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Investigations of Component Carrier Selection Algorithms in Long Term Evolution-Advanced

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ABSTRACT

Given that the demand for real-time multimedia contents that require significantly high data rate are getting of high popularity, a new mobile cellular technology known as Long term Evolution-Advanced (LTE-A) was standardized. The LTE-A is envisaged to support high peak data rate by aggregating more than one Component Carriers (CCs) of the same or different frequency bandwidths. Since the inter-band non-contiguous carrier aggregation is likely to be used due to the current frequency allocation, this paper provides a performance study of a number of CC selection algorithms for use in the inter-band non-contiguous downlink LTE-A. It should be noted that CC selection is of paramount importance in the LTE-A operating in backward compatible mode as the LTE-A contains a mixture of the legacy Long Term Evolution (LTE) users that support packets (re)transmission on a single CC and the LTE-A users that utilize more than one CCs for packets (re)transmission. Simulation results demonstrated the efficacy of the Channel-Throughput Aware (CTA) algorithm for maximizing the system capacity without compromising the required Quality of Service of real-time video users.

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1. INTRODUCTION

Of late, rapid adoption of smartphones and tablet computers have driven for the explosive demand on real-time multimedia contents. This poses new challenges to mobile cellular operators to provide good multimedia experience for all mobile cellular users [1]. As such, new mobile cellular technology known as Long Term Evolution-Advanced (also referred to as Release 10) was standardized by the Third Generation Partnership Project (3GPP) organization in its attempt to meet these crucial challenges. When compared with the legacy 3GPP family, the LTE-A is expected to significantly improve the peak data rates in which it can provide up to 1 Gbps and 100 Mbps for low and high mobility users, respectively [2] and 1 Gbps and 500 Mbs for downlink and uplink packet (re)transmission, respectively [3].

Carrier Aggregation (CA) [4],[5] is one of the methods that have the capability of achieving it. This method permits the LTE-A to support up to 100 MHz Component Carrier (CC) bandwidths, which maps to higher peak data rates, by aggregating more than one contiguous or non-contiguous CCs of the same or different frequency bandwidths [6]. The CC bandwidths supported by the LTE-A are within the range of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz and up to 20 MHz. These ranges are similar to the CC bandwidths supported by the legacy Long Term Evolution (LTE) Release 8 standard.

There are three types of CA specified for the LTE-A. These types are known as intra-band contiguous CA, intra-band non-contiguous CA and inter-band non-contiguous CA (as shown in Figure 1). If two or more adjacent CCs of the same frequency bandwidths are aggregated, then it is called intra-band contiguous CA. It is easier to implement as it requires minimal changes to the radio frequency design of the legacy LTE networks. The intra-band non-contiguous is a CA type that allows multiple CCs of the same frequency bandwidths to be aggregated in a non-contiguous manner. The CA type that aggregates multiple CCs of different frequency bandwidths in a non-contiguous manner is called inter-band non-contiguous CA.

The inter-band non-contiguous CA, which is the focus of the paper, results with additional complexity in the radio frequency design of LTE-A terminals [7]. However, given the current scenario where the spectrum allocation is highly fragmented with large frequency separation, the inter-band non-contiguous CA is likely to be used by the cellular operators for efficient utilization of the current spectrums allocation [8].

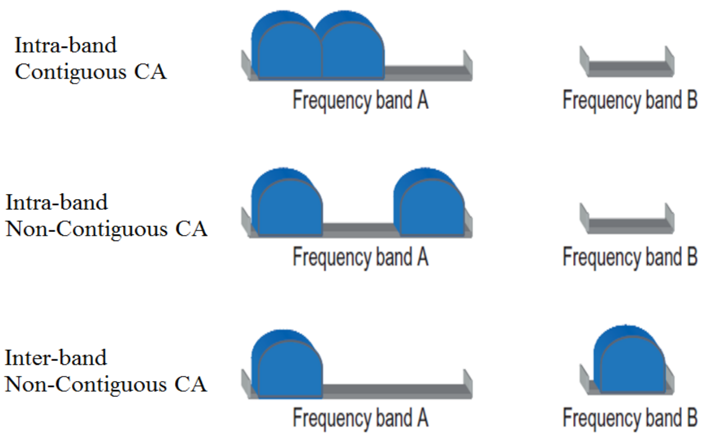

Figure 1. Three types of CA in LTE-A [9]

Another important requirement of the LTE-A is that the technology should be backward compatible with the legacy LTE. This means that the LTE and LTE-A users should be able to co-exist in the LTE-A network. In this Release 10 network, the LTE-A users which have high performance terminals are capable to support packet (re)transmission across multiple CCs. On the other hand, given the limited capability of their terminals, the LTE users can only support packet (re)transmission on a single CC [10].

As more than one CCs available and the LTE users can only support packets (re)transmission on a single CC, CC selection that is responsible to assign a CC to each newly-arrived legacy LTE users is becoming of paramount importance in the LTE-A [11]. Numerous CC selection algorithms operating in backward compatible mode have been developed in the literature (see [12] for a detailed review of CC selection algorithms). However, given the current frequency allocation that is highly fragmented and the current trend has shown an explosive demand for real-time multimedia contents, the performance of these algorithms in supporting the real-time multimedia contents in inter-band non-contiguous downlink LTE-A require further study. Note that this paper focuses in the downlink since significantly higher volume of multimedia traffic are towards the downlink as compared to the uplink. The minimum transmission unit in each CC in the downlink LTE-A is called a Resource Block which is made up of 180 kHz bandwidth in the frequency domain and extend to 1 ms duration in time domain. As such, this paper investigates the performance of a number of CC selection algorithms for maximizing the system capacity in the inter-band downlink LTE-A. This paper contributes to the identification of a suitable CC selection algorithm for use in the inter-band non-contiguous downlink LTE-A which is efficient in maximizing the system capacity without compromising the required Quality of Service (QoS) [13],[14] of the real-time multimedia users.

The remainder of this paper is structured as follows. Section 2 provides detailed review of CC selection algorithms for use when the LTE-A networks are operating in backward compatible mode followed by Section 3 that discussed method of this research where detailed explanations of simulation environment are provided. Section 4 discussed results of the evaluated CC selection algorithms whereas Section 5 remarks the conclusion of the paper.

2. CC SELECTION ALGORITHMS OPERATING IN BACKWARD COMPATIBLE MODE

As previously stated in Section I, CC selection is responsible to assign a CC to each newly-arrived LTE users. Though the majority of Radio Resource Management (RRM) studies focused on either packet scheduling and primary and secondary CC selections, this paper investigates the existing CC selection algorithms given that at the early stage of migration, the LTE-A networks may contain a mixture of LTE and LTE-A users. The algorithms considered in this study include Random [15], Least-Load [16], Queue-Length[6], Maximum Channel Quality Information (Max-CQI) [17] and Channel-Throughput Aware (CTA) [18] CC selection. The Random, Least-Load and Queue-Length algorithms are load-balance CC selection algorithms whereas the Max-CQI and CTA are channel-aware CC selection algorithms [19]. Detailed descriptions of each algorithm are given next.

The Random CC selection randomly assigns a CC to each newly-arrived LTE user such that the load is balanced from the long term point of view. However, given the random nature of CC assignment, the load may not be well-balanced. The Least-Load CC selection algorithm assigns a CC with the least number of users to each newly-arrived LTE user such that the load across each CC is well-balanced. When compared with the Least-Load that makes the decision on the basis of the number of users, the Queue-Length algorithm assigns a CC with the minimum queue length (in terms of total packet size) to each newly arrived LTE user.

The load-balanced CC selection algorithms may not be throughput efficient for not taking channel qualities of each CC into consideration. Given the limitations of these load-balanced CC selection algorithms, the Max-CQI algorithm that assigns a CC with the best channel quality to each LTE user was proposed (see Equation 1). This algorithm has shown good throughput performance for a limited number of users within intra-band contiguous/non-contiguous CCs where the radio propagation environment in each CC is almost similar. Nevertheless, it will lead to inefficient use of resources in the CCs of higher frequency spectrums (i.e. CCs at a higher frequency have poorer channel quality) if it is being implemented in inter-band non-contiguous CA as most of the users are assigned to a CC at a lower frequency.

$$\mu_{i,k} = r\_avg\_user\_CC_{i,k} \tag{1}$$

$$r\_avg\_user\_CC_{i,k} = \frac{1}{RB_{\max}} \sum_{j=1}^{j=RB_{\max}} r_{i,j,k} \tag{2}$$

where $\mu_{i,k}$ is the priority of user i on CC k, $r\_avg\_user\_CC_{i,k}$ is the average channel quality on all RBs of user i on CC k, $r_{i,j,k}$ is the channel quality of user i on RB j on CC k and RB_{max} is the maximum available number of RBs.

The CTA algorithm was developed to address the limitations of the Max-CQI. This algorithm assigns a CC to each newly-arrived LTE user according to Equation 3. The CTA avoids over assignment of a single CC (CC at a lower frequency spectrum) to a majority of users by taking the average channel quality of all LTE users into account when making decision. This allows the algorithm to efficiently utilize resources on all CCs (CC at a lower frequency as well as CCs at higher frequencies.

$$\mu_{i,k} = \frac{\dfrac{r\_avg\_user\_CC_{i,k}}{R_i}}{\displaystyle\sum_{m=1}^{m=N} \dfrac{r\_avg\_user\_CC_{m,k}}{R_m}} \tag{3}$$

where $\mu_{i,k}$ is the priority of user i on CC k, $r\_avg\_user\_CC_{i,k}$ is the average channel quality on all RBs of user i on CC k (as defined in Equation 3), R_i is the average throughput of CC i, N is the maximum number of users.

3. RESEARCH METHOD

Simulation method is used in this paper to evaluate the performance of the CC selection algorithms stated in Section 2. This method is chosen as it is less complex and less expensive as compared to mathematical modelling and real-time measurement methods. The simulation models the downlink LTE-A to consist of a single pico cell of 400 m radius with a base station located at the center of the cell. It is assumed that all users move at 30 km/h speed in a constant direction. Users are uniformly distributed within the cell.

Frequency division duplex mode is used. The inter-band non-contiguous CA is assumed where there are a total of three CCs of 700 MHz, 900 MHz and 2 GHz frequency bandwidth. Each CC is of three MHz bandwidth and contains a total of 15 RBs each. The Hata model for urban environment, a Gaussian log-normal distribution with 0 mean and 8 dB standard deviation and a frequency flat Rayleigh fading are used to model the channel state. Type II Hybrid Automatic Repeat Request (HARQ) with Chase Combining is considered. The HARQ feedback is modeled error-free with a 4 ms delay. All erroneous packets are discarded after they have been retransmitted three times.

The users in the downlink LTE-A is assumed to run real-time video content with average data rate of 256 kbps. The buffer delay threshold, which is the maximum allowable time a packet can reside at the base station buffer, is set at 100 ms. It is also assumed that the QoS requirement of real-time users is satisfied if the mean user throughput is maintained above 234.7 kbps. This is to allow each user to run 2 minutes video streaming session without its buffer running dry (if the size of de-jitter buffer is assumed to be 10 s when the user starts its video session). The downlink LTE-A is assumed to contain 75% legacy LTE users and 25% LTE-A users. This assumption is practical because at the early stage of migration, majority of the users' terminals do not support the advance features and capabilities of the LTE-A.

The metrics use to evaluate the performance of the CC selection algorithms are mean user throughput and Packet Loss Ratio (PLR). These metrics are mathematically expressed as follows:

$$mean\ user\ throughput = \frac{1}{N}\frac{1}{T}\sum_{i=1}^{N}\sum_{t=1}^{T} prx_i(t) \tag{4}$$

$$PLR = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} pdiscard_i(t)}{\sum_{i=1}^{N}\sum_{t=1}^{T} psize_i(t)} \tag{5}$$

where $prx_i(t)$ is the total size of correctly-received packets (in bits) of user i at time t, $pdiscard_i(t)$ is the total size of discarded packets (in bits) of user i at time t, $psize_i(t)$ is the total size of all packets (in bits) arrive into the eNB buffer of user i at time t, N is the total number of users and T is the total simulation time.

4. RESULTS AND DISCUSSIONS

The mean user throughput with increasing system capacity of the evaluated CC selection algorithms are shown in Figure 2. It can be observed in the figure that the mean user throughput degrades with increasing system capacity. This is because more packets available at the base station buffer as more users arrive into the system. Given that there are limited RBs in each CC to (re)transmit all the packets to the users, this leads to the degradation of the mean user throughput. If the QoS requirement of the real-time video is to be satisfied at 234.7 kbps mean user throughput threshold, then it can be observed in Table 1 that CTA algorithm supports more than 25% users compared to the Max-CQI algorithm and it has more than 33.33% system capacity improvement over the Queue-Length, Random and Least-Load CC selection algorithms. It should be noted that system capacity and user are used interchangeably hereafter. Additionally, the PLR performances of the five CC selection algorithms are illustrated in Figure 3. PLR degrades with increasing system capacity since more packets are discarded for delay violation (due to insufficient RBs with good channel quality to (re)transmit all the packets). Figure 3 also demonstrates that the CTA algorithm is capable to minimize the PLR for more users as compared to the other CC selection algorithms.

The significant improvement in the CTA as compared to the other CC selection algorithms can be explained as follows. The Queue-Length, Random and Least-Load are load-balanced CC selection algorithms. A CC is assigned to each newly-arrived LTE user without taking the user's average channel quality into account. Some newly-arrived LTE users located farther away from the base station may be assigned to a CC at a higher frequency which results with less or none packets are received (these users are in deep fade) and hence degrading the mean user throughput and PLR. On the other hand, the Max-CQI shown to have better performance as compared to the load-balanced CC selection algorithms. The Max-CQI makes decision on the basis of the average channel quality of each user. This allows a newly-arrived LTE user to enjoy (re)transmission on RBs of CC with good channel quality (see Equation 1). However, given that the Max-CQI always assigns a user on a CC with a good average channel quality, in the inter-band non-contiguous CA, there is highly likely that majority of LTE and LTE-A users compete for resources in one CC

(CC at a low frequency that has a better average channel quality) while resources in other CCs (CCs at a higher frequency that have poorer channel quality) are wasted.

It is observed in Figure 2 and Figure 3 that the Max-CQI performance significantly degrade with increasing system capacity indicating that the majority of the users are competing for limited resources within a CC of lower frequency whereas some resources in other CCs are wasted as only small number of LTE-A users are (re)transmitting packets on these CCs. Given that the average channel quality on a CC of all users are taken into account in CTA (as discussed in Section 2), this leads to users to be assigned to other CCs (i.e. instead of competing for resources in a CC at a lower frequency) and thus allowing the CTA to maximize its performance. In this case resources on all CCs are highly likely to be efficiently utilized as compared to the Max-CQI where competition of majority of users take place in a single CC.

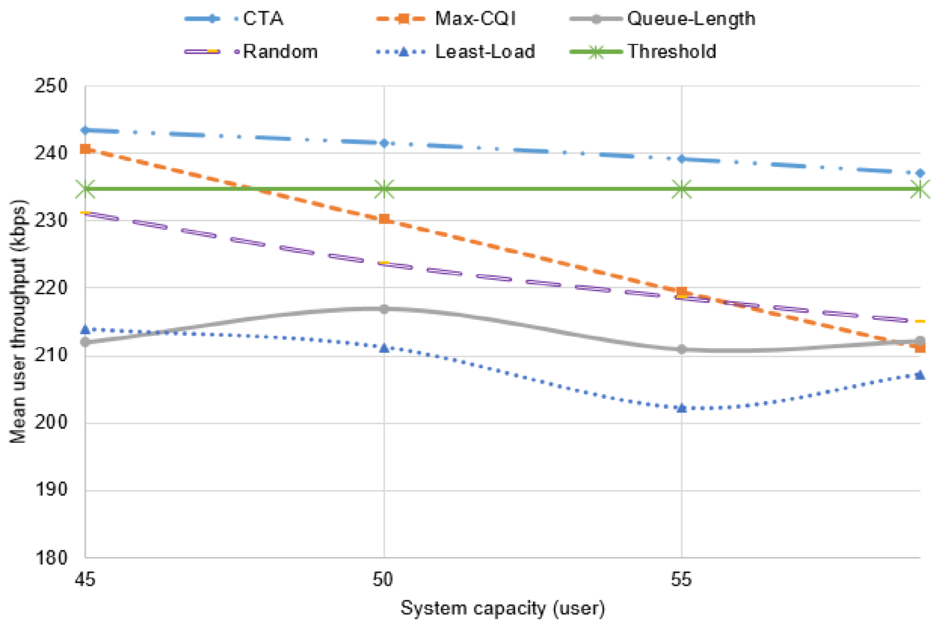

Figure 2. Mean user throughput vs. system capacity

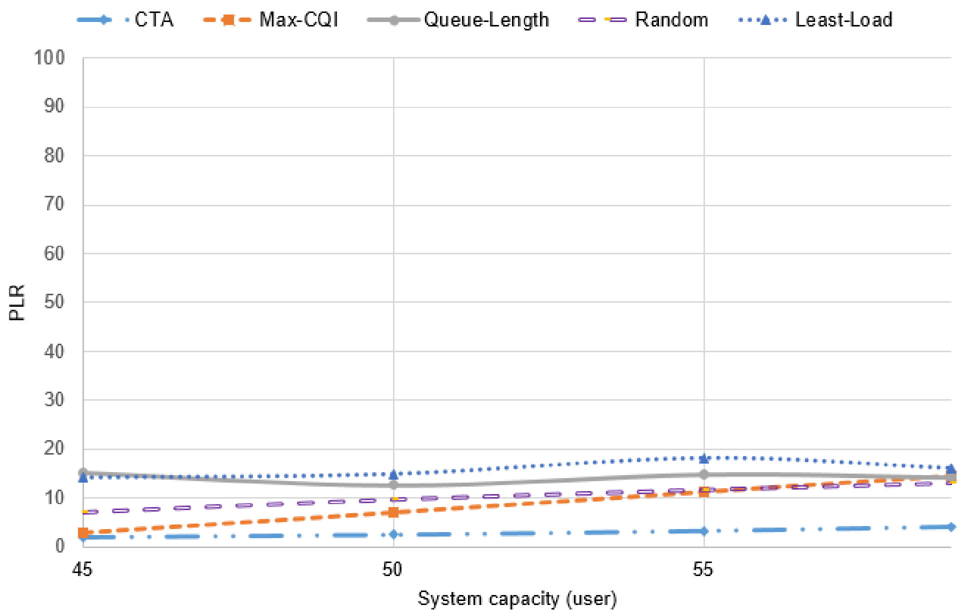

Figure 3. PLR vs. system capacity

Table 1. Maximum system capacities to support mean user throughput of 234.7 kbps

CC Selection Algorithm	*Maximum system capacity*	*CTA improvement over other CC selection algorithms (%)*
CTA	>60	-
Max-CQI	48	>25
Queue-Length	<45	
Random	<45	>33.33
Least Load	<45	

5. CONCLUSION

LTE-A is envisaged to provide significantly high peak data rate via CA method. This promising method demands for good CC selection algorithms when the system is operating in backward compatible mode. This paper studies a number of CC selection algorithms for use in the inter-band downlink LTE-A network. It was demonstrated via a series of computer simulations that the CTA algorithm is efficient in maximizing the system capacity whilst meeting the required QoS of real-time video content in the inter-band downlink LTE-A. The CTA has more than 25% system capacity improvement as compared to the Random, Queue-Length, Least-Load and Max-CQI CC selection algorithms. Future studies include performance comparison of CTA with other CC selection algorithms in the intra-band contiguous and non-contiguous LTE-A. Additionally, performance study of the CTA in supporting a mixture of real-time and non-real-time multimedia contents will be a part of future study.

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