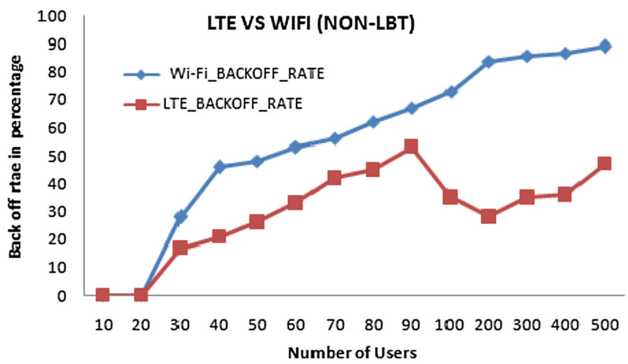

Fig. 8 Back off rate of LTE and Wi-Fi/IoT signals in Non-LBT Scenario

erating multiple signals in random fashion with respective energy and transmission time. Due to the application of CR in this system model, Wi-Fi/IoT systems are considered as the primary users and U-LTE systems as secondary users. Incoming signals from Wi-Fi/IoT sources occupy the channels by following their own MAC protocol by means of Channel allocation system. Whereas, U-LTE signals, in order to accomplish LBT feature, they follows the ETSI standards [28] for channel occupancy through CR system.

The CR system assumed to be in the LTE access point, on getting a transmission request from LTE source, identifies the white space (free channel) in U-NII band and estimates the clear channel assessment (CCA) threshold. CCA threshold is estimated by measuring the energy level of the free channel for a listening period of 20 µs. If the energy level in the channel is below -80 dBm for the listening period of 20 µs, considering it as low interference level in the channel and assumed to be free. The Channel is then allocated for the U-LTE signal transmissions for the duration equal to Channel Occupancy Time of 10 ms. After that, if LTE source wishes to continue its transmission, it has to repeat the white space detection and CCA process for channel allocation. On every channel request and allocation process, the Channel Occupancy time for LTE source is maximum 10 ms. Therefore, the above process is repeated until LTE source completes with its transmission.

On every cycle, the channel allocated for LTE transmissions is different or same based on the free channel availability.

The two scenarios depicting coexistence of U-LTE with Wi-Fi/IoT with LBT using CR at different continuous instances of time for 100 users are shown in Figs. 10 and 11. In Fig. 10, the channel occupancy status during the initial time span of 100ms is shown. During that time, 13 channels out of 23 are occupied by Wi-Fi/IoT signals and the remaining ten channels are occupied by U-LTE signals. Therefore, channels of U-NII band have been occupied almost fairly by U-LTE and Wi-Fi/IoT systems during the initial phase of channel allocation.

Figure 11 depicts the channel occupancy status at later time after 200 ms. Here, Wi-Fi/IoT signals occupy 15 channels and 8 by U-LTE signals. The channel occupancy measure of Wi-Fi/IoT systems is almost same as that of an earlier time span. Maintaining almost the same channel occupancy status even after the later time span depicts the fair and friendly sharing of channels between Wi-Fi/IoT and U-LTE signals. This leads to the reduced back off rate of Wi-Fi/IoT systems.

The simulation was studied with different number of users ranging from 10, 20, and 30 up to 500 in order to analyze the back off rate of Wi-Fi/IoT signals. The average back off rate of Wi-Fi/IoT signals is almost equivalent to LTE and they were maintained at minimum level even with increased number of users and are shown in Fig. 12.

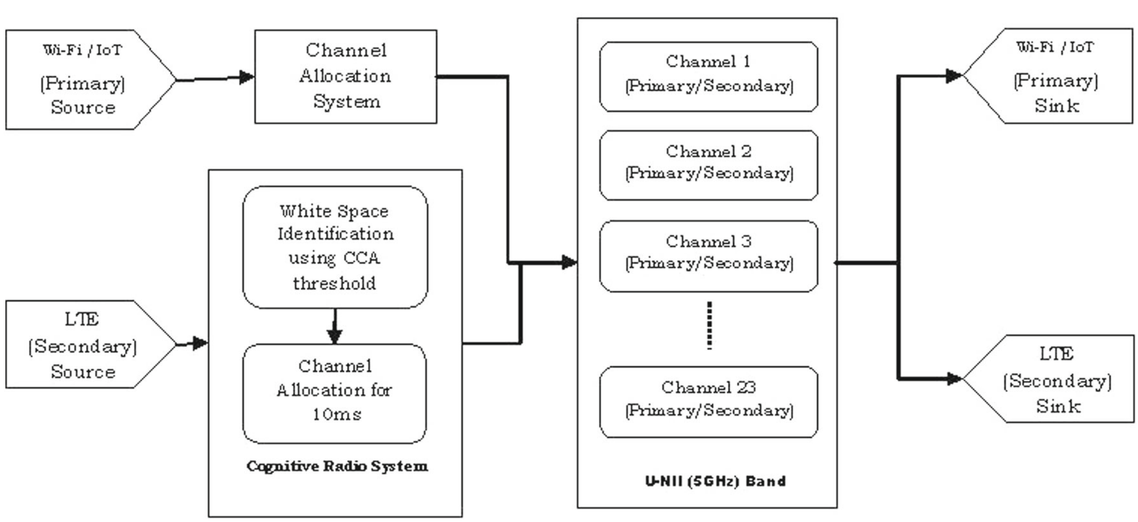

Fig. 9 Block diagram of channel allocation in LBT scenario with application of cognitive radio

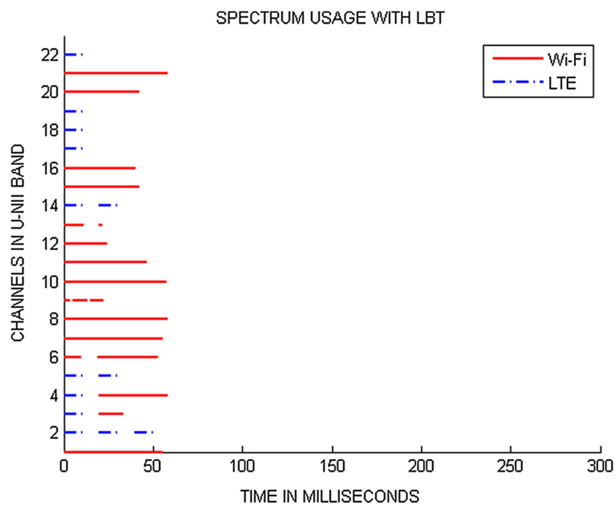

Fig. 10 Scenario 1: initial channel occupancy status between Wi-Fi and U_LTE in LBT using CR

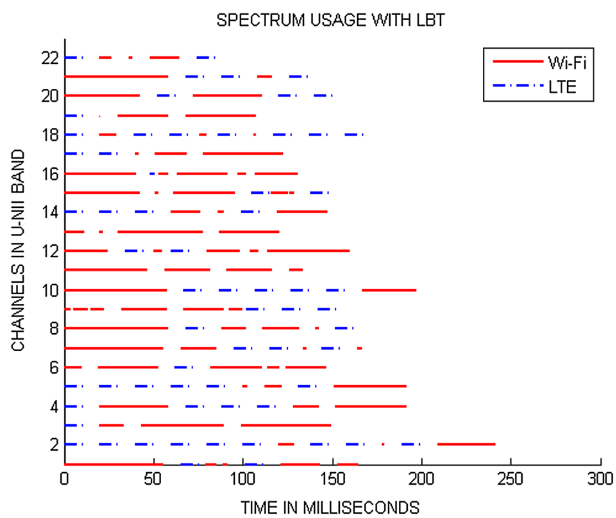

Fig. 11 Scenario 2: initial channel occupancy status between Wi-Fi and U_LTE in LBT using CR

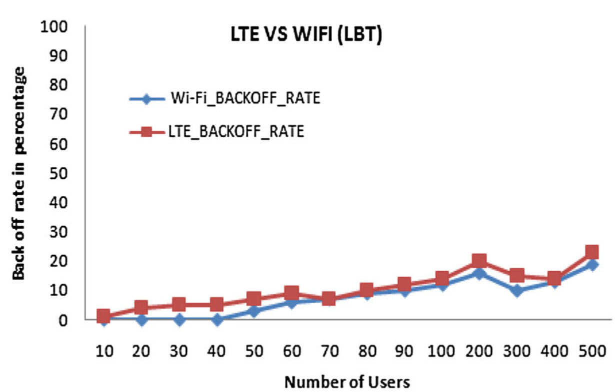

Fig. 12 Back off rate of LTE and Wi-Fi/IoT signals in LBT scenario using CR

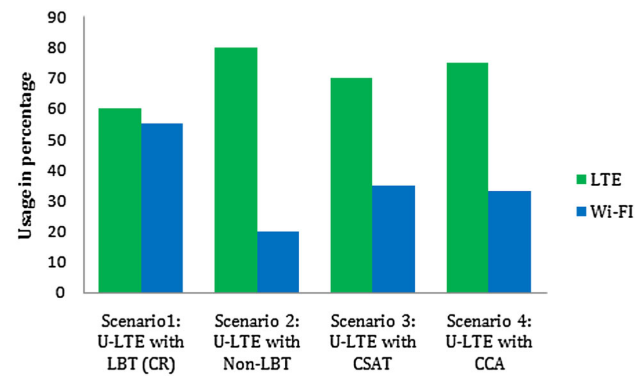

Fig. 13 Performance comparison of and LBT (CR with existing techniques

7 Performance comparison

The proposed system has been evaluated and the performance is compared with three other existing methods. The comparison results of four scenarios are presented in Fig. 13. The performance in terms of channel utilization is analyzed for an average of 100 users in the network. In Fig. 13 for scenario 1, the channel utilization is equal for U-LTE and Wi-Fi/IoT users. In scenario 2, without LBT, Wi-Fi/IoT users are severely deferred by the U-LTE users and the channel utilization is reduced to 36% of scenario 1.

Furthermore, implementing TDM cycling and CCA for coexistence mechanisms are shown in scenario 3 and 4. Though the channel utilization percentage of Wi-Fi/IoT users in those scenarios got increased to 50% of scenario 1, the LTE users are dominating the network and the Wi-Fi back off rate is still prominent. Hence, performance of scenario 1 can be appreciated as it proves the fair and friendly sharing nature of LTE in the unlicensed band by occupying the spectrum at its free time, without causing interference and denying the space for the incumbent Wi-Fi users.

8 Conclusion

The spectrum utilization of radio frequencies is gaining momentum due to the invasion of wireless equipment 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 later 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. Also, the importance of saving 5GHz band for the next generation wireless communications is addressed by utilizing the spectrum in fair and friendly basis. The basic attributes of channel searching and channel allocation 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 simulation results of coexistence of U-LTE and Wi-Fi in unlicensed 5 GHz band in LBT fashion is presented to support the fair and friendly sharing of spectrum between them.

In this work, only SDL mode is considered, where the unlicensed spectrum is used for downlink traffic alone. In future work, the utilization of unlicensed spectrum for both uplink and downlink traffic will be considered and the coexistence of U-LTE along with incumbent users in such scenarios will be studied. The size and the cost of implementing CR in UEs raise the challenges to realize the LBT feature and are under future research.

9 Future reference

In this work, only SDL mode is considered, where the unlicensed spectrum is used for downlink traffic alone. In future work, the utilization of unlicensed spectrum for both uplink and downlink traffic will be considered and the coexistence of U-LTE along with incumbent users in such scenarios will be studied. The size and the cost of implementing CR in UEs raise the challenges to realize the LBT feature and are under future research.

Moreover, in contrast to the above work, CR s can be endowed as "brain" in IoT devices to enable them to choose the best segments of the network and best frequency bands. Their ability to adapt its internal radio parameters to avoid capacity and congestion issues caused by environmental changes ensures to provide optimal service to end-users.

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