Performance Evaluation of Dynamic Point Selection CoMP Scheme in Heterogeneous Networks with FTP Traffic Model

Gregory Morozov, Alexei Davydov, Ilya Bolotin
Standards and Technology
Intel Corporation
Nizhny Novgorod, Russia
{gregory.v.morozov, alexei.davydov, ilya.bolotin}@intel.com

Abstract — High traffic demand is considered as one of the key challenges in modern wireless communication systems which are typically limited by amount of available spectrum. Recently heterogeneous networks (HetNet) have been proposed as an attractive approach to cope with this problem, by enabling cell splitting gain via deployment of an additional layer of pico-cells. While low power and small antenna height of pico-cell base stations simplify search of the site location, the efficiency of cell splitting gain in HetNet is typically limited by small coverage area of pico-cells. To address the issue of HetNet performance in LTE-A Rel-11, coordinated multipoint (CoMP) traffic management schemes were considered. In particular a combination of dynamic point selection (DPS) with dynamic point blanking (DPB) was identified as a promising mechanism to provide cell load balancing and interference mitigation in HetNet. Dynamicity of CoMP schemes is expected to provide performance benefits in various scenarios including non-full buffer traffic models, where scheduling decisions of DPS/DPB can be based on the instantaneous cell's loading conditions. In this paper we provide detailed system level performance analysis for DPS/DPB CoMP scheme in HetNet scenario with non-full buffer FTP traffic model. The performance results are conducted for different traffic loadings of the cells and DPS/DPB scheduling decision granularities.

Keywords: HetNet, CoMP, DPS, Dynamic Point Selection, DPB, Dynamic Point Blanking, Bursty FTP Traffic

I. INTRODUCTION

Heterogeneous Networks (HetNet) are being considered as an efficient mechanism of continuous system capacity improvement by deployment of pico-cells to the existing macro-cells. Adding pico-cells to the network therefore creates an additional layer in the deployment with overlapping coverage area to the macro-cell layer. The purpose of pico-cells deployment in HetNet is to improve capacity in the network, where the capacity of macro-cells only is insufficient. However as pico-cell base stations (BS) have lower transmit power and antenna height the coverage area of pico-cell is typically smaller than coverage area of macro-cell. In this case the pico-cell layer has smaller number of connections and therefore carries less amount of traffic than macro-cell.

To further maximize the capacity of HetNet some traffic management mechanisms were introduced in LTE-A system. The key idea of such schemes is to transfer traffic from macro-cell to high capacity pico-cells even if the reference signal received power (RSRP) from pico-cell is lower. In LTE-A Rel-10 eICIC this can be achieved by handing over of the connection to the preferred pico-cell whenever RSRP is within the predetermined cell range extension (CRE) threshold [1]. The amount of traffic offload in this case depends on the value of CRE threshold, which defines the coverage size of pico-cell and therefore the number of connections. As traffic offload depends on the handover decisions the cell load balancing in LTE-A Rel-10 eICIC is carried out on a semi-static basis.

In LTE-A Rel-11 the traffic management between different layers of the HetNet may be performed in a more dynamic manner by using coordinated multi-point schemes (CoMP) employing for coordination high capacity low latency backhaul links between pico-cell and macro-cell base stations (BS) [2]. In particular dynamic point selection (DPS) CoMP can be used for adaptive selection of the transmitting cell to maximize system capacity by assigning of the transmission node to the user equipment (UE). In contrast to LTE-A Rel-10 eICIC the
traffic offloading in LTE-A Rel-11 DPS CoMP scheme is typically performed within limited set of the base stations having high capacity low latency backhaul link connection between each other, referred to in this paper as CoMP coordination set.

The performance of DPS was addressed in several papers; however the analysis was mostly limited to homogenous networks and/or full buffer traffic models. For example, performance of DPS CoMP scheme was analyzed in [3-4] for homogenous networks. In [5-6] the performance results of DPS was provided for HetNet scenarios, however only full buffer traffic model was used in the evaluations. Additionally evaluation in [6] assumes DPS/DPB scheduling granularity of one sub-frame, which doesn’t utilize flexibility of the time-frequency resource assignment of LTE-A systems. While full buffer traffic model is typically easier to simulate, the practical non full buffer traffic patterns can lead to entirely different system behavior and performance results. Therefore the purpose of this paper is to provide detailed system level performance analysis for DPS/DPB CoMP scheme in HetNet scenarios with more realistic non full buffer traffic model under different loading conditions and DPS/DPB scheduling decision granularities.

The paper is organized as follows. In Section II we describe CoMP model and DPS/DPB procedures in LTE-A Rel-11. Evaluation methodology and system-level performance results of LTE Rel-11 DPS/DPB CoMP scheme are presented in Section III. Section IV summarizes the main results and concludes the paper.

II. DYNAMIC POINT SELECTION CoMP SCHEME

Fig. 1 shows an example of LTE-A Rel-11 CoMP system in HetNet scenario. The CoMP coordination set in such deployment comprises the base stations of high power and low power nodes connected with each other via backhaul link. In conventional network architecture, the base station of macro and pico nodes employs independent scheduling. In other words, the scheduling at each base station is performed without consideration of activity and loading of the neighboring base stations. On the other hand, centralized scheduler architecture of CoMP assumes a common scheduler operation for multiple base stations of CoMP coordination set. It can maximize the overall system performance by joint consideration of multiple system parameters, such as cell load, interference and channel quality information reported by the UEs of CoMP coordination area.

As discussed in Section I, in order to achieve a larger degree of cell splitting gain a dynamic traffic offloading from macro-cell(s) to pico-cells should be considered in HetNet scenario. However in order to maintain a reasonable signal quality at the UEs, the traffic offloading should be limited to pico node with RSRP that falls within a predefined CoMP threshold to the received power of serving macro node, i.e.

\[ \text{RSRP}_{\text{macro}} - \text{RSRP}_{\text{pico}} \leq \text{CoMP threshold} \]  \hspace{1cm} (1)

The criterion (1) above helps to identify cell-edge UEs located in a multi-coverage or handover regions between macro and pico cells, therefore potentially allowing the DPS to select the best communication link for the transmission based on instantaneous channel conditions. However, UEs located near the cell boundary may suffer from other cell interference, which in cellular networks is highly time-frequency-varying and unpredictable due to dynamic scheduling and beamforming decisions at the adjacent cells. Therefore it is desirable for CoMP system to effectively mitigate the negative impact of other cell interference by leveraging the backhaul links.

In this paper we consider the reduction of other cell interference by prohibiting transmission from interfering cell on the set of physical resources. Such concept in literature is referred to as dynamic point blanking (DPB) and often employed in conjunction with DPS [3].

A combination of serving macro node and selected for traffic offloading pico node forms, so called, CoMP measurement set, which is defined as a collection of nodes with relatively good propagation conditions, enough to be considered as a candidate for the physical resource transmissions. Since the CoMP measurement set is formed on per UE basis using long-term RSRP values, it is not expected to change over the time as long as the location of the UE does not change.

A combination of the candidate transmission node in CoMP measurement set along with interference mitigation assumption forms a transmission hypothesis of DPS/DPB for which channel quality information (CQI) reports should be provided by the UE. In LTE-A systems CQI from the UE is typically

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Figure 2. Centralized DPS/DPB scheduling.
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\[ \text{RSRP}_{\text{macro}} - \text{RSRP}_{\text{pico}} \leq \text{CoMP threshold} \]
used to assist link adaptation. It gives information on the preferred Modulation and Coding Scheme (MCS) the transmission node can use and therefore can be accounted by the centralized CoMP scheduler for allocation of the available physical resources in the most efficient manner.

Since the dynamic traffic offloading in HetNet scenario is mostly performed from macro-cell(s) to pico-cells, CQIs calculation can be down selected to the following set of transmission hypotheses:

- simultaneous macro node and pico node transmissions
- pico node transmissions and macro node blanking

Restricting the number of transmission hypotheses, on which CQI reports are provided, allows reducing the complexity at the UE and BS with acceptable performance loss. It is important to note that multiple transmission hypotheses for CQI are only assumed for the pico UEs with dominant macro interferer and for macro UEs when the CoMP threshold rule (1) is satisfied.

Once the CQI reports from the UEs are available, the centralized scheduling runs over each transmission hypothesis as shown in Fig. 2 by considering both the channel quality information for the UEs and cell load balancing of the BSs. The best DPS/DPB transmission hypothesis is then determined for the set of the physical resources based on the sum of the proportional fairness (PF) metrics for the set of scheduled UEs within CoMP coordination area. The transmission hypothesis selection on centralized scheduling can be described as the following

\[
\max_h \sum_{s \in S(h)} \frac{\tau(s, H)}{T(s)}.
\]

where \(S(H)\) is a set of scheduled UEs within CoMP coordination set area, \(T(s)\) is average throughput of UE \(s\), \(\pi_s, H\) is instantaneous throughput of UE \(s\) for transmission hypothesis \(H\). For each transmission hypothesis \(H\), a set \(S(H)\) is determined by optimal scheduling decision for each active node according to the proportional fair criterion.

The transmission hypothesis selection rule (2) can be accomplished on per sub-frame basis to minimize complexity of the scheduling procedure [6] or physical resource block to fully utilize flexibility of time-frequency resource block assignment of LTE-A systems.

It should be noted that no optimization over the transmission hypotheses is applied if the resources are scheduled for HARQ retransmission. In this case the transmission hypothesis is selected in accordance with the hypothesis of the retransmitted packet.

**III. SYSTEM LEVEL PERFORMANCE EVALUATION OF DPS/DPB**

System level performance analysis of DPS/DPB CoMP scheme in HetNet scenario is provided in this section. For the performance evaluation non full buffer traffic model corresponding to FTP traffic model type 1 is used [1].

The FTP traffic model 1 is based on the Poisson process with a number of packet arrivals within time interval \([t, t + \tau]\) follows the Poisson distribution

\[
P\left[N(t + \tau) - N(t) = k\right] = \frac{\exp(-\lambda \tau) (\lambda \tau)^k}{k!}.
\]

where \(\lambda\) is an average packet arrival rate per macro cell area, \(N(t)\) is a number of generated packets by time \(t\). To characterize the average throughput load of the system the offered cell load is defined as a product of packet arrival rate \(\lambda\) and packet size \(S\).

The example of traffic pattern realization for FTP traffic model 1 is depicted in Fig. 3, where each generated packet of size \(S\) is individually assigned for the UE randomly dropped in the macro cell coordination area in accordance with a dropping configuration.

The ‘clustered dropping’ configuration was investigated in this paper [2]. In such a configuration the UE is dropped uniformly in macro cell area with probability of 1/3 and uniformly within a 40 m radius of \(N\) pico nodes with probability of 2/3.

**TABLE I. SIMULATION PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell layout</td>
<td>19 macro sites, 3 cells per site, (N = 4) pico per cell</td>
</tr>
<tr>
<td>Inter-site distance</td>
<td>500m</td>
</tr>
<tr>
<td>Propagation model</td>
<td>UMa/UMi ITU channel models</td>
</tr>
<tr>
<td>UE speed</td>
<td>3 kmp/s</td>
</tr>
<tr>
<td>Antenna pattern</td>
<td>Macro 3D tilt = 12°, Pico 2D</td>
</tr>
<tr>
<td>Downlink transmit power</td>
<td>Macro 46 dBm, Pico 30 dB</td>
</tr>
<tr>
<td>BS antenna configuration</td>
<td>4TX co-polarized</td>
</tr>
<tr>
<td>UE antenna configuration</td>
<td>2 RX co-polarized</td>
</tr>
<tr>
<td>UE receiver</td>
<td>MMSE interference unaware</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Scheduler</td>
<td>Proportional fair in freq/time</td>
</tr>
<tr>
<td>MIMO mode</td>
<td>SU-MIMO</td>
</tr>
<tr>
<td>CoMP threshold</td>
<td>10dB</td>
</tr>
<tr>
<td>Outer loop link adaptation</td>
<td>Target BLER = 10%</td>
</tr>
<tr>
<td>CQI feedback delay</td>
<td>5 mssec</td>
</tr>
<tr>
<td>Overhead</td>
<td>30.95%</td>
</tr>
<tr>
<td>Traffic model</td>
<td>FTP traffic model, (S = 2)Mbytes</td>
</tr>
</tbody>
</table>

For performance analysis FDD LTE-A system with 10 MHz channel bandwidth is considered. The cell layout in the evaluations comprises 19 hexagonal sites with 3 macro cells per site with wrap-around. In each of the 57 macro cells,
\( N = 4 \) low power pico nodes are uniformly deployed. The large and small scale fading are modeled in accordance to ITU channel models as described in [7] with consideration of LOS and NLOS components of the channels. All modeled UEs are placed outdoor, i.e. no penetration loss is considered in the evaluations. The other simulation parameters and assumptions are summarized in Table 1.

Two coordination sets as shown in Fig. 4 are used for evaluation. In the ‘cell coordination’ (DPS/DPB-05) the traffic offloading and interference mitigation is limited to one macro cell area, i.e. no scheduling coordination among macro cells belonging to the same site is considered. For the ‘site coordination’ (DPS/DPB-15) the traffic offloading opportunities and interference mitigation are extended to macro site area by leveraging inter-sector scheduling coordination.

Fig. 5 depicts the performance of DPS/DPB scheme in terms of the average user throughput from the offered load of the system. It can be seen that compared to the conventional LTE-A HetNet system without CoMP the DPS/DPB improves performance of UEs located near cell boundaries in a wide range of cell loadings. The most remarkable gains are observed for medium to high loadings due to HetNet cell splitting gain. It can be also seen from Fig. 6 that site coordination (DPS/DPB-15) offers additional performance improvement over cell coordination (DPS/DPB-05) due to additional opportunity for the traffic offloading to the pico nodes of neighboring macro cell.

Finally Table 2 shows comparison of the cell edge user throughput in case of DPS/DPB scheme with site coordination for different granularities of transmission hypothesis decisions. The numbers are presented for the granularities of one frequency sub-band comprising five adjacent physical resource blocks and one sub-frame. The former scheduling is referred as frequency selective DPS/DPB and fully exploits time-frequency flexibility of the resource allocation provided in LTE-A system. The latter scheduling is non-frequency selective DPS/DPB and takes single transmission hypothesis for the entire sub-frame (i.e. the same for all sub-bands). From Table 2 one can see that the frequency selective DPS/DPB scheme has some performance advantages over the non-frequency selective DPS/DPB scheme, however the performance improvement is limited.

<table>
<thead>
<tr>
<th>Offered load (Mbps)</th>
<th>Conventional LTE-A HetNet</th>
<th>Non-frequency selective DPS/DPB</th>
<th>Frequency selective DPS/DPB</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (( \lambda = 0.3 ) s(^{-1}))</td>
<td>31.55 (0%)</td>
<td>31.66 (+0.3%)</td>
<td>32.09 (+2%)</td>
</tr>
<tr>
<td>11.7 (( \lambda = 0.7 ) s(^{-1}))</td>
<td>21.4 (0%)</td>
<td>22.71 (+6%)</td>
<td>23.02 (+7.6%)</td>
</tr>
<tr>
<td>18.2 (( \lambda = 1.1 ) s(^{-1}))</td>
<td>14.21 (0%)</td>
<td>15.35 (+9.4%)</td>
<td>16.12 (+13.4%)</td>
</tr>
<tr>
<td>24.7 (( \lambda = 1.5 ) s(^{-1}))</td>
<td>9.32 (0%)</td>
<td>10.69 (+14.7%)</td>
<td>11.29 (+21.1%)</td>
</tr>
<tr>
<td>31 (( \lambda = 1.9 ) s(^{-1}))</td>
<td>6.02 (0%)</td>
<td>7.12 (+18.3%)</td>
<td>7.56 (+25.6%)</td>
</tr>
</tbody>
</table>
IV. CONCLUSIONS

In this paper we have analyzed the system level performance of DPS/DPB CoMP scheme in HetNet scenario. More realistic non full buffer FTP traffic model was used in the evaluations. It has been shown that DPS/DPB CoMP remarkably improves throughput performance of the cell edge users by utilizing cell splitting gains in a wide range of cell loadings, especially when the site coordination scenario is considered. The performance of DPS/DPB CoMP scheme was also investigated for different granularities of DPS/DPB transmission hypothesis selection. It has been found that frequency selective DPS/DPB offers additional gains over non frequency selective DPS/DPB for the cell edge user throughput.

REFERENCES