Enabling Fair Spectrum Sharing between Wi-Fi and LTE-Unlicensed

Kuo Chi
College of Computer Science and Technology
Harbin Engineering University
Harbin, P.R.China
chik89769@hrbeu.edu.cn

Longfei Wu
Department of Mathematics and Computer Science
Fayetteville State University
Fayetteville, NC, USA
lwu@uncfsu.edu

Xiaojiang Du
Department of Computer and Information Sciences
Temple University
Philadelphia, USA
dxj@ieee.org

Guisheng Yin
College of Computer Science and Technology
Harbin Engineering University
Harbin, P.R.China
yinguisheng@hrbeu.edu.cn

Jie Wu
Dept. of Computer and Information Sciences
Temple University
Philadelphia, USA
jiewu@temple.edu

Bo Ji
Department of Computer and Information Sciences
Temple University
Philadelphia, USA
boji@temple.edu

Xiali Hei
School of Computing and Informatics
University of Louisiana at Lafayette
Lafayette, USA
xiali.hei@louisiana.edu

***Abstract*—Due to the fast increase of mobile traffic, most mobile network operators face the congestion issue in licensed spectrum bands. Several telecommunication vendors and operators propose to expand LTE service to the unlicensed spectrum bands to relieve the traffic congestion. However, LTE in unlicensed spectrum may interfere with Wi-Fi communications in the same bands and cause significant decrease in the quality of service of Wi-Fi. In this paper, we propose a novel mechanism that enables negotiations between two different wireless technologies (Wi-Fi and LTE), which ensures fair spectrum sharing between Wi-Fi and LTE-Unlicensed (LTE-U) in the same bands. We formulate the co-existence of Wi-Fi and LTE-U as a constrained optimization problem, and we solve the problem. We evaluate the performance of the proposed scheme via NS-3 simulations. The simulation results show that our approach can effectively improve the overall channel utilization and reduce the interference between Wi-Fi and LTE-U.**

Keywords—LTE-U, Wi-Fi, coexistence, spectrum sharing.

I. Introduction

With the fast development of wireless communication technologies, more and more terminal devices have been connected to the network, and the technological standards also have been constantly updated. The former leads to an explosive growth of wireless traffic [1]. At present, mobile data has become a major challenge for mobile operators to maintain high quality of service (QoS) [2]. Although the LTE (Long Term Evolution) network has been widely deployed, the operating frequency bands are overcrowded due to the huge amount of terminal devices to be served. Hence, many OEMs (Original Equipment Manufacturers) and MVNOs (Mobile Virtual Network Operators), such as Qualcomm, Huawei, Ericsson, Verizon, propose to expand LTE to the unlicensed spectrum [3].

However, some unlicensed spectrums, such as 2.4 GHz and 5 GHz bands, have already been in use by the Wi-Fi systems [7]. A new problem has arisen for meeting the QoS requirements of both Wi-Fi and LTE networks. Wi-Fi networks rely on carrier-sensing (CS) and contention-based access to avoid collisions, which makes it hard to compete with the schedule-based LTE networks within the same channel [8]. Therefore, how to enable fair coexistence between Wi-Fi and LTE in unlicensed spectrums has become a critical problem. Several papers (e.g., [6-30]) have studied related wireless issues.

In this paper, we propose a novel mechanism to ensure the fairness among co-existing Wi-Fi and LTE networks. The detail is given in Section III. The remainder of this paper is organized as follows. In Section II, we describe the background and related work about the coexistence of Wi-Fi and LTE. In Section III, we describe the problem and our novel mechanism. In Section IV, we present the optimization problem of the Wi-Fi and LTE spectrum sharing issue. We discuss the performance evaluation in Section V, and conclude the paper in Section VI.

II. Background and Related Work

Wi-Fi, such as 802.11a and 802.11 b/g, mainly operate in the 2.4 GHz band. As the 2.4 GHz band becomes increasingly congested, the 5 GHz band has been used since 802.11n. As the broadband cellular network technology advances to the fourth generation (4G), mobile devices using LTE network produce huge amount of data, and the licensed spectrum bands have been insufficient to satisfy the bandwidth demands. Consequently, attentions from both academia and industry have focused on the unlicensed spectrum bands. It is inevitable to have the competition between Wi-Fi networks and LTE networks in the unlicensed spectrum bands.

In order to reduce the probability of conflict between Wi-Fi and LTE in unlicensed bands, many research works have studied the Wi-Fi and LTE coexistence (e.g., [31-37]). [33] found that the LTE interference may block the transmission of Wi-Fi, which results in a significant decrease of Wi-Fi throughput. [34] leveraged stochastic geometry to characterize the key performance metrics for neighboring Wi-Fi and LTE networks in the unlicensed spectrum bands.

Recently, some approaches (e.g., [35-37]). have been proposed to improve the performance of Wi-Fi and LTE coexistence by providing fairness. However, none of the above works allow Wi-Fi and LTE networks to dynamically exchange information and then adjust their operations accordingly. In this paper, we propose such a mechanism and we present it in the next Section.

III. THE NOVEL SPECTRUM SHARING MECHANISM

A. Problem Description

Consider that an access point (AP) of Wi-Fi provider A and a base station (BS) of LTE operator B within each other's communication range, the AP is connected with a number of mobile stations, and the BS is connected with a number of user equipment devices (UEs). Suppose that we have $n1$ Wi-Fi networks and $n2$ LTE networks co-existing and sharing a number of unlicensed channels for their communications. Without loss of generality, below we consider the case where the networks share a single unlicensed channel.

Let T denote the number of time slots in a communication cycle (a time slot is the minimum time unit for a network to transmit). T_i^w denotes the number of time slots of i^{th} Wi-Fi network within a communication cycle ($i = 1, \dots, n1$), and T_j^l denotes the number of time slots of j^{th} LTE network within a communication cycle ($j = 1, \dots, n2$). A network uses a channel exclusively during its time slots. Let s_i^w denotes the throughput of i^{th} Wi-Fi network in its time slots T_i^w, and s_j^l denotes the throughput of j^{th} LTE network in its time slots T_j^l. s_i^w and s_j^l is the data transmission rate of i^{th} Wi-Fi and j^{th} LTE network, respectively. Table.1 gives the notations that will be used in this paper.

B. The Indirect Communication Mechanism

Direct communication between the AP of one Wi-Fi provider and the LTE BS of another operator is not available because they use different wireless communication technologies.

Considering that many service providers operate both LTE and Wi-Fi networks, e.g., a LTE operator provides both LTE and Wi-Fi service, we propose a novel indirect communication approach between provider A's Wi-Fi and provider B's LTE (see Fig. 1): provider B's LTE BS exchanges information with B's Wi-Fi AP (e.g., via provider B's application layer software), and then B's Wi-Fi AP exchanges information with A's Wi-Fi AP. In this way, one provider's LTE network can indirectly exchange information with another provider's Wi-Fi network. This indirect communication can be utilized to coordinate the two network systems to achieve better fairness in terms of spectrum utilization. The indirect communication may be used for various purposes, such as exchanging spectrum usage information (e.g., throughput, total air time , total amount of transmitted data, etc.), as well as other signaling information relevant to the co-existence of the two systems.

TABLE. 1 SYMBOLS AND THEIR DEFINITION

Symbol	Definition
T	Total numbers of time slots in a communication cycle
T_i^w	Numbers of time slots of Wi-Fi network i in a communication cycle
T_j^l	Numbers of time slots of LTE network j in a communication cycle
$n1$	The numbers of Wi-Fi networks
$n2$	The numbers of LTE networks
s_i^w	Throughput of Wi-Fi network i during time slots T_i^w
s_j^l	Throughput of LTE network j during time slots T_j^l
D_i^w	Transmitted data of Wi-Fi network i in a communication cycle
D_j^l	Transmitted data of LTE network j in a communication cycle
$\bar{D}_i^w$	Minimum threshold of transmitted data of Wi-Fi network i in a communication cycle
$\bar{D}_j^l$	Minimum threshold of transmitted data of LTE network j in a communication cycle
ε_1, ε_2	Preset ratio of transmitted data between Wi-Fi and LTE networks in a communication cycle

The ratio ε_1 and ε_2 are used as the fairness parameters of Wi-Fi and LTE networks, and both are pre-negotiated by the Wi-Fi and LTE operators to balance the spectrum utilization between them. The process of indirect communication between Wi-Fi provider A's AP and LTE operator B's BS can be described as follows: either when one party (e.g., A's Wi-Fi) is not satisfied with the spectrum fairness, or at the end of a communication cycle, A's Wi-Fi AP sends a packet to B's LTE BS via B's Wi-Fi AP, and the packet includes the throughput, total air time, and total amount of transmitted data of A's Wi-Fi AP of this cycle. LTE operator B's BS can compute the new communication time of Wi-Fi and LTE networks based on the pre-negotiated fairness parameters. Then B's LTE BS returns the result to A's Wi-Fi AP via B's Wi-Fi AP. Starting from the next communication cycle, the new communication time of the Wi-Fi and LTE networks will be used. The above process may be repeated as needed.

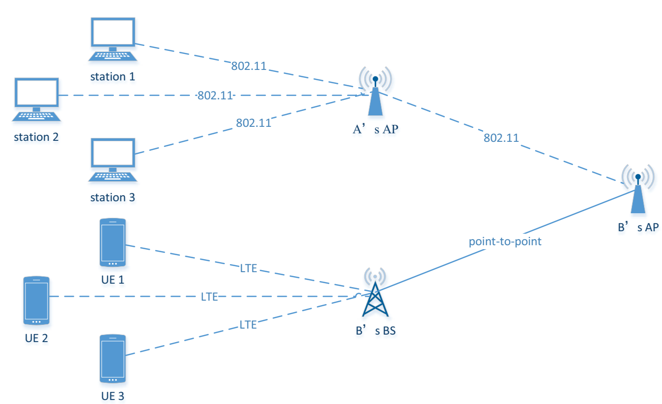

Fig. 1. Indirect communication between A's AP and B's BS via B

IV. THE WI-FI AND LTE COEXISTENCE PROBLEM

The goal of enabling Wi-Fi and LTE networks coexistence in unlicensed bands is to ensure the quality of the communications of all the coexisting Wi-Fi and LTE networks. On this premise, we want to maximize the total amount of data transmitted in a communication cycle.

We formulate this problem as a constrained optimization problem P:

$$\text{Max} \quad \sum_{i=1}^{n1} D_i^w + \sum_{j=1}^{n2} D_j^l \tag{1}$$

$$\text{s.t.} \quad \varepsilon_1 \le \frac{\sum_{i=1}^{n1} D_i^w}{\sum_{j=1}^{n2} D_j^l} \le \varepsilon_2 \tag{2}$$

$$\sum_{i=1}^{n1} t_i^w + \sum_{j=1}^{n2} t_j^l \le T \, , t_i^w, t_j^l = 1, \dots, T \tag{3}$$

$$D_i^w \ge \bar{D}_i^w, \qquad i = 1, \dots, n1 \tag{4}$$

$$D_j^l \ge \bar{D}_j^l, \qquad j = 1, \dots, n2 \tag{5}$$

$$D_i^w = s_i^w \times t_i^w, \qquad i = 1, \dots, n1 \tag{6}$$

$$D_j^l = s_j^l \times t_j^l, \qquad j = 1, \dots, n2 \tag{7}$$

The objective function Eq. (1) is to maximize the transmitted data of all participant Wi-Fi and LTE networks in a communication cycle. In the first constraint condition Eq. (2), the fairness parameter ε_1 and ε_2 are used to balance the need of Wi-Fi and LTE networks. The second constraint condition Eq. (3) is used to guarantee that the transmitted time of all the networks less than the length of a communication cycle. Data thresholds $\bar{D}_i^w$ and $\bar{D}_j^l$ are preset for each Wi-Fi and LTE network and used in the constraint conditions Eq. (4) and (5). Eq. (6) and (7) is the amount of transmitted data of a Wi-Fi or LTE network, respectively.

In order to solve the optimization problem P, we transform it from discrete time to continuous time, and solve the modified problem P'. P' is presented below:

$$\text{Max} \quad \sum_{i=1}^{n1} s_i^w t_i^w + \sum_{j=1}^{n2} s_j^l t_j^l \tag{8}$$

$$\text{s.t.} \quad \frac{\sum_{i=1}^{n1} s_i^w t_i^w}{\sum_{j=1}^{n2} s_j^l t_j^l} = \varepsilon \tag{9}$$

$$\sum_{i=1}^{n1} t_i^w + \sum_{j=1}^{n2} t_j^l \le T \tag{10}$$

$$D_i^w \ge \bar{D}_i^w, \qquad i = 1, \dots, n1 \tag{11}$$

$$D_j^l \ge \bar{D}_j^l, \qquad j = 1, \dots, n2 \tag{12}$$

To simplify the computation, in problem P' we use parameter ε to substitute the original ε_1 and ε_2 (see Eq. (9)). Obviously, Problem P' is a linear constrained optimization problem, and it can be solved by the Lagrangian multiplier method. The Lagrangian is:

$$L(T_i^w, T_j^l, \lambda, \mu, \nu_i, \xi_j) = \left(-\sum_{i=1}^{n1} s_i^w T_i^w - \sum_{j=1}^{n2} s_j^l T_j^l\right)$$
$$+\lambda\left(\sum_{i=1}^{n1} s_i^w T_i^w - \varepsilon \sum_{j=1}^{n2} s_j^l T_j^l\right) + \mu\left(\sum_{i=1}^{n1} T_i^w + \sum_{j=1}^{n2} T_j^l - T\right)$$
$$+\nu_i(\bar{D}_i^w - s_i^w T_i^w) + \xi_j(\bar{D}_j^l - s_j^l T_j^l) \tag{13}$$

where λ, μ, ν_i and ξ_j are the multipliers. The KKT conditions of Eq. (13) are:

$$\frac{\partial L}{\partial T_i^w} = -s_i^w + \lambda s_i^w + \mu - \nu_i s_i^w = 0 \tag{14}$$

$$\frac{\partial L}{\partial T_j^l} = -s_j^l - \varepsilon\lambda s_j^l + \mu - \xi_j s_j^l = 0 \tag{15}$$

$$\sum_{i=1}^{n1} s_i^w T_i^w - \varepsilon \sum_{j=1}^{n2} s_j^l T_j^l = 0 \tag{16}$$

$$\mu\left(\sum_{i=1}^{n1} T_i^w + \sum_{j=1}^{n2} T_j^l - T\right) = 0 \tag{17}$$

$$\nu_i(\bar{D}_i^w - s_i^w T_i^w) = 0, \qquad \nu_i \ge 0 \tag{18}$$

$$\xi_j(\bar{D}_j^l - s_j^l T_j^l) = 0, \qquad \xi_j \ge 0 \tag{19}$$

It can be obtained via the simultaneous equations from Eq. (14) to Eq. (19):

$$\sum_{i=1}^{n1} s_i^w T_i^w + \sum_{j=1}^{n2} s_j^l T_j^l = \mu T - \sum_{i=1}^{n1} \nu_i \bar{D}_i^w - \sum_{j=1}^{n2} \xi_j \bar{D}_j^l \tag{20}$$

Obviously, $\sum_{i=1}^{n1} s_i^w T_i^w + \sum_{j=1}^{n2} s_j^l T_j^l$ can be maximized when $\nu_i = 0$ and $\xi_j = 0$. λ and μ can be solved from Eq. (14) and (15), Then, we plug in μ, $\nu_i = 0$ and $\xi_j = 0$ in Eq. (20), and we have the maximum value given in Eq. (21):

$$\max\left(\sum_{i=1}^{n1} D_i^w + \sum_{j=1}^{n2} D_j^l\right) = \frac{(1+\varepsilon)\sum_{i=1}^{n1} s_i^w \sum_{j=1}^{n2} s_j^l T}{n2 \times \sum_{i=1}^{n1} s_i^w + \varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l} \tag{21}$$

Therefore, the total amount of transmitted data of all Wi-Fi networks is $\sum_{i=1}^{n1} D_i^w = \frac{\varepsilon \sum_{i=1}^{n1} s_i^w \sum_{j=1}^{n2} s_j^l T}{n2 \times \sum_{i=1}^{n1} s_i^w + \varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l}$, the total amount of transmitted data of all LTE networks is $\sum_{j=1}^{n2} D_j^l = \frac{\sum_{i=1}^{n1} s_i^w \sum_{j=1}^{n2} s_j^l T}{n2 \times \sum_{i=1}^{n1} s_i^w + \varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l}$, the total communication time of all Wi-Fi networks is $\sum_{i=1}^{n1} T_i^w = \frac{\varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l T}{n2 \times \sum_{i=1}^{n1} s_i^w + \varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l}$, and the total communication time of all LTE networks is $\sum_{j=1}^{n2} T_j^l = \frac{n2 \times \sum_{i=1}^{n1} s_i^w T}{n2 \times \sum_{i=1}^{n1} s_i^w + \varepsilon \times n1 \times \sum_{j=1}^{n2} s_j^l}$.

The above solution is a continuous-time solution. Usually, discrete time is used in real network operation. To apply the above solution in real networks, we may use the closest discrete values (e.g., integer values) and obtain a near-optimum solution.

After rounding up to the integer values, there will be some remaining time left unassigned. In order to maximize the total transmitted data in a communication cycle, we allocate the remaining time to the networks with the highest throughput. Then time allocated to Wi-Fi and LTE networks can be adjusted to ensure that ε is within the range of the fairness parameters ε_1 and ε_2. The case with the largest amount of transmitted data is the best solution from the above continuous-time based approach. The whole process can be completed in polynomial time; however, it cannot guarantee that this solution is the optimal solution. In the future work, we will try to obtain the optimal solution or prove the NP-completeness.

V. Performance Evaluation

We evaluate the performance of our scheme with simulation experiments using the network simulator software NS-3. We set up two groups of co-existing Wi-Fi and LTE networks. Specifically, the first testbed (CN.1) contains one Wi-Fi network and one LTE network, and the second testbed (CN.2) contains three Wi-Fi networks and two LTE networks.

A. *Throughput Measurement*

In the first communication cycle, in order to measure the throughput of Wi-Fi and LTE networks, we divide a communication cycle into equal shares for each network in CN.1 and CN.2. Since the Wi-Fi network settings are more flexible, we adopt 802.11n protocol for Wi-Fi networks. We can get different throughputs by setting different MCS (Modulation and Coding Scheme) value (each MCS value corresponds to a transmission rate of a set of parameters), channel width, and short GI (Guard Interval). On the other hand, LTE networks provided by the LTE operator can maintain a steady rate. Fig. 2 shows the throughput of Wi-Fi (in different MCS value, channel width, short GI) and LTE networks in CN.1.

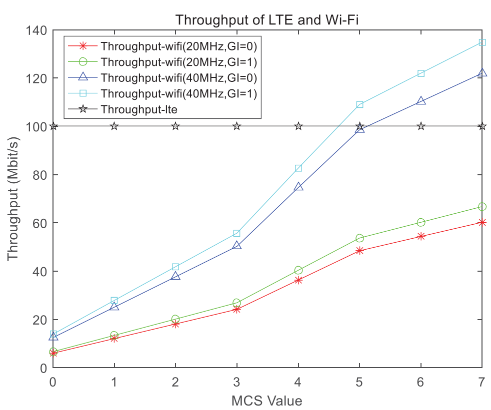

Fig. 2. Throughput of Wi-Fi (802.11n) and LTE in CN.1

B. *Experimental Results*

We set up two coexistent networks: CN.1 and CN.2. CN.1 is composed of one Wi-Fi network and one LTE network. In CN.2, there are three Wi-Fi networks and two LTE networks. We evaluate the performance of the solution in Section IV. In the following, we use the throughput value (data rate) measured in V.A *Throughput Measurement*. Table. 2 shows the detailed information of each Wi-Fi and LTE network of CN.1 and CN.2.

We design three experiments for each coexistence network. (a). timeslot = 1s, $T = 20$; (b). timeslot = 1s, $T = 30$; (c). timeslot = 2s, $T = 15$. The experimental results and analysis are shown as follow.

TABLE. 2 THE DETAIL DEMAND OF EACH WI-FI AND LTE NETWORK

Network		$\bar{s}_i^w$ ($\bar{s}_j^l$) (Mbit/s)	$\bar{D}_i^w$ ($\bar{D}_j^l$) (Mbit)	ε_1	ε_2
CN.1	A (Wi-Fi)	98.555	800	1.2	1.5
	B (LTE)	100.127	700		
CN.2	A (Wi-Fi)	50.3015	240	1.5	1.9
	B (Wi-Fi)	98.555	220		
	C (Wi-Fi)	134.888	230		
	D (LTE)	100.127	400		
	E (LTE)	100.127	250		

(a) timeslot = 1s, $T = 20$;

Fig. 3 shows the variation of time and total transmitted data with fairness parameter ε in continuous-time CN.1.

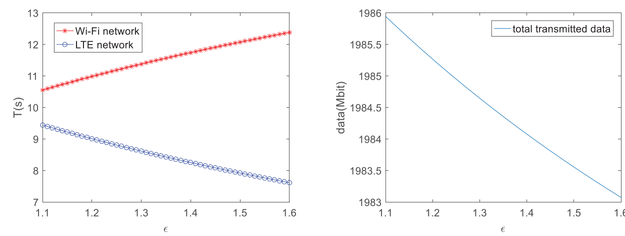

Fig. 3. Variation of time (3(a)) and total transmitted data (3(b)) with fairness parameter in continuous-time CN.1 (timeslot = 1s, $T = 20$)

According to Fig. 3 (a) and (b), the optimal solution of continuous-time CN.1 is 1985.268 Mbit (ε = 1.2) when $T^w = 10.9875$, and $T^l = 9.0125$.

Fig. 4 shows the variation of time and total transmitted data with fairness parameter ε in continuous-time CN.2.

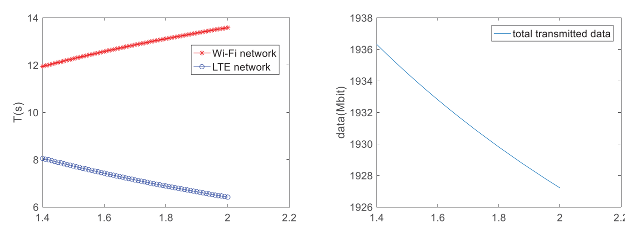

Fig. 4. Variation of time (4(a)) and total transmitted data (4(b)) with fairness parameter in continuous-time CN.2 (timeslot = 1s, $T = 20$)

From Fig. 4 (a) and (b), the optimal solution of continuous-time CN.2 is 1934.486 Mbit (ε = 1.5) when $\sum_{i=1}^{n1} T_i^w = 13.1166$, and $\sum_{j=1}^{n2} T_j^l = 6.8834$. Table. 3 shows the feasible solution, corresponding ε and total transmitted data of discrete time CN.1 and CN.2 in experiment (a).

TABLE. 3 THE FEASIBLE SOLUTIONS OF TIME DISCRETE CN.1 AND CN.2 IN EXPERIMENT (A)

Network	Feasible solution	ε	Total data(Mbit)
CN.1	$t_1^w = 11,\ t_1^l = 9$	1.2030	1985.248
CN.2	$t_1^w = 5,\ t_2^w = 3,\ t_3^w = 5,$ $t_1^l = 4,\ t_2^l = 3$	1.7429	1922.510

(b) timeslot = 1s, $T = 30$;

Similar to experiment (a), the optimal solution of continuous-time CN.1 is 2977.902 Mbit (ε = 1.2) when $T^w = 16.4813$, and $T^l = 13.5187$. The optimal solution of continuous- time CN.2 is 2901.729 Mbit (ε = 1.5) when $T^w = 18.4078$, and $T^l = 11.5922$. Table. 4 shows the feasible solution and corresponding ε and total transmitted data of time discrete CN.1 and CN.2 in experiment (b).

TABLE. 4 THE FEASIBLE SOLUTIONS OF TIME DISCRETE CN.1 AND CN.2 IN EXPERIMENT (B)

Network	Feasible solution	ε	Total data(Mbit)
CN.1	$t_1^w = 17,\ t_1^w = 13$	1.2872	2977.086
CN.2	$t_1^w = 5,\ t_2^w = 3,\ t_3^w = 11$ $\sum_{j=1}^{n2} T_j^l$=11	1.8440	3132.3375

(c) timeslot = 2s, $T = 15$;

Similarly, the optimal solution of continuous-time CN.1 is 2977.902 Mbit (ε = 1.2) when $T^w = 8.2406$, and $T^l = 6.7594$. The optimal solution of continuous-time CN.2 is 2901.729 Mbit (ε = 1.5) when $T^w = 9.2039$, and $T^l = 5.7691$. Table. 5 shows the feasible solution and corresponding ε and total transmitted data of time discrete CN.1 and CN.2 in experiment (c).

TABLE. 5 THE FEASIBLE SOLUTIONS OF TIME DISCRETE CN.1 AND CN.2 IN EXPERIMENT (C)

Network	Feasible solution	ε	Total data(Mbit)
CN.1	$t_1^w = 9,\ t_1^w = 6$	1.4764	2975.514
CN.2	$t_1^w = 4,\ t_2^w = 2,\ t_3^w = 4$ $\sum_{j=1}^{n2} T_j^l$=5	1.8734	2877.006

From the results of three experiments in CN.1 and CN.2, we can find that there are significant differences in the allocated timeslots of each network between time continuous network and time discrete network. However, if the length of a timeslot can be decreased and the length of a communication cycle can be increased, the differences will narrow down. Next, we conduct simulations to model the data transmission in the co-existing networks.

C. Simulation Results

The parameters of Wi-Fi networks are preset, and the throughput of each network in real time and the total transmitted data can be calculated. Table. 6 lists the setting and demand of networks of CN.1 and CN.2 in model simulation.

TABLE. 6 THE DETAIL DEMAND OF EACH WI-FI AND LTE NETWORK OF CN.1 AND CN.2 IN MODEL SIMULATION

Network		Setting (MCS, Channel width, Short GI)	$\bar{D}_i^w$ ($\bar{D}_j^l$) (Mbit)	ε_1	ε_2
CN.1	A (Wi-Fi)	5, 40, 0	800	1.2	1.5
	B (LTE)	LTE	700		
CN.2	A (Wi-Fi)	3, 40 ,0	240	1.5	1.9
	B (Wi-Fi)	5, 40, 0	220		
	C (Wi-Fi)	7, 40, 1	230		
	D (LTE)	LTE	400		
	E (LTE)	LTE	250		

Table. 7 and Table. 8 present the simulate results of the three experiments in CN.1 and CN.2, respectively.

TABLE. 7 SIMULATE RESULTS OF THE THREE EXPERIMENTS IN CN.1

Experiment	CN.1		
	s_i^w(Mbit/s)	*s_j^l(Mbit/s)*	*Total data(Mbit)*
experiment (a)	89.6325	101.089	1895.761
experiment (b)	92.8033	101.097	2891.91
experiment (c)	93.1298	101.089	2889.41

TABLE. 8 SIMULATE RESULTS OF THE THREE EXPERIMENTS IN CN.2

	CN.2					
	s_1^w (Mbit/s)	*s_2^w (Mbit/s)*	*s_2^w (Mbit/s)*	*s_1^l (Mbit/s)*	*s_2^l (Mbit/s)*	*Total data (Mbit)*
exp. (a)	50.267	98.455	134.833	101.09	101.09	1928.49
exp. (b)	50.267	98.455	134.843	101.09	101.09	3141.95
exp. (c)	50.291	98.509	134.835	101.09	101.09	2885.93

The simulation results are different the theoretical results (from Section IV), which are shown Fig. 5. One reason is that the throughput of a network is not fixed during initialization, it gradually increases until reaching a stable value. Another reason is that the interference between Wi-Fi and LTE may exist, and it can cause the results of simulation to be lower than the theoretical results. On the other hand, the simulation results are similar to the theoretical results.

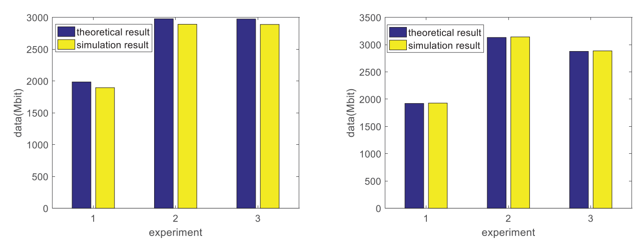

Fig. 5. Comparison of theoretical and simulation results in CN.1 and CN.2

VI. CONCLUSIONS

In this paper, we proposed a novel mechanism to ensure the fair and efficient spectrum sharing of co-existing Wi-Fi and LTE networks. The Wi-Fi AP of the LTE operator is used as a bridge to link the LTE BS and the AP of another Wi-Fi provider. We formulated the spectrum sharing problem as an optimization problem, with the objective function to maximize the total transmitted data. We presented a near-optimum solution. We evaluated the performance of the proposed scheme via NS-3 simulations. The simulation results show that our approach can effectively improve the overall channel utilization and reduce the interference between Wi-Fi and LTE-U.

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