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Abstract—**Large multimedia files (such as high definition audio, video, images, etc.) are accessed by an enormous number of mobile users over the Internet. Therefore, the bandwidth demand for mobile Internet access is increasing exponentially. To answer users' demand, carrier aggregation is proposed in LTE systems. In carrier aggregation, the best available one or more carrier components of each band must be assigned as primary and secondary carrier components to each user for efficient services. The previous works have significantly improved the performance of LTE systems by using efficient carrier components assignment methods. The previous works, however, have two limitations. Firstly, overall system performance is analyzed in order to evaluate methods by ignoring systems behaviors such as packet drops and delay metrics during the time of assignment. Secondly, it is not investigated whether joint or partial secondary carrier components assignment show better performance. Therefore, in this report, packet drops and delay which are experienced by users during assignment process are investigated for two well-known carrier components assignment methods, Least Load and Random, and joint and partial secondary carrier components assignment is compared. Results prove that the partial technique increases efficiency of resource usage and performance of Least Load and Random carrier components assignment methods in LTE systems. Our analysis will help service providers build efficient carrier component assignment methods in LTE systems by considering utilization, throughput, and delay.**

Index Terms—**LTE, LTE-A, carrier component assignment, analytic, simulation.**

I. INTRODUCTION

The usage of Mobile Devices (MD) (such as tablet, smartphones, etc.) is numerously increasing and the number of purchased MDs passed one billion in 2013 and the expected number of MDs purchase is almost two billions in 2017 [1]. The report [1] states that MDs will dominate the future personal computer device market. The most notable reason for the increment of MDs is that users of MDs can reach wide range of applications under different platforms (e.g., GooglePlay, AppStore) [1] by cutting cross time and place restriction [1], [2]. More than hundred billions mobile applications have been downloaded in 2013 and more than 250 billions applications are expected to be downloaded in 2017 [1].

An enormous number of mobile users [1] accesses large multimedia files (such as high definition audio, video, images, etc.) over the Internet. Therefore, the bandwidth demand for mobile Internet access is increasing exponentially [3]. To answer users' demand, Carrier Aggregation (CA) is developed in LTE systems. By CA, bandwidth is extended and supports 1.5 Gbps for uplink and 3 Gbps for downlink peak data rates in LTE-A [4]. In CA, multi bands are used and the bands have different communication ranges (i.e., here range means coverage area of each band). One to two CC are Primary Carrier Component (PCC) and can only be updated during handover [4], and the rest of carriers are Secondary Carrier Components (SCC). After PCC is assigned, selected SCC is activated for a user. Note that PCC of a user can be different that PCC of another user [4].

Fig. 1 demonstrates a multi-band architecture in mobile networks. In the architecture, each band has several Carrier Components (CC). User Equipments (UEs) can simultaneously connect one or multi components of carriers from different bands. Base stations arrange the number of simultaneous connections of UEs from each band. However, if Carrier Components Assignment (CCA) method and policy is not carefully designed, one band can be overloaded while the other band can be idle. Therefore, CCA methods and preceding policies during the assignment process significantly affect system performance [5]–[7].

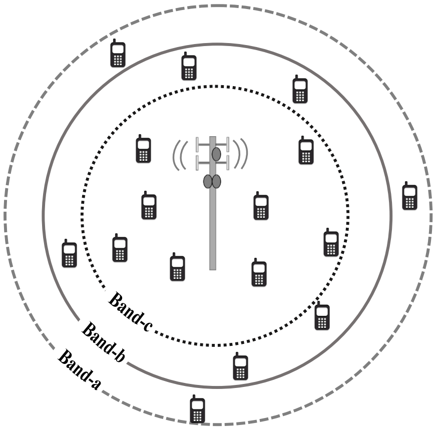

Fig. 1. eNodeB (eNB) with multi bands and several UEs.

Because of recent improvements in LTE systems, there are several proposed CCA methods with their analysis [7]–[18]. In [8]–[11], full or partial feedback is used to obtain Channel Quality Indicator (CQI) in order to find the best available carrier for each UE in bands. In [7], distribution of carriers to users are balanced. In [17], an uplink carrier assignment method has been proposed by considering a ratio function, traffic type and CQI to increase throughput while sending data from users to eNodeB (eNB). While uplink carrier assignment methods try to optimize bandwidth and power usage, main object of downlink carrier assignment is to optimize usage of bandwidth. In [13], [16], service-based carrier assignment methods are proposed by giving priority for some services while allocating UEs to carriers. In addition to the above methods, there exist traditional carrier assignment methods, Least Load (LL) (LL can be called as Round Robin (RR)) and Random (R) [19]. LL allocates UEs to least loaded carrier thus, LL well balances traffic loads across carriers in short and long terms, and R randomly selects carriers for UEs hence, R only well balances traffic loads across carriers in long term. However, both methods ignore CQI of channels and Quality of Service (QoS) requirements of UEs.

The previous works on CCA have significantly improved the performance of LTE systems. They, however, have two limitations. First, overall system performance is analyzed in order to evaluate performance of methods and behaviors of systems such as packet drops and delay metrics during the carrier assignment process are ignored. However, delay and packet drops can occur for the time of assignment because carrier assignment process could consume considerable amount of time based on selected methods due to required time for CQI feedback, QoS measurement, etc. For example, if a method is based on CQI feedback, it increases delay and packet drops for packet waiting for services during the operation of carrier assignment, so does packet retransferring rate. The second limitation is that whether reassign all or partial number of SCC at the same time for a UE. For example, while UE_i is leaving from *Band-c* communication range to enter *Band-b* communication range, simultaneously reassigning all SCCs to UE_i causes delay for packets of UE_i which are waiting for service. However, it may increase performance if CQI of new SCC is higher than the previous SCC (We called the policy of reassignment of all CCs as Joint Carrier Components Assignment (JCCA).) On the other hand, only updating CCs of *Band-c* by allowing carrier components of *Band-b* or *Band-a* to continue serving UE_i, can be another way to prevent packets experiencing delay or drop. However, finding better carriers for SCC in this position may be possible for this user to have better service (We called the policy of reassignment of some of carrier components as Partial Carrier Components Assignment (PCCA)). Therefore, the *aim* of this work is to analyze the impact of packet drops and delay which experienced by UEs during the assignment operation on systems performance and analyze JCCA and PCCA technique in order to observe effects of both techniques on throughput of LTE systems.

The *objective* of this paper is to investigate LTE performance by considering behavior of system during carrier assignment process for LL and R. The key *contribution* of this work are as follows: (i) proposing a new approach to evaluate carrier assignment methods, (ii) developing analytical modeling for JCCA and PCCA, and (iii) comparing performance of JCCA and PCCA with two well-known carrier components assignment methods, R and LL with an extensive simulation. *Results* prove that the new evaluation approach clearly show differences between carrier assignment methods, and PCCA has higher resource usage and performance for LL and R methods in LTE systems. Our analysis will help service providers build efficient CCA methods by considering performances metrics, such as throughput, delay and utilization in LTE systems.

The rest of the paper is organized as follows: In Section II, JCCA and PCCA are explained in LTE system. Analytic analysis of the techniques is presented in Section III and simulation environments with parameters are described in Section IV. In Section V, simulation results are analyzed. Finally, Section VI has the concluding remarks.

II. SYSTEM MODELS

Fig. 2 demonstrates a communication model in LTE systems. There are n number of UEs and each UE can only connect up to m number of CCs. Today, LTE-A system can only support up to five simultaneous carrier components connection for each UE in order to provide peak data rate [4]. One to two CCs are PCC for downlink and uplink, and can only be updated during handover [4], and the rest of carriers are SCC and can be updated for each UE based on quality of channels. After the carrier assignment process finishes, Packed Scheduler (PS) transfers packets over selected carriers in time and frequency dimensions. Currently Proportional Fairness and max-min are common PS methods which are used in LTE systems [6], [7].

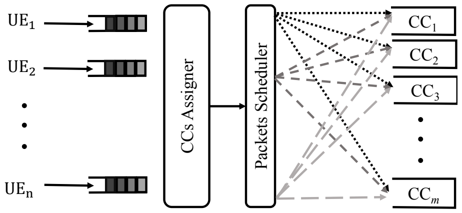

Fig. 2. General System Model with n users and m available CCs.

A. Joint and Partial Carrier Components Assignment

Carrier components assignment methods allocate users to CCs according to mobility, connection lost, CQI requirements, etc. For example, when UE_i moves from one position to another position, uplink and donwlink SCC of UE_i are updated to maintain connection of SCC between UE_i and eNB_j. In JCCA, all carriers of SCC for UE_i are simultaneously updated. For example, while UE_i is leaving from *Band-c* communication range to enter *Band-b* communication range, JCCA reassigns all carriers of SSC for UE_i from all bands at the same time to find better carriers for UE_i. However, packet transferring on these SCC carriers are terminated during the assignment operation in JCCA. On the other hand, in PCCA, each carrier of SCC is considered independently for each UE. For example, while UE_i is leaving from *Band-c* communication range to enter *Band-b* communication range, PCCA reassigns only affected carriers from this movement and other carriers continue serving UE_i to prevent packet transferring interruption on SCC carriers for UE_i. Therefore, packet transferring is not occluded during the assignment process for UE_i except that all of the carriers for UE_i are necessitated to be updated.

III. ANALYTICAL ANALYSIS OF CCA

In this section, JCCA and PCCA are analytically explained by using queuing system for downlink, and delay and drop rate of systems are approximately derived for both techniques. We have used Disjoint Queue Scheduler [**?**] because of realistic approach for LTE systems. Disjoint Queue Schedulers allows all users to have disjoint buffers for each carriers as showed in Fig. 4.

A. Notations

The notations used in the rest of the explanation and analysis are listed in Table I.

TABLE I
TABLE OF NOTATIONS

i	$\in$	$\{1, 2, ..., m\}$
Q_{CC_i}	$\triangleq$	Queue of CC_i
N	$\triangleq$	Size of Q_{CC_i}
λ	$\triangleq$	$\sum_{i=1}^{m} \lambda_i$
μ_i	$\triangleq$	Service rate of CC_i
λ_i	$\triangleq$	Arrival rate of packets to i^{th} queue
τ	$\triangleq$	Required time for assignment operation
δ	$\triangleq$	Average delay
n	$\triangleq$	Average queue length
D	$\triangleq$	Drop probability

B. Queuing Models for Downlink

Fig. 3 illustrates downlink process for SCC in LTE systems. CC_j is represented by a server with service rate μ_j and has Q_{CC_j} queue. Packet arrival rates for CC_j is λ_j and an arrived packet which is requested by UEs is enqueued to one of assigned CCs queues according to PS. During the assignment operation in JCCA for UE_i, the queues are updated as follows; (i) packet transferring is interrupted for UE_i on SCC, (ii) all carriers of SCC for UE_i are updated, (iii) all requested packets of UE_i in related queues are re-enqueued to new carriers queues according to PS by considering minimum arrival rate and priority (real time or non-real time priority), and (iv) packet transferring is commenced for UE_i on SCC. On the other hand, during the assignment operation in PCCA for UE_i, the queues are updated as follows; (i) assume that CCs, C_1, C_2, and C_3 are serving UE_i and packet transferring is interrupted in the carriers which are required to be updated (assume that C_1 and C_2 are required to be updated, thus packet transferring is only interrupted in C_1 and C_2), (ii) new servers are assigned to UE_i (assume that C_1 and C_2 are altered to C_4 and C_5. Note that the number of new CCs can be different than the number of previous CCs), and if the assignment process consumes more time than usual, the packets of UE_i in previous carriers queues (C_1 and C_2 queues) are enqeued to carriers queues which continue serving (in C_3 queue), (iii) if packets of UE_i in related queues (C_1 and C_2 queues) are not processed than the packets are re-enqueued to carriers queues of UE_i according to PS by considering minimum arrival rate and priority (real time or non-real time priority), and (iv) packet transferring continues in previous carriers (C_3) and is commenced in new carriers (C_4 and C_5) for UE_i.

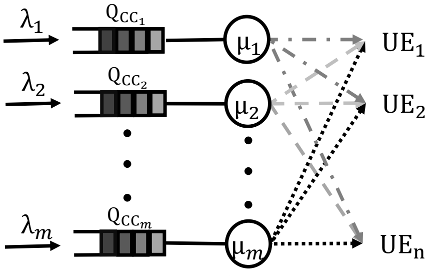

Fig. 3. Downlink System Model with *n* users and *m* available CCs.

C. Assumptions

To make the model analytically tractable, it is assumed that there is only one UE in the system as demonstrated in Fig. 4, all carriers are capable to transfer all type of packets, the queuing system is under heavy traffic flows, packet arrivals follow Poisson distribution, and service times for packets are exponentially distributed. Type of queue discipline used in the analysis is FIFO. Bandwidth size and CQI of carriers can be different, thus service rate of all servers can be different. During the assignment operation, packets transferring of UE_i is paused and restarted again after τ time (CCs assignment time) as is done in JCCA and packets transferring of UE_i continues during τ time as is done in PCCA hence, obtained performance metrics represent the approximated performance metrics for both methods. For clarity, analytical performance metrics are derived for only queues of SCC carriers by ignoring behavior of queues for PCC carriers.

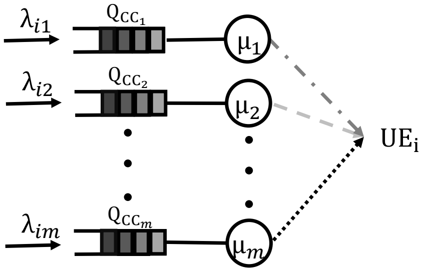

Fig. 4. Downlink System Model with one user and *m* available CCs.

D. Performance Metrics

The packet drop probability of packets in Q_{CC_m} queue for UE_i can be obtained using standard M/M/1/N formula for time interval [0, t+τ] where $t + \tau < 2\tau$ as follow [20]:

$$D_{j_m}(t) = \frac{\rho_{j_m}(t)^N (1 - \rho_{j_m}(t))}{1 - \rho_{j_m}(t)^{N+1}} \quad (1)$$

where

$$\rho_{j_m}(t) = \frac{\lambda_{im}(t)}{\frac{\mu_m(t)}{\tau\mu_m(t)+1}} \quad (2)$$

since the system is interrupted during the assignment process for UE_i and service time of packets is becoming $\tau + 1/\mu_m(t)$ for CC_m in time interval [0, t+τ].

By using all queues and their drop probability, drop probability of a packet from the system can be found in time interval [0, t+τ] as:

$$D_j(t) = \frac{\sum\limits_{k=1}^{m} \lambda_{ik}(t) D_{j_k}(t)}{\lambda(it)} \tag{3}$$

where

$$\lambda(it) = \sum_{k=1}^{m} \lambda_{ik}(t) \tag{4}$$

In the same way, the average queue length of $\mathrm{Q_{CC_m}}$ for $\mathrm{UE_i}$ can be obtained using standard M/M/1/N formula in [0, t+τ] as follow [20]:

$$n_{j_m}(t) = \begin{cases} \frac{\rho_{j_m}(t) - (N+1)\rho_{j_m}(t)^{N+1} + N\rho_{j_m}(t)^{(N+2)}}{\left(1-\rho_{j_m}(t)\right)\left(1-\rho_{j_m}(t)^{N+1}\right)} & \rho_{j_m}(t) \neq 1 \\ \frac{N}{2} & \rho_{j_m}(t) = 1 \end{cases} \tag{5}$$

By summing each average queue length in the system, average queue length of the system can be obtained in [0, t+τ] as:

$$n_j(t) = \sum_{k=1}^{m} n_{j_k}(t) \tag{6}$$

By using $\lambda(it)$, Eqs. (3) and (6), average delay ($\delta_j(t)$) for JCCA in time interval [0, t+τ] for $\mathrm{UE_i}$ can be written as:

$$\delta_j(t) = \frac{n(t)}{1 - D(t)} + \tau\lambda(it) \tag{7}$$

Similarly, drop probability ($D_{p_m}(t)$) and average queue length ($n_{p_m}(t)$) of $\mathrm{Q_{CC_m}}$ for PCCA can be represented by using same Eqs. (1) and (5) in time interval [0, t+τ] where $t + \tau < 2\tau$ thus, drop probability ($D_p(t)$) and average queue length ($n_p(t)$) of the system for PCCA can be written the same as Eqs. (3) and (6), respectively. However, $\rho_{j_m}(t)$ needs to be replaced by $\rho_{p_m}(t)$ and $\rho_{p_m}(t)$ can be written as:

$$\rho_{p_m}(t) = \begin{cases} \frac{\lambda_{im}(t)}{\mu_m(t)} & \text{if } CC_m \text{ is not stopped} \\ \frac{\lambda_{im}(t)}{\frac{\mu_m(t)}{\tau\mu_m(t)+1}} & \text{if } CC_m \text{ is stopped} \end{cases} \tag{8}$$

since PCCA may or may not interrupt packet transferring for $\mathrm{UE_i}$ and service time of packets will be $1/\mu_m(t)$ or $\tau + 1/\mu_m(t)$ for $\mathrm{CC_m}$ in [0, t+τ].

By using $\lambda(it)$, Eqs. (3) and (6), average delay ($\delta_p(t)$) for PCCA in time interval [0, t+τ] can be written as:

$$\delta_p(t) = \frac{n_p(t)}{1 - D_p(t)} + \tau(\lambda(it) - \sum_{k=1}^{v} \lambda_{ik}) \tag{9}$$

where $v \leqslant m$ and by assuming $\mathrm{CC_1}$, $\mathrm{CC_2}$, ... , $\mathrm{CC_v}$ are not updated during the assignment process, hence;

$$\rho_{p_\kappa}(t) = \begin{cases} \frac{\lambda_{i\kappa}(t)}{\mu_\kappa(t)} & 1 \leqslant \kappa \leqslant v \\ \frac{\lambda_{i\kappa}(t)}{\frac{\mu_\kappa(t)}{\tau\mu_\kappa(t)+1}} & v+1 \leqslant \kappa \leqslant m \end{cases} \tag{10}$$

During the assignment process, drop probability and delay performance metrics are obtained by using Eqs. (2) and (10) for JCCA and PCCA, respectively, and $D_p(t) \leqslant D_j(t)$ and $\delta_p(t) \leqslant \delta_j(t)$ because $\rho_{p_i} \leqslant \rho_{j_i}$ where $i \in \{1, 2, ..., m\}$. Therefore, obtained performance metrics prove that performance of PCCA is better than performance pf JCCA during the carrier assignment process. However, overall system performance metrics can be different because service rate of carriers for each user are time and position dependent. Therefore, we have implemented simulation to observe the overall performance of JCCA and PCCA.

IV. SIMULATION OF THE SYSTEM

Discrete event simulation has been implemented in Matlab by considering carrier component assignment methods which are mentioned in Sections II. Assumptions and simulation setups are explained in following subsections.

A. Assumptions for eNBs

It is assumed that there is only one eNB which has three bands to provide service to UEs. Some parameters of eNB is given in Table II.

TABLE II
TABLE OF eNB PARAMETERS

Num. of eNB	≜	1
Used Bands	≜	800MHz, 1.8GHz, 2.6GHz
Num. of CCs in each band	≜	4
Total Num. of CCs	≜	12
Queue Length of all $\mathrm{Q_{CC}}$	≜	50
Bandwidth size of CCs	≜	10MHz
Modulations	≜	QPSK, 16QAM, and 64QAM
CQI Index	≜	3, 5, 7, and 11
Transmission Time Interval	≜	1ms
CCA operation Time	≜	20ms

B. Assumptions for UEs

There are two types of devices (here device means equipment), LTE and LTE-A types devices in the system. Half of devices is LTE type and can only use one CC, and the other half of devices are LTE-A type and can use multiple CCs. In simulation, four CCs can be simultaneously connected by a LTE-A type devices because maximum five CCs can be connected in LTE-A, and one of them must be used for primary carrier components (see Section II) [4]. UEs are uniformly distributed in the simulated field. 50% of UEs can move around of the eNB in specified time interval. Each UE can only download one type of traffic. Packet arrivals follow Poisson distribution and arrival rates of traffic are enlarged when the number of UEs is increased. Selected Transmission Time Interval for a packet is 1ms and CCA operation time is 20ms.

C. Packet Scheduling (PS)

Without PS, the result cannot be obtained. Therefore, we have used the min-delay packet scheduler method in order to compare JCCA with PCCA by using Disjoint Queue

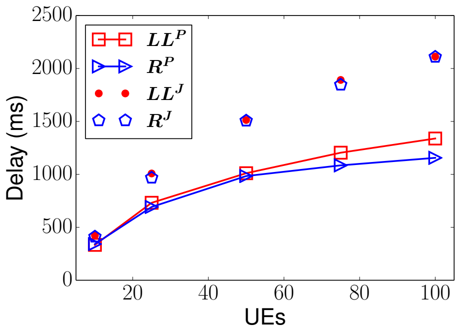

Fig. 5. Total delay of JCCA and PCCA due to assignment process in R and LL.

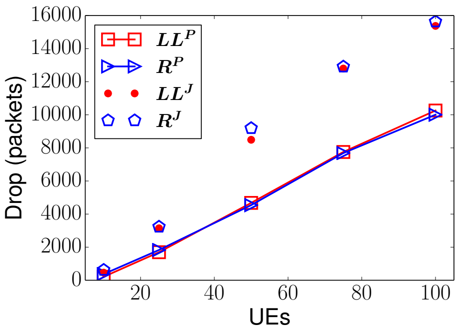

Fig. 6. Total dropped packets of JCCA and PCCA due to assignment process in R and LL.

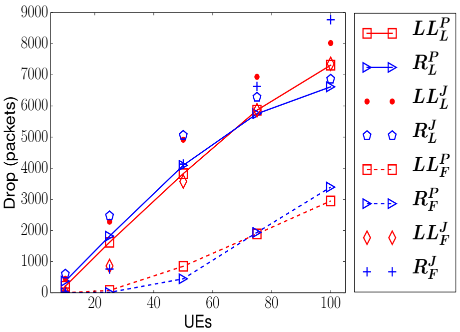

Fig. 7. Total dropped packets of JCCA and PCCA due to assignment process for LTE and LTE-A types UEs in R and LL.

Scheduler [**?**]. Packet arrival traffics are kept same for all test cases. Because of UEs and eNB positions, CQI Index of carriers can be one of four options which are given in Table. II. Each packet is transferred by using one of assigned CCs which minimizes packet delay. If there is no available assigned carriers to serve arrived packets for UEs, packets are enqueued to corresponding CCs queues (assigned CCs queues for each UE) based on minimum delay. If all assigned queues are full, the arrived packets are dropped from the system.

D. Observation Methodology

The results are obtained in the simulation from 100 realizations for different users size. The mean of realizations is demonstrated in Section V. The impact of light and heavy users loads on JCCA and PCCA is investigated by using Random (R) and Least Load (LL). R and LL methods are selected for test cases because of simplicity. Joint Random CCA (R^J), Partial Random CCA (R^P), Joint Least Load CCA (LL^J), and Partial Least Load CCA (LL^P) have been compared ($\ast^J$ and $\ast^P$ represent joint and partial techniques, respectively).

The performance of PCCA and JCCA is presented by comparing total packet drops and delay during the assignment process, system utilization, and overall throughput and delay for a various number of users. Utilization of each band is measured by dividing total packets of active users on each carrier to total capacity of carriers in each band for each district time, then the average utilization is obtained from those measured utilization of three bands. Throughput rates are measured by dividing transferred packets to all generated packets. Therefore, while the number of UEs is increased, throughput per a user decreases due to carriers capacities. Block rate is not given because it is just inverse of throughput rate. Overall delay for each packet is computed based on the waiting time in queues and servers. In order to find the partial delay effects of the assignment operation on the system, partial delay for each packet is measured by only considering waiting time of packets in queues during the assignment operation. Then, overall delay of system and total delay due to the assignment operations are calculated. Further, packet drops are measured by counting dropped packets during the assignment process. Additionally, performance of JCCA and PCCA techniques is evaluated in terms of UEs device types (LTE or LTE-A types) to observe the impacts of both techniques for packet drops, throughput rate and delay. As a consequences of these performance metrics, trade off between resource usage and managed QoS are compared for both PCCA and JCCA.

V. RESULTS

In this section, the system behavior during the carrier assignment process and the overall system performance is given for JCCA and PCCA.

A. System Performance during Carrier Components Assignment

In this section, packet drops and total delay, which is sum of partial delays, due to the assignment operations are presented.

1) Delay: Fig. 5 depicts total delay effects of carriers assignment process for joint and partial techniques. Delay is gradually increasing for all cases however, delay of JCCA is higher than delay of PCCA for both R and LL. In addition, delays of R and LL is almost same in JCCA. On the other hand, delay of R is lower than delay of LL in PCCA due to the nature of carrier assignment differences between two methods. Fig. 5 clearly explains that PCCA significantly decreases delay for packets which are arriving and waiting in queues during the assignment operation as analytically proved in Section III.

2) Packet Drops: Total packet drops during the assignment operation for joint and partial techniques is shown in Fig. 6. The higher number of users, the more dropped packets are for all cases. However, the number of total dropped packets is notably lower in PCCA than in JCCA for R and LL because of uninterrupted packet transferring policy in PCCA. Moreover, total packet drops of LTE and LTE-A type devices due to the assignment operations are shown separately in Fig. 7 for joint and partial techniques, where $\ast_L$ and $\ast_F$ represent LTE and LTE-A types devices, respectively. PCCA has the lowest total number of dropped packet for LTE-A type devices because LTE-A type devices can connect multiple CCs and one CC can continue packet transferring during the assignment process in PCCA. Additionally, although PCCA is not developed for LTE type devices (because LTE type devices can only connect one CC), the total number of dropped packets in PCCA is

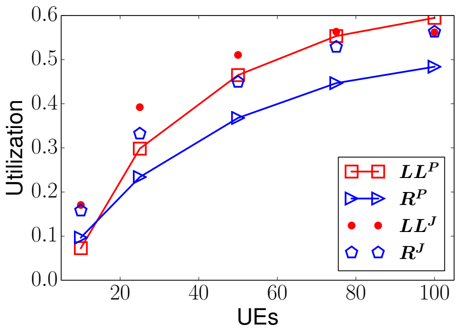

Fig. 8. System utilization of JCCA and PCCA in R and LL.

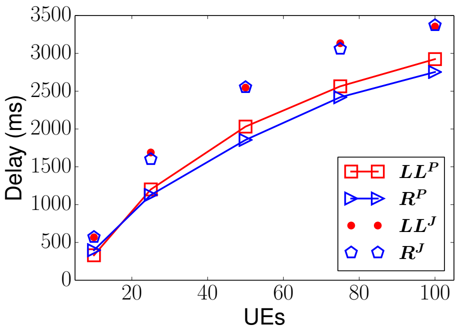

Fig. 9. Overall delay of JCCA and PCCA in R and LL.

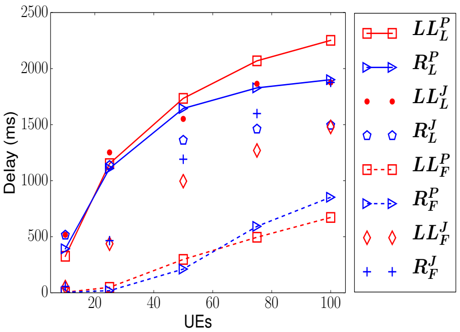

Fig. 10. Overall delay of JCCA and PCCA for LTE and LTE-A types UEs in R and LL.

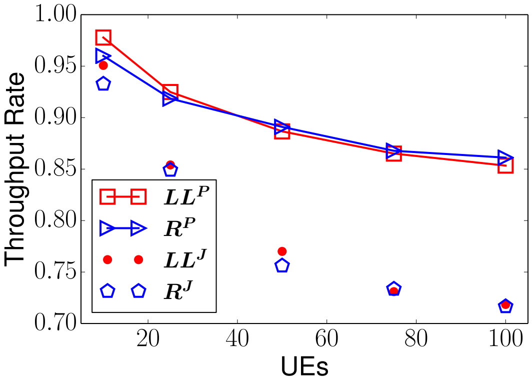

Fig. 11. Throughput rate of JCCA and PCCA in R and LL.

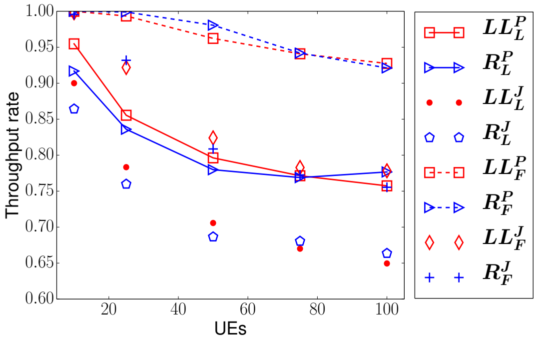

Fig. 12. Throughput rate of JCCA and PCCA for LTE and LTE-A types UEs in R and LL.

also lower than in JCCA for LTE type devices due to the performance of LTE-A type devices in PCCA.

B. Overall Performance of System

In this section, system utilization, overall delay and throughput rate are presented.

1) Utilization: System utilization of joint and partial techniques for R and LL methods is shown in Fig. 8. Utilization slowly increases when the number of users is getting larger for all cases. Though large amount of users, utilization of all cases does not reach peak rate (=1) because uniform distribution of users around eNB decreases the number of users in *Band-b* and *Band-c*. Thus, average utilization does not reach peak rate even though utilization of *Band-a* is high. Moreover, utilization of PCCA is lower than utilization of JCCA for both methods, except that utilization of PCCA and JCCA for LL are almost same when the number of users is higher than 75. It is worth to mention that utilization of R is lower than utilization of LL for both JCCA and PCCA.

2) Delay: Fig. 9 demonstrates system delay of joint and partial techniques. While the number of users is increased, delay is regularly getting higher for all cases. However, delay of JCCA is greater than delay of PCCA for R and LL. Fig. 10 depicts system delay of joint and partial techniques for both LTE and LTE-A types devices. Delay of JCCA is lower than delay of PCCA for LTE type devices because JCCA drops a large number of packets during the assignment operation. Due to packet drops, LTE type device-traffic is not experiencing much delay in JCCA. However, delay of JCCA is remarkably higher for LTE-A type devices because of interruption during packet transferring.

3) Throughput: Throughput rate of joint and partial techniques is shown in Fig. 11. Increasing number of users gradually reduces throughput rate per user for all cases. However, throughput of PCCA is greater than throughput of JCCA for both methods. Fig. 12 depicts throughput rate of joint and partial techniques for both LTE and LTE-A types devices. Although PCCA is not developed for LTE type devices to increase performance, throughput of PCCA is notably higher than throughput JCCA for both device types. Because, performance of LTE-A type devices results in that LTE type device-traffic finds more available carriers while transferring packets in PCCA.

C. Summary of Results

Based on the results, we make the following observations: (i) R and LL show reasonable performance because of their blind CQI carrier component assignment, (ii) min-delay packet scheduler leads that LTE type devices suffer long delay than LTE-A type devices for R and LL, (iii) although performance metrics during the assignment process have some similarity with overall performance metrics, performance metrics analysis during the assignment process clearly displays advantages and disadvantages of carrier component assignment methods, and (iv) PCCA has overall (almost 20%) less delay and (almost 25%) more throughput performance comparing to JCCA for both R and LL.

VI. CONCLUSION

In this paper, joint and partial carrier component assignment are compared according to overall system performance and a new approach, considering behavior of system during the time of carrier component assignment process. Queuing analysis and extensive simulation have been developed to compare performance of joint and partial techniques. Results show that the new evaluation approach clearly show differences between carrier assignment methods, and PCCA has higher resource usage and performance for Least Load and Random methods in LTE systems. Our analysis will help service providers build efficient carrier component assignment methods by considering performances metrics, such as throughput, delay and utilization in LTE systems.

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