On Base Station Coordination in the LTE Downlink With Limited Feedback

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Abstract— **We discuss the potential gains in system performance and the overall stability of different transmit and feedback strategies under LTE relevant limitations. It is evinced that conventional CoMP schemes are dramatically sensitive to channel uncertainties at the transmitters. The Rate Approximation scheme originally introduced for single cell systems is extended to multicellular systems and shown to be enormously robust under minimal feedback rates. We show that incorporating estimates of the out–of-cell interference in the feedback message significantly improve the performance of multicellular systems. Moreover, we show that accurate approximates of the per user rates at the base station are of inestimable value if link adaption is considered.**

I. Introduction

Future cellular wireless standards like LTE Advanced [1] are of great interest as a common method for providing continuous service to indoor and outdoor mobile users. Multiple antenna techniques combined with OFDM enable efficient utilization of the wireless channel and sharing of resources between multiple users (MU-MIMO). To cope with the scarcity of resources spectral reuse on the network level is employed. But so far, conventional data transmission and reception are done independently on a per base station basis, resulting in degraded network performance due to interference from other cells. Coordinated multiple point transmission (CoMP) (i.e. coordinated scheduling/beamforming or joint processing/transmission) has been identified as key tool to overcome these interference limitations and to enhance the overall system performance [1], [2]. If the backhaul network is capable of multicasting individual user data, multiple base stations can simultaneously serve the same user. If all base stations have perfect channel state information (CSIT) the capacity–achieving strategy (i.e. dirty paper coding) is known, but unfortunately it is far from being implementable in practical systems.

A suboptimal strategy for fully cooperating clusters is to use linear beamforming and power allocation. For example, viewing the the downlink model of a cluster of fully cooperating base stations as a vector–valued broadcast channel, the approach of block diagonalization (BD) in [3] can be used to compute the cluster–wise beamforming vectors. But to avoid any interference within a cluster each base station needs perfect CSIT of the whole cluster. Furthermore, data sharing is required which is a challenging task on its own. In contrast, processing the base stations of a cluster sequentially under a cluster–wide zero forcing criterion (SZF) is a coordinated scheduling and beamforming approach where users are only assigned to a single base station. BD and SZF are adaptive beamforming techniques, which require additional dedicated pilots to provide the users a reliable phase reference.

When using fixed beamforming approaches, where the beamforming vectors are taken from a restricted set (i.e. a codebook), such information can be communicated much more efficiently. For instance, within LTE unitary beamforming (UBF) [4]) or other greedy schemes, like the beam blocking method (BB) [5], where proposed to enable MU–MIMO functionalities. The Rate Approximation scheme (RA) was introduced by the authors in [6] and shown to be able to outperform any of the above fixed beamforming schemes. In [7], [8] the authors showed that RA outperforms adaptive beamforming techniques over a profound range of practically relevant SNR values and that the rate loss due to the rate–constrained feedback channel scales double exponentially with the number of feedback bits. This can not be achieved by most other feedback schemes, e.g. zeroforcing (ZF) was shown in [9] to have only an exponential scaling.

One of the main challenges in LTE systems are the imperfections of the CSIT and the strong increase of the out–of–cell interference due to the reuse of resources in neighboring cells. Therefore, we discuss the potential gains in system performance and the overall stability of different transmit and feedback strategies under LTE relevant limitations. Our contributions are manyfold; the main results can summarized as follows.

- We extend the RA scheme to cope with multi-cellular systems and show that it remains enormously robust under minimal feedback rates.
- It is evinced that conventional CoMP schemes are dramatically sensitive under partial CSIT.
- We show that accurate approximates of the per user rates at the base station are of inestimable value if link adaption (i.e. selection of a modulation and coding scheme) is considered.

Notations: Bold face capital and small letters denote matrices and vectors, respectively. $\boldsymbol{a}^H$ is the hermitian conjugate of the vector $\boldsymbol{a}$. $\|\cdot\|$ denotes the Frobenius norm if applied to matrices and the Euclidean norm if applied to vectors. The unit sphere in $\mathbb{C}^N$ is denoted by $\mathbb{S}^{N-1}$ and $\mathbb{E}[\cdot]$ is the expected value.

II. System Model

We consider the downlink of a cellular system comprising of multiple base stations and multiple receivers, i.e. users. We assume that the base stations are grouped in disjoint cooperating clusters. In the sequel we consider an arbitrary but fixed cooperating cluster comprising of B base stations equipped with N_T antennas and M single antenna users (extension to multiple receive antennas are discussed below). OFDM is used in LTE to divide the available bandwidth in orthogonal subcarriers. The subcarriers are grouped in scheduling blocks, i.e. the smallest scheduling unit. In the sequel we consider one arbitrary but fixed scheduling block $\mathcal{F} = \{f_1, f_2, \ldots, f_F\}$. In each transmission interval a central scheduling unit assigns each base station a subset of users; the users assigned to base station b are collected in the set $\mathcal{S}_b$. The signal received by user m on subcarrier $f \in \mathcal{F}$ is given by

$$y_m(f) = \sum_{b=1}^{B} \boldsymbol{h}_{m,b}^H(f) \boldsymbol{V}_b \boldsymbol{x}_b(f) + \boldsymbol{n}_m(f),$$

where $\boldsymbol{h}_{m,b}(f) \in \mathbb{C}^{N_T \times 1}$ is the channel from base station b to user m, $\boldsymbol{x}_b(f) \in \mathbb{C}^{|\mathcal{S}_b| \times 1}$ is vector of complex information symbols intended for users $\mathcal{S}_b$ and $\boldsymbol{n}_m(f) \sim \mathcal{N}_C(0, \sigma_m^2)$ is additive with Gaussian noise. Note that the transmit precoding matrix $\boldsymbol{V}_b \in \mathbb{C}^{N_T \times |\mathcal{S}_b|}$ does not depend on the subcarrier f, i.e. we assume that for each scheduling block $\mathcal{F}$ a common precoding matrix is selected. The beamforming vector assigned to user $m \in \mathcal{S}_b$ is $\boldsymbol{v}_{b,m}$ such that the precoding matrix at base station b is given by $\boldsymbol{V}_b = [\boldsymbol{v}_{b,m}]_{m \in \mathcal{S}_b}$. We assume uniform power allocation between scheduled users and a per base station power constrained, i.e. $\|\boldsymbol{V}_b\| = 1$ and $\|\boldsymbol{x}_b(f)\|^2 = 1$.

III. Feedback and Transmit Strategies

In general each transmission interval can be clustered in three phases: the feedback phase, the scheduling phase and the data transmission phase.

In the feedback phase we assume that each user m has perfect local channel state information. That is, each user m knows the channels $\boldsymbol{h}_{m,b}(f)$ perfectly for all $b = 1, \ldots, B$ and all $f \in \mathcal{F}$. Via a common feedback channel the base station cluster gets knowledge of these channels in form of *one estimate* $\tilde{\boldsymbol{h}}_{m,b} = \vartheta_{m,b} \cdot \boldsymbol{\nu}_{m,b} \in \mathbb{C}^{N_T}$ *for the whole scheduling block* $\mathcal{F}$. We assume that only the normalized channel direction information (CDI) $\boldsymbol{\nu}_{m,b}$ is quantized with a certain amount of feedback bits. The channel quality information (CQI) $\vartheta_{m,b}$ is not quantized which can be justified by noting that for CQI quantization a sufficient amount of feedback bits must be allocated to cope with the fine granularity of available modulation and coding schemes, anyhow.

In the scheduling phase the central scheduling unit assigns each base station $b = 1, 2, \ldots, B$ a subset of users $\mathcal{S}_b$ and each user $m \in \mathcal{S}_b$ a beamforming vector $\boldsymbol{v}_{b,m}$. The scheduling is performed solely on the partial CSIT $\tilde{\boldsymbol{h}}_{m,b}$. The scheduling objective is maximum sum rate, i.e.

$$R(\mathcal{S}) = \sum_{b=1}^{B} \sum_{m \in \mathcal{S}_b} r_m(\mathcal{S}_b, \boldsymbol{V}_b),$$

where $\mathcal{S} = \mathcal{S}_1 \cup \mathcal{S}_2 \cup \ldots \cup \mathcal{S}_B$ and

$$r_m(\mathcal{S}_b, \boldsymbol{V}_b) = \frac{1}{|\mathcal{F}|} \sum_{f \in \mathcal{F}} \log(1 + \gamma_m(\mathcal{S}_b, \boldsymbol{V}_b, f)) \quad (1)$$

is the per–user rate of user m averaged over the frequency resource $\mathcal{F}$ depending on the signal–to–noise–plus–interference ratio (SINR) $\gamma_m(\mathcal{S}_b, \boldsymbol{V}_b, f)$ defined below.

A. Single Cell Processing

The only coordination between base stations within a cluster is the assignment of users to base stations. This assignment is performed based on the path loss, i.e. user m is assigned to the base station b according to $\max_b \|\boldsymbol{h}_{m,b}\|$. The users assigned to base station b are collected in the set $\mathcal{A}_b$. The scheduled users $\mathcal{S}_b$ and the precoding matrix $\boldsymbol{V}_b$ at base station b are chosen to maximize the per base station sum rate $\sum_{m \in \mathcal{S}_b} r_m(\mathcal{S}_b, \boldsymbol{V}_b)$, where the SINR of user $m \in \mathcal{S}_b$ in (1) is given by

$$\gamma_m(\mathcal{S}_b, \boldsymbol{V}_b, f) = \frac{\left|\boldsymbol{h}_{m,b}^H(f) \boldsymbol{v}_{b,m}\right|^2}{I_{m,b}(f) + \sum_{\substack{l \in \mathcal{S}_b \\ l \neq m}} \left|\boldsymbol{h}_{m,b}^H(f) \boldsymbol{v}_{b,l}\right|^2 + \sigma_m^2},$$

and the out–of–cell interference is given by

$$I_{m,b}(f) = \sum_{\substack{a=1\\a\neq b}}^{B} \left\|\boldsymbol{h}_{m,a}^H(f)\boldsymbol{V}_a\right\|^2 .$$

Note that during the feedback phase user $m \in \mathcal{A}_b$ will have no knowledge about $\mathcal{A}_a$ and $\boldsymbol{V}_a$ for any $a = 1, 2, \ldots, B$. Hence, this user will not be able to consider the real out–of–cell interference when computing its channel state information (CSI) feedback message. Fortunately, the out–of–cell interference can be upper bounded by

$$\begin{aligned} I_{m,b}(f) &\leq \sum_{\substack{a=1\\a\neq b}}^{B} \max_{\boldsymbol{v}\in\mathbb{S}^{N_T-1}} \left|\boldsymbol{h}_{m,a}^H(f)\boldsymbol{v}\right|^2 \\ &= \sum_{\substack{a=1\\a\neq b}}^{B} \frac{1}{\|\boldsymbol{h}_{m,a}(f)\|^2} \left|\boldsymbol{h}_{m,a}^H(f)\boldsymbol{h}_{m,a}(f)\right|^2 \\ &= I_{m,b}^{\mathrm{WC}}(f). \end{aligned}$$

Hence, $I_m^{\mathrm{WC}}(f)$ is the worst case out–of–cell interference that occurs if all interfering base stations transmit with full power in direction of user m.

1) Local Zero Forcing (LZF): When ZF is used at the base station to compute the beamforming vectors a common approach to feed back the CSI is to quantize the average channels $\hat{\boldsymbol{h}}_{m,b} = \frac{1}{|\mathcal{F}|}\sum_{f\in\mathcal{F}} \boldsymbol{h}_{m,b}(f)$. We consider two channel quantization approaches, i.e. codebook based (CB) and component–wise real-/imaginary part (IQ) feedback quantization.

When considering CB quantization each user selects its CDI $\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ from a predefined codebook $\mathcal{V} = \{\boldsymbol{t}_1, \boldsymbol{t}_2, \ldots, \boldsymbol{t}_{2^B}\} \subset \mathbb{S}^{N_T-1}$ minimizing the chordal distance, i.e. the CDI of user m available at base station b is

$$\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}} = \arg\min_{\boldsymbol{t}\in\mathcal{V}} \sqrt{1 - \frac{1}{\|\hat{\boldsymbol{h}}_{m,b}\|^2} |\hat{\boldsymbol{h}}_{m,b}^H \boldsymbol{t}|^2}. \quad (2)$$

Note that codebook based quantization requires B bits of feedback per user and per base station.

For component–wise quantization the real and imaginary parts of each component of the CDI $\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ will be taken from a scalar codebook $\mathcal{V}_s = \{s_1, \ldots, s_E\} \subset [-1, 1]$ according to the nearest neighbor mapping. Hence, $2N_T \log_2(E)$ bits of feedback are necessary per base station. The elements of $\mathcal{V}_s$ can be chosen equidistant or, if the channel statistics are known, according to some probability distribution function.

The CQI is given by a function depending on the CDI $\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ and the channels $\boldsymbol{h}_{m,b}(f)$. Our approach is inspired by the results from [10]; but incorporates the worst case out–of–cell interference from base stations within the cluster. The CQI we use is given by

$$\log(1 + \vartheta_{m,b}^{\mathrm{ZF}}) = \frac{1}{|\mathcal{F}|} \sum_{f\in\mathcal{F}} \quad (3)$$
$$\log\left(1 + \frac{|\boldsymbol{h}_{m,b}^H(f)\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}|^2}{\sigma_m^2 + I_{m,b}^{\mathrm{WC}}(f) + \left(1 - |\frac{\boldsymbol{h}_{m,b}(f)^H}{\|\boldsymbol{h}_{m,b}(f)\|}\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}|^2\right)}\right).$$

Having available the partial CSIT $\tilde{\boldsymbol{h}}_{m,b}^{\mathrm{ZF}} = \vartheta_{m,b}^{\mathrm{ZF}} \cdot \boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ at base station b for all $m \in \mathcal{A}_b$ the set of users $\mathcal{S}_b$ is found in a greedy fashion as explained in [10]. Note that for LZF base station b requires only feedback of the users $\mathcal{A}_b$. The beamforming vectors of selected users $m \in \mathcal{S}_b$ are determined according to the zero forcing criterion, i.e. the beamforming vector of user $m \in \mathcal{S}_b$ is selected to lie in the null space of the space spanned by the vectors $\tilde{\boldsymbol{h}}_{i,b}^{\mathrm{ZF}}$ for all $i \in \mathcal{S}_b \setminus \{m\}$.

B. Coordinated Scheduling/Beamforming

1) Sequential zero forcing: The feedback for SZF is the same as for LZF, i.e. the CDI is given by $\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ and the CQI is given by $\vartheta_{m,b}^{\mathrm{ZF}}$, defined above.

Using SZF the base stations of a cluster are processed sequentially in a (per scheduling interval) random ordering. The optimal set of users is found in a greedy fashion. Each base station serves its own user set $\mathcal{S}_b$ which is disjunct from the previous sets $\mathcal{S}_{b'}$ for $b' < b$. Base station b can select users from the set $\mathcal{A}_b = \{1, 2, \ldots, M\} \setminus (\mathcal{S}_1 \cup \mathcal{S}_2 \cup \ldots \cup \mathcal{S}_{b'})$ After the scheduling decision at base station b the full list $\mathcal{S}' = \mathcal{S}_1 \cup \mathcal{S}_1 \cup \ldots \cup \mathcal{S}_b$ of scheduled users will be communicated to the next base station $b+1$. The beamforming vectors of users $m \in \mathcal{S}_b$ are determined according to the zero forcing constrained within $\mathcal{S}'$. This approach is a coordinated scheduling and beamforming scheme. No data sharing is required but base stations must exchange scheduling decisions.

C. Joint Processing/Transmission

1) Block diagonalization: The feedback for BD is the same as for LZF and SZF, i.e. the CDI is given by $\boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ and the CQI is given by $\vartheta_{m,b}^{\mathrm{ZF}}$, defined above. All base stations within a cluster serve the selected users simultaneously, i.e. $\mathcal{S}_1 = \mathcal{S}_2 = \ldots = \mathcal{S}_B$. The cluster–wise precoding matrix is computed as explained in [3] under the assumption that $\tilde{\boldsymbol{h}}_{m,b}^{\mathrm{ZF}} = \vartheta_{m,b}^{\mathrm{ZF}} \cdot \boldsymbol{\nu}_{m,b}^{\mathrm{ZF}}$ are the corresponding channels. Note that the beamforming vectors can be computed in a distributed fashion [11]. The optimal set of users is found in a greedy fashion. This is a joint transmission scheme, i.e. data sharing is necessary.

D. Proposed Multicellular Rate Approximation

The RA scheme was introduced by the authors in [6] and analyzed in [7], [8]. It was originally designed for cellular systems where out–of–cell interference is treated as noise. Here we propose an extension of the RA scheme that incorporates sophisticated out–of–cell interference estimates. As we will see this makes RA an immensely robust transmit scheme.

The RA scheme allows each base station b to approximate the per–user rates $r_m(\mathcal{S}_b, \boldsymbol{V}_b)$ defined in (1) for any user m and any precoding matrix $\boldsymbol{V}_b$. This is enabled by choosing the transmit beamforming vectors from a fixed codebook $\mathcal{C} = \{\boldsymbol{c}_1, \boldsymbol{c}_2, \dots\}$ and using a possibly different codebook for the feedback $\mathcal{V} = \{\boldsymbol{t}_1, \boldsymbol{t}_2, \dots, \boldsymbol{t}_{2^B}\}$. The feedback codebook consists of a collection of normalized test–channels $\boldsymbol{t}_i \in \mathbb{S}^{N_T-1}$ a priori known to all users and the base station. To determine its feedback message to base station b each user m must find a channel quantization $\tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b} = \vartheta^{\mathrm{RA}}_{m,b} \cdot \boldsymbol{\nu}^{\mathrm{RA}}_{m,b}$, with $\boldsymbol{\nu}^{\mathrm{RA}}_{m,b} \in \mathcal{V}$ and $\vartheta^{\mathrm{RA}}_{m,b} \in \mathbb{R}$ that minimizes

$$d(\bar{\boldsymbol{h}}_{m,b}, \tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b}) = \max_{\substack{\boldsymbol{V} \in \mathcal{C}^n \\ 1 \le n \le N_T}} \left| \xi_m(\tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b}, \boldsymbol{V}) - \frac{1}{|\mathcal{F}|} \sum_{f \in \mathcal{F}} \xi_m(\bar{\boldsymbol{h}}_{m,b}(f), \boldsymbol{V}) \right|,$$

where we define the effective channel scaled by noise and *worst precoder out–of–cell interference* $I^{\mathrm{WP}}_m(f)$ (defined below)

$$\bar{\boldsymbol{h}}_{m,b}(f) = \frac{\boldsymbol{h}_{m,b}(f)}{\sqrt{\sigma_m^2 + I^{\mathrm{WP}}_m(f)}} \tag{4}$$

and the function

$$\xi_m(\boldsymbol{x}, \boldsymbol{V}) = \log\left(1 + \frac{\left|\boldsymbol{x}^H \boldsymbol{v}_1\right|^2}{1 + \|\boldsymbol{x}^H \boldsymbol{V}\|^2 - |\boldsymbol{x}^H \boldsymbol{v}_1|^2}\right).$$

Since under RA the possible beamforming vectors are defined by a fixed codebook $\mathcal{C}$ we can define a tighter worst case estimate of the out–of–cell interference given by

$$I^{\mathrm{WP}}_m(f) = \sum_{\substack{a=1 \\ a \ne b}}^{B} \max_{\boldsymbol{v} \in \mathcal{C}} \left|\boldsymbol{h}^H_{m,a}(f) \boldsymbol{v}\right|^2.$$

It can easily be seen that $I^{\mathrm{WP}}_m(f) \le I^{\mathrm{WC}}_m(f)$ since in $I^{\mathrm{WP}}_m(f)$ the worst beamforming vector comes from $\mathcal{C} \subset \mathbb{S}^{N_T-1}$.

The CQI $\vartheta^{\mathrm{RA}}_{m,b}$ of user m to base station b is given by a function depending on the selected CDI $\boldsymbol{\nu}^{\mathrm{RA}}_{m,b}$ and the normalized channels $\bar{\boldsymbol{h}}_{m,b}(f)$. The CQI is given by the dependency

$$\log(1 + \vartheta^{\mathrm{RA}}_{m,b}) = \frac{1}{|\mathcal{F}|} \sum_{f \in \mathcal{F}} \log(1 + |\bar{\boldsymbol{h}}^H_{m,b}(f) \boldsymbol{\nu}^{\mathrm{RA}}_{m,b}|^2).$$

This can be interpreted as the effective rate available over the test–channel $\boldsymbol{\nu}^{\mathrm{RA}}_{m,b}$ which depends on the channels $\bar{\boldsymbol{h}}_{m,b}(f)$. Utilizing the defined CQI and the RA metric $d(\bar{\boldsymbol{h}}_{m,b}, \tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b})$ each user m finds the CDI for base station b by solving

$$\boldsymbol{\nu}^{\mathrm{RA}}_{m,b} = \arg\min_{\boldsymbol{\nu} \in \mathcal{V}} d\left(\bar{\boldsymbol{h}}_{m,b}, \tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b}\right).$$

Having available the partial CSIT $\tilde{\boldsymbol{h}}^{\mathrm{RA}}_{m,b} = \vartheta^{\mathrm{RA}}_{m,b} \cdot \boldsymbol{\nu}^{\mathrm{RA}}_{m,b}$ for all m at all base stations b, efficient scheduling can be performed. Assume each user is assigned to a single base station a priori and collect the users assigned to base station b in the set $\mathcal{A}_b$. Then the scheduling decision at base station b can be found by solving

$$\max_{\mathcal{S} \subseteq \mathcal{A}_b} \max_{\boldsymbol{V} \in \mathcal{C}^{|\mathcal{S}|}} \sum_{m \in \mathcal{S}} \xi_m(\tilde{\boldsymbol{h}}_{m,b}, \boldsymbol{V})$$

Note that this can be solved either by a brute force search over the user sets $\mathcal{S} \subseteq \mathcal{A}_b$ and $\boldsymbol{V} \in \mathcal{C}^{|\mathcal{S}|}$ or more efficiently in a greedy fashion similar to [10] and references within. Alternatively, more sophisticated user selections are now possible. For instance, the base stations within a cluster can be processed sequentially; assume we start with some base station b', then the available users for this base station are $\mathcal{A}_{b'} = \{1, 2, \dots, M\}$. The second base station b'' would have the user pool $\mathcal{A}_{b''} = \{1, 2, \dots, M\} \setminus \mathcal{S}_{b'}$ available for scheduling. In this manner we process all B base stations.

Note that extensions of the RA scheme to multiple receive antennas can be found in [6]. Implementing the multicellular introduced here is straightforward.

IV. Simulations

The channels are modeled by the spatial channel model extended [12], which is configured according to the LTE downlink, i.e user velocity 3 km/h, system bandwidth 10 MHz, 4 correlated transmit antennas. The feedback codebook for ZF based methods and the transmit and feedback codebook for RA are given by the optimized codebook defined in [5] which has 2^3 elements. For IQ quantization the elements of $\mathcal{V}_s$ are chosen according to a Gaussian distribution.

Fig. 1 shows the average spectral efficiency over the number of feedback bits per user. We observe that joint transmission (i.e. BD) is very sensitive to imperfect CSIT. Hence, the performance gain over non–cooperating schemes is completely lost for a number of feedback bits smaller than 120 bit per user. Coordinated beamforming (i.e. SZF) is outperformed by single cell processing if the number of feedback bits is smaller than 72 bits per user. With a reasonable amount of feedback bits (i.e. smaller than

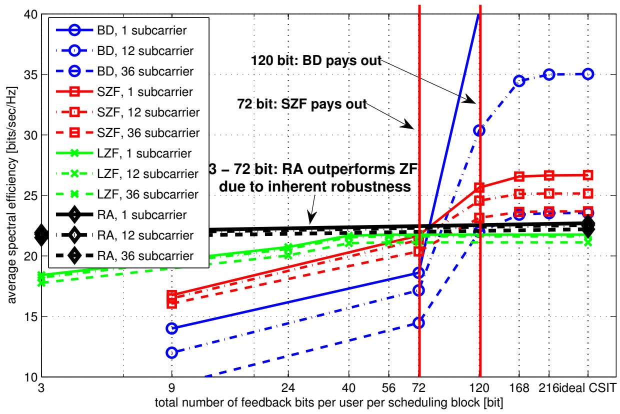

Fig. 1. Average net spectral efficiency over total number of feedback bits per user: comparing CoMP (SZF and BD) with coordinated single cell processing (LZF and RA) for different scheduling block sizes ($|\mathcal{F}| = 1, 12, 36$ subcarrier). Setup: $B = 3$, $N_T = 4$, $M = 12$ user, $|\mathcal{S}_b| \leq 2$, single receive antenna.

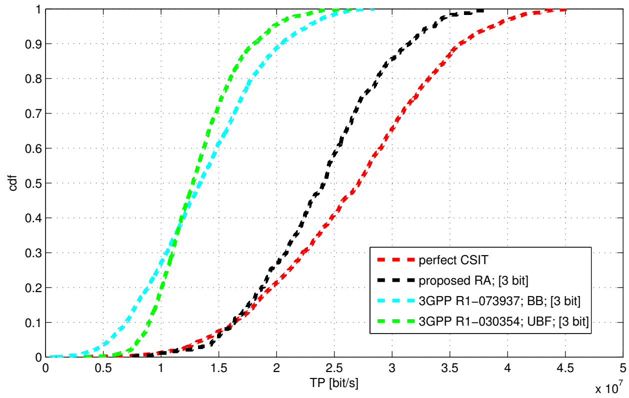

Fig. 2. CDF of base station throughput: Comparison of RA with UBF and BB for 3 bit feedback per user. Setup: $B = 13$, $N_T = 4$, $M = 130$ user, $|\mathcal{S}_b| \leq 2$, 2 receive antennas, $|\mathcal{F}| = 36$.

72 bits) the best performance is achieved with RA. Moreover, RA is immensely robust against CSIT uncertainties at the base station, i.e. the performance loss compared to perfect CSIT is very small.

Two fixed beamforming approaches discussed within LTE are UBF [4] and the BB method [5]. Where each user reports a preferred codebook index chosen from the transmit codebook $\mathcal{C}$ utilizing (2) and a CQI reflecting the expected SINR or SNR, respectively. The user selection is then performed in a greedy fashion based on the partial CSIT. For details we refer to [4] and [5].

Fig. 2 depicts the performance of UBF and BB compared to RA in system level simulations. Based on the partial CSIT the base station cluster performs scheduling and selects a modulation and coding scheme (i.e. link adaption). The RA scheme clearly outperforms UBF and BB due to the accurate approximation of per–user rates at the base station. Moreover, RA performs close to a scheme where the beamforming vectors are taken from a fixed codebook but perfect CSIT is available.

V. Conclusion

We observed that supporting base station coordination or cooperation in a multicellular system requires a considerable amount of feedback and precision on the transmit beamforming vector variations within the resources. We demonstrated that under a reasonable amount of feedback the extended RA scheme yields the best performance. Especially, when link adaption is considered the accurate approximates of per user rates at the base station provided by RA are of inestimable value.

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