Primary Component Carrier Assignment in LTE-A

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Abstract. Bandwidth requirement for 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 3 Gbps 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.

Keywords: 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)

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with 1.5 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz or 20 MHz 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.

Several carrier assignment methods have been proposed and analyzed [2–14] in the literature. In [2,3], Round Robin and Mobile Hashing methods have been investigated. Both of the methods are based on load balancing strategy. In [4], firstly, Channel Quality Indicator (CQI) rates from all users for each component carriers are measured, then according to the highest rate, the carriers are assigned to users. In [7], a service-based method is proposed by giving priority for some traffic types while assigning carriers to users. In [5], absolute and relative carrier assignment methods are proposed according to a predetermined CQI threshold and PCC CQI, respectively. In [6], G-factor carrier assignment method is proposed by considering load balancing for non-edge users and better coverages for edge users. Edge users are the users which are located away from eNB. In [8], firstly, bands of pico and macro cells are decided according to interference, then beamforming is used to give services to each user. In [9], a self-organized method, which assumes availability of CQI for each resource block to avoid interference, is proposed. A resource block is the smallest unit of resources that can be allocated to a user. In [10], the least user loaded carriers with highest CQI are considered to assign carriers to users. In [11], mobility of users is estimated in real time while assigning carriers to users in order to decrease carrier reselection and handover. In [12–14], uplink carrier assignment methods have been proposed by considering a ratio function, traffic type and CQI to increase throughput while sending data from users to eNB. While the aim of uplink carrier assignment is to optimize bandwidth and power limitation, downlink carrier assignment aims to optimize only bandwidth.

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

[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.

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.

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.

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

2 System Model

Figure 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) [15]. Hence, PCC is generally 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 [15]. Therefore, both types of UE equipment should be considered while evaluating the performance in CCA.

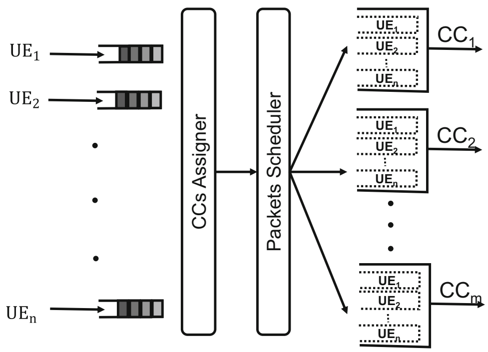

Fig. 1. Carrier assignment model of n users and m available CCs with disjoint buffer system.

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 [3,16]. In addition to PS, there are two Queue Scheduler methods which are Disjoint and Joint Buffer [17]. 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 [17] in this paper because of the realistic approach of Disjoint Queue Scheduler for LTE-A [18].

3 Methods

To analyze the impacts of joint and selective techniques on the carrier assignment, four different carrier assignment methods are used. The methods are based on random, load balancing and CQI and they are Random (RA), Least Load (LL), Least Load Rate (LR) and Channel Quality (CQ). Those methods are selected for test cases because of common usage in the literature and the different properties are considered while assigning the carriers to UEs.

3.1 Random (RA)

RA method is one of the well-known methods in the literature [3,19]. However, RA method ignores QoS requirements of each user and CQI of channels. In this work, R method assigns carriers to users according to Java Random Generator and Java Random Generator is based on Uniform Distribution. Therefore, RA randomly selects available carriers for each user but it only well balances users loads across carriers in long term.

3.2 Least Load (LL)

LL method is also one of the well-known methods in the literature [3]. LL assigns the carriers to users according to load balancing strategy by selecting the least loaded carriers thus, it well balances users loads across the carriers in short and long terms [3]. LL method also ignores QoS requirements of each user and CQI of the carriers. It is important to note that ignoring CQI does not mean the performance of LL method is lower than other methods.

3.3 Channel Quality (CQ)

CQI can be vary according to position of users because of obstacles and distances, Therefore, there are several versions of CQ methods like [5]. In this paper, CQ method assigns the carriers to users by selecting the carriers which have the highest CQI [20] and it is similar to Relative method in [5]. Because of only considering CQI, user loads and QoS requirements of users are ignored.

3.4 Least Load Rate (LR)

LR method assigns the carriers to users by selecting the highest rate which is measured by using the total capacity in terms of the bandwidth, the number of users and CQI for each carrier. The rate is measured as similar to [4] but instead of considering the queue length[2], we have considered the number of users in each carrier as follows:

$$\text{Rate} = \frac{\text{CQI of carrier} * \text{Bandwidth of carrier}}{\text{The number of users on carrier}} \quad (1)$$

4 Simulation

Discrete event simulation has been implemented by considering carrier assignment methods which are mentioned in Sect. 3. Assumptions and simulation setups are explained in the following subsections.

4.1 Assumptions for eNBs

It is assumed that there is only one eNB with three bands to provide service to users. The additional parameters of eNB are given in Table 1.

Table 1. The eNB parameters.

Scenario [21]	b
Number of eNB	1
Used bands	800 MHz, 1.8 GHz, 2.6 GHz
Number of CCs in each band	4
Total number of CCs	12
Queue length of each queue	50 packets
Bandwidth of CCs	10 MHz
Modulations	BPSK, QPSK, 16QAM, and 64QAM
CQI	3, 5, 7, and 11
Transmission time interval	10 ms (10 ms is average, it can be more or less)
Time for CCA	20 ms (at most 20 ms)
CQI threshold	The highest possible
Simulation model	Finite buffer [22]

In the simulation, Scenario *b* is used to represent the general macro model. Only one eNB is considered not to deal with the handover process in case users

[2] we consider the queue length in packet scheduling rather than carrier assignment for all methods.

change base stations. However, assuming one eNB does not affect the obtained results in terms of performance comparison between methods. The eNB provides service to users by using three bands similar to real case scenario and each band can have four CCs with 10 MHz bandwidth. The number of CCs in each band is selected as four because LTE-A type equipment can connect at most four CCs to download data. Therefore, even if a LTE-A type user in the coverage of *Band-a* can connect four CCs to get services similar to real case scenario. To simulate saturation of the system, a higher number of CCs are not selected. 10 MHz and 20 MHz bandwidths are used in LTE-A to provide IMT-A level speed [21]. BPSK, QPSK, 16QAM and 64QAM are the modulations techniques to transfer bits according to CQI in LTE systems. Therefore, to simulate those modulations, four CQI levels are used and each CQI level is modulation changing point. The average Transmission Time Interval (TTI) is 10ms for a packet (TTI can be less or more according to different packet sizes) to simulate the low and high latency requirements because the accepted TTI in LTE is 1ms to meet the low latency requirements [21]. In order to show the lowest improvements with PCC grant technique comparing to without PCC grant, time for CCA is kept as 20 ms and lower because the carrier assignment operations can consume considerable amount of time according to carrier assignment methods. As simulation model, finite buffer is used because finite buffer simulation well presents the reality comparing to full buffer simulation [22].

4.2 Assumptions for UEs

In the network, there are two types of equipment, LTE and LTE-A. 50% of equipment is LTE type equipment which only connect one CC to receive services. On the other hand, the other 50% equipment is LTE-A type equipment which connect multiple CCs (currently, up to five CCs). In simulation, four CCs are simultaneously connected by LTE-A type equipment because maximum five CCs can be used by LTE-A type equipment, and one of them must be for upload primary component carrier [1].

Initially, UEs are non-uniformly distributed in the simulated area. In brief, UEs are mostly located around eNB. 50% of users can move around of the eNB in specified 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 packet arrival traffics are kept same for all test cases. Moreover, total packet arrival is increasing while the number of users is enlarged.

4.3 Packet Scheduling

We have used a min-delay packet scheduling method for packet scheduling. Each packet is transferred by using one of assigned carriers for each user. To increase the efficiency and QoS, packet transferring priority is given to the CC, which is the closest to the eNB and minimizes packet delay if multiple carriers are available. If there are no available assigned carriers to serve arriving packets, packets are enqueued to corresponding user queues in each CC according to min-delay measurement (because of DQS). If there are no empty spaces in queues, arriving packets are dropped. We do not use Proportional Fairness packet scheduler [3] because it can block some packets during the scheduling. Therefore, the results can be misleading on device base performance comparison of the carrier assignment methods.

4.4 Observation Methodology

We present the performance of the carrier assignment methods by comparing throughput ratio and average delay which are experienced by LTE-A type equipment. Throughput ratio is measured by dividing transferred packets to all packets (dropped packets + transferred packets). Therefore, while the number of users is increased, throughput ratio decreases because of carrier capacities. Block rate is not given because it is just inverse of throughput ratio. Average delay is determined based on waiting times of packets in queues and service. It is obtained by dividing the sum of waiting time of the packets to the number of transferred packets. To measure throughout ratio and average delay per packet for LTE-A type equipment, the packets which belong to LTE-A type equipment are considered.

5 Results

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

5.1 Average Delay Time

Figure 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. When the number of user 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, average delay in CQ method is higher in PCC grant. One of the reason for lower average delay in CQ method is that CQ assign CCs which can have high CQI but also 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.

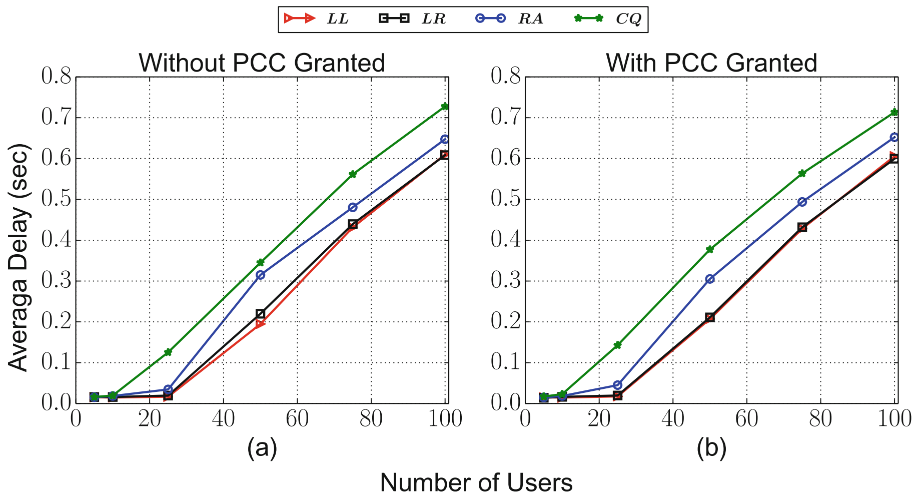

Fig. 2. Average delay experienced by LTE-A equipment types in disjoint queue model.

5.2 Throughput

Figure 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

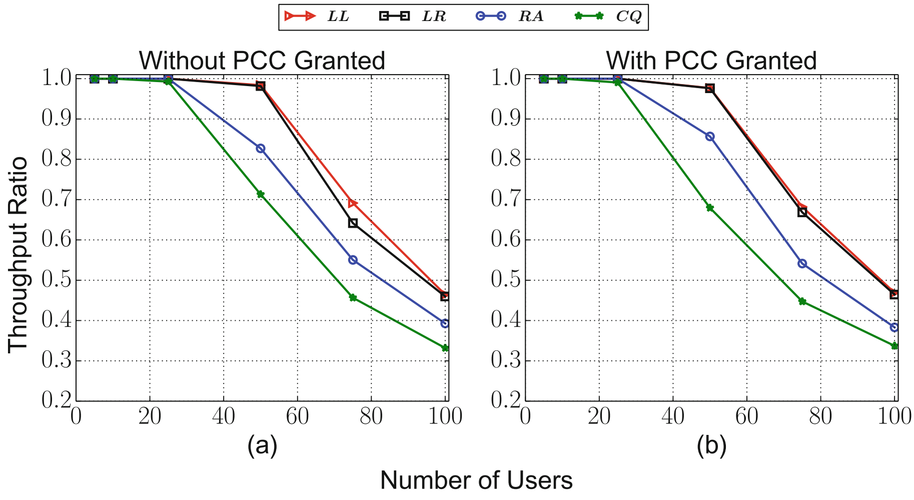

Fig. 3. Throughput ratio experienced by LTE-A equipment types in disjoint queue model.

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.

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; (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.

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