The Potential of Restricted PHY Cooperation for the Downlink of LTE-Advanced

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Abstract— **We investigate the potential of restricted PHY cooperation for the downlink of 4G networks. The cooperation is restricted to a cluster of eNodeBs. We distinguish between low and high mobility users, and propose two appropriate cooperation methods. The goal is to guarantee high user rates even on cell edges. We present a simulation study to analyze the spectral efficiency achieved by cooperation methods for urban micro cells. To investigate their influence on coordinated multipoint (CoMP), we consider different frequency allocation strategies and different sector orientations in a cell. In addition, we compare CoMP transmission to Multiuser MIMO and investigate how cooperation can improve power allocation. Based on the results, we provide important insights into future cell planing aspects.**

I. Introduction

According to the ITU requirements for IMT-Advanced [1], 4G networks as LTE-Advanced have to support peak data rates of up to 100 Mbit/s for high mobility such as mobile access and up to 1 Gbit/s for low mobility such as nomadic/local wireless access. Even with the higher bandwidth of up to 100 MHz in LTE-Advanced, 10% of these rates may be hard to achieve at the cell edges – given the eNodeB transmit (Tx) power mentioned in [2]. Particularly at higher carrier frequencies, that are supported in 4G, cell sizes will decrease. Since it will be difficult to find new sites for eNodeBs in some countries, coverage extension and high throughput at cell edges are important challenges in 4G networks.

Recent research results (e.g. [3]) show that cooperative schemes are able to solve many of the issues faced by future cellular networks. Such cooperative schemes can include cooperation among several eNodeBs, also referred to as base stations (BSs), or between mobile user equipments (UEs), in order to form distributed multiple-input multiple-output (MIMO) arrays to achieve a higher spectral efficiency. Coordinated multipoint (CoMP) transmission and reception [2] is standardized for LTE-Advanced. On the downlink, CoMP transmission implies dynamic coordination among transmitting BSs, e.g. to do joint beamforming to the same UEs. In real networks, i.e. when the number of cells is very high, cooperation between all involved BSs is impractical. Since all sectors of cooperating BSs are coupled with each other, a large number of cooperating BSs results in very stringent requirements on delay and very high computational complexity that would be hard to meet in practice. Hence, cooperation has to be limited to a subset of BSs. In this paper, we investigate the potential of such a locally restricted, cluster based, approach to BS cooperation on the PHY layer of cellular networks. The BSs of the network are grouped into different clusters where the BSs of each cluster cooperate. We consider two different frequency allocations (frequency reuse 3 and 1) and two different user mobility scenarios (slowly moving vs. fast moving users). In addition, we investigate how the orientation of sectorized antenna arrays influences the potential of cooperation. We also show that cooperation can improve power allocation by reducing the required Tx power substantially. Based on the results, we give insights how to use cooperation in upcoming cellular networks.

Related work: An overview of the research done in related fields – from theory to cooperation techniques for multi-cell MIMO cooperation – can be found in [3] and the references therein. In [4], the authors present an approach of clustered linear precoding by cooperating BSs to maximize the sum rate in a mobile network. Inter-cluster interference is taken into account. The authors in [5] and [6] compare approaches based on zero-forcing (ZF) combined with a max-min rate optimization and ZF dirty paper coding. The goal in both cases is to increase the QoS of a cellular network by BS cooperation. Inter-cluster interference is not taken into account.

II. System Model

The entire area is divided into cells of hexagonal shape. Each cell is further divided into three sectors. The BSs in the center of the cells consist of a separate antenna array for each sector. Further, we assume each sector of the network serves exactly one UE at a given time instant (e.g. multiple UEs assigned to the same sector share the resources by a TDMA scheme).

Frequency allocation: Different allocation schemes for the LTE (Advanced) OFDMA downlink are under discussion (see [7] and references therein), for instance fractional frequency reuse (FFR). The goal is to allocate as much bandwidth to a user as reasonable. In most cases, users near the cell edge get only 1/3 of the overall bandwidth (frequency reuse 3) to control interference to other cells, whereas users near the BS can get up to the whole available bandwidth, i.e. frequency reuse 1. In [7] the idea of a load dependent frequency planning for OFDMA systems is introduced. The principle is coordination of frequency allocation for BSs. Inspired by these considerations, we investigate two different frequency allocations: (i) a static FDMA approach where each of the three sectors in a cell gets one third of the overall bandwidth; (ii) an approach where the whole bandwidth is available for

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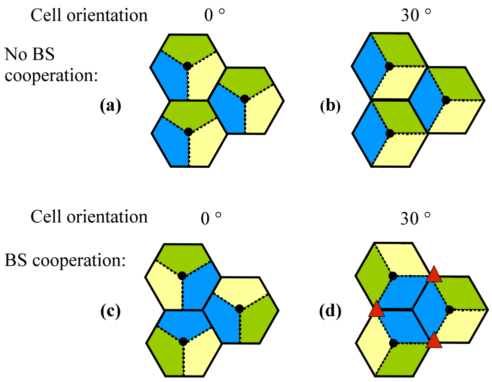


Fig. 1. Investigated cell orientations. For FDMA, the colors indicate sectors using the same frequency band. Red triangles in (d) mark the positions of supporting nodes in case of a distributed antenna system (DAS).

a given user, i.e. frequency reuse 1. Realistic schemes may operate between frequency reuse 1 and 3.

Cooperation scenarios and *cooperation techniques:* A group of BSs applies joint beamforming on the downlink for *low mobility users*. For this network MIMO approach, the cooperating BSs form a virtual MIMO Tx antenna array with a per node power constraint. The technique is based on channel state information (CSI) at the transmitter (CSIT). We assume full cooperation with unlimited backhaul capacities between cooperating BSs. The BSs exchange CSIT and Tx symbols. We focus on the PHY layer, higher layers and the influence of scheduling are not investigated. Each of the clusters of cooperating BSs is referred to as a *cooperation set* $\mathcal{M}$ and consists of $|\mathcal{M}| = M$ BS sectors that are able to cooperate with each other in a cooperation area. The set $\mathcal{M}^c$ is the set of all other BS sectors that belong to other cooperation sets than $\mathcal{M}$. They do not cooperate with $\mathcal{M}$ and cause interference to the communication within the cooperation area of $\mathcal{M}$. The set of UEs in the cooperation area is denoted by $\mathcal{K}$ and consists of $|\mathcal{K}| = K$ UEs. According to our assumption of exactly one UE lying in each sector, $K = M$. BS and UE are each equipped with N_B and N_U antennas, respectively. The antennas of the BSs are assumed to be directional with patterns according to [2], while those of the UEs are omnidirectional. We chose a suboptimal cooperative signaling scheme that is of practical relevance; the achievable rate of the UEs is maximized under a given QoS restriction to guarantee a certain fairness among the UEs. This turns out to be a max-min optimization of the individual user rates.

In case of *highly mobile, fast moving users*, techniques based on CSIT are hardly of practical relevance because CSIT is only valid for a very short period of time. For these users, we investigate a technique that is based on fast handoffs between the cooperating BSs. The goal is to achieve macro diversity. CSIT is not necessary, the BSs do not have to exchange CSI or Tx symbols; it suffices if the different BSs coordinate themselves to schedule different mobiles in a way that all involved UEs can benefit from a diversity gain.

Sector orientation in cells: In this paper we distinguish between two different orientations of cell sectors: (i) 0^o, a typical cell setup usually applied in 2G and 3G cells (see. (a) in Fig. 1); (ii) 30^o, a setup which obviously has advantages regarding cooperation of the three neighboring cells (see (b) in Fig. 1). Note that if the FDMA approach is used, the cooperating BS sectors should be assigned to the same frequency band in order to allow full cooperation, see (c) and (d) in Fig. 1.

A. Input-Output Relation

In the downlink, the BS sector BS_b, $b \in \{1, \ldots, M\}$, belonging to $\mathcal{M}$ transmits a sum of different signals, one intended for each of the K UEs in the cooperation area:

$$\mathbf{x}_b = \sum_{j=1}^{K} \mathbf{x}_{j,b}, \quad \text{with} \quad \mathbf{x}_{j,b} = \mathbf{G}_{j,b} \cdot \mathbf{s}_j, \tag{1}$$

where $\mathbf{x}_{j,b} \in \mathbb{C}^{N_B}$ is the signal from BS_b intended for mobile UE_j. We assume linear precoding and factorize these signals, where $\mathbf{s}_j$ is the Tx symbol vector intended for UE_j and $\mathbf{G}_{j,b}$ is the corresponding precoding matrix. The elements of $\mathbf{s}_j$ are i.i.d. $\mathcal{CN}(0,1)$, variance of the elements of $\mathbf{s}_j$ normalized to unity. Power allocation for each symbol takes place in the precoding matrix $\mathbf{G}_{j,b}$, additional to the beamforming. Note that the idealized assumption of unlimited cooperation means, that each BS_b in $\mathcal{M}$ has full knowledge of the CSIT to all UEs in $\mathcal{M}$ and of all symbol vectors of all BS sectors in $\mathcal{M}$.

The receive signal at the k-th mobile UE_k follows as

$$\begin{aligned}\mathbf{y}_k &= \bar{\mathbf{H}}_k \cdot \bar{\mathbf{x}}_k + \sum_{\substack{j=1\\ j\neq k}}^{K} \bar{\mathbf{H}}_k \cdot \bar{\mathbf{x}}_j + \sum_{b'=1}^{|\mathcal{M}^c|} \hat{\mathbf{H}}_{k,b'} \cdot \hat{\mathbf{x}}_{b'} + \mathbf{w}_k \\ &= \mathbf{y}_k^{(\text{sig})} + \mathbf{y}_k^{(\text{ICI})} + \mathbf{y}_k^{(\text{OCI})} + \mathbf{w}_k,\end{aligned}$$

where $\bar{\mathbf{H}}_k = [\mathbf{H}_{k,1}, \ldots, \mathbf{H}_{k,M}] \in \mathbb{C}^{N_U \times M N_B}$ is the concatenated channel matrix from all BS_b in $\mathcal{M}$ to UE_k, $\bar{\mathbf{x}}_k = [\mathbf{x}_{k,1}^T, \ldots, \mathbf{x}_{k,M}^T]^T$ is the vector that contains all transmit vectors from all BS_b in $\mathcal{M}$ intended for UE_k, $\hat{\mathbf{H}}_{k,b'} \in \mathbb{C}^{N_U \times N_B}$ is the channel matrix from $\text{BS}_{b'} \in \mathcal{M}^c$ to UE_k, $\hat{\mathbf{x}}_{b'}$ is the signal transmitted from $\text{BS}_{b'}$, and $\mathbf{w}_k \in \mathbb{C}^{N_U}$ whose elements are i.i.d. $\mathcal{CN}(0, \sigma_w^2)$ is the noise induced in UE_k.

The part of the signal $\mathbf{y}_k$ that is desired by UE_k is $\mathbf{y}_k^{(\text{sig})}$. The interference contains two contributions that are distinguished as interference from all BS_b belonging to $\mathcal{M}$, referred to as *intra-cooperation interference* (ICI) $\mathbf{y}_k^{(\text{ICI})}$, and interference caused by the transmission of other BS sectors from the set $\mathcal{M}^c$, which is referred to as *out-of-cooperation interference* (OCI) $\mathbf{y}_k^{(\text{OCI})}$. The purpose of the cooperative communication schemes is to control or even exploit the ICI. The OCI, on the other hand, remains, as the $\text{BS}_{b'}$ in $\mathcal{M}^c$ cannot cooperate with the BS_b in $\mathcal{M}$ and the OCI can therefore not be controlled. Combining the OCI and the actual noise of UE_k to the equivalent noise $\mathbf{n}_k = \mathbf{y}_k^{(\text{OCI})} + \mathbf{w}_k$ leads to the input-output relation:

$$\mathbf{y}_k = \bar{\mathbf{H}}_k \cdot \bar{\mathbf{x}}_k + \sum_{\substack{j=1\\ j\neq k}}^{K} \bar{\mathbf{H}}_k \cdot \bar{\mathbf{x}}_j + \mathbf{n}_k. \tag{2}$$

Hence, the achievable rate for user k per OFDM-tone is given by

$$R_k = \log\det\left\{\mathbf{K}_{\text{s}}^{(k)} + \mathbf{K}_{\text{i}}^{(k)} + \mathbf{K}_{\text{n}}^{(k)}\right\} - \log\det\left\{\mathbf{K}_{\text{i}}^{(k)} + \mathbf{K}_{\text{n}}^{(k)}\right\}, \tag{3}$$

where $\mathbf{K}_\text{s} = \mathbb{E}\left[\mathbf{y}_k^{(\text{sig})} \cdot \mathbf{y}_k^{(\text{sig})H}\right]$, $\mathbf{K}_\text{i}$, and $\mathbf{K}_\text{n}$ are the covariance matrices of the desired signal, ICI, and effective noise including OCI, respectively.

On each BS, a sum transmit power constraint is imposed. Thereby, the maximal sum transmit power over the entire bandwidth is given by P_tot. The power constraint per one of the N_c subcarriers follows then as

$$P_b = \text{Tr}\left\{\mathbb{E}\left[\mathbf{x}_b \cdot \mathbf{x}_b^H\right]\right\} \overset{!}{\leq} P_s = \frac{P_\text{tot}}{N_c}, \qquad \forall\, b, \qquad (4)$$

where P_b is the actual transmit power of BS_b in a single subcarrier. Note that the power constraint imposed here (also used in Section IV) implies uniform power allocation across all subcarriers, which is usually suboptimal.

III. Locally restricted BS cooperation

Two approaches for the LTE-Advanced Downlink are considered: (i) joint beamforming in the case of low mobility UEs, and (ii) fast and efficient handoffs between cooperating BSs (use of macro diversity) in the case of high mobility UEs.

A. Low User Mobility: CoMP - Joint Beamforming using Max-Min Optimization

We focus on one specific cooperation set $\mathcal{M}$. The *max-min* optimization approach maximizes the minimal achievable rate within the cooperation area. This increases the performance of the weak users, usually those that are located near the cell edges. The rates of the stronger users, on the other hand, are reduced such that their resources can be used to increase the rates of the weaker ones, usually until all users achieve the same rate. Note that in terms of sum-rate, the max-min approach is generally suboptimal, as the strongest users which contribute the most to the sum-rate normally suffer a large performance loss in order to "help" the weaker ones.

Note that R_k, according to (3), is a function of the precoding matrices $\mathbf{G}_{j,b}$ that can be chosen to optimize the minimum achievable rate. Since each $\text{BS}_b \in \mathcal{M}$ has to fulfill the sum transmit power constraint (4), the optimization problem of maximizing the minimal rate can be formulated as

$$\max_{\{\mathbf{G}_{j,b}\}} \min\{R_1, \ldots, R_K\} \quad \text{s.t.} \quad P_b \leq P_s, \quad \forall\, b. \qquad (5)$$

In $\mathcal{M}$, only the CSI of the communication links within the cooperation area is known at the BSs, while the channel coefficients of all other links are unknown. The OCI cannot be controlled or shaped by the cooperating BSs. The cooperation schemes are thus restricted to optimizing the minimal achievable rate with respect to the desired signal and the ICI only, while the effective noise (actual noise in the mobile terminals plus the OCI) is considered to be a fixed quantity over which the BSs in the cooperation set have no influence.

Here, we are interested in a cooperation scheme that completely eliminates the ICI. To this end, the concatenated precoding matrices are decomposed into the product $\mathbf{G}_k = \mathbf{Z}_k \cdot \mathbf{Q}_k$, where $\mathbf{Z}_k$ is derived as a block zero-forcing (ZF) matrix and $\mathbf{Q}_k$ is used to scale the transmit power of the different streams intended for the different UEs such that the minimal rate is maximized and the power constraint is not violated.

Assuming $N_B > N_U$, the ZF matrix $\mathbf{Z}_k$ can be chosen as basis vectors of the N_D dimensional null space

$$\text{null}\left\{\left[\bar{\mathbf{H}}_1^T, \ldots, \bar{\mathbf{H}}_{k-1}^T, \bar{\mathbf{H}}_{k+1}^T, \ldots, \bar{\mathbf{H}}_K^T\right]^T\right\}.$$

The I-O relation (2) can then be rewritten as

$$\mathbf{y}_k = \bar{\mathbf{H}}_k \cdot \mathbf{Z}_k \cdot \mathbf{Q}_k \cdot \mathbf{s}_k + \mathbf{n}_k$$

where $\mathbf{s}_k \in \mathbb{C}^{N_D}$. The ICI is completely eliminated.

Once the ZF matrices $\mathbf{Z}_k$ are obtained, the matrices $\mathbf{Q}_k$ that optimize the minimal achievable rate need to be found. The BSs have only CSI that corresponds to the communication links within the cooperation area. Therefore, *OCI is ignored in the optimization* and the achievable rate (3) of UE_k simplifies to:

$$\tilde{R}_k = \log\det\left\{\mathbf{K}_\text{s}^{(k)} + \tilde{\mathbf{K}}_\text{n}^{(k)}\right\} - \log\det\left\{\tilde{\mathbf{K}}_\text{n}^{(k)}\right\}, \qquad (6)$$

with $\mathbf{K}_\text{s}^{(k)} = \bar{\mathbf{H}}_k \cdot \mathbf{Z}_k \cdot \mathbf{Q}_k \cdot \mathbf{Q}_k^H \cdot \mathbf{Z}_k^H \cdot \bar{\mathbf{H}}_k^H$ and $\tilde{\mathbf{K}}_\text{n}^{(k)} = \sigma_w^2 \cdot \mathbf{I}$. The optimization problem (5) simplifies accordingly to

$$\max_{\{\mathbf{Q}_j\}_{j=1}^M} \min\{\tilde{R}_1, \ldots, \tilde{R}_K\}$$

$$\text{s.t.} \quad \text{Tr}\left\{\sum_{j=1}^{K} \mathbf{Z}_{j,b} \cdot \mathbf{Q}_j \cdot \mathbf{Q}_j^H \cdot \mathbf{Z}_{j,b}^H\right\} \leq P_s, \quad \forall b \in \mathcal{M}, \quad (7)$$

where $\mathbf{Z}_{j,b}$ are the components of $\mathbf{Z}_j$ that correspond to BS_b. This optimization usually results in equal rates for all users in the optimization area. However, the OCI is ignored and the resulting rates $\{\tilde{R}_1^*, \ldots, \tilde{R}_K^*\}$ are not the true rates that can be achieved by the users. Such rates can be derived by applying (3) and (5), where also the OCI is taken into account.

The optimization (7) is *suboptimal* for three reasons: (i) cooperation is restricted to the BS_b in $\mathcal{M}$; (ii) interference from $\text{BS}_{b'}$ that do not belong to $\mathcal{M}$ is ignored in the optimization; (iii) the ZF approach eliminates the ICI completely, which achieves optimality only in the high SNR regime. Nevertheless, this scheme is simple and the OCI neglecting objective function considered in the optimization step is concave [6]. Therefore, a *convex optimization problem* can be formulated that is efficiently solved by standard optimization tools.

B. High User Mobility: Macro Diversity Approach

To analyze the available macro diversity in the LTE downlink, we consider a scheme based only on fast handoffs. An optimal scheduler is assigning UEs to BSs. There is no further cooperation in $\mathcal{M}$ to control ICI. The BS Tx symbol vectors in (1) are in this case $\mathbf{s}_j \in \mathbb{C}^{N_B}$ and the $\mathbf{G}_{j,b}$ are unity matrices (no beamforming).

IV. Simulation Results: Urban Micro Cells

We start with a cooperation set of $M = 3$ BS sectors as this seems to be the smallest set of practical relevance. Each BS is equipped with $N_B = 4$ antennas per sector and each UE with $N_U = 2$ antennas. To model the interference in the considered cellular network, we simulate a network of 12 cells (36 sectors): a ring of 9 neighboring cells around the three cells shown in Fig. 1. All BSs transmit with maximal power of $P_\text{tot} = 49$ dBm over the entire LTE-Advanced bandwidth of 100 MHz [2]. We assume a noise variance of $\sigma_w^2 = 10^{-12}$W.

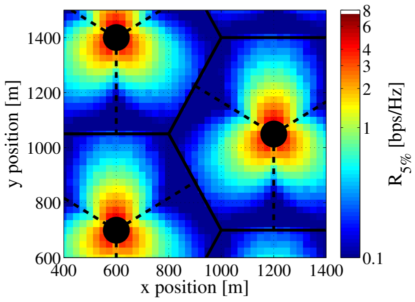


Fig. 2. Reference scenario 5% outage rate: no cooperation, no handoffs, FDMA, 0^o cell orientation (a).

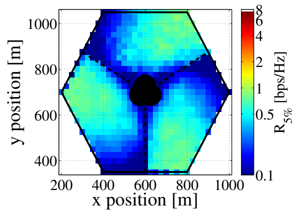
In the computer simulations, frequency flat fading on each OFDM subcarrier is modeled by Rayleigh-fading with a distance dependent pathloss and shadowing that corresponds to scenario C2 in the WINNER II channel model [8]. According to [9], this model is well suited to evaluate the performance of cooperation for LTE-Advanced.

The distance between two adjacent BSs is 700 m. In the reuse-1 case, the transmission in all sectors is over the entire frequency band. In the FDMA case, the frequency assignment is such that the three sectors of a cell transmit in different frequency bands of one third of the overall bandwidth.

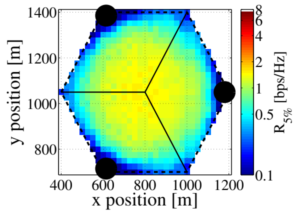
To estimate the spectral efficiency, the achievable rate of a UE is evaluated in the cellular interference scenario for each point on a 25 m grid in a given cell of the cooperation area. ICI is modeled by positioning two UEs on all possible grid points in the two cooperating sectors; OCI is modeled by the remaining 9 BSs transmitting at maximum power. Per grid point 1000 random channel realizations are simulated.

Low user mobility – Joint beamforming of 3 BSs: Optimization according to (7) is applied; afterwards the OCI is considered for evaluating the achievable rates. Comparing the 5% outage rate achieved in the reference system without any cooperation (Fig. 2) with the cooperation results in Fig. 3 shows the gain offered by the used cooperation scheme: In all four cooperative scenarios (reuse-1 and FDMA, each with 0^o, 30^o sector orientation) the spectral efficiency achieved with at least 95% probability is more homogeneously distributed over the cell and it is significantly higher towards the cell edges. At the cell edges, the FDMA schemes perform better due to the reduced interference. The 30^o orientation has advantages – as expected due to the more homogeneous cooperation area.

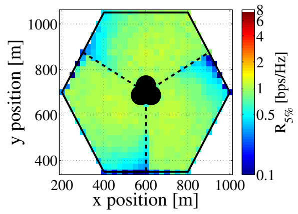
High user mobility - Macro diversity in a set of 12 BSs: In simulations of a setup with three cooperating BSs, the results for fast handoffs in $\mathcal{M}$ showed almost no increase in performance compared to the reference without any cooperation (w.r.t. the minimal UE rate). That is, the macro diversity gain achieved by optimally (in the max-min sense) assigning three UEs to the three BS sectors does not lead to significant gains in the observed achievable rates. Hence, we assume an idealized scheduler that always assigns each UE in $\mathcal{K}$ to that sector of $\mathcal{M}$ that guarantees the highest achievable rate of all cooperating sectors in $\mathcal{M}$. We now focus on one UE located in the middle of $\mathcal{M}$ and determine for $M = 12$ the BS sector that guarantees to this UE the highest rate of all the 36 cooperating sectors in $\mathcal{M}$ - taking ICI and OCI into account.



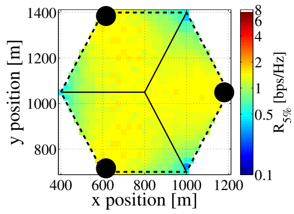
(a) Reuse-1, $0°$ orientation



(b) Reuse-1, $30°$ orientation



(c) FDMA, $0°$ orientation (c)



(d) FDMA, $30°$ orientation (d)

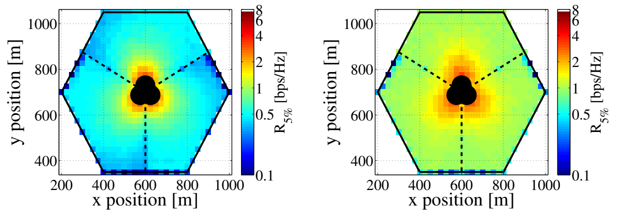
Fig. 3. Cooperation of 3 BSs: 5% outage rate, reuse-1 or FDMA.

Due to this assumption of an *idealized optimal scheduling* not only for one, but for all K UEs and M BS sectors at any time instant, this scheme leads to an upper bound (UB) on the available macro diversity in the cooperation set. Nevertheless, it gives important insights into the potential of BS coordination that is also applicable in the absence of CSIT. Additionally, the scheme could also be interesting for scenarios where certain premium users are privileged among other users and are able to choose a BS with higher priority. Fig. 4 shows the resulting 5% outage rates for the macro diversity UB. Here, reuse-1 outperforms FDMA, while the differences between the sector orientations are smaller than for joint beamforming (Fig. 5).

The CDFs in Fig. 5 give more insight into the results for both considered cooperation methods in urban micro cells. [1] While the 30^o sector orientation shows advantages for the joint beamforming cooperation regardless of reuse-1 or FDMA, the 0^o orientation performs better for the macro diversity UB and for the case of no cooperation. In case of FDMA without cooperation, the orientation (a) in Fig. 1 always achieves higher spectral efficiencies than (c) and (d) - while joint beamforming in (a) is not feasible. The reuse-1 frequency allocation results in higher mean and maximum spectral efficiencies for beamforming and the macro diversity approach; FDMA only shows advantages in two cases: (i) for no cooperation in the reference scenario (a) of Fig. 1; (ii) for beamforming as far as spectral efficiencies below 3 bps/Hz are concerned. However, as the ITU requires higher rates for low mobility [1], FDMA may still be an interesting choice for LTE-Advanced due to the higher rates for low mobility UEs at the cell edges (Fig. 3).

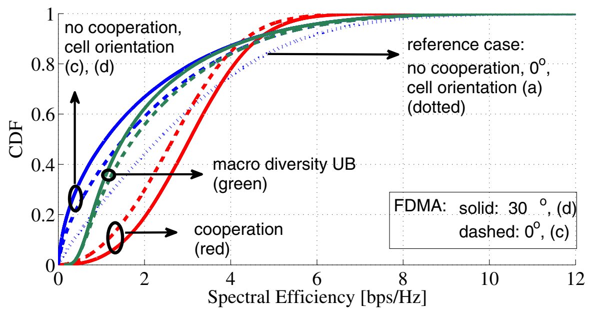
In addition, Fig. 5(b) shows the performance of a *distributed antenna system (DAS)*: The three BS_b with four antennas and three additional supporting nodes (SNs) (or remote radio heads) with 2 antennas cooperate in joint beamforming; while the BS_b transmit with maximal power of 80W, the supporting nodes are limited to 6W, which simplifies deployment in some countries. As there is one SN per BS_b, three SNs are placed on the border of each cell, as shown in (d) of Fig. 1. The large gain due to

[1] Similar trends have been found for simulations of rural macro cells.

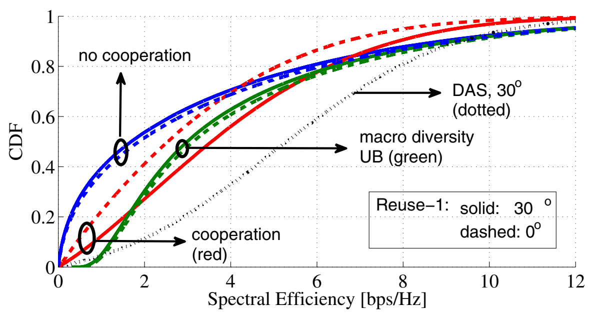


(a) FDMA, 0° orientation (c) (b) Reuse-1, 0° orientation

Fig. 4. 3 BSs macro diversity UB: 5% outage rate, FDMA and reuse-1, 0^o orientation.



(a) CDF of spectral efficiency, FDMA



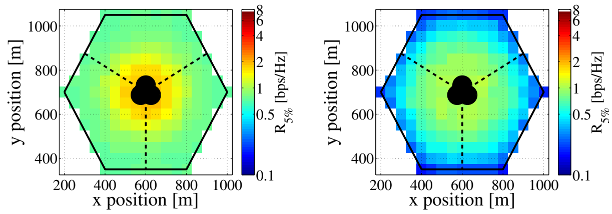
(b) CDF of spectral efficiency, reuse-1

Fig. 5. 3 BSs cooperation: spectral efficiency for FDMA and reuse-1, 0° and 30° orientation.

these low power SNs in a DAS is shown in Fig. 5(b) .

Multiuser MIMO: Fig. 6 shows the results for MU-MIMO in one cell, i.e. all BSs use 12 omnidirectional antennas (no sectorization). In the low mobility case, three UEs are served by beamforming of the 12 antennas using block ZF max-min approach. MU-MIMO performs worse than locally restricted cooperation. However, MU-MIMO needs no exchange of CSIT or data information between different BSs.

BS Tx power reduction by downlink cooperation: Cooperation can also be used to optimize power allocation, i.e. reduce the mean and peak Tx power of BSs. In Fig. 7, the maximum Tx power w.r.t. the three cooperating sectors is plotted, in case of low mobility and reuse-1 (results for the mean power reduction are similar). Determining the peak power required to achieve a given target data rate of 1 bps/Hz by the max-min optimization criterion in 70% of all simulation runs, results in about 37 dBm for DAS and about 43.5 dBm for cooperation of 3 BSs with 4 antennas per sector; in case of no cooperation it would be more than 54 dBm (resulting in significantly higher OCI). These results show clear advantages for DAS, also in the case where the Tx power of the SNs was limited to 6W.



(a) MU-MIMO macro diversity (b) MU-MIMO joint beamforming

Fig. 6. MU-MIMO: 5% outage rate, frequency reuse-1, 12 omnidirectional antennas.

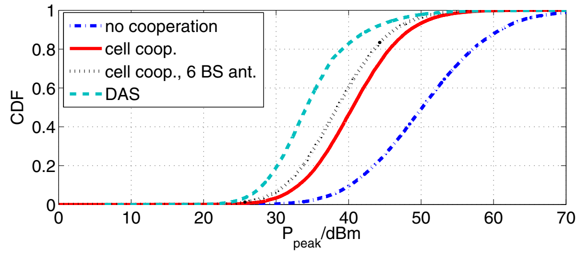


Fig. 7. CDF of max. Tx power of 3 cooperating BSs, target rate 1 bps/ Hz, reuse-1, 30° orientation (BSs with $N_B = 6$ as reference for the DAS case).

V. Summary and Conclusions

Cooperation methods for high mobility users will differ from methods for low mobility users on the downlink of LTE-Advanced networks. For low mobility, beamforming based on block ZF combined with convex max-min optimization leads to a fair and comparatively homogeneous distribution of the spectral efficiency in the cooperation area; additionally it is able to reduce Tx power resulting in reduced OCI. The use of low power SNs is a very efficient way to further improve the coverage. For high mobility, the available macro diversity may be used to achieve the required spectral efficiency. Frequency allocation and sector orientation have a strong influence on the performance; according to our results, there is no combination of these two parameters that is optimal for high and low mobility users.

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