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Dedicated Carrier Deployment in Heterogeneous Networks with Inter-site Carrier Aggregation

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***Abstract*— Heterogeneous networks (HetNets) have been extensively discussed in 3GPP to further enhance the system throughput of traditional well-planned macrocell deployment. In this paper, we consider a HetNet scenario consisting of macro eNBs and low-power nodes implemented as remote radio heads (RRHs) or picos with dedicated carrier deployment. Collaborative inter-site carrier aggregation (CA) is proposed in scenarios with macro+RRH deployment to make an efficient use of the fragmented spectrum from multiple cells. While in scenarios with macro+pico deployment, UEs can only connect to either the macrocell or the picocell using simple cell range expansion (RE). Extensive system-level simulations have been conducted to investigate the performance gains that can be achieved with inter-site CA under different traffic models and user distributions. Results show that using inter-site CA between the macrocell and the small cell obviously offers higher throughput due to larger bandwidth accessibility for the terminals, especially in low load.**

I. Introduction

With advanced technologies proposed in LTE-Advanced [1], the spectral efficiency per link is approaching the theoretical limits. Future gains on wireless networks will be obtained by changing the topology of traditional networks, from homogeneous networks to heterogeneous networks (HetNets), which will bring the network closer to end users [2]. A HetNet is a network that consists of a mix of macrocells and low-power nodes such as picocells, femtocells, remote radio heads (RRHs), or relays, which are overlaid within macrocells [3]. The placement of macro eNode Bs (eNBs) is generally based on careful network planning to maximize the coverage and control the inter-cell interference, while the placement of low-power nodes is more or less ad hoc. They can be either operator deployed or user deployed to eliminate coverage holes in the macrocell or improve capacity at hot-spot areas. Migration from macro-only to heterogeneous networks is expected to accelerate during the years to come. Although this paradigm shift can potentially enhance the spectral efficiency per unit area by cell splitting, it also introduces significant challenges to the proper operation of a HetNet due to unplanned deployment, inter-cell interference, and traffic load variability. To tackle these challenges, load balancing and resource partitioning among different power-level nodes have been extensively discussed in 3GPP [4]. Load balancing can be achieved via cell range expansion (RE) through handover biasing. Depending on the bias value, the network can control the offload of UEs from macrocell to small cells. In scenarios with co-channel deployment, resource partitioning allows configuration and adjustment of interference protected resources, enabling UEs in cell expanded area to receive data.

The performance of RE and time/frequency domain resource partitioning for HetNet scenarios has been studied in [5]-[6], assuming co-channel deployment of macro and pico eNBs. Although co-channel deployment is preferred for operators with moderate LTE spectrum (e.g. 10 MHz), dedicated carrier deployment is attractive for situations with larger availability of bandwidth (20 MHz or more) and high penetration of small cells. With dedicated carrier deployment, collaborative inter-site carrier aggregation (CA) between the macro and small cells can be a powerful tool for efficient utilization of fragmented spectrum between the two layers. The main objective of this paper is to investigate the downlink performance gains brought by inter-site CA compared to the case without inter-site CA. The key factors influencing the performance such as UE cell association and joint multicell packet scheduling will be analyzed. The results can be served as additional insights for the operators on network deployment in HetNets.

The rest of the paper is organized as follows. Section II introduces the considered deployment scenario, UE cell association with/without inter-site CA, and joint multicell packet scheduling. Section III outlines the simulation assumptions. Simulation results and performance analysis are presented in Section IV. Finally, some conclusions are drawn in Section V.

II. System Model

A. Deployment Scenarios

Figure 1 illustrates the considered network deployment scenario with traditional high-power macro eNBs transmitting at 40W and low-power nodes transmitting at 1W. The performance of such a HetNet scenario depends heavily on the carrier deployment strategy of macro and small cells. In this paper, we focus on dedicated carrier deployment, exemplified with two component carriers (CCs) at frequency F1 and F2. One carrier frequency (F1) is allocated to macro eNB providing macrocell coverage, whereas the other one (F2) is allocated to small cells enhancing throughput at hotspots. The dedicated carrier deployment has the benefit of no inter-layer interference, but the disadvantage of not using the full system bandwidth at both macro and small cells resulting in fragmented spectrum between the two layers. The performance can be improved by using collaborative inter-site CA between the two layers, so that the UEs can fully utilize the fragmented ratio resources from multiple cells. To be able to apply such inter-site CA techniques, we assume that the small cells are implemented as RRHs and are connected to macro eNBs via high bandwidth, low latency fibers. Thus, all baseband signal processing for the small cells (RRHs) is placed in the macro eNB, offering further opportunities for optimizations such as joint multicell packet scheduling. Referring to the 3GPP terminology, the dedicated carrier deployment with macro+RRH is denoted CA scenario 4 [7]. Such deployment allows the aggregation of CCs between the macrocell (configured as primary serving cell (PCell)) and the small cell (configured as secondary serving cell (SCell)). UEs configured to operate with inter-site CA naturally have access to higher transmission bandwidth, and therefore opportunities to be served at higher data rates. Besides, the fact that UEs always have macro as PCell helps to offer enhanced HetNet mobility robustness when a UE is traversing between the two layers, since with inter-site CA the UE never breaks the connection to the macro layer. Though macro+RRH deployment has the advantage of allowing CA across the two layers, the major drawback of this scenario is high operation cost in deploying RRHs. In another scenario, the small cells are implemented as picos which are connected to macro eNBs via low bandwidth, high latency X2 interface. Therefore inter-site CA is not feasible in this scenario. The advantage of macro+pico deployment is low CAPEX and OPEX compared to macro+RRH deployment.

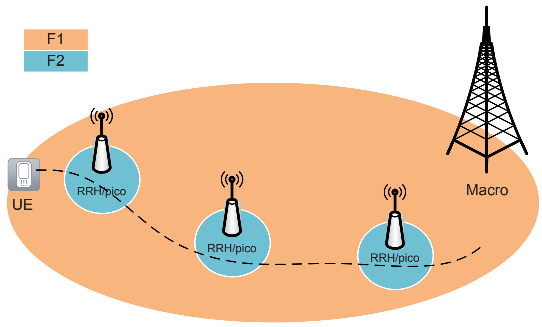

Fig. 1. Considered HetNet scenario with dedicated carrier deployment

B. UE Cell Association with/without Inter-site CA

Depending on the HetNet implementation scenario, two types of network operations are possible: without inter-site CA and with inter-site CA as shown in Fig. 2. In scenarios with macro+pico deployment, inter-site CA is not supported. UEs can only connect to either the macro eNB or the pico based on UE measurements of the received downlink signal strength, e.g., Reference Signal Received Power (RSRP) or Reference Signal Received Quality (RSRQ). While RSRP only reflects the received power from each cell, RSRQ is defined as RSRP divided by the total received power, capturing the channel quality of the respective resources. In traditional homogeneous networks, the eNB offering the highest RSRP or RSRQ is

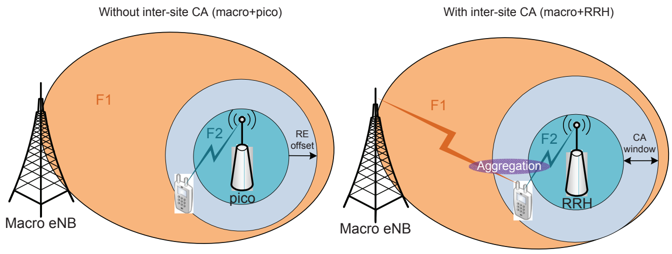

Fig. 2. UE cell association without and with inter-site CA

selected as the serving eNB. However in HetNet scenarios, applying the RSRP or RSRQ cell-selection criterion can lead to a downlink imbalance problem: The coverage of the macro cell is much larger than that of the small cell due to the transmit power disparity between the macro eNB and small eNB, resulting in a small number of UEs being served by the small cell [8]. From the network capacity point of view, it is desirable to balance the load between the macrocell and small cell by expanding the range of small cells. Thus a positive bias denoted as RE offset is added to the received signal strength of small cells during cell association, offloading more UEs from the macro cell to small cells [6]. In dedicated carrier deployment, RSRQ has the advantage of implicit load information as the interference on the two carriers is likely to be significantly different. Therefore RSRQ is used as the comparative metric in our study. The general cell selection procedure without inter-site CA is shown in pseudocode 1.

Algorithm 1 UE cell selection without inter-site CA

if $\mathrm{RSRQ_{pico}} + \mathrm{RE_{offset}} < \mathrm{RSRQ_{Macro}}$ **then**
  UE is connected to the best macro eNB
else
  UE is connected to the best pico
end if

In scenarios with macro+RRH deployment, inter-site CA is supported. CA-capable UEs can connect to both the macro eNB and RRH on different CCs so that they can benefit from the availability of the entire system bandwidth. Intuitively, "boundary" UEs located at the cell edge could benefit more from inter-site CA between the macro and small cells than "center" UEs located close to either macro eNB or RRH. Therefore a CA window is defined to determine if a CA-capable UE should be in inter-site CA mode or not. The general cell selection procedure with inter-site CA is shown in pseudocode 2.

Algorithm 2 UE cell selection with inter-site CA

if $\mid \mathrm{RSRQ_{Macro}} - \mathrm{RSRQ_{RRH}} \mid < \mathrm{CA_{window}}$ **then**
  UE is connected to both macro eNB and RRH using CA
else
  UE is connected to either the best macro eNB or RRH
end if

C. Joint Multicell Packet Scheduling

In scenarios with macro+RRH deployment, as the packet scheduler for the small cells (RRH) is physically located in the macro eNB, joint multicell packet scheduling is recommended to further improve the overall system performance. The difference between independent and joint proportional fair (PF) scheduler lies in the calculation of the scheduling metric. In joint PF scheduler, the denominator of the PF metric is updated as the sum of the average scheduled throughput over all cells where the UE has been scheduled in the past:

$$M_{i,j,k} = \frac{R_{i,j,k}}{\sum_{k=1}^{N} \overline{R}_{i,k}} \qquad (1)$$

where $R_{i,j,k}$ is the estimated throughput of user i at sub-band j on CC k, $\overline{R}_{i,k}$ is the exponentially filtered average throughput of user i on CC k, and N is the number of CCs assigned to user i. It simply requires information exchange on the average scheduled throughput between the scheduler for macro and small cells. In that way, the scheduler can essentially offer fast and efficient load balancing between the macro and small cells, thereby allowing for more equitable distribution of radio resources among UEs. The comparisons between independent and joint PF scheduling across multiple CCs can be referred to [9] in the context of CA.

III. Simulation Assumptions

The performance of different HetNet deployment scenarios is evaluated in a quasi-static downlink multi-cell system-level simulator that follows the LTE specifications, including detailed modeling of major radio resource management (R-RM) functionalities such as packet scheduling, hybrid ARQ (HARQ), link adaptation, 2×2 closed loop MIMO with precoding and rank adaptation, etc. A network layout defined by 3GPP for evaluating HetNet scenarios [10] is simulated. The network topology consists of 7 hexagonal macrocells with 3 sectors per site. Four RRHs/picos are randomly placed within each sector. Both full buffer and bursty traffic models are considered. For the full-buffer traffic model, a fixed number of 13 UEs are generated within the coverage area of macrocell with full buffer traffic. For the bursty traffic model, the call arrival follows a Poisson process with fixed payload size of 10 Mbits per call. The average offered load per macrocell area is calculated as the product of the user arrival rate and the payload size. Both hotspot and uniform UE distributions are simulated. In hotspot UE distribution, 2/3 of the UEs are dropped inside the hotspots[1] while the remaining UEs are uniformly distributed within the macrocell area. In uniform UE distribution, all UEs are uniformly distributed within the macrocell area. Two contiguous CCs, each with 10 MHz bandwidth, are configured. One CC is allocated to macro eNB while another CC is allocated to RRH/pico. RSRQ measurement reports from terminals are used for cell association. In scenarios with inter-site CA, joint PF scheduling across multiple cells is used in order to achieve better performance in terms of user fairness and coverage. Table I summarizes the main parameters used in the system-level simulations.

[1]A hotspot is the area within 40m radius of each RRH

TABLE I
SUMMARY OF MAIN SIMULATION PARAMETERS

Parameters	Settings
Network layout	7 macro sites (21 macrocells), wrap-around 4 RRHs/picos randomly placed per macrocell
ISD / cell radius	Macrocell: 500 m / small cell: 40 m
Transmit power	Macro eNB: 46 dBm; RRH/pico: 30 dBm
Bandwidth	2×10 MHz @ 2GHz band
Antenna configuration	2×2 MIMO with rank adaptation and interference rejection combining
Antenna gain	Macro: 14 dBi; RRH/pico: 5 dBi
Bursty traffic model	Poisson arrival Fixed payload size of 10 Mbits per UE
Full-buf. traffic model	Fixed number of UEs per sector (13 UEs) with full buffer traffic
Packet scheduling	Throughput based joint proportional fair
Cell association metric	RSRQ
Available MCSs	QPSK (1/5 to 3/4), 16QAM (2/5 to 5/6) 64QAM (3/5 to 9/10)
BLER target	10%
HARQ modeling	Ideal chase combining with max 4 trans.
Path loss	Macrocell: $140.7 + 36.7 \log_{10}(R[\text{km}])$ small cell: $128.1 + 37.6 \log_{10}(R[\text{km}])$
Shadow fading	Lognormal, std.=8 dB for macrocell std.=10 dB for small cell

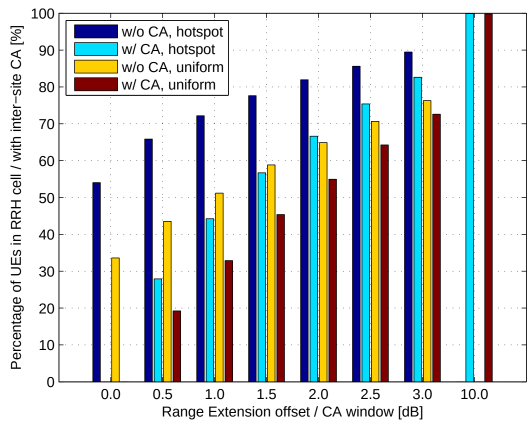

Fig. 3. Percentage of UEs offloaded to small cells / Percentage of UEs operating with inter-site CA, full buffer traffic model

IV. Simulation Results

We start our analysis by first looking at results with fixed number of UEs and full buffer traffic model. Fig. 3 shows the ratio of UEs that are offloaded to the small cell versus RE offset, and the ratio of UEs operating in inter-site CA mode versus CA window size. In scenarios without inter-site CA, increasing the RE offset significantly increases the number of UEs connecting to the small cell. In case of hotspot UE distribution, 78% of UEs are offloaded to the small cell with 1.5 dB RE offset. With uniform UE distribution, the offloading ratio is lower than that with hotspot UE distribution as expected. In scenarios with inter-site CA, increasing the CA window size allows more UEs to aggregate between macrocell

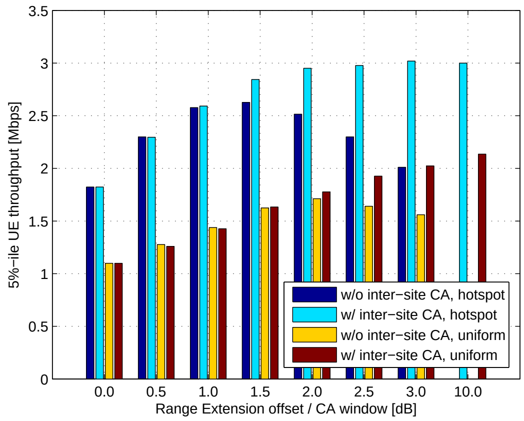

Fig. 4. Coverage (5-percentile) with/without inter-site CA, hotspot/uniform UE distribution, full buffer traffic model

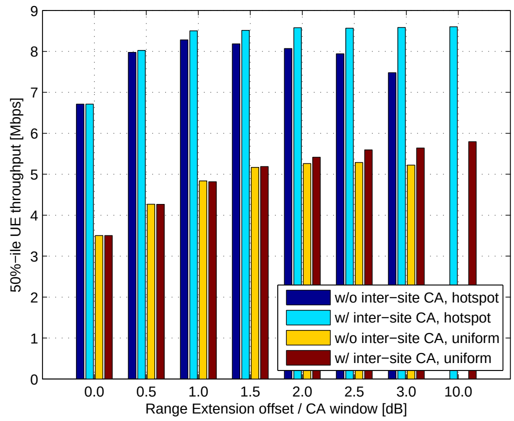

Fig. 5. Median UE throughput with/without inter-site CA, hotspot/uniform UE distribution, full buffer traffic model

and RRH cell. When the CA window is set to 10 dB, all UEs are operating in inter-site CA mode.

Fig. 4 shows the cell edge (5-percentile) user throughput with and without inter-site CA under different UE distributions. Without inter-site CA, UEs can only connect to either the macro eNB or pico based on the received signal strength and RE offset. The cell edge user throughput improves with the increase of RE offset until a certain point where the maximum value is reached, then the throughput starts to drop with further increase of RE offset. Increasing the RE offset would push more macrocell UEs into small cells, therefore offloading the load from macrocell to pico cells. However, high RE offset would not only cause imbalanced load between macrocell and pico cell, but also would decrease the SINR of range-expanded pico cell UEs and reduce the control channel reliability. Hence the value of RE offset has to be chosen carefully. In our study, the optimal RE offsets that maximize the coverage performance without inter-site CA are 1.5 dB and 2.0 dB for hotspot and uniform UE distributions, respectively.

With inter-site CA, UEs can connect to both the macro eNB and RRH on different CCs depending on the CA window size. Increasing the CA window size would allow more UEs to operate in inter-site CA mode. UEs aggregating the CCs between the macrocell and the small cell can benefit from the advantages of larger transmission bandwidth and the joint PF scheduler can efficiently perform cell load balancing by scheduling UEs on the appropriate cell. Therefore the performance with inter-site CA is monotonically increasing with the increase of CA window size. The best performance is achieved when all UEs are in inter-site CA mode. In that case, the coverage gain with inter-site CA is 15% compared to the best case without inter-site CA ($\mathrm{RE_{offset}} = 1.5\mathrm{dB}$), assuming hotspot UE distribution. It is worth mentioning that for the full buffer traffic model, the throughput gain by using inter-site CA is not coming from larger transmission bandwidth, but mainly from increased multi-user diversity (scheduling gain).

For uniform UE distribution, the throughput performance is lower than that with hotspot UE distribution. It is as expected because with hotspot distribution, 2/3 of UEs are dropped inside the RRH cell, which allows for more efficient spatial reuse of the spectrum, whereas with uniform distribution, less UEs benefit from the deployment of RRHs. The coverage gain with CA is 25% compared to the best case without CA ($\mathrm{RE_{offset}} = 2\mathrm{dB}$), assuming uniform UE distribution.

Fig. 5 shows the median (50-percentile) user throughput with and without inter-site CA under different UE distributions. Similar phenomena can be observed as in coverage. In scenarios with inter-site CA, the median user throughput increase quite sharply with the increase of CA window size, then the performance reaches on a steady level with further increase of CA window size. As mentioned previously, with joint multicell PF packet scheduler, the calculation of scheduling metric takes the sum of the average scheduled user throughput over all cells into account in order to achieve fair distribution of resources among users. With small CA window size, only cell "boundary" UEs are operating in CA mode, of which benefit a lot from inter-site CA as the scheduler favors those "boundary" UEs with poor SINR by scheduling them on both macrocell and small cell. When the CA window size becomes large, cell "center" UEs are also operating in CA mode. But they usually don't benefit a lot from inter-site CA since they already get satisfied throughput on one of the cells. Therefore, the gain by using inter-site CA between macrocell and small cell is mainly coming from cell "boundary" UEs by scheduling them on both cells and let the scheduler take care of the rest.

Then we present the results with bursty traffic model. Fig. 6 and 7 show the coverage and median user throughput with/without inter-site CA versus the offered load and different number of small cells per macro cell area, respectively. In scenarios with inter-site CA, we assume that all UEs are connecting to both the macro eNB and RRH. In scenarios without inter-site CA, only the performance with optimal RE offset that maximizes the coverage is plot in each offered load. It is observed that both the coverage and median user

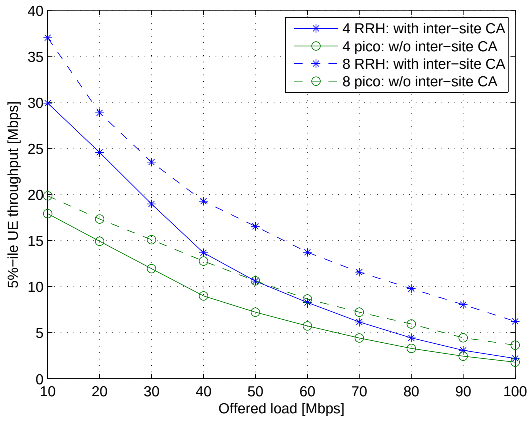

Fig. 6. Coverage (5-percentile) with/without inter-site CA, 4 or 8 RRHs/picos per macro area, bursty traffic model with hotspot UE distribution

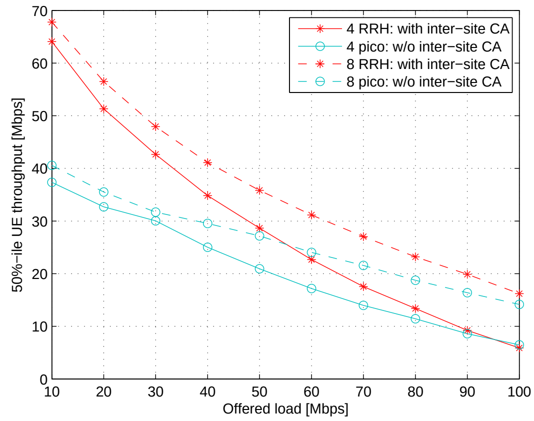

Fig. 7. Median UE throughput with/without inter-site CA, 4 or 8 RRHs/picos per macro area, bursty traffic model with hotspot UE distribution

throughput with inter-site CA are significantly higher than without inter-site CA. The gain brought by inter-site CA is up to 70% at low load conditions. However, the gain decreases as the load increases. At high load, the performance with inter-site CA is almost the same as without inter-site CA. This behavior can be explained as follows: at low load (small number of UEs in each cell), UEs using inter-site CA benefit from larger transmission bandwidth and increased multi-user diversity. Since the SINR experienced at macro and small cell layers is typically quite different, the highest gain with inter-site CA is lower than the theoretical 100% gain achievable by doubling the transmission bandwidth. When the load is high (large number of UEs in each cell), it does not really matter whether a UE is assigned on one cell only or assigned on both cells using inter-site CA since the system is saturated and the scheduler tries to allocate the available resources among all UEs in a fair manner. However, at high load, the use of inter-site CA still offers advantages in terms of enhanced HetNet mobility robustness and faster inter-layer load balancing via use of joint packet scheduling for both macro and RRHs. The performance with 8 RRHs/picos per macro cell area is obviously better than the case with 4 RRHs/picos per macro cell area. With more small cells deployed, not only the UE has better chance to be served with better channel quality, but also the network capacity is increased as dedicated carrier deployment is assumed. Although increasing the number of RRHs/picos would increase the interference level among small cells, it is not a big problem as small cells are transmitting with low power (30 dBm).

V. Conclusions

In this paper, we have investigated the downlink performance of dedicated carrier deployment in HetNet scenarios with/without inter-site CA. Without inter-site CA, UEs can only connect to either the macrocell or the small cell based on UE measurements of RSRP/RSRQ and RE offset. RSRQ is the preferred cell selection metric since it has the advantage of implicit load information compared to RSRP in dedicated carrier deployment. RE can be used to balance the load between the two layers, but the value of RE offset should be chosen carefully to optimize the overall performance. With inter-site CA, UEs can connect to both the macro and the small cells depending on the CA window size. The best performance is achieved when all UEs are in CA mode. The benefit of inter-site CA was shown in both full buffer and bursty traffic models. The throughput gain could be up to 70% in low load due to larger transmission bandwidth, but decreases gradually as the load increases. The gain brought by inter-site CA is mainly coming from cell "boundary" UEs with the help of joint multicell PF scheduler which allocates resources among UEs in a fair manner. Other benefits of inter-site CA are faster load balancing and easier mobility management.

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