12th EAI International Conference on
Heterogeneous Networking for Quality, Reliability, Security and Robustness

Primary Component Carrier Assignment in LTE-A

Husnu S. Narman[1] and Mohammed Atiquzzaman[2]

[1] Holcombe Department of Electrical and Computer Engineering, Clemson University,
Clemson SC, 29634 USA
`husnu@ou.edu`
[2] School of Computer Science, University of Oklahoma, Norman OK, 73019 USA
`atiq@ou.edu`

Abstract. Bandwidth requirement for the mobile data traffic is on the rise because of increasing number of mobile users. To answer the requirement, Carrier Aggregation is proposed. With Carrier Aggregation and MIMO, operators can provide up to 3Gbps download speed. In Carrier Aggregation, several component carriers from multiple bands are assigned to users. The assigned Component Carriers are classified as Primary and Secondary Component Carriers. The Primary Component Carrier (PCC) is the main carrier and only updated during the handover and cell reselection, but Secondary Component Carriers (SCC) are auxiliary carriers to boost data rates and can be activated/deactivated anytime. During the carrier assignment operations, PCC reassignment can lead packet interruptions because reassignments of PCC to users can lead SCCs reassignment. Several methods have been proposed to increase the efficiency of the carrier assignment operations. However, none of them shows the system performance if LTE-A can have a procedure which allows one of SCCs to handle the duties of PCC during the PCC reassignment to eliminate packet transfer interruption. Therefore, we have used four different carrier assignment methods to investigate the performance of LTE-A with and without the procedure. Results show that distinct carrier assignment methods are differently affected by the procedure. Our results and analysis will help service providers and researchers to develop efficient carrier assignment methods.

Key words: LTE, LTE-A, component carrier assignment, resources allocation, analysis.

1 Introduction

Data traffic over mobile network is increasing with the rise in the number of mobile users. Therefore, new advanced techniques are required to satisfy users. One of the important technology is LTE-A which provides 1.5 Gbps for uplink and 3 Gbps for downlink peak data rates to mobile users by using Carrier Aggregation (CA) and MIMO technology [1]. In CA, several Component Carriers (CC) with 1.5MHz, 3MHz, 5MHz, 10MHz, 15MHz or 20MHz bandwidth from a number of different or same bands are assigned to users. [1]. Therefore, there are three types of Carrier Aggregation, and they are *Intra-band contiguous, Intra-band non-contiguous and Inter-band non-contiguous* [1].

In Carrier Aggregation, the assigned Component Carriers are classified as Primary and Secondary Component Carriers. The Primary Component Carrier (PCC) is the main carrier and only updated during the handover and cell reselection but Secondary Component Carriers (SCC) are auxiliary carriers to boost data rates and can be activated/deactivated anytime. During the carrier assignment operations, PCC reassignment can lead packet interruptions because reassignments of PCC to users can lead SCCs reassignment.

The carrier assignment methods have been widely investigated by the researchers [2–14]. In [2, 3], Round Robin and Mobile Hashing methods have been investigated. Both of the methods are based on load balancing strategy. In [4], Channel Quality Indicator (CQI) is measured for each user by considering all component carriers; then the user connect to the carrier which has the highest rate to get the service. In [7], Liu et al. proposed a priority based carrier assignment method by giving priority for some services. In [5], absolute and relative methods have been studied. In [6], Wang et al. proposed G-factor for non-edge users to provide better coverages. Edge users are the users which are located away from eNB. In [8], bands of pico and macro cells are determined based on link collision and interference; then beamforming techniques are applied while serving to users. In [9], Shahid et al. proposed a self-organized method by considering the availability of CQI for all resource blocks not to interfere each other. A resource block is the smallest frequency that can be used to transfer data. In [10], Tang et al. used load balancing with CQI while assigning carriers. In [11] Chen et al. investigated mobility of users in real time to decrease the selection of carriers and handover frequencies. In [12–14], uplink carrier assignment strategies have been proposed. The uplink carrier assignment is mainly proposed to optimize bandwidth and energy while downlink carrier assignment aims to optimize only bandwidth. Moreover, the extensive literature review can be found in [15–17].

However, none of them shows the system performance if LTE-A can have a procedure which allows one of SCCs to handle the duties of PCC during the PCC reassignment to eliminate packet transfer interruption. Therefore, the *aim* of this work is to analyze the performance of four component carrier assignment methods with and without the procedure according to average delay and throughput ratio which are experienced by LTE-A type equipment.

The *objective* of this paper is to analyze PCC reassignment procedure in terms of throughput ratio and average delay which are LTE-A users[1] by considering the availability of duty switching between a CC of SCCs and PCC for four different carrier assignment methods based on Random, Load Balancing (LB) and Channel Quality Indicator (CQI). The key *contributions* of this work are as follows: (i) Duty switching procedure between PCC and a CC of SCCs is discussed; (ii) The system model for disjoint queuing system is explained; (iii) Comparing Random (RA), Least Load (LL), Least Load Rate (LR) and Channel Quality (CQ) carrier assignment methods by an extensive simulation with and without the procedure in terms of throughput ratio and average delay.

---

[1] Currently, LTE type equipment can only connect one CC to get services, but LTE-A type equipment can connect up to five CCs to receive services.

Results show that distinct carrier assignment methods are differently affected by the procedure. Our results and analysis will assist cellular network industries and researchers to improve carrier assignment by increasing efficiency.

The rest of the paper is organized as follows: In Section 2, the system model for carrier assignment with Disjoint Buffer System is discussed and followed by explanations of the used methods in Section 3. Simulation environments with parameters are explained in Section 4. In Section 5, results are discussed and studied. Finally, Section 6 has the concluding remarks.

2 System Model

Fig. 1 shows system model for CCA. n users are connected to m available CCs. Today, UE can only connect up to 5 CCs at the same time to provide 4G standard peak data rate. One of CCs must be PCC and is only updated during handover or cell reselection in LTE-A (Rev. 10 and above) [18]. Hence, PCC is usually the CC which has the highest coverage area and CQI. Moreover, PCC of one UE can be different from PCC of other UE. On the other hand, other CCs (besides PCC) are called SCC and can be activated or deactivated according to users' needs. UE can only connect one CC in LTE (Rev. 8) for communication [18]. Therefore, both types of UE equipment should be considered while evaluating the performance in CCA.

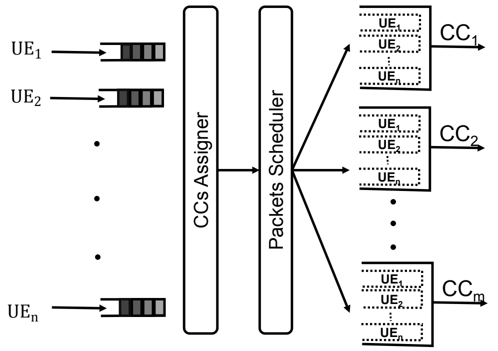

Fig. 1. Carrier Assignment model of n users and m available CCs with disjoint buffer system.

Packed Scheduler (PS) transfers packets over selected carriers in time and frequency domains after the carrier assignment process finishes. Currently, Proportional Fairness and max-min are common PS methods which are used in LTE-A [3, 19]. In addition to PS, there are two Queue Scheduler methods which are Disjoint and Joint Buffer [20]. In Joint Queue Scheduler (JQS) method, each CC has only one queue for all UEs. However, each CC has distinct queues for all UEs in Disjoint Queue Scheduler (DQS) as showed in Fig. 1. We have used Disjoint Queue Scheduler [20] in this paper because of the realistic approach of Disjoint Queue Scheduler for LTE-A [21].

3 Analysis

In this section, we briefly explain the process of properties switching between different carriers during the carrier reselection and the used methods for carrier assignment.

3.1 PCC and SCC Assignments

Primary Component Carrier (PCC) is the main carrier In LTE-A and when PCC is reassigned, it may result in that SCC also reassign. Therefore, the reassignment process can cause delays due to interruption of packet scheduling over carriers. Therefore, in this paper, we analyze the system by assuming the existence of the switch properties between PCC and SCC, thus does not lead the reassignment of SCC even if for PCC reassignment case.

3.2 Methods for Analyze

To analyze the impacts of PCC carrier assignment, four different carrier assignment methods are used. The methods are Random (RA), Least Load (LL), Least Load Rate (LR) and Channel Quality (CQ). Those methods are selected because of common usage in the literature, and the different strategies are used to in each method. The details about the methods can be found in [15, 16]. However, we also briefly explain the methods as follows.

3.3 Random (RA)

RA method randomly assigns carriers to users by ignoring QoS [3, 22]. In this paper, we used Java Random Generator which is based on Uniform Distribution to simulate this method. Therefore, RA balances carrier loads.

3.4 Least Load (LL)

LL method assigns carriers to users according to user loads on each carrier [3]. It balances users loads [3] but not guarantee QoS.

3.5 Channel Quality (CQ)

CQI depends on the frequency, the position of the users, obstacles, etc. Therefore, CQ methods can be proposed by considering distinct properties. For example, [5] choose the carrier which has the highest CQI to assign carriers to users. However, this type of methods ignores the load balancing and QoS.

3.6 Least Load Rate (LR)

For this type method, different rates and ratio parameters can be considered to optimize the performance. Here, CQI, the number of the users, and load factors are considered as similar to [4]. In [4], the queue length was used instead of the number of users. However, we considered queue length in packet scheduling for all methods. The rate function which we used in this paper is as follows:

$$\text{Rate} = \frac{\text{CQI of each carrier} * \text{Carrier bandwidth}}{\text{The number of users on the carrier}} \tag{1}$$

4 Simulation

We implemented the simulation with Java Programming Language according to described carrier assignment method procedures with disjoint buffers. Assumptions and simulation environments are discussed in the subsections.

4.1 eNBs

The parameters of eNB are summarized in Table 1 and the detail explanation of the parameters can be found in [15, 16].

Table 1. The eNB parameters.

Scenario [24]	b
Number of eNB	1
Used Bands	800MHz, 1.8GHz, 2.6GHz
Number of CCs in Each Band	4
Total Number of CCs	12
Queue Length of Each Queue	50 packets
Bandwidth of CCs	10MHz
Modulations	BPSK, QPSK, 16QAM, and 64QAM
CQI	3, 5, 7, and 11
Transmission Time Interval	average 10ms
Time for CCA	at most 20ms and at least 10ms
CQI Threshold	The highest possible
Simulation Model	Finite buffer simulation [25]

4.2 Assumptions for UEs

In the network, LTE and LTE-A type of devices are simulated. The half of devices is LTE type, and the other half is LTE-A type devices. LTE devices can get services over at most one CC while LTE-A devices can connect at most five CCs to get services but one

CC is used for uplink [1]. In our simulation, we simulate downlink carrier assignment scenario. Therefore, only four CCs are simulated for LTE-A devices to get service at the same time.

UEs are randomly distributed around eNB. To make the simulation close to the reality, UEs are mostly places around eNB. The half of users can freely and regularly replaced in time interval to simulate mobility. Because of UE mobility and eNB position, CQI Index for all carriers can be one of four options which are given in Table 1. Only one type of data traffic is downloaded by each user. Packet arrival follows Pareto Distribution with 250 packets per second for each user (shape parameter for Pareto Distribution is 2.5), and all test cases have the same packet arrival rates. Moreover, the packet arrival rate is gradually increased while the number of users is getting higher to simulate low and high data arrivals to the system.

4.3 Packet Scheduling

Packet scheduling method is min-delay scheduling, and the packet is transferred over the CC which can give the optimum performance for the packet. However, if there are multiple carriers which are available to serve the incoming packets, the CC, which has the lowest range and highest CQI, is used. By following this approach, the efficiency is increased. If the all carriers are busy with packets, packets are added to the related buffers (the user queue in each carrier for Disjoint Buffer system). If the buffers are full, the arriving packets are not getting service and dropped.

4.4 Observation Methodology

The performance of the four different methods have been compared by considering the throughput and delay based on with and without PCC grants. The results are only for the LTE-A type devices because LTE devices do not have PCC and SCC distinction. Throughput ratio is the ratio of the successfully transferred packets to all generated packets (dropped packets + transferred packets). Block rate is not given because it is just 1 throughput ratio. On the other hand, the average delay is measured according to the delay times of packets by calculating the division of the total time to the transferred packets. In all cases, the packets which belong to LTE-A devices are considered.

5 Results

The results are an average of 40 realizations for different size of users with 10000 packet samples. The impact of light and heavy users loads of carrier assignment methods are investigated by using the packet and queue scheduling techniques which are explained in Sections 3 and 4.3.

5.1 Average Delay Time

Fig. 2 shows average delay per packet which is experienced by only LTE-A type equipment for four carrier assignment methods according to without and with PCC grant.

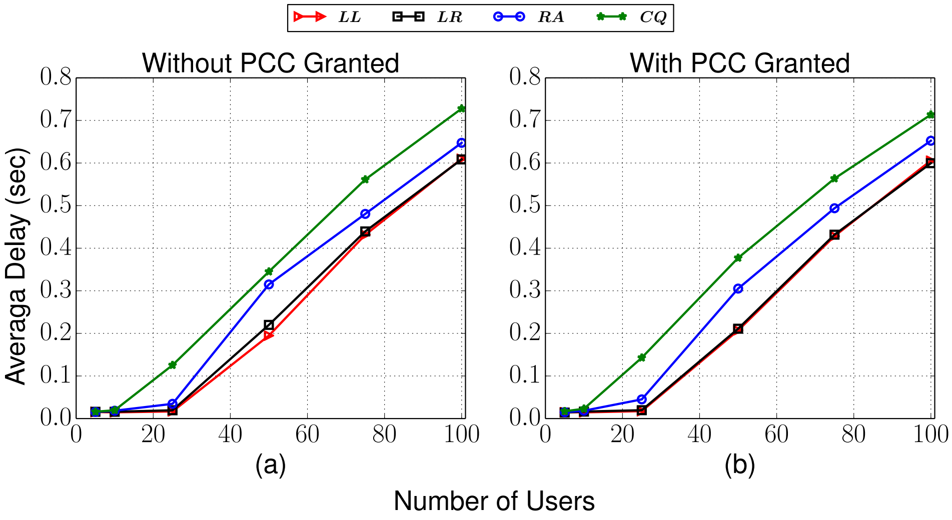

Fig. 2. Average delay experienced by LTE-A equipment types in disjoint queue model.

When the number of users is 10 or below, RA, LL, LR and CQ methods have almost zero average delay for all cases. When the number of users increases, LL methods are not affected by PCC grant, but RA and LR method performances are slightly improved. However, the average delay in CQ method is higher in PCC grant. One of the reasons for the lower average delay in CQ method is that CQ assigns CCs which can have high CQI but also a high number of users.

Moreover, if the methods are compared with each other, while LL method is the best in terms of average delay without PCC grant, LL and LR methods are the best in terms of average delay with PCC grant. CQ is the worst in terms of average delay for without and with PCC grant.

5.2 Throughput

Fig. 3 shows throughput ratio which is experienced by only LTE-A type equipment for four carrier assignment methods according to without and with PCC grant. When the number of users is 25 or less, RA, LL, LR and CQ methods have the optimum throughput (=1) in all cases. It is because RA, LR, LL and CQ assign enough and appropriate CCs to LTE-A type equipment. When the number of users is 50 and more, throughput ratios in all methods are decreasing. However, RA and LR with PCC grant have slightly higher throughput ratios than RA and LR without PCC grant. It is reverse for CQ.

Similar to average delay, if the methods are compared with each other, while LL method is the best in terms of average delay without PCC grant, LL and LR methods are the best in terms of average delay with PCC grant. CQ is the worst in terms of average delay for without and with PCC grant.

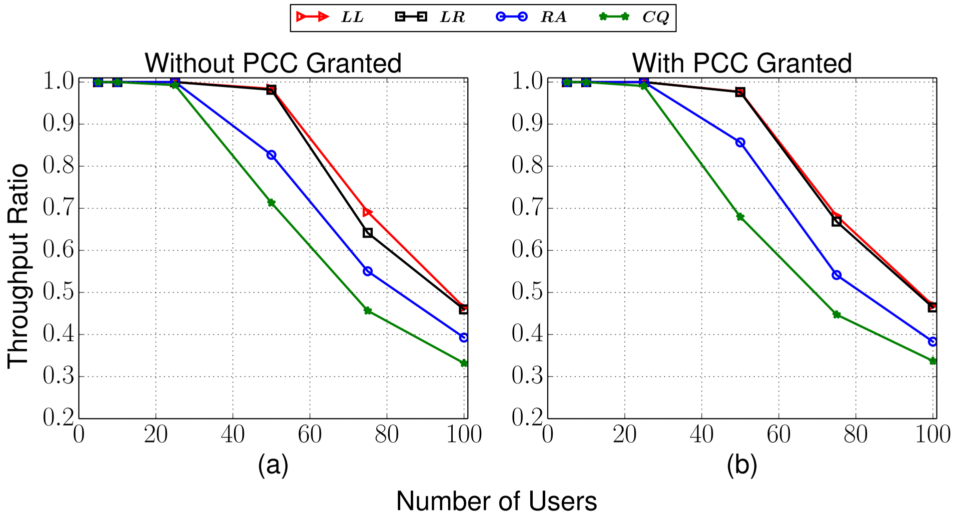

Fig. 3. Throughput ratio experienced by LTE-A equipment types in disjoint queue model.

5.3 Summary of Results

Based on the results, we make the following observations: (i) CQI decreases system performance more than load balancing when the system is under heavy data traffic load; (ii) PCC grant procedure can increase performance of RA and LL methods and decrease CQ method; (iii) With PCC grant, the performances of LL and LR are same and higher than the performances of RA and CQ methods and, without PCC grant, the performance of LL is higher than the performances of LR, RA and CQ methods.

6 Conclusion

In this paper, four different component carrier assignment methods are compared by considering LTE-A equipment type by an extensive simulation. Moreover, effects of a procedure which allows one of secondary component carriers to handle the duties of primary component carriers during the primary component carrier reassignment to eliminate packet transfer interruption on four carrier assignment methods are investigated. Results show that Least Load and Least Load Rate methods have higher throughput and delay comparing to other methods and distinct carrier assignment methods are differently affected by the procedure. Our comparison and related analysis will help service providers and researchers build efficient component carrier assignment methods in order to improve performances metrics such as throughput and delay.

References

1. J. Wannstrom. (2013, June) LTE-Advanced. Accessed: Mar 18, 2015. [Online]. Available: http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced
2. Y. Wang, K. Pedersen, P. Mogensen, and T. Sorensen, "Resource allocation considerations for multi-carrier LTE-Advanced systems operating in backward compatible mode," in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Tokyo, Sep 13-16, 2009, pp. 370–374.
3. Y. Wang, K. Pedersen, T. Sorensen, and P. Mogensen, "Carrier load balancing and packet scheduling for multi-carrier systems," *IEEE Transactions on Wireless Communications*, vol. 9, no. 5, pp. 1780–1789, May 2010.
4. H. Tian, S. Gao, J. Zhu, and L. Chen, "Improved component carrier selection method for non-continuous carrier aggregation in LTE-Advanced systems," in *IEEE Vehicular Technology Conference (VTC Fall)*, San Francisco, CA, Sep 5-8, 2011.
5. L. Liu, M. Li, J. Zhou, X. She, L. Chen, Y. Sagae, and M. Iwamura, "Component carrier management for carrier aggregation in LTE-Advanced system," in *IEEE Vehicular Technology Conference*, Budapest, May 15-18, 2011.
6. H. Wang, C. Rosa, and K. Pedersen, "Performance analysis of downlink inter-band carrier aggregation in LTE-Advanced," in *IEEE Vehicular Technology Conference*, San Francisco, CA, Sep 5-8, 2011.
7. F. Liu, W. Xiang, Y. Zhang, K. Zheng, and H. Zhao, "A novel QoE-based carrier scheduling scheme in LTE-Advanced networks with multi-service," in *Vehicular Technology Conference*, Quebec City, Canada, Sep 3-6, 2012.
8. C. Sun, H. Qing, S. Wang, and G. Lu, "Component carrier selection and beamforming on carrier aggregated channels in heterogeneous networks," *Communications and Network*, vol. 5, no. 3B, pp. 211–216, Sep 2013.
9. A. Shahid, S. Aslam, S. Sohaib, H. S. Kim, , and K.-G. Lee, "A self-organized metaheuristic approach towards inter-cell interference management for LTE-Advanced," *EURASIP Journal on Wireless Communications and Networking*, Oct 2014.
10. H. Tang, Y. Tian, H. Wang, and R. Huang, "A component carrier selection algorithm based on channel quality for LTE-Advanced system with carrier aggregation," *Journal of Computational Information Systems*, pp. 8953–8962, Oct 2014.
11. Z. Chen, G. Cui, C. Zhai, W. Wang, Y. Zhang, and X. Li, "Component carrier selection based on user mobility for LTE-Advanced systems," in *IEEE 78th Vehicular Technology Conference (VTC Fall)*, Las Vegas, NV, Sep 2-5, 2013.
12. H. Wang, C. Rosa, and K. Pedersen, "Uplink component carrier selection for LTE-Advanced systems with carrier aggregation," in *IEEE International Conference on Communications*, Kyoto, June 5-9, 2011.
13. R. Sivaraj, A. Pande, K. Zeng, K. Govindan, and P. Mohapatra, "Edge-prioritized channel- and traffic-aware uplink carrier aggregation in LTE-Advanced systems," in *International Symposium on a World of Wireless, Mobile and Multimedia Networks*, San Francisco, CA, June 25-28, 2012.
14. S. N. K. Marwat, Y. Dong, X. Li, Y. Zaki, and C. Goerg, "Novel schemes for component carrier selection and radio resource allocation in lte-advanced uplink," in *Mobile Networks and Management*, ser. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, R. Agero, T. Zinner, R. Goleva, A. Timm-Giel, and P. Tran-Gia, Eds. Springer International Publishing, 2015, vol. 141, pp. 32–46.
15. H. S. Narman and M. Atiquzzaman, "Joint and selective periodic component carrier assignment for LTE-A," *Computer Networks*, Feb 2016.

16. H. S. Narman, “Design and development of carrier assignment and packet scheduling in LTE-A and Wi-Fi.”
17. H. S. Narman and M. Atiquzzaman, *Design and Development of Carrier Assignment and Packet Scheduling in LTE-A and Wi-Fi*.
18. J. Wannstrom. (2008, June) HSPA. Accessed: Mar 18, 2015. [Online]. Available: http://www.3gpp.org/technologies/keywords-acronyms/99-hspa
19. X. Cheng, G. Gupta, and P. Mohapatra, “Joint carrier aggregation and packet scheduling in LTE-Advanced networks,” in *Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, New Orleans, LA, June 24-27, 2013, pp. 469–477.
20. L. Chen, W. Chen, X. Zhang, and D. Yang, “Analysis and simulation for spectrum aggregation in LTE-Advanced system,” in *70th Vehicular Technology Conference*, Anchorage, AK, Sep 20-23, 2009.
21. H. Lee, S. Vahid, and K. Moessner, “A survey of radio resource management for spectrum aggregation in LTE-Advanced,” *IEEE Communications Surveys Tutorials*, vol. 16, no. 2, pp. 745–760, Second quarter 2014.
22. T. Dean and P. Fleming, “Trunking efficiency in multi-carrier CDMA systems,” in *56th Vehicular Technology Conference*, Vancouver, Canada, Sep 24-28, 2002, pp. 156–160.
23. L. xiang Lin, Y. an Liu, F. Liu, G. Xie, K. ming Liu, and X. yang Ge, “Resource scheduling in downlink LTE-Advanced system with carrier aggregation,” *The Journal of China Universities of Posts and Telecommunications*, vol. 19, no. 1, pp. 44 – 49, Feb 2012.
24. 3GPP. (2015, Feb) LTE; evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN); overall description; stage 2 (3GPP TS 36.300 version 12.4.0 Release 12) . Accessed: Mar 18, 2015. [Online]. Available: http://www.etsi.org/deliver/etsi_ts/136300_136399/136300/12.04.00_60/ts_136300v120400p.pdf
25. P. Ameigeiras, Y. Wang, J. Navarro-Ortiz, P. Mogensen, and J. Lopez-Soler, “Traffic models impact on OFDMA scheduling design,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, no. 1, pp. 1–13, Feb 2012.