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Enhanced Grant-Less Multiple Sub Frame Scheduled Uplink Transmission For Enhancement On U-Lte-Wi-Fi/Iot Through Cognitive Radio

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Abstract—The Unlicensed Long Term Evolution (U-LTE) is actually one of the interesting research fields that allows 5GHz unlicensed connectivity, thereby improving the efficiency and reliability of communications. The primary drawback of contributing to these frequency bands is the necessity for co-occurrence with Wi-Fi/IoT devices. This limitation was resolved by the Cognitive Radio Network (CRN) which utilizes the Enhanced Conflict Tolerance (ECT) and Listen-Before-Talk (LBT) schemes to co-occur with U-LTE and Wi-Fi/IoT networks. Nevertheless, it was addressed that the efficiency of scheduled Uplink Transmission (UT) in unlicensed band and the channel access likelihood for the UE were decreased because of the dual LBT requirements at both eNB and User Equipment (UEs). Therefore in this article, a novelUTmechanism in the co-occurrence of U-LTE-Wi-Fi/IoT systems including ECT-LBT is proposedto enhance the UTautonomously based on the Grant-less Multiple Subframe Scheduled Uplink (GMSSUL) transmission. This scheme has the objective of effectively enhancing the efficiency of uplink and downlink together in data transmission.In this scheme, the channel sensing is executed by the UE with uplink data and the fair co-occurrence is preserved by implementing Cat.4 LBT. The UE uses total Highest Channel Possession Time (HCPT) for packet transfer and requires feedback information for Amalgam Automatic Repeat Request (AARQ) process. Further, the uplink subframe is enhanced by proposing Multi-Subframe Scheduling (MSS) that allows multiple channel sensing and simultaneous data transmission. Eventually, the simulation outcomes illustrate the proposed system achieves higher spectral efficiency and throughput than the existing system.

Keywords—Unlicensed LTE, Cognitive radio network, Wi-Fi/IoT, ECT-LBT, Grant-less UT, Multi-subframe scheduling.

Introduction

Mainly, cellular networks of the fourth generation (4G), commonly termed as LTE networks are evolved with the goal of transmitting a large amount of data through digital platforms.

The reduction in cell size is not only the response to data demands; it also needs more bandwidth. A promising opportunity for LTE providers is extended by the allocation of unlicensed spectrum together with licensed bands to fulfil the network demands of their users. The 3rd Generation Partnership Project (3GPP) has supported the implementation of LTE to support very high data requirements in new digital systems.In fact, 3GPP LTE-A has established an integration of authorized and unauthorized spectrum in femtocells to gain improved login awareness [1-5]. By comparison, the distribution of authorized frequencies limits service providers. As a part of these limitations, LTE is permitted to run on the unauthorized spectrum utilized by the Wi-Fi/IoT applications [6-8]. As 5GHz has several hundred MHz of spectrum coverage, U-LTE has been promoted to provide 5GHz Industrial Scientific and Medical (ISM) exposure [9-10]. The aim of U-LTE is to utilize the characteristics in the most modern LTE 3GPP specifications and adapting them to unlicensed operation in states such as the US and China that do not mandate LBT [11]. It supports supplemental downlink only within the frequency bands 5150-5250MHz and 5725-5850MHz, whereas the frequency bands 5250-5725MHz has been reserved for future use [12-13]. The main limitation of using such frequencies is that the use of LBT is required with other Wi-Fi/IoT applications [14].To overcome this criterion, the LBT specifications of CRN for the effective use of the 5GHz band have been enhanced by the U-LTE [15]. This strategy has two main goals: a) accomplish a U-LTE LBT specification [16] and b) improve their co-occurrence with Wi-Fi/IoT clientsthrough minimizing the back-off threshold of Wi-Fi in a non-interference manner. In fact, U-LTE's key features for new channel requests and the co-occurrence of secondary users with main users have been streamlined by using the basic feature of channel selection and allocation. Nevertheless, the unauthorized bandwidth was utilized only for downlink traffic. The performance and reliability of the spectrum were also not improved. As a result, improvement on opportunistic co-occurrenceof U-LTE-Wi-Fi/IoT with ECT-LBT using CRN was proposed (shortly known as E-U-LTE-Wi-Fi) [17]. The License Assisted Access (LAA) platform was first developed to improve the LBT process. In complex implementation situations, the channel control issue hence was resolved by adopting the LTE duty cycle. In addition, a Low Amplitude Stream Injection (LASI) mechanism was planned for facilitating concurrentWi-Fi-LTE data sharing on a common channel and the recovery of information from collisions was also suggested. CTCA algorithms have further developed for optimizing the channel distribution and maximizing bandwidth use at 5GHz.In fact, it was suggested to implement an improved Cell ON/OFF method that could greatly enhance the bandwidth utilization and maximize cellular services by extending LTE to unauthorized spectrum. Therefore, the Spectrum Efficiency (SE) and throughput were maximized with reduced Transmission Delay (TD).Nevertheless, it was observed that the expected UT performance was greatly degraded in the unlicensed spectrum by eNB and UE dual LBT criteria. In addition to this problem, efficiency loss was occurred due to the reduction in channel access likelihood for the UE.Hence in this article, anUT enhancement ofE-U-LTE-Wi-Fi/IoT,namely Desirable U-LTE-Wi-Fi (D-U-LTE-Wi-Fi) is proposed. In this enhancement, a novel UT scheme is considered that does not require any eNB scheduling scheme to enhance the uplink performance based on the GMSSULtransmission for LTE in unlicensed band. Initially, Cat4.LBT based channel sensing is performed by the UE with uplink data for achieving the fair co-occurrence. For detecting the Uplink Burst(UB) at anchored eNB, a preamble signal is essential before the data transfer and a reservation signal is crucial for supporting the predefined boundary. After that, the whole HCPT is used by the UE for transferring data and the feedback information for AARQ is required by the eNB. Moreover, the MSS is applied to enhance the uplink subframe by allowing a UE to enclose many channel sensing chances and constantly transfer data for many subframes. Thus, this system improves the UT on both licensed and unlicensed band.

II. LITERATURE SURVEY

Plets et al. [18] investigated the effect of reducingthe uplink and downlink coverage in different scenarios. Also, the impact of uplink utilization on the entire coverage was characterized and downlink coverage reduction was noticed for different number of base stations. However, it requires analysing the effect of the number of users and their profile use on the original duty cycle of an AP. Sumathi et al. [19] realized the U-LTE-Wi-Fi-LBT for identifying the white spaces in unlicensed band using CRN that achieves the LBT regulatory demand in U-LTE. But, the spectrum distribution among U-LTE-Wi-Fi was not effective. Asheralieva&Miyanaga [20] proposed a combined spectrum and energy distribution in LTE-CRN on the basis of user's buffer use in both uplink and downlink directions to assign the network resources. Nonetheless, this method has high computational complexity. Li et al. [21] proposed a LBT with an adaptive threshold algorithm in which the transmission was modelled via M/GI/1 queuing method [22]. After that, the Clear Channel Assessment (CCA) threshold [23] was controlled by the BS based on the queue size for adjusting the varied traffic under QoS criteria. However, SE was not analysed. Further, a co-occurrence scheme [24] was proposed using Direction of Arrival (DoA) estimation [25] for creating chances for LTE-LAA-Wi-Fi systems [26] in order to transfer the data concurrently. However, the resource allocation and scheduling mechanisms were required to increase the SE. Karaki et al. [27] investigated uplink efficiency of enhanced LAA (eLAA) in unlicensed spectrum to tackle grant, Scheduling Request (SR) overhead and delay. However, the uplink channel access probability was reduced due to the utilization of two stage modality for LBT. Ajami&Artail [28] considered Wi-Fi where stochastic geometry was used for modelling and analysing the co-occurrence of LTE with concurrent uplink and downlink transfers. However, the QoS performance was not effective and the interference among LTE-Wi-Fi was not avoided.

III. PROPOSED METHODOLOGY

In this section, the D-U-LTE-Wi-Fisystem is explained briefly. At first, the primary users are initiated via communicating UE devices with Wi-Fi AP by means of an unlicensed spectrum. Additionally, the secondary users are via communicating UE with eNB. To enhance the uplink performance, UE performs the channel sensing by means of uplink information and considers the Cat.4 LBT for maintaining the better co-occurrence. In this system, a preamble signal is essential before the data transfer to identify the UB at the anchored eNB. Also, a reservation signal is needed for aligning the predefined boundary of uplink subframe. Then, anentire HCPT is used by the UE for transferring the information rather than distributed with downlink. Moreover, the ACK/NACK feedback data is required by eNB for AARQ procedure. The flow diagram of this proposed system is shown in Fig. 1.

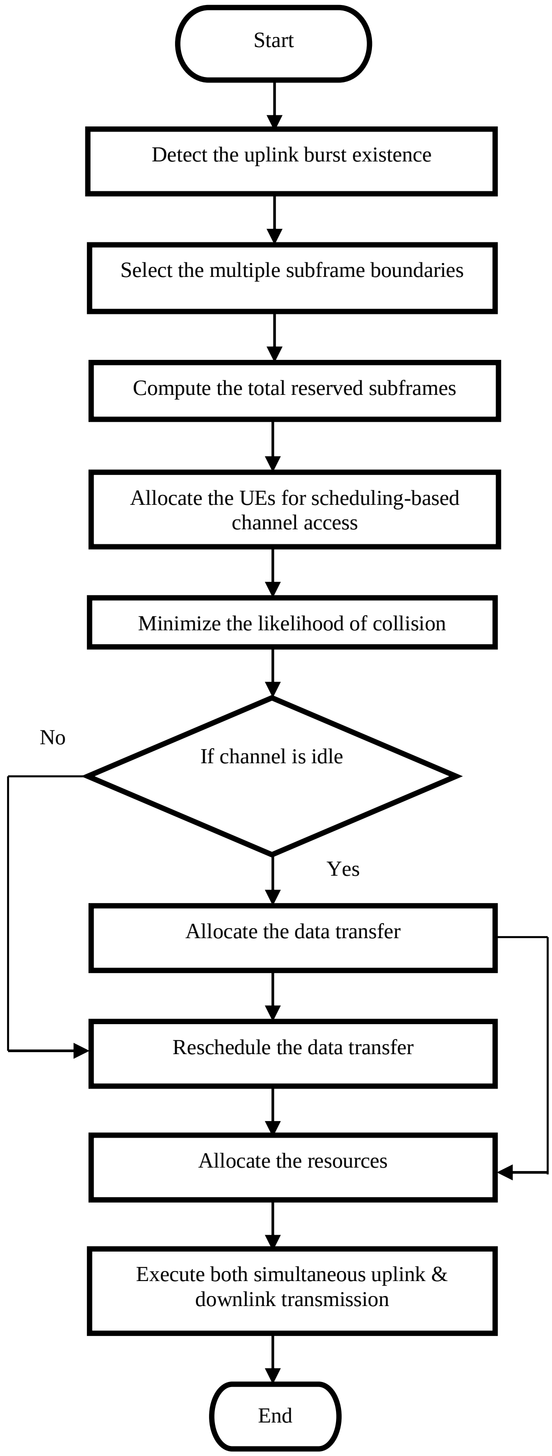

Fig. 1Flow Diagram of the D-U-LTE-Wi-Fi System

A. Detection of Uplink Burst Existence

The existence of the UB is detected by the UE on the basis of two schemes such are:

- Direct scheme: The direct scheme uses the uplink controller to give an additional data concerning the UB.

- Indirect scheme: The indirect scheme executes the blind detection of the demodulation Reference Signal (RS) to collect the information about the occurrence of Physical (PHY) uplink distributed channel.

B. Choice of Multiple Subframe Boundaries for Enhancing Uplink Performance

To enhance the uplink performance, the uplink subframes are required to make use of the time intervals from the LBT ends to the primary user subframe boundary. For this reason, different kinds of uplink subframes are adopted. They are:

- Synchronous subframe: This kind of subframe is aligned with the primary user subframe boundary to reduce the influence on execution. In this model, a partial subframe is defined on the subset of Orthogonal Frequency Division Multiplexing (OFDM) symbols within the uplink subframe while the primary user still associated in terms of timing correlation with the UBtransfer. In this scenario, the PHY uplink distributed channel communication is initiated by the UE at locations of specified OFDM symbol in a subframe to reduce the UE scheduling difficulty.
- Asynchronous subframe: This kind of subframe is not associated with the primary user boundary. Only if the channel is acquired through LBT, the UT is achieved by the UE on the basis of the legacy 1ms subframe choice.

In particular, the UE needs to allocate the multiple possible partial subframes respective to the various hypotheses of potential partial subframes since the UE knows the partial time duration. Nevertheless, this acquires the large computation and buffer complexity at the UE. In this scenario, the timing correlation with the UB transfer is not kept for channel access over an unlicensed band resulting in lacks of resource allocation. To solve this problem and achieve effective resource usage, two categories of MSS is introduced across multiple subframes.

- In the primary category, the data is transferred for multiple subframes by the UE to increase the throughput while increasing the number of subframes allocated for data transfer.
- In the secondary category, the chance of multiple channel sensing is defined to increase the likelihood of the UE for detecting an inactive/busy channel and the resource usage.

Let each UE be regularly demanding for data transfer and the eNB scheduling UEs for UT. Consider the time interval of each subframe is s and

$$\mathrm{s} \geq \mathrm{L} + \mathrm{K} - 1 \text{ for } \mathrm{S}(\mathrm{K}, \mathrm{L}) \quad (1)$$

In Eq. (1), K refers to the channel and L refers to the subframe since L and $\mathrm{K} - 1$subframes are kept for data transfer and further CCA chances, correspondingly. The total reserved subframes are called as the LAA chance.

$$\begin{cases} \mathrm{s} > L + K - 1, & \text{Inactive time length} > 0 \; between\ twoy\ LAA\ opportunities \\ \mathrm{s} < L + K - 1, & \text{Inactive time of length} < 0 \\ \mathrm{s} = \mathrm{L} + \mathrm{K} - 1, & \text{Inactive time of length equal to } 0 \end{cases}$$

(2)

A specific UE is allocated for the scheduling-based channel access by the eNB to achieve possible UT in every round. The allocated UE can execute the CCA prior to execute the LAA chance. If the channel is identified as inactive, then the packet is transmitted for Lms. Or else, the data transfer is rescheduled for 1ms and the CCA is executed after the delay. This process is continued until all the K CCA chances are applied. On the other hand, all N UEs are allocated for random access by the eNB to achieve the possible data transfer. In this scenario, the CCA is executed before executing the LAA chance by all UEs. The following model is adopted for reducing the likelihood of collision since the collision may exist if many UEs detect the inactive channel and transfer the data: For the detected inactive channel, every UE allocates the data transfer with likelihood p_i and allocates no data transfer with likelihood $1 - p_i$. If the UE senses the channel to be busy, then the packet transfer is rescheduled for 1ms and the CCA is executed after the retransfer. This process is repeated for all K CCA chances are applied. Consider that $1 < K \leq L$ with the intent that if UE initiates data transfer after i^{th} CCA, then the channel is detected as busy by other UEs for the remaining CCAs i.e., CCA $i + 1$, CCA $i + 2$,...,CCA K.

C. Resource Allocation and Scheduling for Simultaneous Uplink and Downlink Transmission

Instead of the signal from the serving eNB, the UE will assign the resources separately in GUL mode. For both UE scheduling and eNB demodulation, a precise Channel State Information (CSI) is essential. As well, the feedback information is needed for UE for retransmitting the AARQ.The process for resource allocation and scheduling is the following:

- Initially, the uplink CSI is measured by the eNB on the basis of RSs from the UE. Particularly, the RSs are reused and transferred in the last OFDM symbol along with the CSI demand.
- Then, the suitable MCS for UE is decided by the eNB. In contrary, the UE itself requests CSI to decide the suitable modulation and coding mechanism.
- Then, the data including the scheduling information is transferred by the UE via PHY uplink controller.
- After the uplink information is received, the ACK/NACK feedback information is sent by eNB via PHY downlink controller.

For both uplink and downlink adaptation, the following solutions are considered:

- The eNBs feedback the uplink CSI dynamically for deciding the modulation and coding mechanism while indicating the AARQ ACK/NACK feedback.
- The UEs decide the modulation and coding mechanism which is indicated in the latest downlink control information.

During simultaneous uplink and downlink transmission, the carrier signal in the UT is preserved by multiplexing the control signal and data carrier to the Discrete Fourier Transform (DFT). The control signal consists of:

- Network short-term identifier;
- AARQ process number;
- New information indicator to declare whether the current broadcast is a rebroadcast or not;
- HCPT and UB related data;
- Carrier signal;
- CSI and AARQ ACK/NACK data

For reducing the control overhead, few data like CSI and AARQ ACK/NACK data are chosen for transmission whereas the other data are transferred in each subframe.

IV. SIMULATION RESULTS

In this part, the efficiency of D-U-LTE-Wi-Fisystem is analysed in MATLAB 2016a and compared to the existing E-U-LTE-Wi-Fi system in terms of SE, throughput, Average Transmission Number (ATN), TD, Signal-to-Interference Noise Ratio (SINR) and interference. The system model is simulated by using the simulation parameters in [17].

A. Spectrum Efficiency

It defines the fraction of transmission number and spectrum bandwidth.

$$\text{Spectrum Efficiency} = \frac{\text{Transmission number}}{\text{Spectrum bandwidth}} \qquad (3)$$

The results of SE for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi systems are provided in Table 1.

Table 1: Analysis of SE

No. of UEs	Spectrum Efficiency (MHz)	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
50	163.121	173.061
100	176.810	186.95
150	185.375	195.549
200	205.051	215.442
250	230.040	241.524
300	246.807	260.730
350	282.422	291.235
400	322.228	331.57
450	345.263	356.45
500	388.285	399.425

Fig. 2 illustrates the SE of E-U-LTE-Wi-Fi and D-U-LTE-Wi-Fi. When the amount of UEs is 500, the SE of D-U-LTE-Wi-Fi is 4.76% superior to E-U-LTE-Wi-Fi system. This indicates that the D-U-LTE-Wi-Fi system achieves higher SE than the existing E-U-LTE-Wi-Fi. For enhancing the uplink efficiency, the proposed D-U-LTE-Wi-Fi adopts GMSSUL scheme whereas existing E-U-LTE-Wi-Fi system adopts ECT-LBT scheme for enhancing only the downlink efficiency. Thus, the performance in terms of SE for both downlink and uplink can be increased by the proposed D-U-LTE-Wi-Fi system that enhances performance of both uplink and downlink transmission.

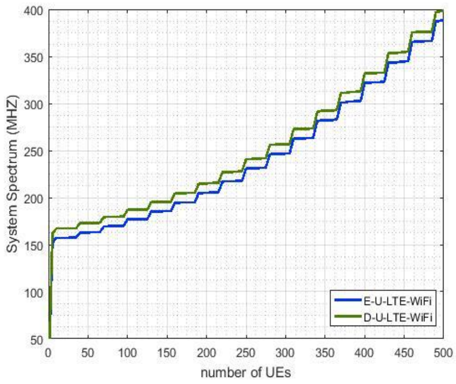

Fig. 2 SE vs. Number of UEs

B. Throughput

It defines the amount of data forwarded between channels in aunit time.The results of throughput for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi are given in Table 2.

Table 2: Analysis of Throughput

No. of UEs	Throughput (Mbps)	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
50	52	62
100	64	75
150	81	93
200	95	105
250	110.5	120
300	123	129.5
350	124	135
400	119	130
450	114	126
500	111	122.5

Fig. 3 demonstrates the throughput of D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi. For 500 UEs, the throughput of D-U-LTE-Wi-Fi is 5.88% increased than E-U-LTE-Wi-Fi system. Thus, it notices that the D-U-LTE-Wi-Fi system has the maximum throughput than the E-U-LTE-Wi-Fi. While GMSSUL scheme is adopted for the enhancing uplink performance and that the proposed D-U-LTE-Wi-Fi system facilitates to improve significantly its performance. As for the downlink enhancement, ECT-LBT scheme is adopted. As a result, performance in terms of network throughput of both downlink and uplink is significantly increased with the proposed D-U-LTE-Wi-Fi system compared to the E-U-LTE-Wi-Fi system.

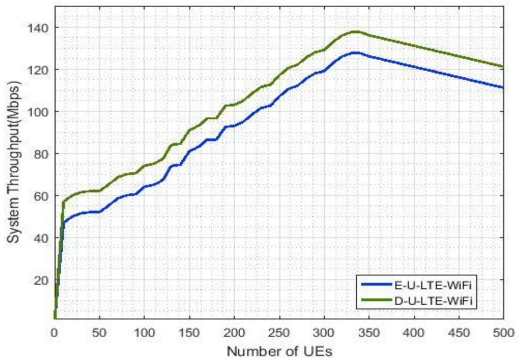

Fig. 3 Throughput vs. Number of UEs

C. Transmission Time Delay

It refers to the time taken to transmit a packet.The results of system TD for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi are given in Table 3.

Table 3: Analysis of System TD

No. of UEs	System TD (sec)	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
50	26.14	23.31
100	26.22	23.25
150	26.36	23.22
200	26.42	23.18
250	26.55	23.16
300	26.67	23.15
350	26.76	23.13
400	26.88	23.10
450	26.95	23.08
500	26.99	23.05

Fig. 4 illustrates the system TD for E-U-LTE-Wi-Fi and D-U-LTE-Wi-Fi systems. If the amount of UEs is 500, then the system TD of D-U-LTE-Wi-Fi system is 6.01% less than E-U-LTE-Wi-Fi. As a result, it observes that the D-U-LTE-Wi-Fi system has the reduced TD than the E-U-LTE-Wi-Fi significantly. While using grant-less multiple subframes for uplink data transmission, the TD can be minimized significantly. As for downlink performance, enhanced cell ON/OFF mechanism is adopted for simultaneous data transmission. By having both mechanisms in the proposed D-U-LTE-Wi-Fi system, the TD can be reduced significantly compared to the E-U-LTE-Wi-Fi system.

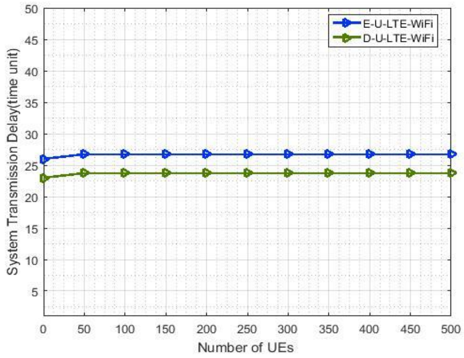

Fig. 4 System TD vs. Number of UEs

D. Average Transmission Number

It indicates that number of packets might be sent/second/link. The links include both LTE and Wi-Filinks

$\mathrm{ATN} = \sum_{i=1}^{n} \mathrm{TN_i} + \sum_{j=1}^{m} \mathrm{TN_j}$ (4)

In Eq. (4), $n$is the number of Wi-Ficonnections, $m$is the amount of LTE connections, $\mathrm{TN_i}$ and $\mathrm{TN_j}$are the transmission number of Wi-Fi link i and LTE link j. The results of ATN for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi are given in Table 4.

Table 4: Analysis of ATN

No. of UEs	Average Transmission Number	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
50	223.41	254.24
100	210.86	246.14
150	207.82	228.62
200	201.34	224.19
250	194.58	223.29
300	178.43	215.28
350	174.34	198.79
400	172.77	198.26
450	171.33	192.56

Fig. 5 shows the ATN for E-U-LTE-Wi-Fi and D-U-LTE-Wi-Fi systems. While the amount of UEs is 500, the ATN of D-U-LTE-Wi-Fi is 13.29% increased than E-U-LTE-Wi-Fi. Through this observation, it indicates that the D-U-LTE-Wi-Fi system has high average number of transmission than the E-U-LTE-Wi-Fi. By achieving the data transmission through grant-less multiple subframes and conflict-tolerant channels, the proposed D-U-LTE-Wi-Fi system increases the ATN compared to the E-U-LTE-Wi-Fi system.

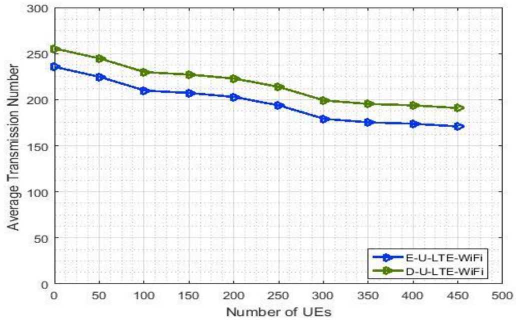

Fig. 5 ATN vs. Number of UEs

E. SINR

The SINR for user i in the D-U-LTE-Wi-Fi scenario is computed as:

$$\mathrm{SINR_i} = \frac{p_{\mathrm{D-U-LTE-Wi-Fi,i}} \times G_{\mathrm{D-U-LTE-Wi-Fi}}}{I_{\mathrm{D-U-LTE-Wi-Fi\ network}}} \quad (5)$$

In Eq. (5), $p_{\mathrm{D-U-LTE-WiFi,i}}$ is the total power at eNB from UE i, $G_{\mathrm{D-U-LTE-WiFi,i}}$ is the channel gain between U-LTE and Wi-Fi and $I_{\mathrm{D-U-LTE-WiFi\ network}}$ is the total interferences in the D-U-LTE-Wi-Fi. The results of SIR for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi are given in Table 5.

Table 5: Analysis of SINR

UE Distance from eNB (m)	SINR (dB)	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
5	11.0	9.9
20	9.8	8.2
40	7.6	6.0
60	6.1	4.9
80	5.9	3.7
100	4.3	2.0
120	2.1	1.1

Fig. 6 shows the SINR for E-U-LTE-Wi-Fi and D-U-LTE-Wi-Fi systems. While the amount of UEs is 120, the SINR of D-U-LTE-Wi-Fi is 47.62% decreased than E-U-LTE-Wi-Fi. Through this observation, it indicates that the D-U-LTE-Wi-Fi system has reduced SINR than the E-U-LTE-Wi-Fi. By tolerating the conflict channels during data transmission and allocating the grant-less multiple subframes, the proposed D-U-LTE-Wi-Fi system reduces the SINR compared to the E-U-LTE-Wi-Fi system.

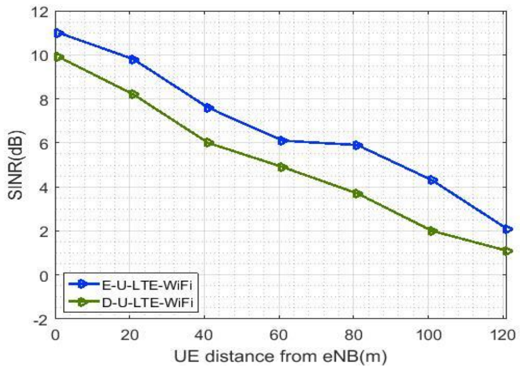

Fig. 6 SINR vs. UE Distance from eNB

F. Interference

It refers to the total interferences caused by the D-U-LTE-Wi-Fi scenario. The results of interferences for D-U-LTE-Wi-Fi and E-U-LTE-Wi-Fi are given in Table 6.

Table 6: Analysis of Interference

UE Distance from eNB (m)	Interference (dB)	
	E-U-LTE-Wi-Fi	D-U-LTE-Wi-Fi
0	-180	-200
20	-162	-185
40	-143	-168
60	-125	-152
80	-108	-132
100	-98	-111
120	-82	-89

Fig. 7 shows the interference for E-U-LTE-Wi-Fi and D-U-LTE-Wi-Fi systems. While the amount of UEs is 120, the interference of D-U-LTE-Wi-Fi is -89dB which is less than the interference of E-U-LTE-Wi-Fi i.e., -82dB. Through this observation, it indicates that the D-U-LTE-Wi-Fi system has less interference than the E-U-LTE-Wi-Fi due to the allocation of conflict-free channels and grant-less multiple subframes.

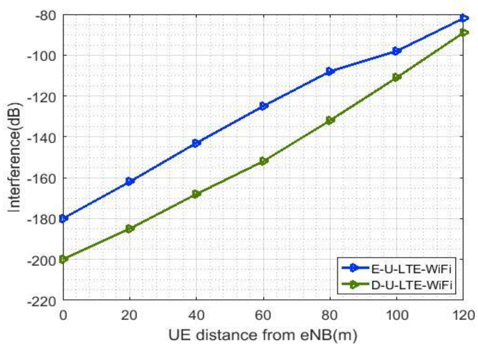

Fig. 7Interference vs. UE Distance from eNB

V. CONCLUSION

In this article, a novel UT scheme is proposed included E-U-LTE-Wi-Fi for improving the uplink performance. In this scheme, GUL transmission is proposed in which the UE performs the channel sensing with the aid of uplink data. During channel sensing, the fair co-occurrence is maintained by adopting Cat.4 LBT. For improving the UT performance, the UE uses whole HCPT for data transmission and feedback information for AARQ retransmission.However, the resource allocation is performed on the single subframe whereas the UE requires multiple subframes to enhance the simultaneous uplink & downlink transmission efficiently and reduce the inefficient resource utilization. Therefore, MSS is proposed to further improve the uplink subframe that allows multiple channel sensing and simultaneous packet transfer. Finally, the experimental outcomes proved that the D-U-LTE-Wi-Fisystem achieves better SE and throughput with reduced TD, SINRcompared to the existing system.

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