Improving Uplink Resource Batch Utilization in LTE Licensed-Assisted Access

Chih-Cheng Tseng(✉), Hwang-Cheng Wang, and Ling-Han Wang

National Ilan University, No. 1, Sec. 1, Shennong Rd., Yilan 26047, Taiwan R.O.C.
{tsengcc,hcwang}@niu.edu.tw, a561975400@gmail.com

Abstract. Due to network congestion, access to unlicensed spectrum gives new hope for extending the available bandwidth. Licensed-Assisted Access (LAA) is the technology that can be applied to deliver services in the 5 GHz unlicensed spectrum. In general, there are two schemes to access the unlicensed spectrum, namely, random access and scheduled access. Two types of UEs, basic and premium, with two different preferences are considered. Without violating the size of a coalition, UEs with the same preference are put into disjoint coalitions. Likewise, the resource batches are partitioned into two parts and are allocated to the coalitions. The resource batch utilization (RBU) is used to measure the uplink utilization of the resource batches. Compared to the case when all resource batches are under random or scheduled access by all UEs, the numerical results show that the proposed approach is a viable solution in the design of LAA under different degrees of interference from Wi-Fi.

Keywords: LAA · Coalition · Resource batch utilization · Uplink

1 Introduction

Due to the growing mobile traffic, the demands for radio resources are increasing exponentially. Hence, new technologies have to be developed to meet this forthcoming demand. LTE-A was finalized as a solution that met the full system requirements of the 4G mobile communications with several added features and modifications. Carrier Aggregation (CA), one of the important features of the LTE-A, is used to add secondary component carrier in the unlicensed spectrum to deliver data to the users with best effort QoS requirement. Further, LTE-A Pro, a name for the 3GPP releases 13 and 14, was announced by 3GPP with one of the enhanced features [1], Licensed-Assisted Access (LAA), to extend the LTE technology into 5 GHz unlicensed spectrum. However, this 5 GHz unlicensed spectrum, which is also called U-NII (Unlicensed National Information Infrastructure), is currently used by Wi-Fi and radar systems. Hence, it is a challenging issue for the LTE technology to harmonize with the legacy systems in the 5 GHz unlicensed spectrum. In particular, unlike the traditional LTE systems which is operated in the licensed spectrum, transmission collisions and interference between systems are possible and unpredictable when operated in the 5 GHz unlicensed spectrum. Hence, increasing the radio resource in the 5 GHz unlicensed spectrum to be successfully utilized is one of the key challenges in the design of

J.-L. Chen et al. (Eds.): WiCON 2018, LNICST 264, pp. 3–13, 2019.
https://doi.org/10.1007/978-3-030-06158-6_1

LAA. Conceptually, coalition is regarded as an alliance or union between groups, factions, or parties, especially for some temporary and specific reason. The coalition can be formed based on different criteria and approaches. In this paper, UEs form coalitions based on preferences and radio resources are partitioned into resource batches to improve the uplink utilization of the resource batches in the LAA and Wi-Fi coexistence environment.

The rest of this paper is organized as follows. All the preliminaries are provided in Sect. 2. Section 3 describes the ideas of coalition formation and the allocation of resource batches. The performance metric used in this paper, i.e., the resource batch utilization (RBU), is also defined and derived in this section. In Sect. 4, the numerical results are presented. Finally, Sect. 5 concludes this paper.

2 Preliminaries

Game theory deals with scenarios where two or more individuals, called players, make decisions that determine the final outcome [2]. It is a study about the processes of how and why people make decisions. There are different types of games. Cooperative game [3] is a type in which players are convinced to adopt a particular strategy through negotiations and agreements between players while the non-cooperative games refer to the games in which each player simply decides a strategy that maximizes its own profit. Coalition game is a type of cooperative game.

LTE-U (unlicensed) and LAA are two application modes which originated from the supplemental downlink (SDL) and CA techniques. SDL, the first major technique enables LTE technology in the unlicensed spectrum, significantly enhances the network downlink capacity and user experience by employing the unpaired spectrum. The second major technique enables LTE technology in the unlicensed spectrum is the CA, which allows network operators to logically obtain a single large spectrum by combining a number of separate carriers or component carriers. With the CA, the peak user data rate and overall network capacity are greatly improved. The third major technique enables LTE technology in the unlicensed spectrum is the dynamic frequency selection (DFS) [4], which allows the UE to switch from one channel to another frequently in order to mitigate the interference from Wi-Fi stations. In addition, the selected channel can be updated with the changing traffic based on the occupancy of Wi-Fi. Specifically, to expand the system spectrum, LTE-U and LAA allow UEs to use the LTE radio communications in the unlicensed spectrum by aggregating the licensed spectrum and the 5 GHz unlicensed spectrum. Figure 1 shows one of the application scenarios of the coexistence of the Wi-Fi and LTE-U/LAA in the unlicensed spectrum. This figure shows the uplink/downlink transmissions of the UE can be performed in the licensed primary carrier and unlicensed secondary carrier. Besides, in the SDL application scenario, the whole secondary carrier in the unlicensed spectrum can only be used for downlink transmissions. In such application scenario, all the uplink communications are performed through the primary carrier in the licensed spectrum to the LTE-eNB.

One of the main challenges of utilizing the 5 GHz unlicensed spectrum is to share the spectrum with the existing systems, e.g. Wi-Fi and radar systems. For example, as indicated in Fig. 1, the downlink transmissions of the unlicensed Wi-Fi AP#1 may interfere with the UE in receiving the downlink transmissions from the LAA-eNB. In addition, the uplink transmission of the UE to the LAA-eNB may also be interfered by the downlink transmissions of the unlicensed Wi-Fi AP#2. In fact, as pointed out in [5], the above-mentioned interference is caused by the well-known hidden terminal problem. To minimize the interference between systems operated in the 5 GHz unlicensed spectrum, DFS technique has been adopted by the Wi-Fi systems and is also mandatory for radar systems. However, since the DFS has been recognized by 3GPP as an implementation issue, it is not part of the LTE specifications [6].

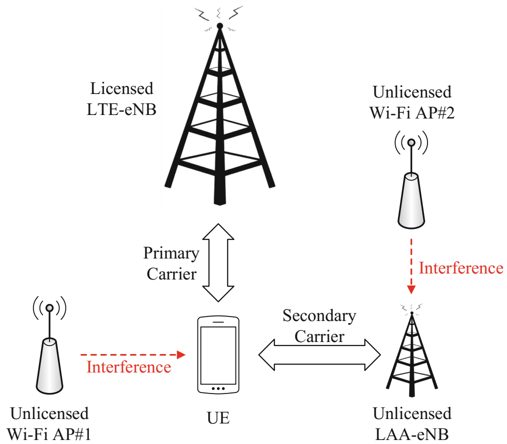

Fig. 1. Application scenario of LAA.

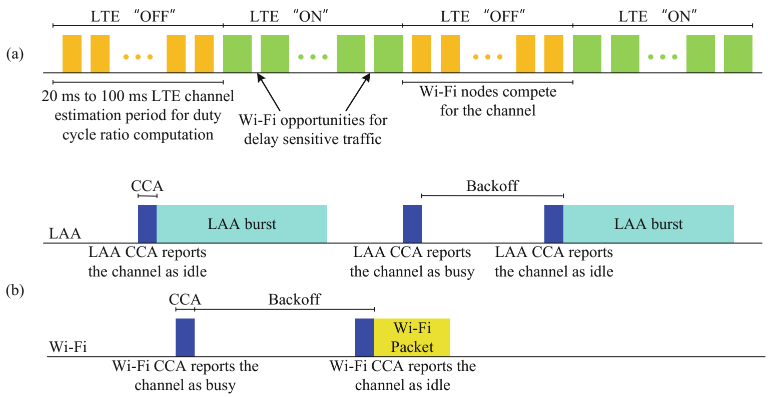

Fig. 2. (a) LTE "ON" and LTE "OFF" periods in the CSAT. (b) The CCA used for the coexistence of LAA and Wi-Fi.

The main difference between LTE-U and LAA is the mechanism used to determine the availability of a channel in the unlicensed spectrum. In LTE-U, carrier sense adaptation transmission (CSAT) proposed by Qualcomm is used to sense the activity of the shared medium. Based on the long-term carrier sensing of the Wi-Fi activities on the shared medium, the LTE "ON" and LTE "OFF" periods of the TDM transmission of the LTE-U eNBs are adaptively adjusted as illustrated in Fig. 2a. Jointly proposed by 3GPP and IEEE, listen before talk (LBT) or clear channel assessment (CCA) [7] is adopted in LAA to comply with the global regulations. In LAA, as shown in Fig. 2b, a channel can be utilized only when CCA reports its state as idle. Otherwise, a backoff procedure is activated. The CCA can be done by two major functions called carrier sense (CS) and energy detection (ED). Compared with the LTE-U, LAA is concluded as a feasible alternative to increase the overall system throughput [8].

3 The Proposed Approach

In [5], the authors assumed that all UEs employ either random or scheduled access scheme to access the resource batches. In other words, the preference of UE is not considered. In [7], although the preference of UE is implicitly considered in allocating resource batches, the idea of coalition is not employed. Different from [5, 7], the author in [9] considered the downlink resource batch allocation problem. Inspired from [5, 7, 9], in this section, we will describe how the coalitions are formed, how the resource batches are allocated, and how the basic and premium UEs access the allocated resource batches. The analysis used to evaluate the performance of the proposed approach is also developed.

3.1 Coalition Formation

The key idea to form coalitions is inspired by the hedonic coalition [10]. In hedonic coalition, preference is strongly related to the formation of coalitions. A hedonic game is a pair $(N, \succeq)$ where $N = \{1, 2,\ldots, N\}$ is the set of UEs and $\succeq$ is a preference profile that specifies a complete, reflexive, and transitive relation for every UE $x \in N$ in the coalitions that include UE x. The UEs are classified into two types: basic and premium. Basic UEs are with the preference to receive services at a normal cost while premium UEs are with the preference to receive services with extra payment. A UE joins a coalition based on its preference. A collection of disjoint coalitions that partitions N is called a coalition structure. In this paper, a simple model of coalition formation is used by assuming that each UE only cares about the coalition it joins and only joins exactly one coalition.

Assume there are P possible preferences. At time i, let $\Pi(i) = \{\Theta_1(i), \Theta_2(i),\ldots, \Theta_P(i)\}$ be the coalition structure of the resulted coalitions, $\Theta_p(i) = \{C_{1,p}(i), C_{2,p}(i), C_{n_p(i),p}(i)\}$ be the set of coalitions with preference p, $C_{j,p}(i)$ be the j-th coalition in $\Theta_p(i)$, and $n_p(i)$ be the total number of coalitions in $\Theta_p(i)$. Besides, let $C_{\max}$ be the maximum allowable number of UEs in a coalition. Hence, at time i, if the number of UEs in $C_{j,}$

$_p(i)$ reaches C_{max}, a new coalition $C_{(j+1),p}(i)$ is created to accommodate the UE that does not belong to any coalition yet. Based on the above descriptions, at time i, we have

$$\sum_{p=1}^{P}\sum_{j=1}^{n_p(i)}\left|C_{j,p}(i)\right| = N, \tag{1}$$

where |•| is the cardinality of a set.

To simplify our study, only two preferences are considered, i.e., p = 1, 2, and are assigned to premium and basic UEs, respectively. For example, consider a network with 10 premium UEs and 30 basic UEs at time i. If C_{max} = 10, as demonstrated in Fig. 3, the 10 premium UEs form the coalition $C_{1,1}(i)$, while the 30 basic UEs form three coalitions $C_{1,2}(i)$, $C_{2,2}(i)$, and $C_{3,2}(i)$. Hence, the corresponding coalition structure is $\Pi(i)$ = { $_1(i)$, $\Theta_2(i)$}, where $\Theta_1(i)$ = {$C_{1,\ 1}(i)$} and $\Theta_2(i)$ = {$C_{1,2}(i)$, $C_{2,2}(i)$, $C_{3,2}(i)$}.

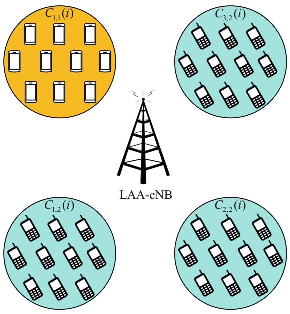

Fig. 3. Example of the hedonic coalition structure.

3.2 Resource Batch Allocation

The ideas of the coalition-based resource batch allocation are illustrated in Fig. 4. In Fig. 4, the time is divided into periods of two different lengths. The length of the short period is 20 μs. The short period is used to sense the availability of the channel, i.e., it is used to perform the CCA. As mentioned earlier, in the 5 GHz unlicensed spectrum, a UE can access a channel only when the report of CCA indicates that channel is available. As shown in Fig. 4, after each short period, a long period of length τ ms is used to perform the data transmission and is called an access opportunity. The value of τ can be either 4 in Japan or 10 in Europe and 4 is used in Fig. 4. Besides, as indicated on the right of Fig. 4, the consecutive resource blocks over an access opportunity is called a resource batch. In this paper, it is the resource batches that are allocated to the UEs and accessed by the UEs when CCA reports they are available.

Before allocating the resource batches to the UEs, all the radio batches of the considered 5 GHz unlicensed spectrum at the i-th access opportunity are divided into two sets $R_1(i)$ and $R_2(i)$. Specifically, at the i-th access opportunity, the resource batches

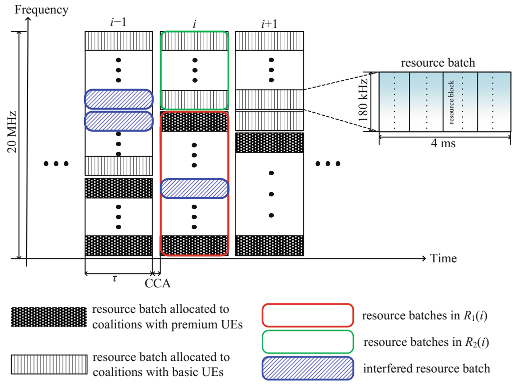

Fig. 4. Example of the resource batch allocation.

in $R_1(i)$ and $R_2(i)$ are allocated to coalitions whose members are premium and basic UEs, respectively. Since the QoS requested by the premium UEs is more rigid than that requested by the basic UEs, the premium UEs are given higher priority to access the allocated radio batches. Hence, to avoid potential collisions with other UEs, at any access opportunity i, the premium UEs always employ the scheduled access scheme to access the allocated radio batches in $R_1(i)$. On the contrary, at the i-th access opportunity, basic UEs can only access the allocated radio batches in $R_2(i)$ by utilizing random access scheme. In this paper, the resource batches are first allocated to the coalitions. After that, based on the preference of each coalition, scheduled access and random access schemes are employed by the premium and basic UEs to access the allocated resource batches, respectively. For simplicity, we assume each UE, regardless of premium or basic, requires only one resource batch at any access opportunity. Under this assumption, the number of resource batches allocated to a coalition is equal to the number of UEs in that coalition. When the total number of requested resource batches is higher than the total number of resource batches in the system, proportional fair allocation approach is employed. Besides, the floor function is used if the total number of resource batches in the system cannot be divided evenly by the total number of coalitions. In the following, $R_{j,p}(i)$ denotes the number of resource batches allocated to $C_{j,p}(i)$. Hence,

$$\left|R_p(i)\right| \geq \sum_{j=1}^{n_p(i)} \left|R_{j,p}(i)\right|, \tag{2}$$

where p can be 1 or 2 in this paper. If the total number of resource batches in the system is N_{RB}, we have

$$N_{RB} \geq \sum_{p=1}^{2} \left|R_p(i)\right|. \tag{3}$$

As shown in Fig. 4, since the bandwidth of the considered 5 GHz unlicensed spectrum is 20 MHz, there are totally 100 resource batches at any access opportunity i. The sets $R_1(i)$ and $R_2(i)$ and the values of $n_1(i)$ and $n_2(i)$ are updated at the beginning of every access opportunity i.

3.3 Resource Batch Utilization (RBU)

Due to the hidden terminal problem in the LAA and Wi-Fi co-existence scenario as mentioned in Sect. 2.1, even if CCA reports that a particular resource batch is idle, it is possible for that particular resource batch to be interfered by Wi-Fi when a UE is utilizing it to transmit data. According to the assumption made in [5], the interference from Wi-Fi to a particular resource batch at any access opportunity i is modelled as an independent and identical distribution (i.i.d.) with probability q. At any access opportunity i, since the resource batches are divided into two sets, $R_1(i)$ and $R_2(i)$, we need to derive the RBU of the resource batches allocated to these two sets, respectively.

First, at the i-th access opportunity, let $u_{j,1}(i)$ be the RBU of the resource batches in $R_{j,1}(i)$ and be defined as the expected number of interference-free resource batches in $R_{j,1}(i)$. A resource batch is regarded as successfully utilized by a premium UE to transmit data to the LAA-eNB only when this resource batch is not interfered by Wi-Fi. Since the scheduled access scheme is employed by the premium UEs in each $C_{j,1}(i)$ to access the resource batches, there is no need to consider the contention and collision issues among the premium UEs in each $C_{j,1}(i)$. Because each premium UE is assumed to request for only one resource batch at each access opportunity, we have the constraint $|C_{j,1}(i)| \geq |R_{j,1}(i)|$. Hence, $u_{j,1}(i)$ is given by

$$u_{j,1}(i) = (1-q)|R_{j,1}(i)|. \tag{4}$$

Let $U_1(i)$ be the RBU of the resource batches allocated to all the coalitions in $\Theta_1(i)$ at the i-th access opportunity. Hence, $U_1(i)$ is given by

$$U_1(i) = \sum_{j=1}^{n_1(i)} u_{j,1}(i). \tag{5}$$

Next, unlike the derivations in (4) and (5), since the random access scheme is employed by basic UEs in each $C_{j,\,2}(i)$ to access the allocated resource batches $R_{j,\,2}(i)$, in addition to the interference from Wi-Fi, the contention and collision issues among the basic UEs in the same $C_{j,\,2}(i)$ also need to be considered. Let $u_{j,\,2}(i)$ be the RBU of a resource batch in $R_{j,\,2}(i)$ at the i-th access opportunity and be defined as the expected number of basic UEs served by an interference-free and collision-free resource batch in $R_{j,\,2}(i)$ at the i-th access opportunity. First, similar to the derivations above, the probability for a resource batch in $R_{j,\,2}(i)$ to be interference-free is $(1-q)/|R_{j,\,2}(i)|$. Then, since the number of basic UEs in $C_{j,\,2}(i)$ is $|C_{j,\,2}(i)|$, the probability for a randomly selected resource batch in $R_{j,\,2}(i)$ to be interference-free and collision-free is given by

$$\eta_{j,2}(i) = |C_{j,2}(i)|\left(\frac{1-q}{|R_{j,2}(i)|}\right)\left(1-\frac{1-q}{|R_{j,2}(i)|}\right)^{|C_{j,2}(i)|-1}. \tag{6}$$

Since each basic UE is assumed to request for only one resource batch at each access opportunity, with $\eta_{j,\ 2}(i)$ in (6), $u_{j,\ 2}(i)$ is given by

$$u_{j,2}(i) = \eta_{j,2}(i)|R_{j,2}(i)| = |C_{j,2}(i)|(1-q)\left(1-\frac{1-q}{|R_{j,2}(i)|}\right)^{|C_{j,2}(i)|-1}. \tag{7}$$

Let $U_2(i)$ be the RBU of the resource batches allocated to all the coalitions in $\Theta_2(i)$ at the i-th access opportunity. Then, $U_2(i)$ can be obtained by

$$U_2(i) = \sum_{j=1}^{n_2(i)} u_{j,2}(i). \tag{8}$$

When random and scheduled access schemes are employed, the RBU at the i-th access opportunity $U(i)$ is defined as the total RBU obtained by (5) and (8) and is given by

$$U(i) = \sum_{p=1}^{2} U_p(i). \tag{9}$$

4 Numerical Results

The numerical results of the proposed approach are demonstrated in this section. The bandwidth of the considered 5 GHz unlicensed spectrum is assumed to be 20 MHz. Hence, there are 100 resource batches in each access opportunity. Each UE is assumed to request for only one resource batch.

4.1 The RBU if Only Random Access Scheme Is Allowed

First, we study the RBU under the scenario where all UEs can only use the random access scheme to access the allocated resource batches (i.e., $U_1(i) = 0$). We compared the RBU achieved 'with' and 'without' forming UEs into coalitions, respectively. In the case of 'without coalition', all UEs are conceptually in a coalition and the 100 resource batches are randomly accessed by all UEs, regardless of the type of UE. While, in the case of 'with coalition', although the UEs are grouped into coalitions based on their preferences, the resource batches allocated to each coalition can only be accessed by random access scheme. Based on the above-mentioned criterion, we study the RBU of the resource batches under different traffic load with the number of UEs being 50, 100, and 200, respectively. Hence, the green, red, and black lines shown in Fig. 5 are the results for 50, 100, and 200 UEs, respectively. Clearly, higher RBU can always be achieved when UEs are grouped into coalitions. Besides, reducing the size of a coalition provides another way to further improve the utilization.

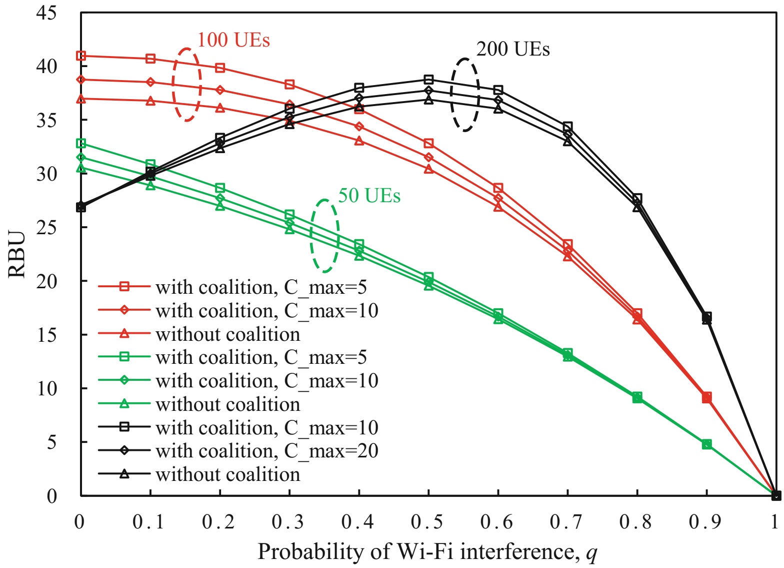

Fig. 5. The RBU if only random access scheme is allowed.

Next, Fig. 5 also demonstrated, when the number of UEs is smaller than the number of resource batches, the RBU is increased as the number of UEs is increased and achieved the maximum as the number of UEs equals the number of resource batches, i.e., 100 UEs in this case. However, when the number of UEs is greater than the number of resource batches, e.g., 200 UEs, an interesting observation can be made. As the interference from Wi-Fi to LAA is increased, we noticed that the RBU achieved when the number of UEs is 200 is increased also and is higher than that achieved when the number of UEs is 50 and 100 as $q \geq 0.4$. This is mainly because, when the number of UEs is 200 and the number of resource batches is 100, the probability for a randomly selected resource batch to be both interference-free and collision-free as given in (6) increases as the value of q increases. Hence, it is recommended to use random access scheme to access the resource batches when UE is heavily interfered by Wi-Fi.

4.2 The RBU if Both Scheduled and Random Access Schemes Are Allowed

Now, we study the RBU achieved by 200 UEs consisting of 50 premium UEs and 150 basic UEs. By setting $C_{\max}$ to 10, among the 20 formed coalitions, there are 5 and 15 coalitions formed by the premium and basic UEs, respectively. The RBU is calculated by changing the number of allocated resource batches in the sets $R_1(i)$ and $R_2(i)$ and is illustrated in Fig. 6. The RBU achieved when only scheduled (i.e., $U_2(i) = 0$) or random (i.e., $U_1(i) = 0$) access scheme is allowed for the 200 UEs are also depicted in Fig. 6. In the case when only scheduled access scheme is allowed, all UEs are scheduled by the LAA-eNB to access the allocated resource batches. Hence, the RBU is obtained according to (4) and (5) by letting $|R_{j,\ 1}(i)| = 5$ and $j = 1,\ldots,\ 20$. In Sect. 4.1, we have mentioned that, when only random access scheme is allowed, the RBU for 200 UEs is lower than that for 100 UEs when $q \leq 0.3$. However, compared with the brown dash line for 100 UEs with random access scheme only depicted in Fig. 6, a higher RBU can be achieved for 200 UEs employing both scheduled and random access schemes. In addition, Fig. 6 also shows the achieved RBU of using scheduled and random access schemes is closing to that of only using random access scheme as q approaches to 1. Hence, it is suggested that differentiating the access to the resource batches of premium and basic UEs at any access opportunity with the scheduled and random access schemes is a feasible approach to improve the utilization of the allocated resource batches.

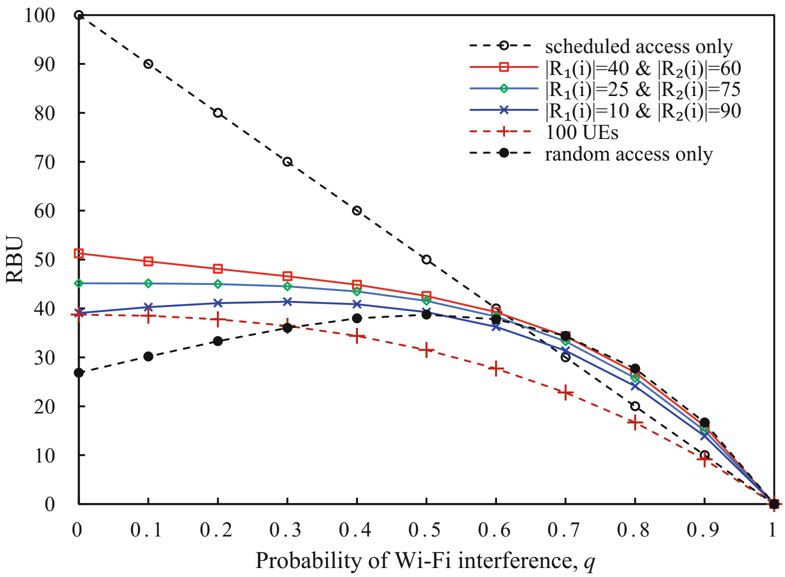

Fig. 6. The RBU if both scheduled and random access schemes are allowed.

5 Conclusions

Efficiently using the resource batches in the 5 GHz unlicensed spectrum is one of the important objectives in the design of LAA. When UEs are classified into premium and basic, this paper suggests that grouping UEs into coalitions based on their preferences before allocating resource batches is beneficial. After forming coalitions, differentiating the schemes for coalitions consisting of the premium and basic UEs to access the resource batches is further suggested. By allocating different number of resource batches to coalitions, the results show that, when the interference from the Wi-Fi is small, the RBU achieved by the proposed approach is higher than that achieved by using random access scheme only. In situations where the interference from Wi-Fi is high, the results also show that the RBU achieved by the proposed approach is very close to the maximum RBU that is achieved by using random access scheme only.

Acknowledgement. The authors would like to thank Jennifer Pounjeba. P for her help to this paper.

References

1. Mukherjee, A., et al.: Licensed-assisted access LTE: coexistence with IEEE 802.11 and the evolution toward 5G. IEEE Commun. Mag. **54**(6), 50–57 (2016)
2. Bonanno, G.: Game Theory, 1st Edn, Chapter 1, p. 17 (2015)
3. https://cours.etsmtl.ca/mgr816/game_apC.pdf
4. Maglogiannis, V., Naudts, D., Shahid, A., Giannoulis, S., Laermans, E., Moerman, I.: Cooperation techniques between LTE in unlicensed spectrum and Wi-Fi towards fair spectral efficiency. Sensors **19**(9), 1–26 (2017). https://doi.org/10.3390/s17091994
5. Lien, S.-Y., Lee, J., Liang, Y.-C.: Random access or scheduling: optimum LTE licensed-assisted access to unlicensed spectrum. IEEE Commun. Lett. **20**(3), 590–593 (2016)
6. GPP TR 36.889 v13.0.0. Feasibility Study on Licensed-Assisted Access to Unlicensed Spectrum; 3GPP: Malmo, Sweden (2015)
7. Zhang, M., Zhang, X., Chang, Y., Yang, D.: Dynamic uplink radio access selection of LTE licensed-assisted access to unlicensed spectrum: an optimization game. IEEE Commun. Lett. **20**(12), 2510–2513 (2016)
8. https://www.qualcomm.com/invention/technologies/lte/laa
9. Jennifer Pounjeba, P.: Resource allocation in unlicensed spectrum for 5G: a hedonic coalition approach, Master Thesis, National Ilan University (2018)
10. Han, Z., Niyato, D., Saad, W., Baar, T., Hjrungnes, A.: Game Theory in Wireless and Communication Networks. 1 Edn, Chapter 12, p. 210 (2012)