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Centralized Scheduling for Joint Transmission Coordinated Multi-Point in LTE-Advanced

Stefan Brueck, Lu Zhao, Jochen Giese and M. Awais Amin
Qualcomm CDMA Technologies
Nordostpark 89, 90411 Nuremberg, Germany
{sbrueck, luz, jgiese, mamin}@qualcomm.com

Abstract— **Coordinated multi-point transmission/reception is considered for LTE-Advanced as a tool to improve the coverage of high data rates, the cell-edge throughput and/or to increase the system throughput [1]. Joint transmission schemes are mentioned in [1] as an example of coordinated transmission between cells for the downlink. Here, data are transmitted simultaneously either coherently or non-coherently from multiple cells to a single mobile station. In this paper, a centralized MAC scheduling approach for joint transmission coordinated multi-point (JT CoMP) is proposed. Since several base stations transmit jointly to a single mobile station, the base stations are grouped together in so-called clusters. Several cluster strategies are investigated as well. The focus is on schemes that add only low complexity to the existing 3GPP LTE Release 8 system. Simulation results are provided for non-coherent transmission for full buffer and bursty traffic models with various system loads for different static cell clustering approaches.**

Keywords - LTE-Advanced, Coordinated Multi-Point, Joint Transmission, Scheduling

I. INTRODUCTION

In order to maintain future competitiveness of the 3GPP cellular system, Long Term Evolution (LTE), also known as Evolved Universal Terrestrial Radio Access (E-UTRA), is currently being standardized [1]. Orthogonal frequency division multiple access (OFDMA) has been chosen for the downlink direction. Since time and frequency resources are typically reused in adjacent cells, inter cell interference becomes the limiting factor. In order to overcome this problem, interference mitigation techniques such as interference cancellation, interference coordination and interference randomization are currently investigated within 3GPP [1]. However, the performance improvements offered by these techniques are limited since inter cell interference cannot be completely removed. A promising candidate to provide high spectral efficiency in downlink direction is coordinated multi-point (CoMP) between base stations [2], also sometimes called network MIMO. CoMP is one of the techniques under investigation to achieve the spectral efficiency requirements for LTE-Advanced [3]. Joint transmission (JT) CoMP is mentioned in [1] as a major category of CoMP techniques to improve the overall system performance, in particular, to improve the coverage of high data rate and the cell edge user throughput by allowing more than one base stations to transmit data to a single user equipment (UE) simultaneously. However, as the analysis in [2] shows, CoMP requires a high-speed backhaul enabling information (data, control/synchronization, and channel state) exchange between the base stations. Further, channel state information is required at the base stations to calculate the transmit filters [2]. Both requirements cause significant impact to the existing 3GPP LTE Release 8 standard. In this paper, we therefore analyze a JT CoMP approach that adds only low complexity to the LTE Release 8. In order to keep the exchange of channel state information between base stations low, we focus on non-coherent transmission. The remainder of the paper is organized as follows: In Section II, we provide a proposal for the system architecture for JT CoMP with centralized scheduling. In Section III, several cluster approaches are introduced and potential gains by JT CoMP are analyzed. In Section IV a two stage MAC scheduling approach is described that is used for the simulations in Section V. Conclusions of the paper are summarized in Section VI.

II. ARCHITECTURE PROPOSAL FOR JT COMP

As baseline for our proposal the 3GPP LTE Release 8 architecture as outlined in [4] is assumed. In Figure 1 an example of a clustered layout is shown. In this example, two mobiles are served by a cluster consisting of three cells[1]. Throughout this paper, it is assumed that the cluster stays unchanged during a time span of a couple of seconds. For example, the cluster could be statically configured by OAM (Operation and Maintenance) or semi-statically updated by a network-wide entity based on UE measurements during network operation. We further assume that all UEs are connected to one cluster only, i.e. all radio legs of a mobile belong to one cluster. This assumption is made to keep the amount of signaling messages that are required for the coordination of cells low. A mobile station is said to be connected to a cluster if its serving cell belongs to the cluster. We assume no coordination between clusters, which also means that a cell belongs to one and only one cluster.

[1] Cells and sectors have the same meaning in this paper.

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In order to allocate the radio resources most efficiently to the users of a cluster, the channel state information/channel quality information (CSI/CQI) of all UEs should be taken into account by the scheduler. This can easily be achieved if a central scheduler is applied in the cluster that has knowledge of the CSI/CQI information of all users being served by the cluster. Therefore, one of the cells of the cluster is pre-configured in the proposed architecture as master sector. All other cells within the cluster act as slaves. As in 3GPP LTE Release 8, one Hybrid Automatic Repeat Request (HARQ) entity per UE is configured at E-UTRAN side [5][2]. In contrast to LTE Release 8, it is proposed that the HARQ entities are not located in the Medium Access Control (MAC) layer of the serving cell any more, but in the MAC layer of the master cell. This is the case even if the serving cell does not coincide with the master cell. One central scheduler per cluster manages all resources of the cluster. This central scheduler is also located in the MAC layer of the master cell.

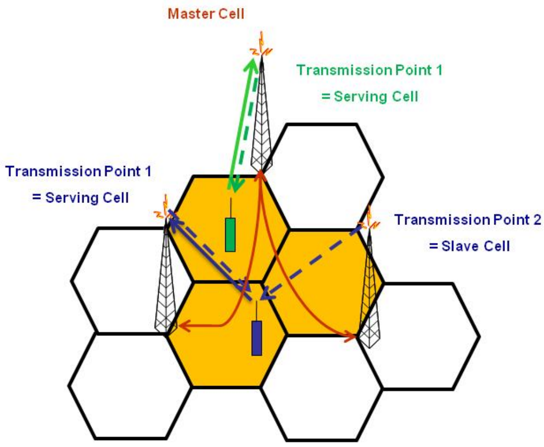

Figure 1: Clustered layout

Once the central scheduler has allocated the resources per transmission time interval (TTI) to the scheduled UEs, the information of the resource allocation is distributed over the X2 interface to the individual transmission points. This proposal assumes that there are no stringent capacity and delay constraints of the X2 interface between the base stations[3]. Therefore, the architecture proposal is most suited for macro cells that are equipped with powerful X2 interfaces and for remote radio heads since the communication between cells of the same site can take place over the backplane of the eNB instead of over the X2 interface. In the following we only refer to the X2 interface, but we keep in mind that the involved interface can be the backplane of the eNB as well.

In the example of Figure 1, two UEs are served by a cluster. As in LTE Release 8, all mobiles report, in addition to the CQI, also the desired precoding matrix index (PMI) as well as a rank indicator (RI) to their serving cells. As stated before, the serving cell does not necessarily coincide with the master cell. If serving cell and master cell are different, the serving cell forwards the CQI/PMI/RI information to the master cell over the X2 interface. According to [1], the CQI/PMI/RI is determined at radio legs of the measurement set. We assume that the measurement set is a subset of the cluster, i.e. only radio legs being transmitted from cells within the cluster are measured.

As already mentioned, the scheduling information is distributed over the X2 interface to all transmission points of a UE. These transmission points are the cells that actively transmit the physical downlink shared channel (PDSCH) to the UE [1]. There are principally two options for the kind of information that shall be distributed over the X2 interface from the master to the slaves.

a) User data (packet data converge protocol (PDCP) service data units (SDUs)) are stored in all transmission points of a mobile station. This approach assumes that all transmission points receive the raw data from the serving gateway (S-GW) across the S1 interface as well. All the required HARQ information like allocated physical resource blocks (PRBs), transport block size, modulation and coding scheme (MCS) and HARQ process ID is then forwarded by the master cell to the slave cell. This information is similar to the content of the PDCCH that is sent over the air to the mobile station. Since entire PDCP SDUs are stored in the eNBs, also segmentation/concatenation information of the radio link control (RLC) protocol needs to be transmitted from the master cell to the individual transmission points across the X2.
b) Only the master cell stores the user data (PDCP SDUs) being sent from the S-GW. Once the scheduling decision is available, the master cell then forwards the entire transport blocks (MAC protocol data units (PDUs)) to the transmission points over the X2 interface in addition to the selected MCS and the allocated PRBs. In this case, no raw data need to be stored in the transmission points, but the required capacity of the X2 interface increases as compared to option a) since the entire payload is sent from the master cell to the slave cells.

It is outside the scope of this paper to investigate the benefits and drawbacks of both approaches. In the following sections, it is assumed that all transmission points of a UE have the same data and signaling information available in order to transmit the same data with the same MCS using the same PRBs over the air interface.

As already mentioned, it is assumed in this paper that the clusters do not change within the time span of interest. However, in case of semi-static clustering, additional cells may be added to the clusters or some may be removed from the clusters. This may also require a change of the master cell within a cluster. An example for such a need is the situation when a new cell is added that does not have a sufficient X2

[2] The terminology of a HARQ entity at UTRAN side is defined in [6] and implicitly applied to E-UTRAN in [5] as well.

[3] Following 3GPP LTE Release 8 terminology, we denote a base station as eNB.

interface to the old master cell. In this case, a reconfiguration of the master cell may help to improve performance. Therefore, all cells require the software and hardware capabilities to act as a master cell as well. From an eNB feature capability point of view, there is no difference between master and slave cells.

III. STATIC CELL CLUSTERING

The proposed architecture is suitable for all cluster sizes. In this paper, we focus on a cluster size of three, i.e. at most three cells are involved in cooperation. Three different cluster layouts are investigated in this section. Figure 2 illustrates these three different approaches.

Common to all investigated clusters is the size of three cells. The arrows in the hexagons in Figure 2 indicate the boresights of the antennas according to [7]. Cluster 3/3 (left) and cluster 1/3 (middle) are static clusters predefined by OAM. The first number in this notation refers to the number of involved sites. The second number denotes the number of involved sectors. Cluster 3/3 is, therefore, a cluster consisting of three cells that belong to three different sites. Cluster 1/3 has the same size, but all three cells belong to the same site.

Figure 2: Cluster 3/3, cluster 1/3, UE specific cluster of size 3 (from left to right)

The area of cooperation is indicated by the dashed red lines in Figure 2 in the left and middle clusters. The static clusters have the disadvantage that it is implicitly assumed that the strongest interference stems from cells belonging to the cluster. This does not need to be the case in particular if the standard deviation of the shadow fading is large as is typically the case for macro cellular scenarios without a line-of-sight component. The third cluster is UE specific. Here, it is assumed that each UE is able to add the three strongest radio legs to the cooperating set as shown in the right hand scheme of Figure 2. The red arrows indicate the antenna boresights of the cooperating cells. In this case, also the impact of shadow fading can also be taken into account.

For a first evaluation of the suitability of the different cluster approaches, the geometry (also known as wideband SNR) improvement compared to LTE Release 8 is considered. Generally, the geometry G in linear domain is defined as

$$G = \frac{P_S}{\sum_{i=1}^{M} P_{I,i} + N}.$$

The sum in the denominator is over all interfering cells M. P_S is the long term average received power of the serving leg, $P_{I,i}$ is the received interfering power of the i-th interferer and N is the noise power in the entire transmission bandwidth. JT CoMP transforms part of the interference into useful signal power since the same data are transmitted over multiple legs. For a cluster of size three, the average linear cluster gain with respect to LTE Release 8 can therefore be defined as

$$\text{Cluster Gain} = \frac{P_S + P_{I,j} + P_{I,k}}{\sum_{i \in \{1,\cdots,M\} \backslash \{j,k\}} P_{I,i} + N} \Big/ G.$$

The cells with indices j and k whose interfering power is transformed into useful signal power depend on the used cluster strategy.

This cluster gain was investigated for a transmission bandwidth of 10 MHz, inter site distance of 500 m and suburban macro path loss model with a carrier frequency of 2 GHz. The network consisted of 19 3-sector sites, the wrap around simulation methodology was applied. The amplifier power was set to 46 dBm, the background noise power density was assumed to be -174 dBm/Hz. The maximum attenuation of the antennas was 20 dB.

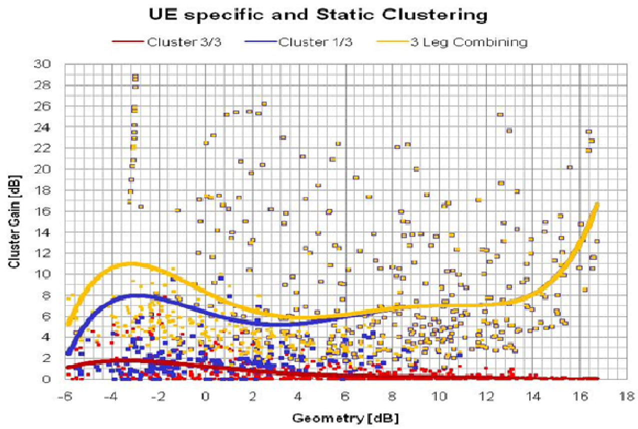

Figure 3: Cluster gain of different cluster approaches

In the simulations, a downtilt of 15 degrees has been assumed according to [1]. The vertical and horizontal antenna patterns have been combined according to the formula provided in [1]. The dots in Figure 3 indicate the cluster gain for each simulated mobile with the three cluster approaches. UE specific clustering is denoted as three legs combining in the figure. Additionally, a trend line curve is provided to illustrate the average cluster gain for a given geometry. It is seen that the UE specific cluster approach provides the best results as expected. Cluster 3/3 only provides gains for low geometries, i.e. at cell edge. The gains diminish the closer the UE is located to cell center. This is expected since the neighbor cells do not contribute much to the interference power at cell center in LTE Release 8. Therefore, in JT CoMP they also provide only small gains.

Cluster 1/3 provides gains across the entire geometry range. At high geometries, the gains for the UE specific cluster and cluster 1/3 coincide. This indicates that at cell center the almost all inter cell interference in LTE Release 8 comes from the cells of the same site. The large cluster gain at very high geometries is due to the fact that almost the entire interference from other cells is transformed into useful signal power. In this case, the interference limited system becomes noise limited due to JT CoMP.

An interesting observation can be made at geometries of about -3 dB. Here the cluster gains for a couple of mobiles are extremely large. The explanation is that the system again becomes noise limited due to JT CoMP. According to [1], the horizontal and vertical antenna patterns are combined by a superposition of both individual patterns by

$$A(\varphi,\theta) = -\min\left(-\left[A_H(\varphi) + A_V(\theta)\right], A_m\right).$$

As stated above, the maximum attenuation A_m was assumed to be 20 dB for both patterns. If a mobile is located directly in the boresight of the horizontal pattern and is already close to the center of the serving cell, the vertical pattern attenuates the transmitted power by 20 dB. In this case, the attenuation of the other cells of the same site is 20 dB as well. The overall geometry is then close to -3 dB since path loss and shadow fading are identical for all three cells. Cluster 1/3 and the UE specific cluster approach then provide very large gains since the entire relevant LTE Release 8 interference is transformed into useful signal power. However, cluster 3/3 does not achieve any gains in this case since the dominant interfering cells do not belong to the cluster[4].

Overall, it is seen in Figure 3 that the gains for static clustering of size three are rather low or even zero for many mobile stations. This is the case when the dominant interferers for the UE are not part of the static cluster. If the standard deviation of the shadow fading is large, interference may be caused from cells that are not adjacent to the serving cell. Then clustering of size three does not provide large gains for large shadow faing standard deviation. Alternatively, UE specific cluster approaches could be applied. A disadvantage of UE specific clusters, however, is that scheduling coordination becomes more complex since information needs to be exchanged between a large set of cells.

IV. MAC Scheduling for Joint Transmission CoMP

This section describes the MAC scheduling as it is applied in the following simulations for non-coherent JT CoMP. The first subsection describes how the measurement set is defined. In the second subsection the proposed scheduling approach is introduced.

A. Determination of the Measurement Set

Serving cell selection in LTE Release 8 is based one the long term average reference signal received power (RSRP). The cell with the strongest RSRP acts as the serving cell. The serving cell also defines the cluster the mobile is connected to. Since each cell uniquely belongs to one cluster, the serving cluster is determined once the serving cell is selected. As already mentioned in Section II, it is assumed that the measurement set of a UE is a subset of the cluster. This means that the UE measures the radio channels of a subset of cells of the cluster the UE is now connected to.

Additional legs are added to the measurement set if the RSRP of a candidate leg is Δ_{thres} dB lower than that of the serving leg, i.e.

$$\text{RSRP (serving leg)} - \text{RSRP(candidate leg)} \leq \Delta_{\text{thres}}.$$

The measurement set is, therefore, based on long term average values and established at call set up of a mobile. In this paper, it does not change over time as long as the location of the mobile does not change.

B. Two-Stage Scheduling with PRB Reuse

According to the architecture proposal in Section II, the MAC layer of the master cell receives the CQI/PMI/RI information from all mobile stations connected to the cluster. PMI and RI are not used by the scheduler since no precoding is applied. In case the measurement set size of a UE is larger than one, CQI/PMI/RI information from combinations of radio legs can be fed back to the serving cell. This offers the MAC scheduler the possibility of dynamically updating the transmission points. However, for the investigations in this paper, it is assumed that the transmission points keep static and are identical to the measurement set. This means that the same set of transmission points is used for a mobile station during the entire simulation duration. It is further assumed that the UE reports CQI/PMI/RI values reflecting the over the air (OTA) combined channel of all transmission points of the mobile station since non-coherent transmission is applied at the base stations.

The scheduling at MAC layer takes place in two steps. Since the entire CQI/PMI/RI information of all UEs connected to the cluster is available in the MAC layer of the master cell, the same scheduler as in LTE Release 8 can be applied in the first stage. This means that the PRBs are interpreted as a cluster resource instead as of a resource per cell as is the case in LTE Release 8. In the first stage, each PRB is allocated at most to one UE in the cluster. The frequency reuse for each PRB after the first stage of the scheduling is therefore identical to the cluster size, i.e. there is no intra cluster interference for any PRB. In particular for high cell loads, this approach does not exploit the frequency spectrum efficiently and results in a loss of peak data rate. Therefore, the PRBs should be allocated in a second scheduling stage running in the same TTI to other users as well. This approach introduces an intra cluster SDMA component. The second stage consists of the steps shown in the flow chart in Figure 4.

The second stage passes serially through all PRBs, i = 1,…,N, in the transmission bandwidth and determines whether it can be allocated to other users as well. Calculating a second user ranking is not required. The rationale is that a double allocation of a PRB according to the described approach adds intra cluster interference from a cell that is at least Δ_{thres} weaker in long term average than the serving cell of the UE the PRB was allocated to in the first stage. Otherwise, that cell would have been added to the measurement set of the UE

[4] It still needs to be verified whether the observed gains for locations close to cell center are due to the artificial antenna pattern used in [1] or also exist for more realistic antenna patterns.

according to the determination of the measurement set as described in Section IV A.

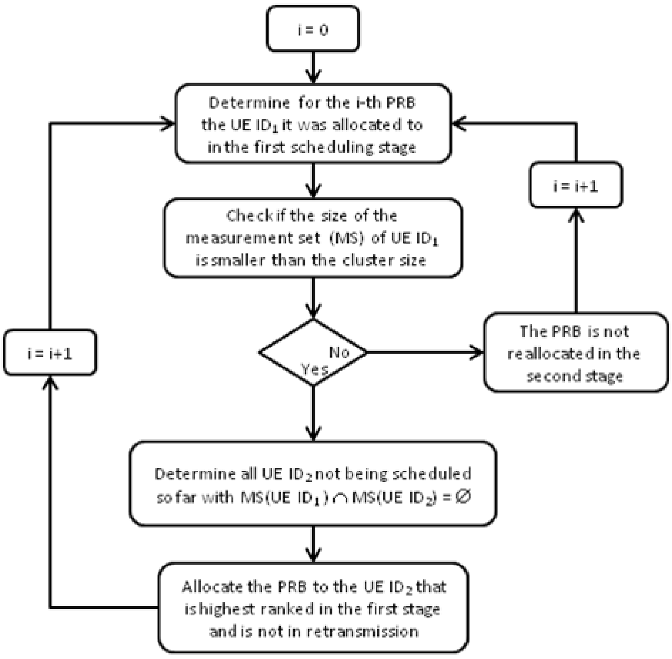

Figure 4: Second stage scheduling approach

V. SIMULATION ASSUMPTIONS AND RESULTS

In this section, simulation results are provided for the architecture and the algorithms introduced in the previous section.

A. Simulation Assumptions

The chosen simulation assumptions are summarized in Table 1 and Table 2. The simulations were carried out applying a full buffer model and a bursty traffic model for different inter arrival times. Since the number of average users per site as well as the mean burst size was kept constant, the traffic load in the system is reduced with increasing inter arrival time. General simulation assumptions are provided in Table 1. JT CoMP specific assumptions are given in Table 2.

Table 1: General Simulation assumptions

Network	19 sites, 57 cells, wrap around Eight strongest interferers modeled as spatially colored, remaining interferers modeled as spatially white
	43 dBm amplifier, 15 degrees downtilt, antenna patterns according to [1], 20 dB maximum attenuation
	5 MHz bandwidth
	2 GHz carrier frequency
	NGMN channel model 'urban macro', 3 km/h
	500 m inter site distance
	-174 dBm/Hz noise density of white Gaussian background noise
	30 UEs/site on average for full buffer traffic model 10 UEs/site on average for bursty traffic model
LTE Release 8	1 Tx antenna/cell, 2 Rx antennas/UE
specific assumptions	6 TTI ACK/NACK round trip time
	Max 4 HARQ ReTx
	Tx power equally split across entire bandwidth (static power allocation)
	PF scheduling in time and frequency in the first stage
Bursty traffic model	Truncated log-normal distribution of bursts at MAC layer (mean = 12.5 kbytes, max = 22.5 kbytes, sigma = 0.01825 kbytes) Exponential distribution of inter-arrival time of burst (mean = 0.01 - 0.5 seconds)
Performance metric	Average user throughput for full buffer model Average user perceived throughput for bursty traffic model [1]
Simulation time	1.8 second for full buffer model 18 seconds for bursty traffic model

Table 2: JT CoMP related assumptions

Clustering	Static clusters 1/3 and 3/3 as defined in Section III
Measurement set threshold Δ_{thres}	5 dB relative to serving leg RSRP
CQI reporting	CQI report for the OTA combined channel of all transmission points (transparent JT CoMP scheme for the UE) No CQI reports for individual links
Reference signals	Reference signals according to LTE Release 8
SNR loss model for CQI reporting and equalization	$\text{SNR Loss [dB]} = \max(1\text{ dB}, -0.35 \cdot \text{Ideal SNR [dB]} + 1.6\text{ dB})$
2^{nd} stage scheduling	Enabled or disabled (SDMA, no SDMA)
Transmission scheme	No precoding across cells (non-coherent transmission) No spatial multiplexing between cells Transmission points and measurement set are identical and static during the simulation duration No dynamic selection of transmission points
Backplane/X2 interface	Variable delay and infinite capacity

B. Impact of System Load

First the system performance of JT CoMP was analyzed for the full buffer traffic model under the assumptions in Table 1 and Table 2. For the analysis of the system load impact we assume zero delay of the X2 interface as well as no processing delay in the eNB when receiving a X2 message.

Figure 5 shows the user throughput at MAC layer for LTE Release 8 as well as for JT CoMP with clusters 1/3 and 3/3 with and without second stage scheduling, respectively. The second stage scheduling is labeled as SDMA in both figures. In Figure 6, the gains of the JT CoMP schemes relative to the LTE Release 8 performance are given for user throughput quantiles of 5%, 50% and 95%.

It is seen from Figure 5 that the performance of JT CoMP without SDMA at high user throughput quantiles is very poor. At low quantiles, however, both JT CoMP cluster approaches without SDMA perform well. The gains relative to LTE Release 8 are visible in Figure 6.

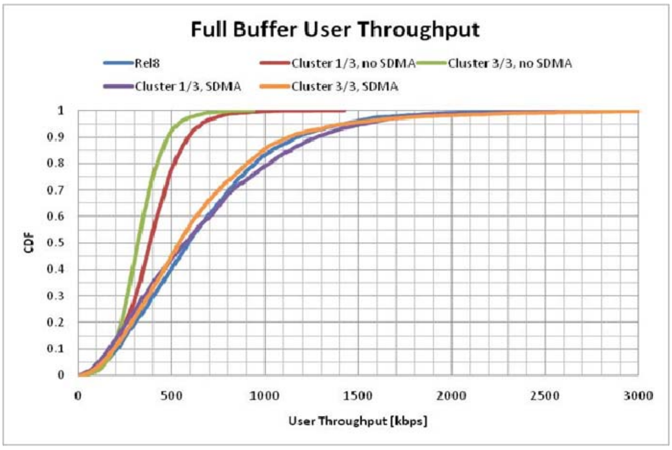

Figure 5: Full buffer performance

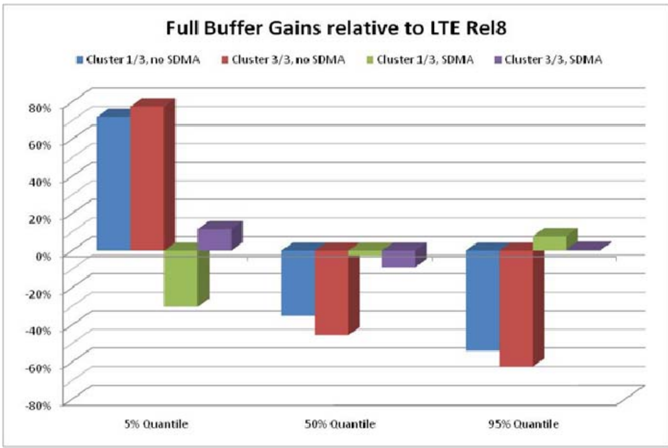

Figure 6: Full buffer performance relative to LTE Release 8

Without SDMA the 5% quantile is improved significantly by around 80% by both JT CoMP schemes. If no SDMA is applied, each PRB is only used once within a cluster. This corresponds to a frequency reuse of the cluster size. This indicates that applying frequency reuse for cell edge users could improve performance. At higher quantiles, not applying a SDMA component, however, causes losses between 40% – 70%. If the PRBs are only allocated to one user per cluster, the scheduling of users even in good conditions is delayed, which results in throughput losses at high quantiles. With SDMA the losses compared to LTE Release 8 are mostly overcome for the 95% user throughput quantile. Cluster 1/3 with SDMA even improves LTE Release 8 by about 7% at this quantile.

Full buffer corresponds to a fully loaded system, which is not a common scenario in reality. This means that simulations do not provide full insight into the behavior of JT CoMP. Therefore, systems with smaller loads are also considered in the following. The cell load is varied by applying a bursty traffic model. For bursty traffic, first the LTE Release 8 performance was analyzed under the simulation assumptions as given in Table 1 and Table 2. As a measure for the system load with bursty traffic, the LTE Release 8 PRB utilization was chosen as defined in [8].

Figure 7 shows the mean user perceived throughput [1] for various PRB utilizations. It is seen that the mean user perceived throughput increases as expected with reduced PRB utilization, i.e. reduced system load.

For lower system load, neighbor cells cause less interference and a lower number of users compete for resources in the serving cell.

In a next step, the proposed architecture and algorithms for JT CoMP were simulated. The following three figures show results both for the cluster approaches 1/3 and 3/3 as well as with and without the second stage scheduling as defined in Figure 4. The second stage scheduling is labeled again as SDMA in the following figures.

The JT CoMP performance was compared with the LTE Release 8 performance at the 5%, 50% and 95% quantiles taken from Figure 7. The gain at a quantile of the mean user perceived throughput is given as a relative quantity. A negative gain means that JT CoMP scheme results in a throughput loss compared to LTE Release 8.

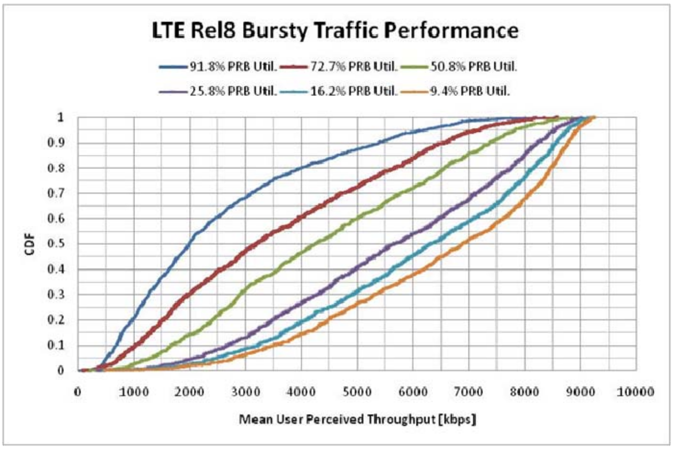

Figure 7: LTE Release 8 performance for different PRB utilizations

Figure 8 shows the gains of the investigated JT CoMP schemes at the 5% quantile of the LTE Release 8 mean user perceived throughput. It is seen that cluster approach 3/3 with second stage scheduling (SDMA) provides around 15% gain for all PRB utilizations. Cluster 1/3 with SDMA also provides some gains up to a high system load, but they are considerably lower as compared to cluster 3/3. This is obvious since in cluster 1/3 the three cells of a site cooperate with each other, which does not allow serving users at cell edge very well.

It is also seen in the figure that both cluster approaches without SDMA component lead to significant losses up to high very traffic load. At a PRB utilization of larger than 90%, however, the second stage scheduling is not efficient. Without SDMA, a PRB is only used once in a cluster, i.e. intra cluster interference is completely avoided without SDMA. This effect is similar to the one in fractional frequency reuse that also avoids interference by not using frequencies in a certain cluster. Since the 5% quantile corresponds to cell edge users, it can be concluded from the results in Figure 8 that PRB utilization and interference can be traded-off with each other at least at cell edge.

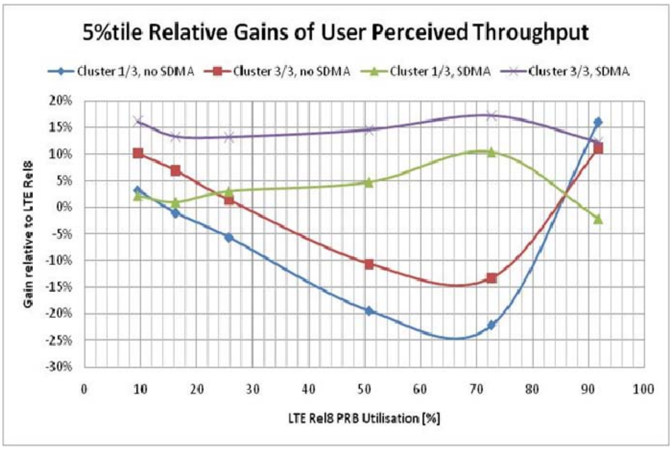

Figure 8: Relative gains at 5% quantile

Figure 9 shows the relative gains of the JT CoMP schemes at the 50% quantile of Figure 7. Here, cluster approach 3/3 always causes a loss relative to LTE Release 8 independent of whether the SDMA component was used or not. However, cluster 1/3 achieves gains of up to 15% for a medium PRB utilization. Interestingly, without SDMA the performance was improved for PRB utilizations up to very high loads.

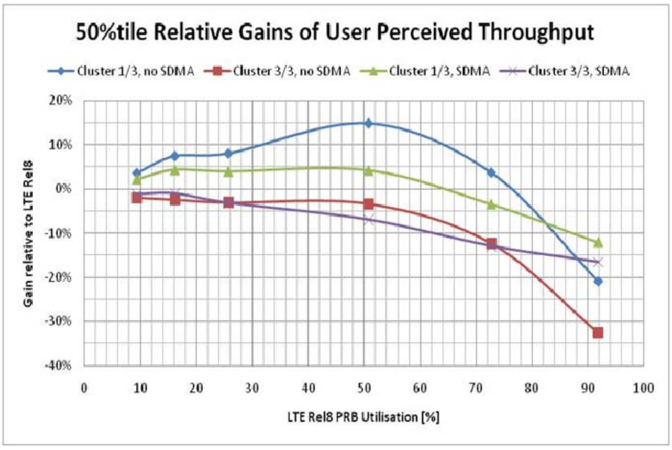

Figure 9: Relative gains at 50% quantile

A similar effect is seen in Figure 10 for the 95% quantile. Up to high PRB utilizations, cluster 1/3 without SDMA again outperforms the other approaches. Only at very high load, the SDMA component improves performance for cluster 1/3. The explanation can be seen in Figure 3 where no SDMA was taken into account. From this figure, it becomes clear that cluster 1/3 without SDMA provides large gains for some users across all geometries. This results in an increase of throughput at different quantiles. Only at very large traffic load not using all PRB in a cluster efficiently causes a loss in throughput. Both figures also reveal that cluster 3/3 with and without SDMA is always worse than LTE Release 8 at the 50% and the 95% quantiles. The loss increases with increasing traffic load.

Comparing the full buffer performance with the results for bursty traffic at high system load shows similar behavior of the investigated schemes. Not using SDMA at cell edge performed best in both scenarios. Cluster 1/3 with SDMA is the most promising one at the 95% quantile. However, for more realistic system loads around 50%, cluster 3/3 with SDMA at cell edge and cluster 1/3 without SDMA for the 50% and 95% quantiles showed best performance. This reveals that also low and medium system loads should be considered to get full insight into the system behavior.

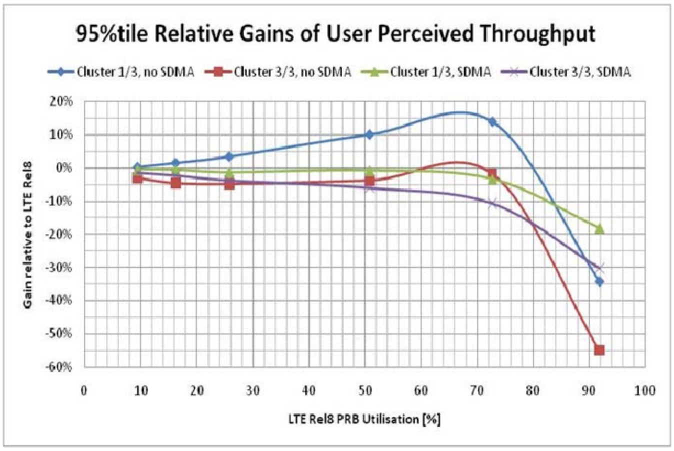

Figure 10: Relative gains at 95% quantile

In summary, the results demonstrated that the performance of the different cluster approaches as well as of the SDMA component depend strong on the traffic load in the system. At cell edge, for all PRB utilizations, a gain was reached with cluster 3/3 applying SDMA. However, at higher LTE Release 8 throughput quantiles that correspond to the mid of the cell and to cell center, cluster 1/3 without SDMA was the most beneficial scheme up to high cell loads. For very large PRB utilizations SDMA improved performance, however, was still not able to overcome losses relative to LTE Release 8.

Overall, it can be concluded that the selection of the most suitable cluster strategy should be based on geographical aspects of the mobile station. Whether the SDMA component is beneficial or not depends both on the location of the mobile station as well as on the traffic load.

C. *Impact of X2 Delay*

By X2 delay we understand the accumulation of the time needed to send a message across the X2 interface as well as the required time to process the X2 message in the eNB. The X2 delay has impact both on ACK/NACK round trip and the CQI delay. Hereby, we understand:

- The ACK/NACK round trip time (RTT) is defined by the time interval between the first transmission of the PDSCH (Physical Downlink Shared Channel) using a certain HARQ process ID and the earliest re-transmission or fresh transmission applying the same HARQ process ID again.
- The CQI delay is the timing interval between the CQI measurement period at the UE and the next TTI data transmission from the eNB that is based on the knowledge of this CQI.

Since both CQI as well as ACK/NACK information need to be transmitted from the serving cells to the master cell of a cluster across the X2 interface, the X2 delay impacts both ACK/NACK RTT as well as CQI delay. The ACK/NACK RTT states how many HARQ processes are needed to guarantee continuous transmission if the mobile station is scheduled all the time. Therefore the impact of enlarged ACK/NACK RTT is important for low to medium cell loads. In highly loaded cells the number of required HARQ processes decreases since each mobile station gets less access to the channel. This impact is therefore dependent on the cell load. Due to the increased CQI delay the CQI contains less information about the channel at the time when it is accessed. This means that it becomes more difficult to adapt the MCS to the instantaneous channel conditions.

In the following we assume that a sufficient number of HARQ processes is available such that the impact of the X2 delay on the ACK/NACK RTT can be neglected. This is ensured by setting the number of available HARQ processes to infinity. To investigate the impact of X2 delay on the CQI delay, we simulated X2 delays of 0 ms, 1ms, 3 ms, 5 ms, 10 ms, 15 ms and, finally, 20 ms. The bursty traffic model of Table 1 was applied. All the other simulation assumptions are identical as stated in Table 1 and Table 2.

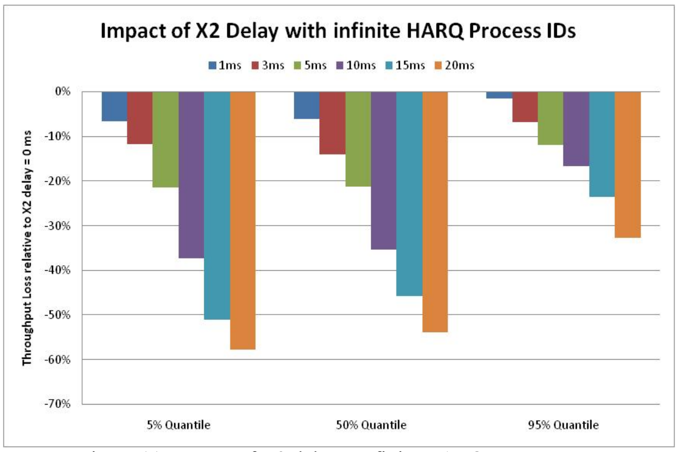

Figure 11: Impact of X2 delay - Infinite HARQ process IDs

Figure 11 shows the losses in mean user perceived throughput for various X2 delays > 0 ms relative to an ideal interface with 0 ms loss. The losses are given for the 5%, 50% and 95% quantiles of the user perceived throughput CDF without X2 delay. Only throughput samples of those mobiles are included in the figure if the mobile does not have a single leg connection to the master cell and therefore suffers from an increased CQI delay. It is seen in the figure that the losses become the larger the larger the X2 delay is. Even for a X2 delay of 5 ms they are in the order of 20% for the 5% and the 50% quantile. This indicates JT CoMP is very sensitive to X2 delays. In order to exploit most if the gains of CoMP the X2 delay should be in the order of 1 ms and lower.

VI. Conclusion

In this paper, non-coherent joint transmission CoMP with centralized scheduling was investigated. First a centralized architecture was proposed with a master cell as the central entity of the cluster. The master cell hosts both the central MAC scheduler as well as the HARQ entities of all mobile stations being connected to the cluster.

Two different static cluster approaches were introduced and the gains were analyzed with respect to long term average geometry. Furthermore, a two stage scheduling method for JT CoMP was proposed. In dynamic system level simulations, the gains of the proposed architecture and algorithms were evaluated further for full buffer and bursty traffic models. It was demonstrated that the performance for the clustering approaches depends both on the location of the mobile station as well as on the traffic load. In other words, the cluster strategy for a specific mobile station should be adapted according to its location and the system load. Finally, the impact of the delay of the X2 interface was analyzed. It was shown that the JT CoMP performance significantly decreases with increasing X2 delay. A backhaul with low latency is therefore essential to exploit the gains of JT CoMP.

So far, the gains of the investigated low complex approaches are still relatively small and depend on the system load. Therefore, in a next step the proposal shall be extended to coherent transmission and an enhanced SDMA component.

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References

[1] 3GPP TR 36.814, "Further Advancements for E-UTRA Physical Layer Aspects (Release 9)", v.1.5.2, January 2009

[2] M. Karakayali, G. Foschini and R. Valenzuela, "Network Coordination for spectrally efficient Communications in Cellular Systems", August 2006, IEEE Wireless Communications Magazine.

[3] 3GPP TR 36.913, "Requirements for further Advancements for E-UTRA (LTE-Advanced) (Release 8)", March 2009, v8.0.1.

[4] 3GPP TS 36.300, "Evolved Universal Terrestrial Radio Access (E-UTRA) Overall description; Stage 2 (Release 8)", March 2009, v8.11.0.

[5] 3GPP TS 36.321, Evolved Universal Terrestrial Radio Access (E-UTRA), "Medium Access Control (MAC) protocol specification (Release 8)", v.8.8.0, January 2010.

[6] 3GPP TS 25.321, "Medium Access Control (MAC) protocol specification (Release 8)", v.8.8.1, January 2010.

[7] 3GPP TR 25.996, "Spatial channel model for multiple input multiple output (MIMO) simulations (Release 7)", v.7.0.0, June 2007.

[8] 3GPP TS 36.314, "Evolved Universal Terrestrial Radio Access (E-UTRA) Layer 2 – Measurements (Release 8)", v8.3.0, January 2010.