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Combining Dynamic Clustering and Scheduling for Coordinated Multi-Point Transmission in LTE

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***Abstract*—A promising concept to increase the efficiency of future cellular networks is to facilitate cooperation between Base Stations (BSs), which is known as Coordinated Multi-Point (CoMP). Various coordination techniques have been proposed and are partly standardized in Long Term Evolution (LTE). In this paper we focus on downlink Joint Transmission (JT), because this scheme offers the highest increase of spectral efficiency. In JT the same data is transmitted from multiple BSs such that the signals interfere constructively at the receivers.**

A major drawback of CoMP is the increased effort for channel measurement and precoding before data transmission. One way to cope with the additional complexity of CoMP is to group BSs into CoMP clusters. Cooperation of BSs is then only allowed between BSs belonging to the same cluster. In this paper we propose a new dynamic clustering algorithm. The novelty of the algorithm is that it not only defines clusters according to the current situation in the network, but also provides hints to the schedulers how to best serve the mobiles. Thereby the complexity of the scheduling process is reduced. The approach is evaluated in a realistic urban scenario, including a traffic model of Web-traffic and vehicular user mobility. The performance of the proposed clustering algorithm is compared with the performance of a traditional network without any cooperation as well as with two static clustering variants.

I. Introduction

A. Background

Coordinated Multi-Point (CoMP) is a candidate to improve the spectral efficiency in future wireless networks like 5G or the next releases of Long Term Evolution (LTE). The idea of CoMP is to allow cooperation between Base Stations (BSs). One variant of CoMP is Joint Transmission (JT), where the same data is sent from multiple BSs such that the transmitted signals interfere constructively at the served User Equipments (UEs). JT improves the spectral efficiency significantly, because the received signal power is increased and interference is suppressed. In combination with Multi-User Multiple Input Multiple Output (MU-MIMO) the network performance can be increased drastically [1]. One drawback of CoMP in traditional mobile network architectures is the requirement of tight synchronization between BSs, which is demanding for the network interconnecting the BSs. Additionally, in the case of JT the data has to be available at all cooperating BSs. However, in upcoming network architectures like Cloud Radio Access Network (C-RAN) it becomes easier to cope with these challenges, as the processing is moved from the individual BSs to a central data center and the BSs are replaced by simpler Remote Radio Heads (RRHs). So, synchronization and data exchange become feasible. Nevertheless, the high overhead of channel measurement and the complexity of precoding for a high number of transmit (TX) antennas is demanding. One possibility to deal with the high complexity is the introduction of CoMP clusters. This means that only BSs belonging to the same cluster may cooperate. Another challenge are the network dynamics, e. g., the movement of UEs or the variations of traffic demands. Instead of defining the clusters statically, they should be adapted to the current situation, to further increase the performance.

In this paper we propose a new dynamic clustering algorithm for non-overlapping clusters. The algorithm is executed centrally and depends on the possibility of cluster reconfigurations. Therefore, the architecture of the cellular network must be implemented as a C-RAN. The benefit of the algorithm is that it provides the schedulers in the system with additional information in order to reduce the complexity of Resource Allocation (RA).

B. Related Work

The need for clustering of BSs has been identified in [2]. The publication compares dynamic with fixed clustering schemes and highlights the superiority of dynamic clustering. A greedy clustering algorithm is developed. In [3] scheduling is considered together with dynamic clustering to improve the system performance and fairness between users. A greedy scheduler is proposed and evaluated via simulations. Clusters can be overlapping i. e., a BS may belong to multiple clusters. In contrast, in [4] a greedy dynamic joint clustering scheduling algorithm is developed for non-overlapping clusters. [5] also assumes a dynamic user centric clustering. The objective is the design of an algorithm for joint clustering and linear precoding. Clusters may be overlapping and the cluster size is configurable.

The combination of C-RAN and CoMP is evaluated in [6]. The primary constraints are the limited backhaul capacity of the C-RAN architecture and overhead for channel measurement if dynamic clustering is applied. [7] states that C-RAN allows significantly larger cluster sizes, since coordination in a centralized system is easier to achieve. The performance gain of JT is evaluated for cluster sizes of up to 105 BSs.

These publications have in common that rather short durations are considered. Therefore, user mobility and realistic traffic are not covered. However, both have a great impact on the performance of dynamic clustering. [8] uses realistic application traffic models to evaluate CoMP. However, Dynamic Point Selection (DPS) instead of JT is evaluated.

[9] considers scheduling in combination with CoMP in more detail. It states, that because of the influence of the clustering on the scheduling and vice versa, finding an optimal solution is hardly possible. Therefore, often greedy scheduling approaches are used instead [4], [10].

C. Structure

The paper is structured as follows. Section II introduces the scenario in which CoMP is applied. Section III presents the proposed dynamic CoMP clustering algorithm. In Section IV we show the simulation model used for the evaluations presented in Section V. Finally, Section VI concludes this paper.

II. Scenario

A. Overview

We focus on the downlink performance of a network consisting of single antenna UEs and multi antenna BSs. We use LTE as a basis, but the presented approaches are also applicable to upcoming 5G systems, as long as Orthogonal Frequency Division Multiplexing (OFDM) and the segmentation of time and frequency resources into Physical Resource Blocks (PRBs) are applied.

We assume a C-RAN architecture, which facilitates CoMP, as synchronization and data exchange can be performed with short latency and high bandwidth within the data center. Cluster creation and reconfiguration is performed by a central instance, the Cluster Manager (CM), located in the data center. The CM is responsible for all RRHs connected to the data center. Resource allocation is performed for each cluster individually by its own scheduler. Thus, no synchronization or data exchange is needed between the schedulers. We will use the term BS as synonym for RRH and sector.

B. Clustering

To reduce the complexity introduced by CoMP, BSs are grouped into clusters. We will denote the set of used clusters in the system as clustering $\mathcal{C}$. The size of a cluster is defined as the number of BS in the cluster.

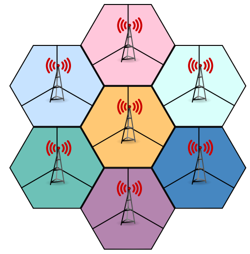

Figure 1. *Site* clustering

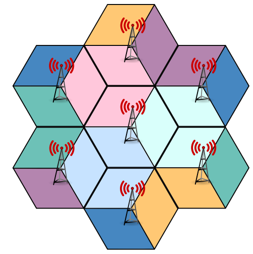

Figure 2. *Facing* clustering

To compare our proposed dynamic clustering algorithm we utilize two static clustering variants. In the *Site* clustering all sectors/BSs of one site cooperate. This is illustrated in Figure 1 for a hexagonal scenario of tri-sectorized sites. BSs belonging to the same cluster share the same color. *Site* clustering can be easily implemented in existing systems, because processing and data exchange have to be performed in a single site. The principle of the *Facing* variant is shown in Figure 2. The idea is that sectors whose antenna beams point to each other cause high interference in the neighboring sectors. Therefore, cooperation between those sectors might be beneficial.

III. Dynamic Clustering Algorithm

We propose a dynamic clustering algorithm that is inspired by [11] and [12]. The algorithm is executed centrally by the CM. The main idea of the algorithm is to use measurements provided by the UEs and to create cluster candidates from these measurements. Then a valid clustering is derived from the candidates and finally the schedulers are provided with additional knowledge, that reduces the complexity of RA. This additional knowledge is generated from the cluster candidates by further dividing a cluster into multiple partitionings.

In the following a cluster is denoted as C. It has the attributes $C.BSs$ and $C.UEs$ to store the set of BSs and UEs, respectively. The additional information for the schedulers in terms of partitionings is stored in $C.Partitionings$.

A. Cluster Creation

The algorithm is controlled by two parameters. The maximum size of the created clusters is defined as $S_{C,\max}$. The time between cluster reconfigurations is defined by the cluster reconfiguration interval T_R.

System state measurements are provided by the UEs in terms of Cluster Measurement Reports (CMRs). Each UE sends one CMR per cluster reconfiguration interval T_R to the CM. The CMR m contains an individual weight of the reporting UE ($m.w$) and a list of Reference Signal Received Power (RSRP) measurements ($C.BSs$). This list contains RSRP measurements of the $S_{C,\max}$ BSs with highest RSRP. The weight is defined as $w = {}^{1}/{v_u}$, where v_u is the speed of the reporting UE, which is measured by the UE. The idea behind this weight

Algorithm 1 Create cluster candidates

1: $\mathcal{C}_{\text{cand}}, \mathcal{C}_{\text{mobiles}} \leftarrow$ new map
2: **for all** received CMR m **do**
3:   Sort m.BSs in descending order of the RSRP
4:   $\mathcal{C}_{\text{mobiles}}[m.UE] \leftarrow m.BSs[0]$
5:   **for** $S_C = S_{C,\max} \dots 1$ **do**
6:     $C \leftarrow$ new cluster
7:     $C.BSs \leftarrow \{m.BSs[0], \dots, m.BSs[S_C]\}$
8:     $\mathcal{C}_{\text{cand}}[C] \leftarrow \mathcal{C}_{\text{cand}}[C] + m.w$
9: Sort $\mathcal{C}_{\text{cand}}$

Algorithm 2 Determine the clustering

1: $\mathcal{C}, \mathcal{B}_{\text{considered}} \leftarrow \emptyset, \emptyset$
2: **for all** $C \in \mathcal{C}_{\text{cand}}$ **do**
3:   **if** $C.BSs \cap \mathcal{B}_{\text{considered}} = \emptyset$ **then**
4:     $\mathcal{C} \leftarrow \mathcal{C} \cup C$
5:     $\mathcal{B}_{\text{considered}} \leftarrow \mathcal{B}_{\text{considered}} \cup C.BSs$
6: **for all** Cluster $C \in \mathcal{C}$ **do**
7:   $C.UEs \leftarrow \{u | \mathcal{C}_{\text{mobiles}}[u] \in C.BSs\}$
8:   ADDPARTITIONINGS(C)
9: Configure new clustering $\mathcal{C}$ and wait for time T_R

definition is that slowly moving UEs will profit longer, if a suitable clustering is configured for them. Therefore, the weight of these UEs should be higher. The UE issuing a CMR is stored in $m.UE$.

The creation of cluster candidates is performed according to Algorithm 1. The algorithm creates the maps $\mathcal{C}_{\text{cand}}$ and $\mathcal{C}_{\text{mobiles}}$. The map $\mathcal{C}_{\text{cand}}$ stores all cluster candidates and their weights as calculated by Algorithm 1, so the keys are clusters and the values are the weights. The map $\mathcal{C}_{\text{mobiles}}$ stores for each UE the BS with highest RSRP. In the next step all received CMRs are processed (Lines 2 to 8). First, the list of BSs is sorted in descending order of the RSRP. The best BS is then inserted into $\mathcal{C}_{\text{mobiles}}$ as value for UE u (Line 4). From each CMR multiple clusters with sizes of $S_{C,\max}$ down to 1 are created (Lines 5 to 8). The candidates are inserted as keys into $\mathcal{C}_{\text{cand}}$. Thereby, the weight reported in the CMR is used as value. If the candidate already exists in the map, the weight is added to the existing value (Line 8). In the final step of the candidate creation, the map $\mathcal{C}_{\text{cand}}$ is sorted. First the candidates are sorted according to their size in descending order. Clusters of same size are then sorted according to their total weights also in descending order. So the largest cluster with the highest weight is the first entry of $\mathcal{C}_{\text{cand}}$. This order makes sure that first larger clusters are considered in the next step, because with larger clusters the inter-cluster interference can be reduced and generally more users profit from the cluster. In case of same cluster sizes, the cluster which is more beneficial comes first.

Based on the cluster candidates the clustering $\mathcal{C}$ is defined by Algorithm 2. In the first step the clustering $\mathcal{C}$ is defined as an empty set. The set $\mathcal{B}_{\text{considered}}$ is also

Algorithm 3 Add partitionings

1: **function** ADDPARTITIONINGS(C)
2:   $\mathcal{C}_{\text{cand},C} \leftarrow \{P \in \mathcal{C}_{\text{cand}} | P.BS \subseteq C.BSs\}$
3:   $Partitionings, Partitioning \leftarrow \emptyset, \emptyset$
4:   CREATE(C, $\mathcal{C}_{\text{cand},C}$, $Partitioning$, $Partitionings$)
5:   **for all** $Partitioning \in Partitionings$ **do**
6:     **for all** $P \in Partitioning$ **do**
7:       $P.UEs \leftarrow \{u | \mathcal{C}_{\text{mobiles}}[u] \in P.BSs\}$
8:   $C.Partitionings \leftarrow Partitionings$

Algorithm 4 Recursively create partitionings

1: **function** CREATE(C, $\mathcal{C}_{\text{cand},C}$, $Partitioning$, $Partitionings$)
2:   **if** COMPLETE(C, $Partitioning$) **then**
3:     $Partitionings \leftarrow Partitionings \cup Partitioning$
4:   **else**
5:     **for all** Partition $P \in \mathcal{C}_{\text{cand},C}$ **do**
6:       **if not** CONTAINS(P, $Partitioning$) **then**
7:         $\mathcal{C}_{\text{cand},C,r} \leftarrow \mathcal{C}_{\text{cand},C} \setminus P$
8:         $NewPart \leftarrow Partitioning \cup P$
9:         CREATE(C, $\mathcal{C}_{\text{cand},C,r}$, $NewPart$, $Partitionings$)

initialized as an empty set and will be used to store BSs already selected to avoid overlapping clusters. Then an iteration over the cluster candidates is started. If the BSs of the currently considered candidate are disjoint from the set $\mathcal{B}_{\text{considered}}$, i. e., the intersection of both sets is empty, the cluster is selected and added to $\mathcal{C}$. Also all the BSs of the cluster are added to $\mathcal{B}_{\text{considered}}$. After the loop the clustering has been determined and the next loop adds the UEs to the selected clusters. Therefore, the UEs are added to the cluster containing their best BS (Line 7). In this loop partitionings are also added to all selected clusters, which will be explained in the next section. The final step is to configure the selected clustering and wait for the next reconfiguration interval.

B. Concept of Cluster Partitionings

To reduce the complexity of RA, we introduce the concept of partitionings. The task of the scheduler is to determine which UEs are served by which BSs. If a cluster consists of multiple BSs and UEs, this becomes challenging, because the number of scheduling options grows rapidly. Although many of the options are not meaningful. E. g., in a cluster consisting of two BSs and UEs using JT is not beneficial if the UEs are located close to different BSs, because TX power is wasted to achieve constructively overlapping signals. Instead it is better to serve the UEs by a single BS and accept interference. In this case two options exist. The UEs can be served by the closer BS or by the BS far away. Even if it is obvious which option is better, a scheduler relying on exhaustive search has to consider both. With the concept of partitionings, the scheduler only has to consider meaningful options.

After the selection of the clusters a set of partitionings is assigned to each of them. A partitioning thereby consists of multiple partitions. A partition is very similar to a cluster, i. e., it consists of sets of BSs and UEs. The difference is that a cluster has its own scheduler, while the partition is served by the scheduler of the cluster it belongs to. All BSs of a partition cooperatively serve the UEs selected by the scheduler by using JT. The scheduler of the cluster decides every Transmission Time Interval (TTI) and for each PRB which UEs are served by which BSs, by selecting the partitioning that provides the best performance.

A partitioning is defined such that all BSs and UEs of the cluster are contained in the partitions of the partitioning. The partitionings are defined similar to the clusters in the previous step by using the created cluster candidates (see Algorithm 3). The first step is to filter the cluster candidates, such that the map $\mathcal{C}_{\text{cand},C}$ contains candidates related to cluster C, i. e., clusters whose set of BSs are subsets of $C.BSs$. Then the sets $Partitionings$ and $Partitioning$ are initialized. $Partitionings$ will contain the found partitionings. $Partitioning$ is a helper set in the following recursion. The recursion is started by calling the function CREATE. After the partitions have been generated, UEs are assigned to the partitions that contain their best BS (Line 7).

CREATE (see Algorithm 4) uses the functions COMPLETE and CONTAINS. COMPLETE checks if the passed $Partitioning$ is complete, i. e., the partitions of the partitioning contain all BSs of C. CONTAINS checks if the currently created partitioning $Partitioning$ already contains the candidate partition P, i. e., if the partitions of $Partitioning$ contain at least one of the BSs of P. This check is required to avoid overlapping partitions. The recursion is stopped, if the currently created partitioning $Partitioning$ is complete. In this case $Partitioning$ is added to the set of partitionings (Line 3). Before the next iteration is started in Line 9, the currently examined partition P is removed from the available cluster candidates and a new partitioning is created. The new partitioning consists of the partitioning $Partitioning$ and partition P (Lines 7 and 8).

C. Scheduling

Finally, we show, how the scheduler uses the partitionings (see Algorithm 5). Our proposal is independent of the used scheduling algorithm. RA is performed by the function RESOURCEALLOCATION, which returns a scheduling metric w_C and the resource allocation A_C. The scheduling metric depends on the used scheduling variant and could be the sum data rate or a weighted sum data rate. The resource allocation A_C indicates how the UEs are scheduled, i. e., it describes which UEs are served on which PRBs by which BSs. Thus, A_C also includes information if CoMP is applied to serve the UEs. The returned scheduling metric is evaluated for all partitionings in $C.Partitionings$. The scheduling metric of a partitioning is thereby defined as the sum of the scheduling metrics of the partitions in the partitioning. The function returns the RA that results in the highest scheduling metric.

Algorithm 5 Usage of partitionings in the RA process

function SCHEDULE(Cluster C)
  $w_C, A_C \leftarrow 0, \emptyset$
  for all $Partitioning \in C.Partitionings$ **do**
    $w_p, A_p \leftarrow 0, \emptyset$
    for all Partition $P \in Partitioning$ **do**
      $w_P, A_{C_p} \leftarrow$ RESOURCEALLOCATION(P)
      $w_p, A_p \leftarrow w_p + w_P, A_p \cup A_P$
    if $w_p > w_C$ **then**
      $w_C, A_C \leftarrow w_p, A_p$
  return A_C

IV. SIMULATION MODEL

In this chapter we present all parts of our simulation model, as implemented in a system level simulation.

A. Wireless Transmission & Performance

As we investigate network dynamics in the range of seconds and minutes, the transmission model has to be calculated quickly. Therefore, a detailed model of precoding and power allocation is not applicable. Instead, we use an idealistic approach based on transmit power and channel attenuation.

The received signal power of UE u that is served by partition P on PRB r is modeled as:

$$P_{\text{signal},u,r} = \sum_{b \in P.BSs} P_{TX,r} \cdot h_{b,u} \cdot N_{TX,b} \cdot \frac{1}{N_{P,r}} \quad (1)$$

Where $P_{TX,r}$ is the TX power per antenna spent to serve PRB r, $h_{b,u}$ is the channel attenuation between BS b and UE u, $N_{TX,b}$ is the number of TX antennas available at BS b and $N_{P,r}$ is the number of UEs served on PRB r in the partition. The last term in Equation (1) states that the TX power is distributed equally between all served UEs. Additionally, the TX power of one antenna is distributed evenly to all PRBs. Therefore, $P_{TX,r} = P_{TX}/N_r$ holds, with P_{TX} being the total TX power per antenna and N_r the total number of PRBs per TTI.

The interference power received by a UE can be decomposed into intra-cluster and inter-cluster interference. Here we assume that the intra-cluster interference can be completely suppressed by using appropriate precoding techniques ($P_{\text{intra-cluster interf.},u,r} = 0$). E. g., Zero Forcing or Dirty Paper Coding could be used. Thus the inter-cluster interference becomes:

$$P_{\text{inter-cluster interf.},u,r} = \sum_{b \in \mathcal{B} \setminus P.BSs} a_{b,r} \cdot P_{TX,r} \cdot h_{b,u} \cdot N_{TX,b} \quad (2)$$

The set $\mathcal{B}$ contains all BSs. The binary variable $a_{b,r}$ is equal to 1, if BS b is transmitting on PRB r and 0 if it is not transmitting. Note that this approach in general results in a pessimistic estimation of the received signal power and overestimates the inter-cluster interference. Applying precoding would result in higher signal power and less inter-cluster interference.

The Signal to Interference and Noise Ratio (SINR) is:

$$\gamma_{u,r} = \frac{P_{\text{signal},u,r}}{P_{\text{inter-cluster interf.},u,r} + \sigma^2} \quad (3)$$

Where σ^2 is the noise power at the receiver. The Shannon-Hartley theorem yields the amount of data transmitted to UE u in PRB r:

$$d_{u,r} = B_r \cdot T_r \cdot \log_2 \left(1 + \min(\gamma_{u,r}, \gamma_{max})\right) \quad (4)$$

B_r is the bandwidth of a PRB ($180\,\text{kHz}$ in LTE) and T_r the duration of one TTI ($1\,\text{ms}$ in LTE). The SINR is bounded to $\gamma_{max} = 24\,\text{dB}$. With this value a spectral efficiency of approximately $8\,\text{bit/s/Hz}$ is achieved which equals the highest modulation scheme specified in LTE release 12 (256-QAM).

B. *Traffic Model*

Because the traffic pattern in the network influences possible CoMP gains, we do not apply a full buffer approach. Instead, we model the traffic between a server in the Internet and the UEs on object level. The object sizes are based on measurements in a campus network [13]. The object size distribution is clipped at $100\,\text{MB}$. The offered load is controlled by varying the negative exponentially distributed Inter-Arrival Time (IAT) of new object transmissions.

C. *User Mobility Model*

To model the user mobility, we employ the virtual track model introduced in [14]. We configure the model to represent the mobility of vehicles in an urban environment. In the model, UEs move in groups and the number of groups is configurable. UEs belonging to the same group are randomly placed around the group center, with a maximum distance of $10\,\text{m}$. The speed of the UEs is set to $50\,\text{km/h}$. Figure 3 shows an example street topology without wrap-around, 50 junctions and at maximum 4 streets per junction. The minimal distance between junctions is $100\,\text{m}$. In this example 20 groups of UEs are deployed, indicated by colored dots. We use these street topology parameters for the evaluations, but allow wrap-around of streets.

D. *Cellular Network*

We assume a network consisting of 19 sites, arranged in a hexagonal layout. Each site supplies three sector cells, resulting in 57 sectors. Wrap-around is used to avoid border effects. We model the radio channel with path-loss and shadowing. The parameterization is summarized in Table I and complies with 3GPP specifications, with the difference that we utilize an antenna downtilt of $10°$,

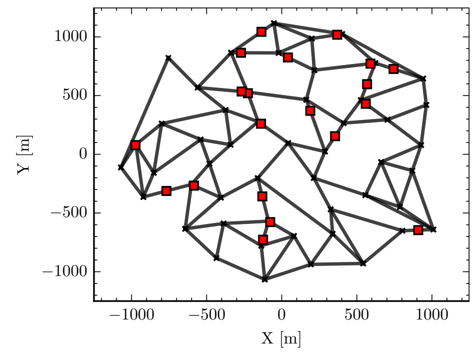

Figure 3. Example of a virtual track topology

Table I
SIMULATION MODEL PARAMETERS

Property	Value
Inter site distance	$500\,\text{m}$, wrap-around
BS TX power per antenna	$P_{TX} = 46\text{dBm}$
Noise Power	$-174\,\text{dBm/Hz}$
BS / UE height	$32\,\text{m}$ / $1.5\,\text{m}$
Path-loss [dB]	$128.1 + 37.6 \cdot \log_{10} d[\text{km}]$, [15]
BS antenna model	3D, 10° tilt, from [15]
Shadowing	$8\,\text{dB}$ log-normal
Carrier frequency	$2\,\text{GHz}$
Subframe duration (TTI)	$1\,\text{ms}$
System bandwidth	$1.4\,\text{MHz}$, ($N_r = 6$ PRBs per TTI)

which is beneficial for inter-site cooperation. To model the core network we add a constant delay of $20\,\text{ms}$ between server and UE.

Scheduling follows the Proportional Fair (PF) principle. For each configured cluster, the scheduler performs Algorithm 5, but it does not perform an exhaustive search to find the best RA. Instead, the scheduler decides for each PRB how many UEs should be served on this PRB by performing a greedy algorithm. The scheduler allocates a new MIMO layer to the UE that offers the highest increase of the scheduling metric. In case the scheduling metric is not increased by assigning more MIMO layers, it is also possible to use fewer layers than the maximum number. The maximum number of MIMO layers is determined by the number of TX antennas within the partition.

V. EVALUATION

For the evaluation $800\,\text{s}$ have been simulated, including a warm-up phase of $400\,\text{s}$. The results show mean values and 95% confidence intervals of ten independent replications. Each replication uses a randomly created virtual track topology. All 420 UEs are randomly assigned to groups. The groups are randomly placed on streets before the movement starts. Perfect channel knowledge is assumed and overhead to perform RSRP measurements or transmit the CMR is neglected.

We evaluate the system performance from a user's point of view. Therefore, we use the data rate as an indicator of the service quality. The data rate r is measured per object generated by the traffic model and is defined as $r = \frac{\text{object size}}{\text{transmission time}}$.

A. Influence of the Clustering Variant

The results in Figures 4 and 5 show the relation between offered and carried traffic for different clustering variants, different number of groups in the mobility model and different numbers of TX antennas at the BSs. For a fixed number of groups, we can see that the maximum carried traffic is increased by all clustering schemes in comparison to a system without CoMP. However, *Site* clustering performs better than *Facing*. Our proposed dynamic clustering algorithm performs best. The reason for these results are that the *Facing* clustering is mainly beneficial for UEs located on the border between different sites. At these locations the overall channel attenuation is high and therefore the additional CoMP gain is comparatively small. The *Site* clustering is beneficial for UEs on the sector borders, so also UEs benefit from CoMP which are located closer to the serving BSs. Finally, the dynamic clustering adapts to the actual locations of the UEs and therefore results in the best performance.

Comparing the results for different numbers of groups, we observe that more groups lead to higher carried traffic rates. The reason is that the UEs are better distributed if more groups are configured, which leads to a better utilization of the available BSs. It is also visible that the gains of dynamic clustering are higher, if fewer groups are configured. The reason is that the similarity between the movements are higher, if the same number of UEs are grouped into fewer groups. So the dynamic clustering algorithm configures clusters that are beneficial for more UEs at the same time.

The influence of different numbers of TX antennas can be seen by comparing Figures 4 and 5. The general behavior is similar, however, more TX antennas improve the system capacity. But increasing the number of TX antennas by factor 4 does not increase the system capacity by factor 4, too. Instead, the system capacity is approximately doubled in most cases. The reason is that adding more TX antennas increases the received signal power as well as the inter-cluster interference.

B. Influence of the Cluster Size

Figure 6 shows how the average data rate r per traffic object is influenced by the cluster size. For this evaluation an offered traffic rate of $150\,\mathrm{Mbit/s}$ and 1 TX antenna per BS are configured. Note that *No CoMP* is only defined for cluster sizes of 1 and the variants *Facing* and *Site* are defined for cluster sizes of 3. The results for these clustering variants are extended to other cluster sizes to allow an easier comparison with the results of the dynamic clustering algorithm. Independently of the clustering scheme, r increases with increasing number of groups. The reason is again that more groups lead to a better distribution of the UEs. The data rate achieved by dynamic clustering increases with increasing $S_{C,\max}$. The performance of dynamic clustering with $S_{C,\max} = 2$ even outperforms the static clustering variants. The gain from increased cluster sizes becomes smaller for larger $S_{C,\max}$, because the additional BSs have a higher distance to the served UEs and thus a high channel attenuation. Nevertheless, larger clusters improve the performance by reducing the inter-cluster interference.

The performance gain introduced by CoMP is higher if less groups are configured. Additionally, r reaches similar values for the dynamic clustering and $S_{C,\max} = 7$ for 10, 20 and 60 groups. Larger clusters allow to serve the UEs of a group by more BSs, which results in more served UEs and the served UE experience higher rates. Thus, this effect is mainly caused by the dependency between UE distribution and the number of groups.

C. Influence of the Cluster Reconfiguration Interval

In Figure 7 we vary the cluster reconfiguration interval between $1\,\mathrm{ms}$ and $25\,\mathrm{s}$ and evaluate the effect on the rate r. As a reference also the static clustering variants are included, even if they are not influenced by the cluster reconfiguration interval. The results clearly indicate that r is hardly affected by the reconfiguration interval for $T_R \leq 1\,\mathrm{s}$. Only for larger values of T_R the rate decreases. We can conclude from the results, that it is possible to integrate the proposed dynamic clustering in existing systems, because even if cluster reconfigurations are performed relatively seldom, the achievable performance gains are significant. Noteworthy is that relatively high values for T_R are tolerable even if the UEs move fast compared to average speeds in urban scenarios, which includes vehicles, pedestrians and stationary UEs.

VI. Conclusion

In this paper we proposed a dynamic CoMP clustering algorithm, tailored for the application in urban scenarios. The novelty of the algorithm is the combination with the scheduling process, which is achieved by providing the schedulers with additional information. The information is generated similar to the clustering based on measurements performed by the UEs. This approach reduces the number of scheduling options the schedulers have to evaluate and thus the additional complexity caused by CoMP. The simulation results of a realistic network including a vehicular mobility model indicate that the algorithm significantly improves the total performance in terms of sum data rate, but also the individual data rates perceived by the UEs. In comparison to static clustering schemes, significant improvements are achieved.

The results also reveal that the performance of the dynamic clustering algorithm is influenced by the mobility pattern. Especially, the similarity or correlation of the movement and the density has an important effect. In a follow-up publication we will examine the relation of mobility and performance improvement in more detail.

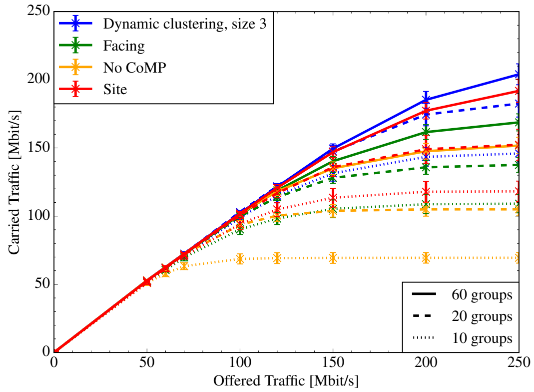

Figure 4. Relation between offered and carried traffic for 1 TX antenna per BS

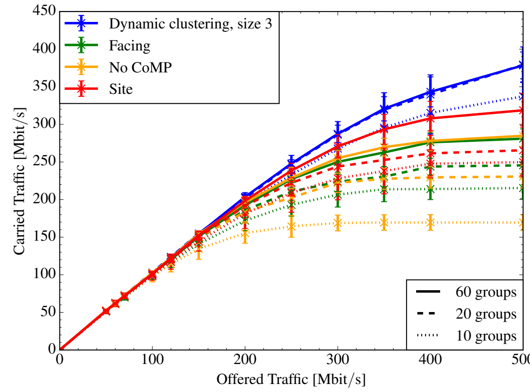

Figure 5. Relation between offered and carried traffic for 4 TX antennas per BS

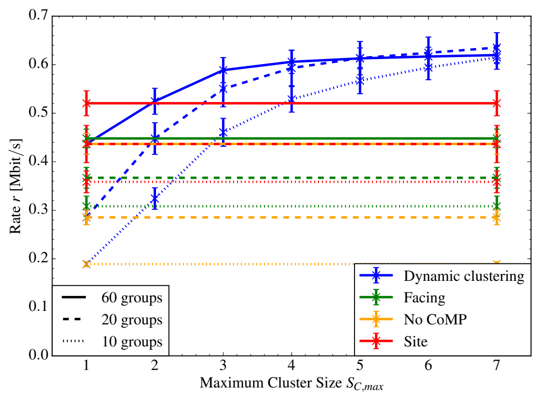

Figure 6. Influence of the cluster size for 150 Mbit/s offered traffic and 1 TX antenna per BS

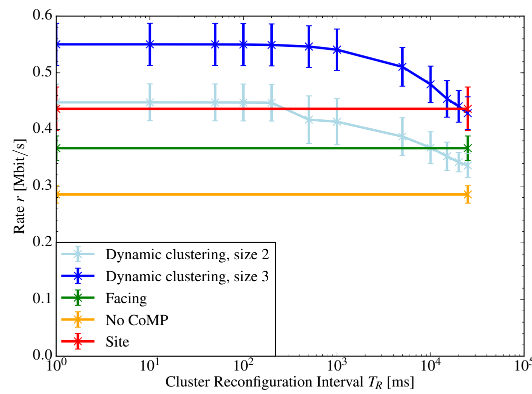

Figure 7. Influence of the cluster reconfiguration interval for 20 groups, 150 Mbit/s offered traffic and 1 TX antenna per BS

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