Performance Analysis of Cross Component Carrier Scheduling in LTE Small Cell Access Point System

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ABSTRACT

With respect to the carrier aggregation (CA) in a LTE small cell access point system, the performance of an independent and cross component carrier (CC) scheduling is simulated and analyzed in this paper. According to the results, we obtained a capacity increase of about 17~46% for the cross CC max rate (MR) algorithm and about 12~45% for the cross CC proportional fair (PF) algorithm. On the other hand, in the round robin (RR) scenario, we cannot notice the differences between the independent CC and cross CC scheduling policies on allocating resources. We also found that CA frequency combination 1.8GHz CC + 800MHz CC has a better performance when comparing to the other combinations with respect to total average UE throughput.

KEYWORDS

LTE, Small Cell Access Point, Carrier Aggregation, Cross Carrier Scheduling.

1 INTRODUCTION

A small cell access point (AP) is a nomadic or mobile access point with small size supporting a cheap wired and wireless convergence service by connecting a mobile phone with an internet in an indoor environment such as home and office. Although it is similar to a Wi-Fi access point in a functional aspects point of view, it is different that a primary role of a small cell access point is to relay a mobile phone call unlike a Wi-Fi AP.

It is an evolved technology in a view point of serving an internet as well as a voice unlike a legacy wired and wireless convergence service such as Onephone and Homezone services. In a long term, a small cell access point based on long term evolution (LTE) will become a practical application of integration of a voice and data service in a home and office. It is also able to recognize an exact location and an indication of coming or going of their families through an individual small cell access in terms of a location-based service (LBS), and to provide new supplementary services by combining various home local area network (LAN) technologies.

3GPP has attempted to find a new technology that can provide both higher data-rate support in a wider bandwidth (BW) with an LTE system extended up to 100MHz, and backward compatible co-existence in LTE systems with an aggregation of multiple component carriers into an overall wider bandwidth.

Carrier aggregation (CA) is an important technology that combines multiple radio channels within and across bands to increase the user data rates and reduce latency. Two or more component carriers (CCs) are aggregated in an LTE system to support wider bandwidths of up to 100 MHz. This feature allows the scalable expansion of the effective bandwidth delivered to a user terminal through the concurrent utilization of radio resources across multiple carriers. These carriers may be of different bandwidths, and may be in the same or different bands to provide maximum flexibility in utilizing the scarce radio spectrum available to operators. Support for this feature requires an enhancement to the PHY, MAC, and RRC layers of LTE Release 8 and Release 9 while ensuring that LTE Release 10 preserves backward compatibility with the LTE Release 8 and Release 9 specifications.

As a matter of fact, LTE user equipment (UE) can simultaneously receive or transmit on one or multiple CCs aggregated up to 100MHz, but Release 8 and 9 UE can only receive and transmit on a single CC. According to the 3GPP Release 10 specifications in [1]-[4], all CCs shall be LTE Release 8 and 9 compatible, but existing mechanisms such as barring may be used to avoid Release 8 and 9 UEs to camp on a CC. Moreover, CA have been required in small cell AP to maximize system capacity with both macro base station and small cell AP as well.

According to [5], in practice, spectrum allocation for an operator is often dispersed along the frequency bands with large frequency separation. Hence heterogeneous CC is considered in this paper. In uplink resource allocation aspects, [6] claimed the 2 CC simultaneous access scheme outperforms CC selection and performs almost equally to the m-CC simultaneous access scheme ($m \geq 3$).

On the other hand, with respect to the downlink CA in a LTE system, a downlink cross component carrier (CC) scheduling algorithm is analyzed in this paper. The performance of the cross CC scheduling algorithm on heterogeneous CCs with different channel characteristics has been compared through computer simulations.

The rest of this paper is organized as follows. Section 2 describes the small cell AP architecture considered in this paper. The LTE protocol stack interaction for CA is mentioned in section 3. Details of the scheduling algorithm for carrier aggregation are presented in section 4. We then provide the simulation environments and results in section 5, and offer some concluding remarks in section 6.

2 SMALL CELL AP ARCHITECTURE

Figure 1 shows a logical interface for the small cell AP that has a set of S1 interfaces to connect the small cell AP to the EPC [1]. The evolved universal terrestrial radio access network (E-UTRAN) consists of the macro eNode B (eNB), the home eNode B (a.k.a. small cell AP) and the evolved packet core (EPC) corresponding to the mobility management entity (MME) and the serving gateway (SGW).

The E-UTRAN architecture may deploy a small cell AP gate way (GW) to allow the S1 interface between the small cell AP and the EPC to scale to support a large number of small cell APs. The small cell AP GW serves as a concentrator for the control-plane (C-Plane), specifically the S1-MME interface. The S1-U interface from the small cell AP may be terminated at the small cell AP GW, or a direct logical user-plane (U-Plane) connection between small cell AP and SGW may be used. The small cell AP GW appears to the MME as an eNB. The small cell AP GW appears to the small cell AP as an MME. The S1 interface between the small cell AP and the EPC is the same whether the small cell AP is connected to the EPC via a small cell AP GW or not. The small cell AP GW shall connect to the EPC in a way that handover to cells served by the small cell AP GW shall not necessarily require inter-MME handovers.

One small cell AP serves only one cell. The functions supported by the small cell AP shall be basically the same as those supported by a macro eNB and the procedures run between a small cell AP and the EPC shall be the same as those between an eNB and the EPC.

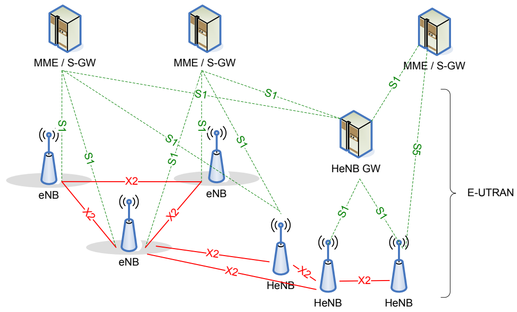

Figure 1. Small Cell AP Interface.

Figure 2 shows some of the potential deployment scenarios for CA.

Scenario #1 is that F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. Scenario #2 is that F1 and F2 cells are co-located and overlaid, but F2 has smaller coverage due to larger path loss. Scenario #3 is that F1 and F2 cells are co-located but F2 antennas are directed to the cell boundaries of F1 so that cell edge throughput is increased. Scenario #4 is that F1 provides macro coverage and on F2 remote radio heads (RRHs) are used to improve throughput at hot spots. Scenario #5 is similar to scenario #2, but frequency selective repeaters are deployed so that coverage is extended for one of the carrier frequencies.

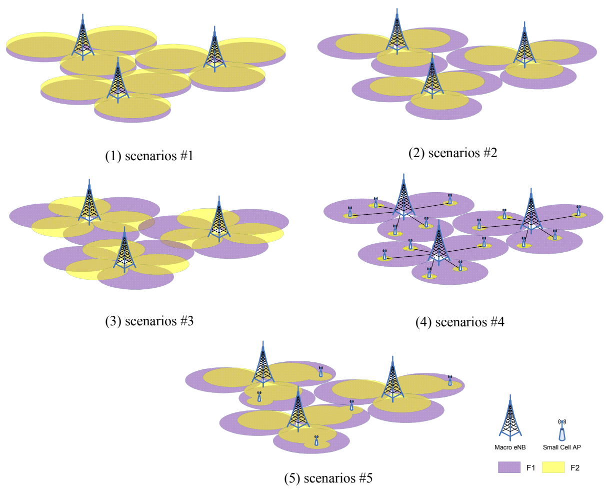

Figure 2. Carrier Aggregation Deployment Scenarios (F2 > F1).

3 LTE PROTOCOL STACK INTERACTION FOR CARRIER AGGREGATION

Figure 3 presents LTE protocol interactions to support the CA.

As mentioned in section 1, support for CA requires an enhancement to the PHY, MAC, and RRC layers of LTE Release 8 and Release 9. A device capable of CA has one downlink (DL) primary component carrier (PCC) and one associated uplink (UL) PCC. Basic linkage between the DL and UL is signaled in SIB Type 2 described in [3]. The device may have one or several secondary component carriers (SCCs) added in RRC CONNECTED mode only. The configuration of PCC is not cell-specific but UE-specific. The handover is performed using a PCC, and the network may decide to switch the PCC for another device using a handover procedure.

Radio resource management (RRM) application controls all procedures and configurations of these protocol layers such as PHY, MAC, and RRC regarding CA. The basic role of RRM is to ensure that the radio resources are efficiently used, taking advantage of the available adaptation techniques, and to serve the users according to their configured Quality of Service (QoS) parameters. 3GPP specifies the RRM related signaling but the actual RRM algorithms in the network are not defined in 3GPP. Those algorithms can be dependent on vendor and operator.

A UE can be configured by radio resource control (RRC) message on non-configured CCs as well as configured CCs. The configurations of the PCell and SCell are performed by RRM control. A UE has only one RRC connection with the network. PCell indicates a cell configured on a PCC, and SCell indicates a cell configured on an SCC.

When adding a new SCC, dedicated RRC signaling is used to send all required system information of the SCC. PCC can only be changed using a handover procedure (i.e., with

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a security key change and RACH procedure). PCell provides non-access stratum (NAS) mobility information for an RRC connection establishment, re-establishment, or handover. A re-establishment procedure is triggered when PCell experiences a radio link failure (RLF), but not when SCells experience such a failure. Data received from an RLC is aggregated in MAC and distributed into individual HARQ processes.

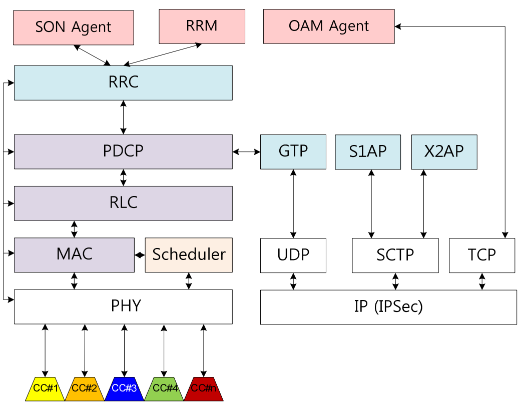

Figure 3. LTE Protocol Stack Interaction for Carrier Aggregation

Resource scheduling with downlink control signaling is shown in **Figure 4**.
Resource can be assigned to a UE in two ways as follows.
Independent carrier component scheduling separates PDCCH for each CC and reuses PDCCH structure and DCI formats in Release 8 and 9. On the other hand, cross component carrier scheduling shares common PDCCH for multiple CCs and reuses PDCCH structure in Release 8 and 9. It have new 3-bit carrier Indicator Field (CIF) added to DCI in Release 8. PCC cannot be cross scheduled, it is always scheduled through its own PDCCH.
Main motivation of cross component scheduling was load balancing and interference management for control channels in heterogeneous networks.

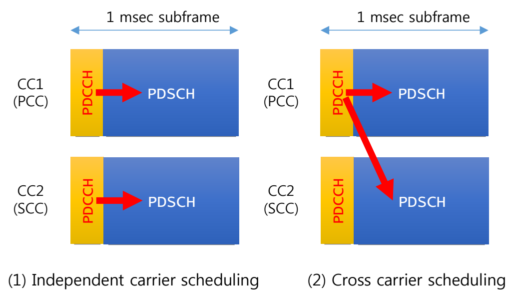

Figure 4. Resource Scheduling with Downlink Control Channel Signaling

4 SYSTEM MODEL

The perfect channel state information (CSI) is assumed at both the UE and small cell AP. Each subcarrier within all CCs can be used by only one user at any given time. CC and subcarrier allocation are performed at the small cell AP, and the users are notified of the CCs and subcarriers chosen for them. A system with K users, N component carriers (CCs), M subcarriers, and the time divided into time slots is considered. At each time slot, each scheduled user k will transmit on the allocated CC and subcarrier. Equal power and equal bandwidth allocation algorithms in all CCs are taken into consideration, which simply distribute the transmission power and bandwidth equally among the CCs and subcarriers.
The total average UE throughput, $E[R^n_{k,m}(t)]$, can be formulated as follows.

$$E\left[R^n_{k,m}(t)\right] = \frac{B}{N^2KMT}\sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{t=1}^{T}\frac{1}{M^n}log_2\left(1+\frac{P\left|H^n_{k,m}(t)\right|^2}{N_0B}\right) \quad (1)$$

where $E[R^n_{k,m}(t)]$ indicates the total average UE throughput on every user, which means the small cell AP average system capacity. $R^n_{k,m}(t)$

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indicates the instantaneous data rate of each user at each CC, and for each subcarrier and time slot. N is the total number of CCs, K is the total number of users, and M is the total number of subcarriers. T indicates the total number of time slots, and M^n indicates the total number of subcarriers belonging to the nth CC. B and P indicate the total bandwidth and power. $H^n_{k,m}(t)$ indicates the channel gain on the nth CC, mth subcarrier of the kth user, and tth time slot. N_0 is the power spectral density of the AWGN.

Round robin (RR), max rate (MR), and proportional fair (PF) scheduling that are representative algorithms among traditional scheduling policies is considered in this paper [7]-[8]. Two different types of scheduling, the independent CC scheduling and cross CC scheduling for carrier aggregation (CA), were compared for system resource allocation. In addition, RR, MR, and PF scheduling applying the independent CC scheduling algorithm and cross CC scheduling algorithm policies were evaluated to compare the simulation results from the average UE throughput.

5 SIMULATIONS

Component carrier characteristics and CA frequency combination applied to simulation are described in **Table 5** and **Table 6** respectively, the results of which are shown in this section. The simulations assume that equal power and equal bandwidth allocation algorithms in all CCs are taken into consideration, and the transmission power and bandwidth are distributed equally among the CCs and subcarriers. This paper simulates an urban environment where the users are walking at 3 km/h. **Table 7** describes the simulation environments using the detailed system parameters and assumptions in this paper.
The equations (1) is used for the simulation and performance evaluations between the independent CC and cross CC scheduling algorithm.

Table 5. Component Carrier Characteristics.

Carrier frequency	Bandwidth	Carrier type
2.1GHz	20MHz	PCC
1.8GHz	20MHz	PCC
900MHz	10MHz	SCC
800MHz	10MHz	SCC

Table 6. CA Frequency Combination.

CA Combination Index	CA frequency combination
A	2.1GHz CC + 800MHz CC
B	2.1GHz CC + 900MHz CC
C	1.8GHz CC + 800MHz CC
D	1.8GHz CC + 900MHz CC

Table 7. System Parameters.

Parameters	values
AP Tx Power	20 dBm
Traffic Type	Full buffer
MAC Packet scheduling	RR, MR, PF
Maximum number of users	32
tc	1000 [9]
Total time slot	2048
mobile speed	3 km/h

As can be seen from the figures, CA combination index C in **Figure 10** has a better performance compared to the other combinations with respect to total average UE throughput. This information indicates that CA frequency combination with a lower frequency band exhibits better channel gain than combinations with a higher frequency band. Hence, we found that CA frequency combination with a lower frequency band should be taken into account with high priority when performing CA.
Figure 10 shows the simulation results of CA combination index C. As we can see in the figure, the cross CC MR and PF algorithms

outperform the independent CC MR and PF algorithms. We obtained a capacity increase of about 17~46% for the cross CC MR algorithm and about 12~45% for the cross CC PF algorithm. However, the scheduling gain (i.e. gap) between the cross CC PF and independent CC PF algorithms is decreased consistently when the number of simultaneous users is increased, since the PF algorithm was designed basically for maximizing the system throughput and maintaining fairness. On the other hand, in the RR scenario, there are no apparent differences between the independent CC and cross CC scheduling policies in terms of allocating resources, since all users have the same average channel response within all CCs in the RR algorithm, which allocates all subcarriers of each CC to one user at each time slot independently of the user's channel response. Plots on **Figure 8**, **Figure 9**, and **Figure 11** have same pattern with **Figure 10** in total average UE throughput aspect. It means that scheduling policy is not in association with CA frequency combination.

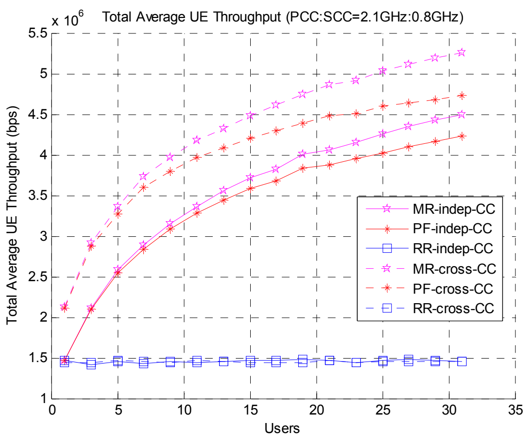

Figure 8. Total Average UE Throughput of CA Combination Index A.

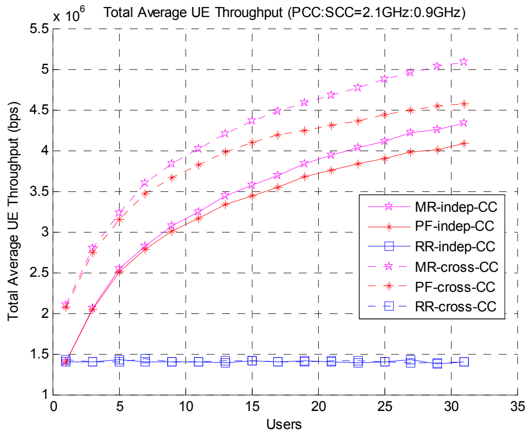

Figure 9. Total Average UE Throughput of CA Combination Index B.

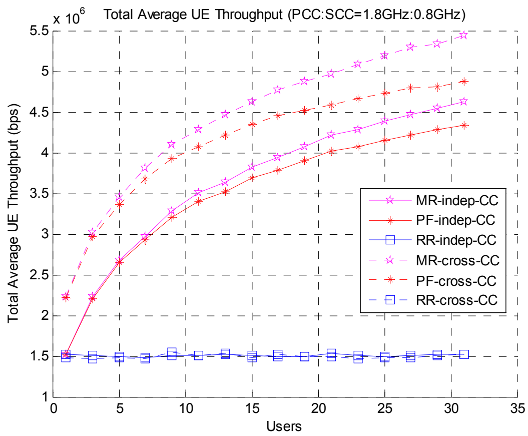

Figure 10. Total Average UE Throughput of CA Combination Index C.

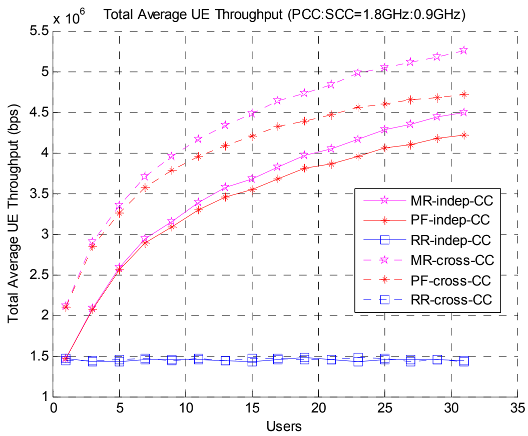

Figure 11. Total Average UE Throughput of CA Combination Index D.

6 CONCLUSION

In this paper, we discussed important properties that take place in a carrier aggregation environment of an LTE system in which the system resources are shared among users over all CCs, and where their channel responses change independently on heterogeneous CCs.

To analyze and evaluate the performance of cross component carrier scheduling considering different scheduling policies such as MR, PF, and RR algorithms, wireless urban environments where users are walking at 3km/h were simulated. The performance of the independent and cross CC scheduling algorithms has been analyzed and compared through computer simulations as well.

As we can see in the simulation results of section 5, CA combination index C has a better performance when comparing to the other combinations with respect to total average UE throughput. This information indicates that CA frequency combination with a lower frequency band exhibits better channel gain than combinations with a higher frequency band. Hence, we found that CA frequency combination with a lower frequency band should be taken into account with high priority when performing CA.

Furthermore, we observed a capacity increase of about 17~46% for the cross CC MR algorithm and about 12~45% for the cross CC PF algorithm. On the other hand, in the RR scenario, we cannot notice the differences between the independent CC and cross CC scheduling policies on allocating resources, since all users have the same average channel response within all CCs in the RR algorithm, which allocates all subcarriers of each CC to one user at each time slot independently of the users' channel response.

We leave the study of the cross CC scheduling performance of various modulations and coding techniques over wireless channels for further research.

7 ACKNOWLEDGMENT

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