The study of dynamic resource allocation on aggregation of unlicensed spectrum in LTE-A networks

Jung-Shyr Wu

Department of Communication Engineering,
National Central University,
Zhongli, Taoyuan City 32001, Taiwan
Email: jswu@ee.ncu.edu.tw

Abstract: The 3GPP formulated the fourth-generation LTE-Advanced specifications, in which Carrier Aggregation technology can increase the data transmission rate by aggregating continuous and non-continuous carriers to meet the transmission needs of a large number of users. However, users' demand for multimedia network application services continues to increase and makes the licensed spectrum more and more overwhelming. Therefore, this article hopes to combine the licensed and unlicensed spectrum to provide a wider data channel with higher data transmission. We focus on improving the throughput of the downlink system, and propose a genetic algorithm to optimise the weights which referring to the carrier unit channel quality and load conditions to select the most suitable carrier unit for the user. Afterwards, resource allocation methods are presented for the different traffic of GBR and Non-GBR effectively. Finally, we show the simulation results to prove that the proposed method is effective in improving system throughput and user satisfaction.

Keywords: LTE-A; carrier aggregation; genetic algorithm; resource allocation.

Reference to this paper should be made as follows: Wu, J-S. (2022) 'The study of dynamic resource allocation on aggregation of unlicensed spectrum in LTE-A networks', *Int. J. Internet Protocol Technology*, Vol. 15, No. 1, pp.53–59.

Biographical notes: Jung-Shyr Wu received the PhD in electrical engineering from the University of Calgary, Calgary, Canada, in 1989. He is a Full Professor with the Graduate Institute of Communication Engineering, National Central University, Chung-Li, Taiwan. His research interests include computer networks, wireless and mobile networks, internet of things and queueing theory.

1 Introduction

The LTE-A is an evolution of the LTE (Ghosh et al., 2010). In terms of uplink and downlink, it is still the same as the LTE where the downlink uses OFDMA and the uplink uses SC-FDMA technology. In terms of data transmission rate, the LTE-A is defined as the transmission rate of 500 Mbps and 1 Gbps for uplink and downlink respectively. In order to significantly increase the data transmission rate to meet the needs of a large number of users, the LTE-A proposes four technologies (Ghosh et al., 2010; Iwamura et al., 2010, Garcia et al., 2009) to achieve this goal: carrier aggregation, advanced Multi-input Multi-output (MIMO), Coordinate Multipoint (CoMP) and Relay, of which Carrier Aggregation technology is the focus of this article. Its technology can aggregate the existing LTE bandwidth, therefore, continuous or non-contiguous carriers can be aggregated together by carrier aggregation technology to increase the bandwidth up to 100 MHz, thereby achieving a higher data transmission rate.

With the popularity of smart phones, users' demand for multimedia network application services continues to increase which making the licensed spectrum more and more overwhelming. In this article, we combine licensed and unlicensed spectrum to provide a wider data channel, thereby providing users with a higher data transmission rate. When allocating carrier units in the licensed spectrum, the most suitable carrier for the user will be selected according to the channel quality and load conditions. Resource allocation methods for different traffic types of GBR and Non-GBR are also presented to improve system throughput.

2 Related works

With the rapid development of communication networks and the popularity of mobile devices, the 3GPP proposes to expand the spectrum of carrier aggregation technology to unlicensed spectrum, namely the LTE-U (Hadi, 2015).

The LTE-U increases the bandwidth by aggregating unlicensed spectrum which will interfere with other technologies that use unlicensed spectrum, such as WiFi. Owing the different communication specifications for unlicensed spectrum in various countries, the LTE-U and other technologies that use unlicensed spectrum will coexist in two ways (Hadi, 2015; Ratasuk et al., 2014). The first, such as the United States and China's specifications, is for unlicensed spectrum. It does not stipulate that Listen Before Talk (LBT) is required before using unlicensed spectrum. Instead, there is another coexistence mechanism for the LTE-U and other technologies that use unlicensed spectrum, such as the Carrier-Sensing Adaptive Transmission (CSAT) mechanism (Cano and Leith, 2016). The second type, such as European and Japanese regulations, stipulates that Listen Before Talk (LBT) is required before using unlicensed spectrum. Before using a channel, we must first listen to whether the channel is occupied. If not occupied, we can use this channel. After that, this channel will be released. To want to continue to use the channel, we perform LBT again to coexist with other technologies that use unlicensed spectrum.

Ali et al. (2017) formulated an optimisation problem for joint user association and power allocation for licensed and unlicensed spectrum with objective to maximise sum rate of LTE-U/WiFi heterogeneous network.

In Wu et al. (2019), both throughput and fairness for the LTE-U system are maximised by a multi-objective optimisation problem and a log-sum exp approximation method is developed to convert the multi-objective optimisation into a single objective optimisation problem.

Dai and Shen (2018) proposed a fair coexistence criterion and design the duty cycle allocation that optimises the Carrier Sensing Adoptive Transmission (CSAT) mechanism for LTE-U/WiFi. This following will introduce the Carrier Component (CC) Assignment algorithm. The main purpose is to assign users to a certain carrier.

2.1 Circle allocation (CA) algorithm

The Circle Allocation (CA) algorithm takes into account the number of people in the carrier component. When the user is allowed to enter the system service range by the base station, the carrier component will be allocated to the user according to the circular sequence. The advantage of this algorithm is that it can improve the load balance between the carrier components and also make the transmission rate fairer between users. However, because each user's transmission rate in different carrier components is not the same, so it may cause a gap in the transmission performance between carrier units.

2.2 Greedy algorithm

The Greedy Algorithm does not take into account the number of people in the carrier. When the user is allowed to enter the system service range by the base station, it will select the carrier component that can provide the user with the maximum transmission rate to allocate to users. This algorithm may cause multiple users to enter the same carrier component with load imbalance. However, it is conceivable that the system will have the highest throughput.

We propose a genetic algorithm to optimise the weights which referring to the channel quality and load conditions of carrier component to select the most suitable one for the user in this paper.

The main purpose of the resource allocation algorithm is to allocate the resource block to the most suitable user to use it to transmit data. Therefore, the quality of the algorithm will also affect the throughput of the system. There are two objectives of the resource allocation algorithm. The first is to pursue the fairness of the allocated resources so that each user can have considerable resources. The second is to pursue the transmission efficiency of the system, so that the overall system throughput, utilisation rate and transmission rate of resources can be maximised. The following introduces common packet allocation algorithms (Basukala et al., 2009).

2.3 Maximum rate algorithm

The Maximum Rate (Max-Rate) algorithm pursues the maximum throughput of the system. The Max-Rate algorithm allocates resources based on the user's channel quality where users with better channel quality can get a better transmission rate. It is conceivable that when each resource block uses a better transmission rate, the throughput of the system will reach the maximum, but the disadvantage is that if the user is located at the edge of the cell where the channel quality is relatively poor. So low probability of obtaining resources makes it difficult to meet the required transmission rate, resulting in lower throughput and greatly reducing the fairness among users.

2.4 Round robin (RR) algorithm

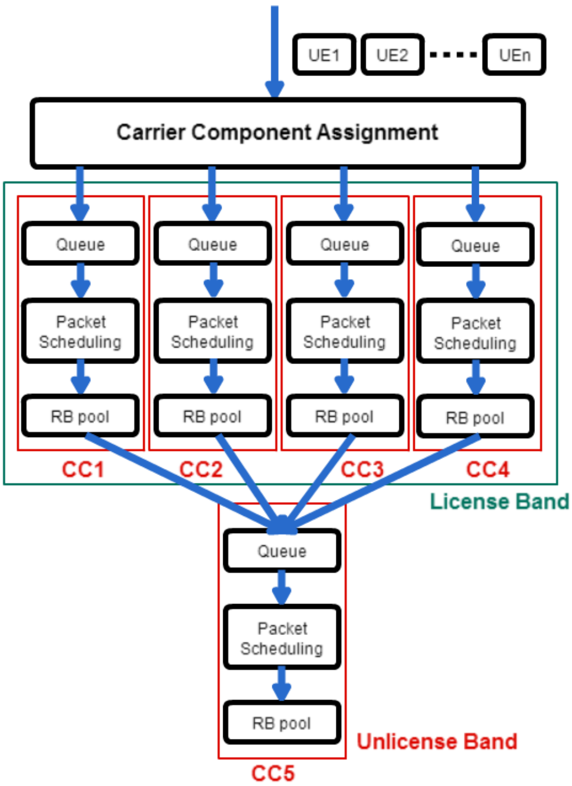
The Round Robin (RR) algorithm is just the opposite of the Max-Rate algorithm which ensuring fairness among users. Therefore, the user's channel quality is not considered when allocating resources. In order to evenly allocate resources to waiting users in a round-robin manner, long-term fairness among users can be guaranteed, but effective resource allocation cannot be carried out according to the actual situation which resulting in low resource utilisation and overall system throughput.

3 Proposed method

As the users enter the system, they will be assigned to enter the carrier component block according to the carrier component (CC) assignment algorithm and wait in the queue. Then, each CC will be allocated resources according to the packet allocation algorithm. It will be determined which user in the scheduling queue can use a certain resource block on the CC, so there are two levels of allocation. The above scenarios are all performed in the licensed spectrum. Afterwards, the users in the unlicensed spectrum service range will then wait in the CC scheduling queue of the unlicensed spectrum. Likewise, resource allocation will be performed so that users within the authorised and unlicensed services can obtain more resources to help data transfer.

Figure 1 is a schematic diagram of the system architecture. The authorised spectrum is divided into four carrier components, namely CC1, CC2, CC3 and CC4 which are regarded as Primary CCs. Then as long as the user is in the unlicensed spectrum service range, CC5 can be used to help transmit resources, which is regarded as Secondary CC. This article assumes that only one carrier component CC5 can be used in the unlicensed spectrum.

Figure 1 System architecture



3.1 Genetic algorithm (GA)

In recent years, the genetic algorithm (Goldberg, 1989) has been widely used to search for the best solution to various problems and it is an effective optimisation search method. The calculation process uses a random search for multiple points at a time, avoiding the general single point. The sequential search method is limited to the regional best solution, not the global best solution. Although it is a random search method which is different from the search method that generally requires the design of initial values, it can be based on the evolution of each generation. Using the fitness function as an indicator, individual with poor fitness function will be gradually eliminated, and individual with better fitness functions will be retained. Through mating and mutation, a better-quality next generation will be produced. Through such repeated cycles, the fitness function will be improved until it reaches the termination condition is to produce the best solution.

This paper assumes that the base station currently has four available carrier components in the licensed spectrum, namely CC1, CC2, CC3 and CC4. Once the user enters the system, the base station will first allocate the carrier components in the licensed spectrum. The allocation will refer to the total throughput of all users, the channel quality, and the load condition in the carrier component. Therefore, it is hoped that the weight value of the reference factor of formula (1) can be optimised by genetic algorithm to achieve the best fitness function, i.e. the best solution, which is the most suitable carrier component for the user.

The following will briefly introduce the steps of the genetic algorithm:

Step 1: Randomly generate the initial matrix: The initial matrix of the genetic algorithm is randomly generated. It is hoped that the final result will be the best solution in the entire domain, not local optimum. The range of the initial matrix will also affect the efficiency and results of the entire algorithm. If setting too large search range, the calculation time and cost are higher. Therefore, it is necessary to set an appropriate initial matrix range to have both the efficiency and result of the algorithm.

Step 2: Calculate the fitness function: The fitness function is an important indicator in the genetic algorithm. It judges the fitness of each individual, and then decides whether to select the individual for mating. The higher the fitness function, the higher the survival rate and the higher the chance of being selected for mating with higher the probability. On the contrary, the lower the fitness function, the less likely it is to be selected and even gradually eliminated in the evolution process. The fitness function is also used to measure whether each individual has reached or is close to the maximum in the algorithm process. For a good solution, the ideal fitness function hopes to be as high as possible, so getting closer or closer to the best solution.

The fitness function used in this paper uses the Simple Additive Weighting (SAW) method (Tzeng and Huang, 2011) and the formula is as follows:

$$fitness = CC_i = \frac{T_i \times W_r + RSRP_i \times W_{RSRP} + L_i \times W_L}{W_r + W_{RSRP} + W_L} \tag{1}$$

where *i* is the current carrier unit that the base station can use in the licensed spectrum, and T_i (Throughput) is the normalised throughput of all users in carrier component *i*. The higher the throughput, the transmission performance is better. The $RSRP_i$ (Reference Signal Received Power) is the normalised reference signal received power of carrier component *i*, which is the normalised value. The higher the RSRP value, the better the channel quality. The L_i (Load) is normalised load status where the heavier the load, the more competitors in this channel and the less resources that can be allocated. W_r, W_{RSRP}, W_L, respectively represent their weights. We expect to use genetic algorithms to optimise the weights to maximise the fitness function, that is, the highest CC_i score means that the carrier component is most suitable for the user which can provide a better data transmission rate and increase the overall system throughput.

Step 3: Choice: In the process of evolution, in order to reproduce a better next generation, a better parent will be selected for mating. It is hoped that the reproduced offspring will be as good as the mother or even better than the mother. Therefore, in the initial mother stage, the larger fitness function, the greater the chance that they will be selected for mating to reproduce the next generation. On the contrary, the less adaptable one will be gradually eliminated.

Step 4: Mating: We select two individuals randomly from the race to mate and hope to produce a better next generation by mating with excellent mothers.

Step 5: mutation: The advantage of mutation is to avoid premature convergence in the evolution process and limited to local optimum solution. The new individual after mutation may not be better or worse. However, it is hoped that mutations will produce some different changes, which may cause the generation acquires some characteristics that the mother generation does not.

Step 6: End of evolution: When the evolution process has reached the specified number of generations, the evolution is complete.

3.2 Resource allocation algorithm

In this section, we will introduce the resource allocation algorithm classified according to the packet type. There are two main types. One is the packet type that requires immediate service, represented by Guaranteed Bit Rate (GBR). The GBR means that even in the case of resource shortage the system will still ensure that the smallest bit rate can be used. The other represented by non-GBR is a packet type that does not require immediate service and not guarantee the quality of service. It will not start transmission until there are extra Resource Blocks (RBs). Therefore, the priority of GBR will be better than that of non-GBR. After the packet is classified, the priority of GBR users will be calculated first and then RB will be allocated according to the order of GBR priority. Only if there are extra RBs, Non-GBR users can get the RB resource.

Before allocating RB, the priority of each GBR user must be calculated before determining the priority of the allocation. The following will introduce the priority calculation method proposed in this article:

$$P_{GBR} = \frac{Rate_{GBR}}{Rate_{avg}} \tag{2}$$

where P_{GBR} is the priority, $Rate_{GBR}$ represents the minimum bit rate guaranteed by GBR, and $Rate_{avg}$ is the average rate of the packet before transmission. The higher priority represents the lower average rate obtained before which means that the packet lacks more resources so can get RB more preferentially. Hence based on fairness, RB will be given first to those users who lack resources.

In terms of RB allocation, the method of dynamically adjusting RB is adopted as follows. It is hoped that the system throughput can be maximised while also being fair. Initially, let's assume that the number of RBs that GBR users can use is x. On the contrary, the number of RBs that can be used by non-GBR users is $(100–x)$, and we assume the initial value of x is 50. In order to prevent the possibility of continuous full load for GBR users, this mechanism will still reserve a bit of RB for non-GBR use, so the maximum value of x is set to 99 to avoid the possibility that non-GBR will not be able to allocate resources for a long time. When GBR user satisfaction is higher than the threshold, the value of x will gradually decrease, otherwise it will gradually increase. Here, the GBR user satisfaction threshold is set to 90%. Hence, the real-time service type packets can be transmitted as soon as possible and the rest resources can continue to serve non-GBR users without causing waste of resources.

4 Simulation results

Table 1 shows the simulation parameters of this system. It is assumed that the system has four usable Carrier Components (CCs) fixed in the licensed spectrum, and there is one usable carrier component in the unlicensed spectrum. The bandwidth is 20 MHz in each CC and each sub-Frame (1 ms) will have 100 RBs. In the system, three different types of traffic will be used, namely GBR VoIP and Video Stream and non-GBR FTP. The minimum bit rate guaranteed by VoIP is 40 kbps, and the minimum bit rate guaranteed by video stream is 2 Mbps. It is assumed that VoIP and Video Stream will generate a packet every 20 ms and 5 ms, respectively.

Table 1 Simulation parameters

下行無線存取技術	OFDMA
CC Bandwidth	20MHz
Number of RB per CC	100
Number of Licensed CC	4
Number of Unlicensed CC	1
Traffic Mode	GBR1 – VoIP GBR2 – Video Non-GBR – FTP
Number of User	GBR1 : 60~240 GBR2 : 60~240 Non-GBR : 80
GBR(kbps)	GBR1 : 40 Kbps GBR2 : 2 Mbps
Generating Packets Cycle	GBR1 : 20ms GBR2 : 5ms

Performance parameters are defined as follows:

1 *Load balanced index*: After all users in the system are allocated using the carrier component algorithm, the load status of the four CCs in the authorised spectrum is calculated as follows:

$$Load\ Balanced\ Index \frac{\left(\sum_{i=1,2,3,4} Load_{CC_i}\right)^2}{4 * \sum_{i=1,2,3,4} \left(Load_{CC_i}{}^2\right)} \tag{3}$$

2 *Wastage ratio*: The rate of waste of resources allocated by the system but not used.

$$wastage_{GBR} = \frac{RB_{GBR\_total} - RB_{GBR\_use}}{RB_{GBR\_total}} \tag{4}$$

where RB_{GBR_total} is the total number of data allocated to GBR users by the system.

3 Satisfied ratio of GBR user is defined as:

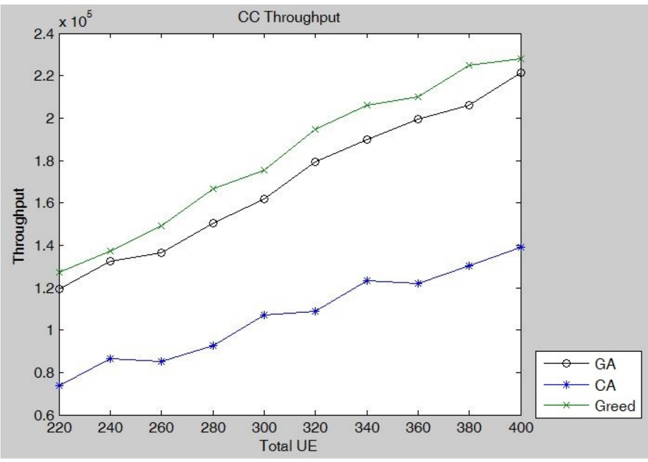
$$Sat_{GBR} = \frac{RB_{GBR\_use}}{RB_{GBR}} \tag{5}$$

where RB_{GBR_use} means the data actually sent by GBR users and RB_{GBR} is equal to (40 kbps × VoIP users) + (2 Mbps × Video users) representing the minimum amount of data guaranteed by GBR.

This section will discuss and analyse the simulation results. This simulation uses three carrier allocation algorithms, namely Genetic Algorithm (GA), Circle Allocation (CA) and Greed. The algorithm proposed in this article is GA, and the rest are comparison objects during simulation. The resource allocation algorithm uses Round Robin (RR) and Max Rate to compare with the GA proposed in this article. This simulation will observe the impact on the system when the number of video users is changed and the number of VoIP and FTP is fixed.

When the user enters the system for the first time, one of the carrier components in the authorised spectrum will be allocated to the user according to the genetic algorithm. Figure 2 shows total throughput of the four authorised carrier component that when the total number of people in the system is different. The higher the total throughput, the better the transmission performance of this channel. For the total throughput, the genetic algorithm is slightly less than the Greed algorithm because the genetic algorithm considers both the channel quality and load conditions. However, the Greed algorithm selects the carrier with the best channel quality and assigns it to the user every time while ignoring load balancing. As shown in Figure 3, the Greed algorithm has the highest total throughput but it is the worst in terms of load balancing.

Figure 2 CC throughput



First, fix the number of VoIP and non-GBR to 80 people each, and increase the number of Video people from 60 to 240. As shown in Figure 4, VoIP will always generate a packet every 20 ms during talk. The packet size is 100 Byte. The packet generation cycle is long and the packet size is small, so the three methods can transmit the data of the VoIP packet completely.

Figure 3 Load balance

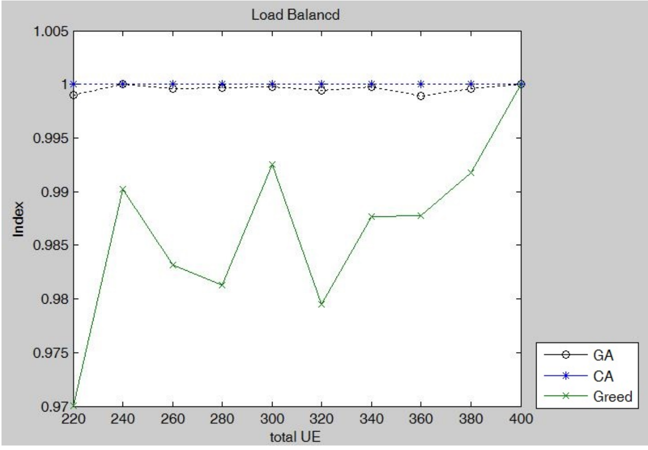
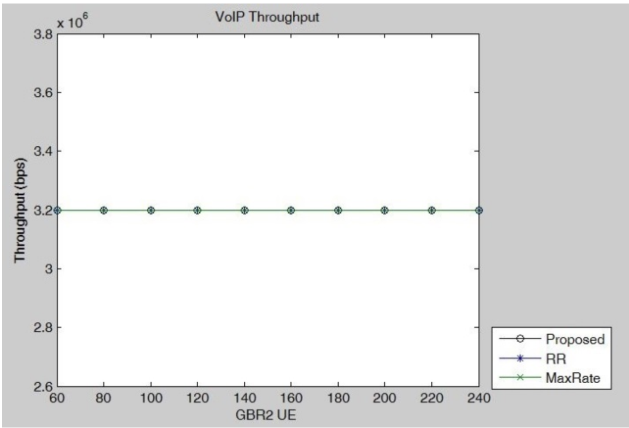
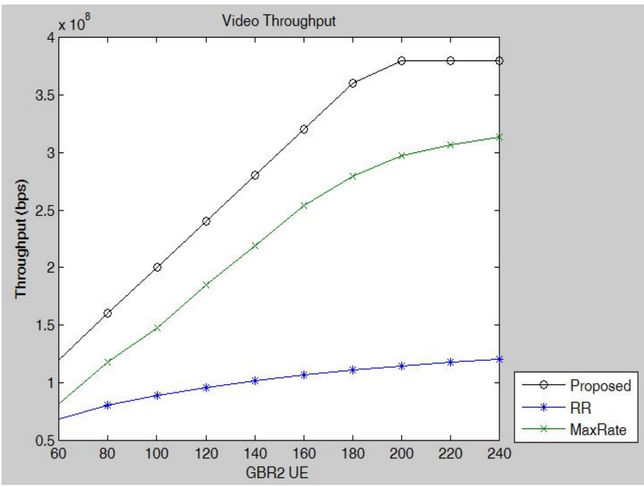


Figure 4 VoIP throughput



For video, each frame has a spacing of 40 ms, and each frame contains 8 packets with an average of 1250 Bytes. It can be seen from Figure 5, that when the total number of resource that can be allocated is fixed, and the video curve will gradually become flat as the number of videos increases which indicating the system has begun to be nearly full. It can be found that the use of proposed method can more effectively allocate resource making the average throughput of video higher than the other two methods.

Figure 5 Video throughput



When the number of people in the system increases, resource will be given priority to GBR users, and the average throughput of non-GBR will gradually decrease as shown in Figure 6. However, this proposed method will dynamically adjust RB during allocation and some RB will still be allocated for non-GBR use in order to prevent non-GBR from starvation.

Figure 6 Non-GBR throughput

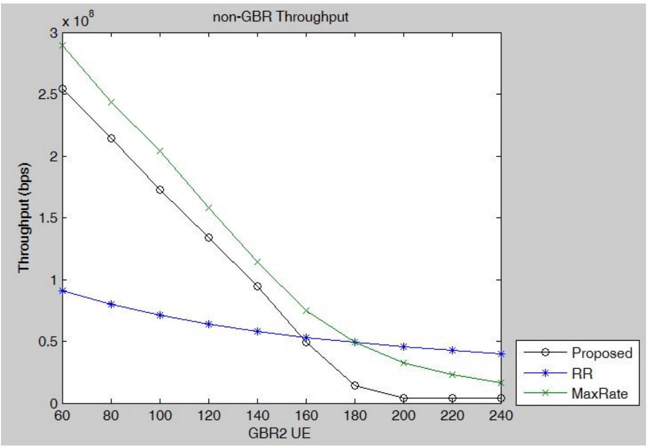
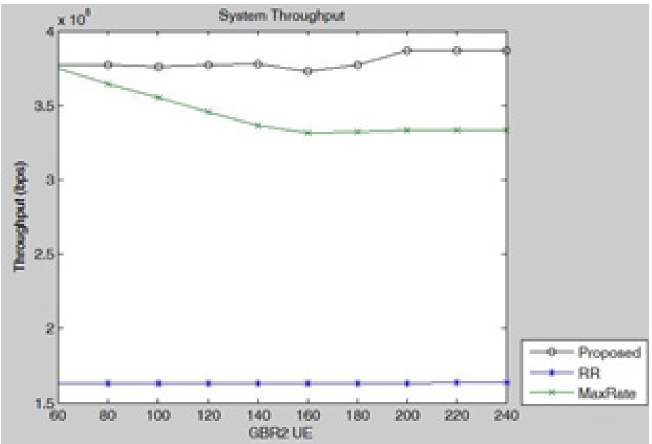


Figure 7 shows the average throughput of the system for changing the number of video users. It can be found that the resource allocation method proposed makes the results better than the other two and allocate resources more effectively.

Figure 7 System throughput



The other two methods do not consider weighting when allocating resources. The RR is a circular allocation which is impossible to predict whether the RB allocated to users is good or bad. Therefore, resources cannot be allocated effectively. As shown in Figures 8 and 9, the RR has always been lower in satisfaction than the other two. Because the allocated resources are less than the used resources, so the resource waste rate in RR is naturally not high. The Max Rate method will directly allocate the best RB to users which leads to increased waste rate and decreased satisfaction. It can be seen that the proposed method is better both in user satisfaction and resource wastage since it avoids excessive resource waste which can enable more users to use resources.

Figure 8 GBR satisfaction

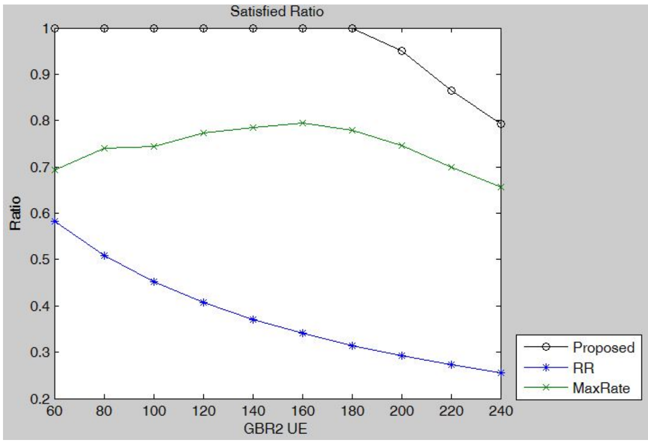
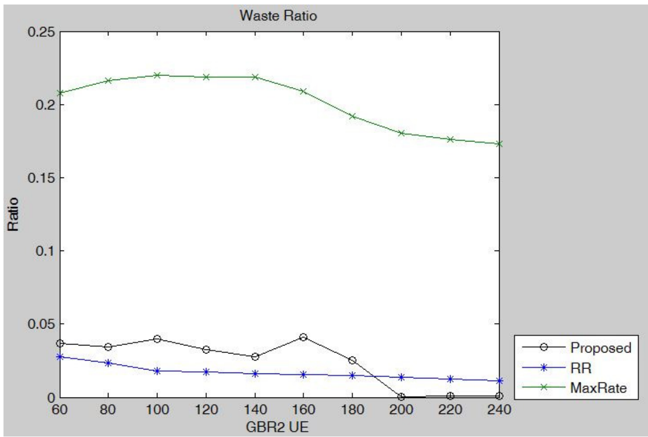


Figure 9 GBR wastage



In this simulation, it is assumed that the system has fixed four usable carrier components in the licensed spectrum, and one usable carrier component in the unlicensed spectrum as shown in Table 1.

This section will introduce the benefits of aggregation of unlicensed spectrum as shown in Figures 10 to 12 where $L + U$ represents aggregated unlicensed spectrum, and L indicates that only licensed spectrum is used. In Figure 10, it can be seen that the curve that only uses the licensed spectrum will quickly and flatten indicating that the system has begun to be close to full load while the curve with aggregated unlicensed spectrum will be slower and flatten, indicating that more users can be served. Therefore in terms of satisfaction, it can be seen that aggregating unlicensed spectrum is better than using only licensed spectrum, as shown in Figure 12.

In Figure 11, it can be clearly seen that among the three methods, the throughput of system that aggregate unlicensed spectrum is higher than that of only licensed spectrum and the method proposed in this paper is higher than the other two methods.

Figure 10 Aggregated video throughput (varying video users)

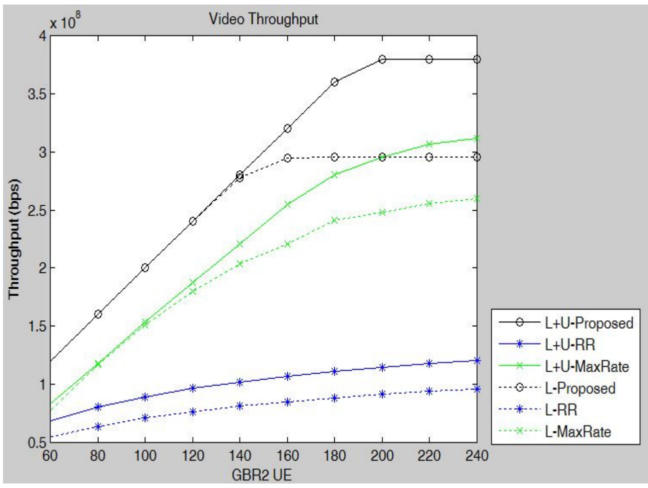


Figure 11 Aggregated system throughput

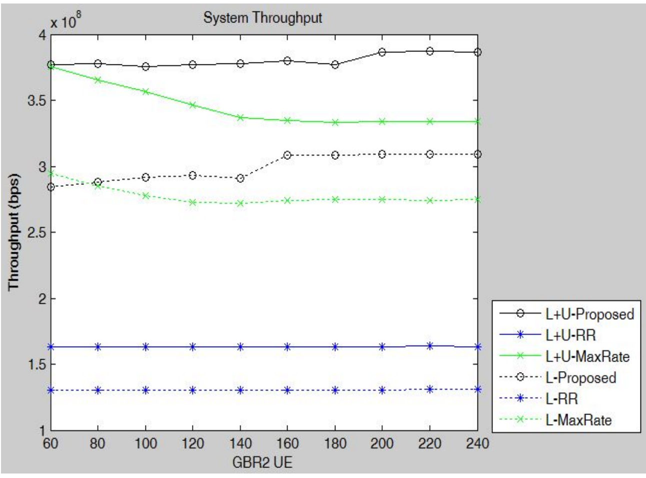
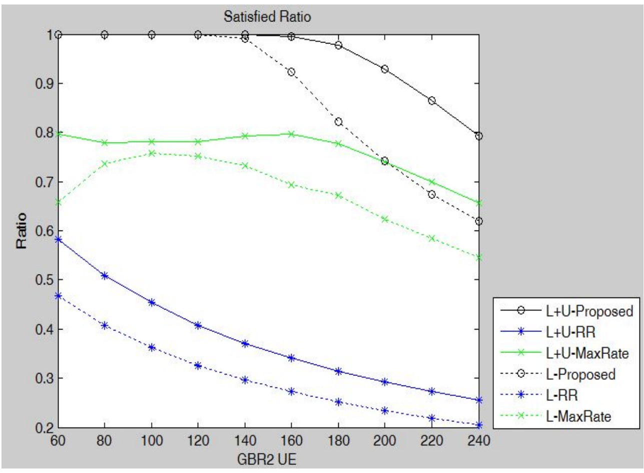


Figure 12 GBR user satisfaction (aggregated spectrum)



5 Conclusions

The work of this paper expects to increase the overall system throughput by aggregating licensed and unlicensed spectrum. In the carrier component assignment algorithm, a genetic algorithm is proposed to allocate a carrier that is most suitable for users and the channel quality and load status of the carrier unit are considered. In terms of resource allocation, we design a weighting scheme to improve the load balanced index and user satisfaction and it can also reduce waste of resource allocation.

References

Ali, M., Qaisar, S., Naeem, M. and Mumtaz, S. (2017) 'Joint user association and power allocation for licensed and unlicensed spectrum in 5G networks', *GLOBECOM IEEE Global Communications Conference*, Singapore, pp.1–6.

Basukala, H., Mohd Ramli, A. and Sandrasegaran, K. et al. (2009) 'Performance of well-known packet scheduling algorithms in the downlink 3GPP LTE system', *Proceedings of the IEEE 9th Malaysia International Conference on Communications*, Kuala Lumpur, Malaysia, pp.815–820.

Cano, C. and Leith, D. (2016) 'Unlicensed LTE/WiFi coexistence: is LBT inherently fairer than CSAT?', *Proceedings of IEEE* ICC, Kuala Lumpur, Malaysia, pp.1–6.

Dai, J. and Shen, C. (2018) 'Adaptive resource allocation for LTE/WiFi coexistence in the unlicensed spectrum', *International Conference on Computing, Networking and Communications*, Hawaii, USA, pp.1–6.

Garcia, L., Pedersen, K. and Mogensen, P. (2009) 'Autonomous component carrier selection: interference management *in local area environments for LTE-Advanced', IEEE Communication Magazine*, Vol. 47, No. 9, pp.110–116.

Ghosh, A., Ratasuk, R., Mondal, B., Mangalvedhe, N. and Thomas, T. (2010) 'LTE-Advanced: next-generation wireless broadband technology', *IEEE Wireless Communications*, Vol. 17, No. 3, pp.10–22.

Goldberg, D.E. (1989) *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley, Boston.

Hadi, M. (2015) 'Extending the benefits of LTE to unlicensed spectrum' in ICICT', *Proceedings of International Conference on Information and Communication*, Karachi, Pakistan, pp.1–4.

Iwamura, M., Etemad, K., Fong, M., Nory, R. and Love, R. (2010) 'Carrier aggregation framework in 3GPP LTE-Advanced', *IEEE Communication Magazine*, Vol.48, No.8, pp.60–67.

Ratasuk, R., Mangalvedhe, N. and Ghosh, A. (2014) 'LTE in unlicensed spectrum using licensed-assisted access', *Proceedings of Globecom Workshop*, TX, USA, pp.1–6.

Tzeng, G. and Huang, J. (2011) *Multiple Attribute Decision Making: Methods and Applications*, CRC Press, Florida.

Wu, W., Yang, Q., Liu, R. and Kwak, K. (2019) 'Protocol design and resource allocation for LTE-U system utilizing licensed and unlicensed bands', *IEEE Access*, Vol. 7, pp.67068-67080.