A UNIFIED FEEDBACK SCHEME FOR DISTRIBUTED INTERFERENCE MANAGEMENT IN CELLULAR SYSTEMS: BENEFITS AND CHALLENGES FOR REAL-TIME IMPLEMENTATION

Lars Thiele[⋆], *Thomas Wirth*[⋆], *Thomas Haustein*[⋆], *Volker Jungnickel*[⋆], *Egon Schulz*[†], *and Wolfgang Zirwas*[†]

[⋆] Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Einsteinufer 37, D-10587 Berlin, Germany
[†] Nokia Siemens Networks GmbH & Co.KG, St. Martinstrasse 76, D-81617 Munich, Germany
email: {lars.thiele, thomas.wirth, thomas.haustein, volker.jungnickel}@hhi.fraunhofer.de

ABSTRACT

This paper contributes to the system concept of collaborative base stations from the perspective of distributed computing. Promising signal processing approaches based on terminal feedback are reviewed. Their specific advantages and disadvantages are discussed and a framework for feedback provision is presented. All proposed schemes have in common, that a mobile terminal can choose its desired receive strategy independently from other mobile terminals according to its computational capabilities. The effective multi-cell channel after receiver processing is fed back and distributed within the collaboration area. This allows distributed processing at each base station and makes real-time implementation feasible.

1. INTRODUCTION

Multiple antenna systems have been shown to allow an active exploitation of the spatial degrees of freedom in order to increase the spectral efficiency and boost throughput in wireless communication systems. In particular, spatial separation of simultaneously transmitted data streams can be performed either at the transmitter or the receiver depending on the available channel state information (CSI) and the possibilities of joint signal processing. multiple-input multiple-output (MIMO) signal processing got high momentum in standardization on link level utilizing spatial multiplexing or space-division multiple access (SDMA) in standards like IEEE 802.11n, WiMAX and 3G Long Term Evolution (3G-LTE). If these so called point-to-point MIMO systems are operated isolated from each other, multi-antenna signal processing provides signal diversity reception in fading channels and multiplexing options in full rank channels at medium and high SNR. Early real-time measurements proved the expected gains in throughput and coverage in a field trial in downtown Berlin in 2007 and 2008 [1], [2].

If these MIMO systems connecting a base station and several terminals are deployed in a cellular environment with full frequency reuse cochannel interference (CCI) becomes a limiting factor. It has been discussed early that the concept of MIMO signal separation can be applied for active interference management. Suppression of interference from adjacent cells will become a key issue in cellular mobile communication systems. In principle, the MIMO concept has to be extended to a higher number of antennas involved in the joint signal processing. Higher order MIMO systems do not only scale the computational complexity but also face serious challenges regarding distributed channel data collection and coherent signal transmission or reception at antenna locations which might easily have distances of more than 1000 meters in between. Important issues like synchronization of collaborative base stations and signal flows in collaborative MIMO systems were addressed in [3].

In this paper we will focus on the active interference management of collaborative base stations (BSs) signal processing in the cellular downlink, see Fig. 1. Methods to efficiently pre-process and collect CSI from distributed mobile terminals (MTs) before feeding back this information to the serving BS are compared. We consider a cellular deployment with a decentralized signal processing architecture as proposed for 3G-LTE-Advanced. We approach the solution from the view point of coordinated and distributed computing and show that this approach allows channel adaptive and coherent signal transmission from several BSs for active interference management in a cellular collaboration area (CA).

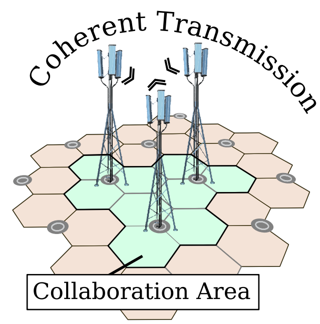

Figure 1: Coherent transmission of collaborative base stations

2. SYSTEM MODEL

The downlink MIMO-OFDM transmission system for an isolated sector with N_T transmit and N_R receive antennas per MT is described on a per sub-carrier basis

$$\mathbf{y} = \mathbf{H}\mathbf{C}\mathbf{x} + \mathbf{n}\,, \tag{1}$$

where $\mathbf{H}$ is the $N_R \times N_T$ channel matrix and $\mathbf{C}$ the unitary $N_T \times N_T$ pre-coding matrix; $\mathbf{x}$ denotes the $N_T \times 1$ vector of transmit symbols; $\mathbf{y}$ and $\mathbf{n}$ denote the $N_R \times 1$ vectors of the received signals and of the additive white Gaussian noise (AWGN) samples, respectively, with covariance $\mathrm{E}\{\mathbf{n}\mathbf{n}^H\} = \sigma^2\mathbf{I}$.

In the following we consider the downlink channel of a cellular system where the frequency resources are reused in all neighboring cells. Depending on the deployment of BS sites and the actual position of the MT, the user will receive interfering signals sent to other users in addition to its desired signal.

As an initial step, assume that all BSs provide Ω fixed unitary beam sets $\mathbf{C}_\omega$, $\omega \in \{1,...,\Omega\}$. In general, each beam set contains αN_T fixed pre-coding vectors (beams) $\mathbf{b}_{\omega,u}$ with $u \in \{1,...,\alpha N_T\}$, where α denotes the size of the CA. Each CA i independently selects one of these sets. In the following we assume that each user m is served with a single data stream, while the CA uses αN_T active beams. The received downlink signal $\mathbf{y}^m$ at the MT m in the cellular environment is given by

$$\mathbf{y}^m = \underbrace{\mathbf{H}_i^m \mathbf{b}_{i,m}}_{\bar{\mathbf{h}}_{i,m}} x_{i,m} + \underbrace{\sum_{\substack{j=1 \\ j\neq m}}^{\alpha N_T} \mathbf{H}_i^m \mathbf{b}_{i,j} x_{i,j}}_{\zeta_{i,m}} + \underbrace{\sum_{\substack{\forall l \\ l\neq i}} \sum_{j=1}^{N_T} \mathbf{H}_l^m \mathbf{b}_{l,j} x_{l,j} + \mathbf{n}}_{\mathbf{z}_{i,m}} \tag{2}$$

The desired data stream $x_{i,m}$ transmitted to the m-th user from the i-th CA is distorted by the intra-CA and inter-CA interference aggregated in $\zeta_{i,m}$ and $\mathbf{z}_{i,m}$, respectively. $\mathbf{H}_i^m$ spans the $N_R \times \alpha N_T$ channel matrix for user m formed by the CA i. Thus, $\zeta_{i,m}$ denotes the interference generated in the CA. In the scope of this paper, it is assumed that all αN_T beams in the beam set $\mathbf{C}_i$ are simultaneously active, whereby the total available power p_i is assumed to be uniformly distributed over the αN_T beams. Thus, $E\left\{|x_{i,j}|^2\right\} = p_i/(\alpha N_T)$ holds, and $p_i = \sum_{j=1}^{\alpha N_T} \mathrm{E}\left\{|x_{i,j}|^2\right\} = \alpha p_s$ with p_s being the transmit power per sector.

In case of non-cooperative transmission we assume to keep the chosen set of pre-coders fixed [4], e.g. to

$$\mathbf{C}_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ i & -i \end{bmatrix} \qquad \mathbf{C}_i = \mathrm{diag}\underbrace{[\mathbf{C}_1 \ldots \mathbf{C}_1]}_{\alpha\text{-times}} \tag{3}$$

where $\mathbf{C}_1$ is defined for $N_T = 2$ transmit antenna (Tx antenna) per sector. This approach differs conceptually from schemes as discussed e.g. in 3G-LTE Release 8, but ensures CCI to be predictable. This is a benefical property especially for mobile users.

Assuming that antennas from different BSs can be grouped for coherent transmission of data signals, we define a so-called collaboration area (CA). The CA manages interference actively, by the use of joint signal processing prior to transmission over the wireless channel. Data signals coming from outside this CA will be treated as inter-CA interference, where the spatial structure can be measured, e.g. by estimation of the interference covariance matrix. The choice of BSs belonging to a CA can be done network-centric or user assisted (user-centric). The user-centric choice may be found by measuring the broadband channels to all nearby BSs and reporting a set of strongest BS antennas to its serving BS. The serving BS may initialize the setup of a new CA or allocate this particular MT into a user group served inside a predefined CA. The overlap of CAs including different BS antenna combinations can be separated, e.g. in frequency domain by resource partitioning.

For downlink cooperation among a selected set of α cooperating BS sectors, we allow to modify the collaborative pre-coder $\mathbf{C}^{CA_i}$ to any kind of beamforming, as depicted in Fig. 2. Each collaborating BS in the CA distributively determines the whole pre-coder $\mathbf{C}^{CA_i}$ on the given user feedback, but then uses the corresponding parts $\mathbf{C}_1^{CA_i}$ and $\mathbf{C}_2^{CA_i}$, respectively, for coherent joint transmission.

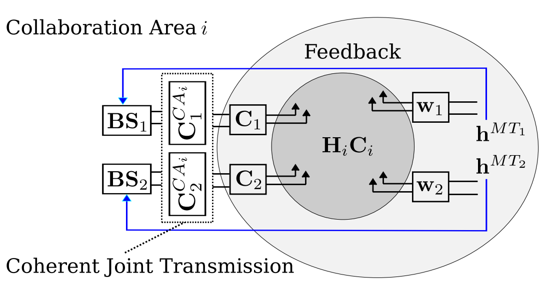

Figure 2: True and effective multi-cell channel. The pre-coder for coherent joint transmission is distributively calculated, while the corresponding parts are used at each of the collaborating BSs.

3. MT ASSISTED FEEDBACK PRE-SELECTION

For channel adaptive transmission to one or several MTs, the users have to provide limited or full CSI to the BSs. In general uplink resources are limited, especially due to limited power supply at the MTs. In order to reduce CSI feedback overhead, and thus saving valuable uplink resources, we propose the following concept of MT assisted channel pre-processing. Having in mind that transmitting a single stream to each of the multiple users in the cell provides a significant portion of the achievable capacity of the system [5], we focus on multi-user MIMO (MU-MIMO) transmission mode solely. For $N_R > 1$ we will exploit the spatial degrees of freedom at the MT receiver side for the purpose of interference rejection combining (IRC) [6], according to

$$\mathrm{SINR}_m = p_i \frac{\mathbf{w}_m^H \overline{\mathbf{h}}_{i,m} \overline{\mathbf{h}}_{i,m}^H \mathbf{w}_m}{\mathbf{w}_m^H \mathbf{Z}_m \mathbf{w}_m}\ , \tag{4}$$

where $\mathbf{Z}_m$ is the covariance matrix of the interfering signals aggregated in $\zeta_{i,m}$ and $\mathbf{z}_{i,m}$, i.e. $\mathbf{Z}_m = \mathrm{E}\left[\left(\zeta_{i,m} + \mathbf{z}_{i,m}\right)\left(\zeta_{i,m} + \mathbf{z}_{i,m}\right)^H\right]$, with $E[.]$ being the expectation operator.

The interference-aware[1] minimum mean square error (MMSE) receiver is given by

$$\mathbf{w}_m^{\mathrm{MMSE}} = \frac{p_i \mathbf{R}_{yy}^{-1} \overline{\mathbf{h}}_{i,m}}{\alpha N_T} \tag{5}$$

where $\mathbf{R}_{yy}$ denotes the covariance matrix of the received signal $\mathbf{y}^m$, i.e.

$$\mathbf{R}_{yy} = \mathrm{E}\left[\mathbf{y}^m \left(\mathbf{y}^m\right)^H\right] = \mathbf{Z}_m + \overline{\mathbf{h}}_{i,m} \overline{\mathbf{h}}_{i,m}^H \tag{6}$$

According to [4], the MMSE receiver yields a post-equalization SINR

$$\mathrm{SINR}_m^{\mathrm{MMSE}} = \frac{p_i}{\alpha N_T} \overline{\mathbf{h}}_{i,m}^H \mathbf{Z}_u^{-1} \overline{\mathbf{h}}_{i,m} \tag{7}$$

All proposed schemes have in common, that each MT can choose its desired receive strategy independently from other MTs according to its computational capabilities and knowledge on channel state information at the receiver (CSIR) including interference. The only agreed assumptions between all MTs and the CA is that a minimum intra-CA interference pre-coder will be applied. The performance of different linear receivers to obtain an effective channel will be different after zero forcing (ZF) pre-coding at the BSs. However, a detailed analysis, throughput performance comparison and robustness against different types of errors is subject of another paper.

Without loss of generality we will limit ourselves to the case of $N_R = 2$ receive antennas (Rx antennas) per MT. The basic principle is the following: Each MT pre-computes an effective multiple-input single-output (MISO) channel and reports this to the serving BS in the CA. In the following we categorize some possible examples using effective MISO channel reporting. Receiving this feedback from several users in the CA, the BSs may use different methods for user orthogonalization, e.g. linear pre-coding as ZF, MMSE or block diagonalization or non-linear as Tomlinson-Harashima precoding.

3.1 Feedback on true MISO channel

For baseline systems, consider the MT has only a single Rx antenna and therefore reports the true MISO channel to the BS according to:

$$\mathbf{h}^{MT_1} = \underbrace{[\overline{\mathbf{h}}_{BS_1}\ \overline{\mathbf{h}}_{BS_2}]}_{\overline{\mathbf{h}}_i} \tag{8}$$

where $\overline{\mathbf{h}}_{BS1} = \mathbf{H}_{BS_1} \mathbf{b}_{BS_1,j}$ is the vector containing all j complex valued effective channel coefficient between all Tx antennas from BS_1 and the single Rx antenna of MT_1.

Feedback information: According to this concept, we suggest to feedback the MISO channel $\mathbf{h}^{MT_m}$ received at m-th MT and the achievable SINR additionally.

Disadvantage: MT has no degrees of freedom to combat inter-CA interference, which limits the SINR. For the achievable SINR, we assume the CA to provide the data stream to MT_m, while all

[1] Either full knowledge, i.e. spatial structure, or partial knowledge, i.e. power on the inter-CA interference may be considered

other data streams used for residual MTs are completely orthogonalized by use of the ZF pre-coder. Thus, the MTs in the CA do not experience any intra-CA interference.

$$\mathrm{SINR}^{MT_m} = \frac{\beta^{MT_m}}{\sum_{l=1}^{L}\sum_{j=1}^{N_T}\left|\mathbf{H}_l\mathbf{b}_{l,j}\right|^2 + \sigma_N^2} \quad (9)$$

β^{MT_m} is a transmit power scaling factor applied on the data stream send to the m-th MT, while σ_N^2 the received noise power at the single Rx antenna. Note, if no transmit power limit would be applied, β^{MT_1} would be equal to 1. The entire path-loss is pre-compensated at the transmitter, resulting in unit signal power at the receive antenna.

3.2 Mobile MTs: Feedback on desired beamformer

Static DFT-based non-cooperative pre-coding
For sake of completeness, we briefly summarize a system concept from [4], where all sectors operate independently, while the CCI is accounted for at the multi-antenna MTs only. This transmission concept is of major importance if MTs are moving and channel conditions are highly time variant. Each BS provides a static matrix $\mathbf{C}$ consisting of unitary DFT beams. Assuming that the CCI is ideally known at each MT, the MTs evaluates the achievable rate per beam and convey this information to their serving BS. At the BS, the feedback from different MTs is collected, and the DFT beams from matrix $\mathbf{C}$ are assigned individually to the MTs.

Feedback information: The MTs are assumed to provide their preferred matrix index (PMI) and the corresponding SINRs.

Advantage: This simple approach has the convenient property that with the static beam set $\mathbf{C}$ used for all BSs, the CCI, i.e. $\zeta_{i,m} + \mathbf{z}_{i,m}$, becomes fully predictable, enabling interference-aware scheduling in a cellular system. In combination with fair, interference-aware scheduling policies, it has been shown that users profit from almost doubled spectral efficiencies in the MIMO 2×2 system, as compared to the SISO setup ([4] and references therein). Recently, this concept was shown to approach the performance achievable with an near-optimum beamforming concept under the assumption of a single-stream transmission to each of the N_T MTs in the cell [7].

Disadvantage: However, downlink cooperation may not be directly enabled. Thus, the cellular system is still interference-limited and the achievable system throughput is restricted. Especially in scenarios with a large number of active users, joint beamforming is expected to pay off [7].

3.3 Stationary MTs: Effective MISO channel

In the following, we consider the MTs to be equipped with multiple Rx antennas for the purpose of IRC. Again BSs are assumed to provide N_T data streams to N_T MTs.

In this case, the MTs are assumed to use linear receive filters to transform the MIMO channel into an effective MISO channel [8, 3], according to Fig. 3.

$$\mathbf{h}^{MT_m} = \mathbf{w}_m^H \mathbf{H}_i^m \quad (10)$$

Feedback information: The MT is assumed to provide feedback for the achievable SINR and the effective MISO channel $\mathbf{h}^{MT_m}$.

Furthermore, if true ZF pre-coding is assumed at the BSs, feedback can be split into amplitude and phase instead of general I and Q samples to describe the channel. Thus, the amplitude is of much less importance and can be reduced to a mean path-loss in extreme. On the other hand, precise phase information is required to allow proper ZF pre-coding. Note, that this approach has the potential to further reduce feedback rate, but makes SINR prediction more difficult after ZF pre-coding since the reconstructed signal power is not exactly unit power anymore.

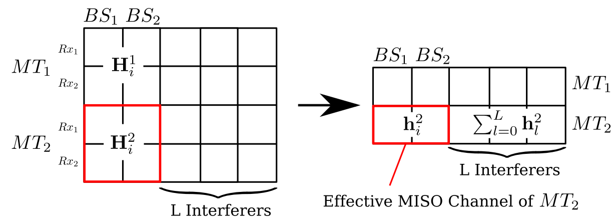

Figure 3: Transforming a MIMO channel into an effective MISO channel with known SINR.

Effective MISO channel transformed by MRC filter
Consider a fixed set $\mathscr{M}$ of users, which are served in a resource block (RB). Each user m decomposes its $N_R \times \alpha N_T$ channel matrix $\mathbf{H}_i^m$ according to the singular value decomposition (SVD), yielding $\mathbf{H}_i^m = \mathbf{U}_i\mathbf{\Sigma}_i\mathbf{V}_i^H$. Assume each MT is applying for a single data stream only, i.e. MU-MIMO service. In this case, it is favorable to select the dominant eigenmode, i.e. the eigenvector corresponding to the highest eigenvalue. The effective channel after maximum ratio combining (MRC) equalization using the dominant left eigenvector is given by

$$\mathbf{h}^{MT_m} = \mathbf{u}_{i,1}^H\mathbf{U}_i\mathbf{\Sigma}_i\mathbf{V}_i^H = \Sigma_{i,1}\mathbf{v}_{i,1}^H \quad (11)$$

Advantage: The scheme maximizes the signal power transfered from collaborative BSs to the MT. MTs should preferably be grouped such that their eigenmodes show highest orthogonality. This keeps the costs in received power reduction as small as possible.

Disadvantage: The effective SINR is determined by the eigenmode receive filter $\mathbf{u}_{i,1}$ and the arbitrary projection of external interference into this spatial filter. However, for data detection the MMSE receiver may be used which helps to combat residual interference, e.g. caused by channel estimation or quantization errors.

Effective MISO channel transformed by MMSE filter
This combines the preceding concept, i.e. dominant eigenmode pre-coder with a MMSE equalization at the MT. Here, report on the effective MISO channel $\mathbf{h}^{MT_m}$ behind the linear MMSE filter is assumed.

$$\mathbf{h}^{MT_m} = \left[\mathbf{w}_m^{\mathrm{MMSE}}\right]^H [\mathbf{H}_i] \quad (12)$$

The linear receive filter is determined under the assumption of eigenmode pre-coding for the dedicated data stream and predictable inter-CA signals. Other data streams inside the CA are assumed to be transmitted orthogonal in space.

$$\mathbf{w}_m^{\mathrm{MMSE}} = \frac{p_i}{\alpha N_T}\mathbf{R}_{yy}^{-1}\underbrace{\mathbf{H}_i\mathbf{v}_{i,1}}_{\bar{\mathbf{h}}_{i,m}} \quad (13)$$

Advantage: The initial spatial channel assumption concentrates on outside interference as the limiting interference contribution, while the effective MISO channel inside the CA is chosen such that the desired signal from the set of BS to the MT is maximized. The final SINR can be fully pre-computed at the BS since the initial SINR reported from the MT under ideal pre-coding assumption will be altered by the power normalization per Tx stream only.

Disadvantage: The performance depends mainly on the possible user grouping based on the effective MISO channel, which should be orthogonal between the active MTs if possible. This might be a drawback if only few users are available to form sets for pre-coding.

3.4 Implementation issues: effective channel estimation

Single-cell transmission is usually based on fixed pre-coding matrices $\mathbf{C}_i = \mathbf{C}_\omega$ where the i identifies the base station. To enable IRC at the terminal, the true multi-cell channel $\mathbf{H}_i$ from all BSs to a given terminal m has to be estimated. To keep multi-cell interference predictable, pre-coding matrices are not allow to change frequently. Hence, a first channel estimation based on multi-cell pilot symbols is required at this step to determine $\mathbf{H}_i\mathbf{C}_i$.

In order to estimate the effective MISO channel at the output of each linear receive filter, it is reasonable to calculate $\mathbf{h}^{MT_m}$ according to sections 3.1-3.3. However, it seems to be more robust passing the pilot symbols like data through the receive filter. Thus, the effective MISO channel can directly be estimated on the common reference signals.

4. COOPERATIVE AND DISTRIBUTED PRE-CODER CALCULATION

As discussed in section 3, report a virtual MISO channel is favorable and can be orthogonalized by the collaborative BSs like a single antenna receiver. Once users are grouped and assigned to a collaboration area (CA), the pre-coder and its power normalization are determined by the used algorithm which is the same on all distributed processing units. Note, we assume that the same software and hardware is used on all processing units inside a CA.

4.1 Joint Pre-coder Weight Calculation

A maximum number of αN_T MISO channels experienced from different MTs are composed to form a compound virtual MIMO channel of size $\alpha N_T \times \alpha N_T$. The compound channel matrix can be orthogonalized by any linear or non-linear pre-coding technique, if a full rank is assured. This condition may easily be met in a multi-point-to-multi-point channel having independent links [9, 10]. The proposed approach allows us to benefit from two major advantages: First the multiple receive antennas are efficiently used for suppression of external interference at the MT side. Second by reducing the number of data streams per MT, we can exploit the degrees of freedom in multi-user grouping such that the number of all active data streams is smaller or equal to the number of active transmit antennas.

Unique identifiers for distributed processing
After each pre-coder processing unit at the BS has received the multi-casted CSI from the other BSs inside the CA, a cross-check of all contents, respectively origin (MT and BS identifier) and time stamp (frame number and eventually sub-frame number) is performed. Next, all valid CSI data will be loaded in a pre-agreed order, assuring that the compound channel matrices put together at different BS are identical in each entry. This has to be assured per sub-carrier or per physical RB in OFDM systems where transmit collaboration is applied. A pre-agreed order can be realized by simply numbering all active BS Tx antennas within the CA, while keeping track of the corresponding MT identifier. This antenna numbering has to be known to all MTs. Assuming the compound channel matrix is available and valid, all processing units have to use identical deterministic algorithm to determine the joint pre-coder $\mathbf{C}^{CA_i}$.

CA protocols for stable joint transmission
As a final hand-shake before calculating the joint pre-coding matrix $\mathbf{C}^{CA_i}$, all BSs distribute via multi-cast a *correctly received CSI* message to all BSs in the CA. If one BS has incomplete data, e.g. due to lost packets, other BSs within the CA can provide the missing pre-coder weights and the calculation of the post-detect SINR. This ensures that joint spatial pre-processing can still successfully be performed. Note that several protocols, e.g. strict master-slave or central controller approaches, can be utilized but will cause additional traffic and latency on the X2 interface for pre-coder and modulation and coding scheme (MCS) level exchange. This assures data consistency at all distributed points, which is an important issue whenever a distributed approach is considered.

Meeting the transmit power constraint
The rational behind stringent transmit power constraints per transmit antenna and per site lies on one hand in operating the power amplifier at the BS at an optimum operation point with respect to the high Peak-to-Average-Power-Ratio of the OFDM time domain signal and on the other hand keeping the emitted power spectral density flat which is favorable for reliable broadband channel measurements and for more spectrally balanced interference to other cells. In order to meet the general requirements of a fixed maximum transmit power per Tx antenna, we have to normalize the pre-coder matrix column-wise such that the average transmitted power per data stream is constant. In average and considering slightly different phases and amplitudes over the entire frequency range of the OFDM symbol, we will achieve a rather constant transmit power per Tx antenna as well. Since the normalization for all elements of one and the same pre-coder column are the same, the resulting post detect SNRs per data stream are normalized differently.

Selecting the right matrix row for coordinated local spatial pre-coding
According to the pre-agreed order of the BS antennas, each BS knows which row out of the finally calculated joint pre-coder matrix is belonging to its own transmit antennas. This particular row is selected and stored for further processing together with the user data which are expected for each user to arrive via multi-cast on X2. The time stamp allows a synchronization of pre-coder and data content which is essential for successful coherent transmission of data and active interference management inside the CA.

Determination of Post-Detector SINR
Considering that additionally to CSI per sub-carrier or RB each MT reports the effective post-equalization SINR, we now can directly predict the final SINR after ZF pre-coding and application of the pre-chosen receive filter per MT.

The normalization factors β_{MT_m} for the m-th column of the spatial pre-coder and therefore for the data stream to m-th MT is calculated and multiplied with the reported SINR per MT.

The calculation of the final post-detection SINR considering joint transmit pre-coding and the reported effective SINR from each MT is again calculated in distributed way by the serving BS of each MT. This BS is in charge of the current and future continuation of higher layer protocols, such as H-ARQ. After deciding for the final effective post-detect SINR to be expected at the MT for the allocated stream, the MCS level, puncturing and PDU size can be chosen, such that each spatial layer is utilized optimally for data transmission. The finally decided MCS level for each spatial layer is tagged to the belonging encoded data stream and is again multicasted to each BS belonging the the active set of antennas in the CA which will perform mapping onto higher modulation formats locally and the mapping to the correct spatial pre-coder input queue.

In parallel all MTs have to be informed about the allocated resources and MCS levels. Since resource allocation announcement is in charge of the serving BS for each MT, this can either be done in cooperative transmit mode or in non-cooperative per BS mode. Both options are possible, but should not be mixed with each other.

4.2 Zero-Forcing (ZF)

Having established CAs and having found a suitable user group, the joint MIMO channel between BS and MT antennas is treated as a standard point-to-multi-point MIMO channel. Thus, the spatial signal separation is performed at the BS antennas based on the known CSI. By exploiting this channel adaptive spatial pre-coding we can actively reduce the interference inside the CA and ideally achieve an intra-CA interference free transmission. Since collaborative signal processing over the whole network is infeasible, we focus on a realistic size of the CA including 3 to 4 BS sectors. The residual inter-CA interference may limit the performance of the CA. Thus, we will focus on a joint SINR maximization including the spatial structure of the inter-CA interference experienced by the selected MTs accoring to (12).

To mitigate intra-CA interference we consider spatial ZF pre-coding [11] adapted to the joint channel $\mathbf{H}$ by choosing the pre-coder according to the Moor-Penrose pseudo-inverse of the channel $\mathbf{C}^{CA_i} = \mathbf{H}_i^{\dagger} = \mathbf{H}_i^H(\mathbf{H}_i\mathbf{H}_i^H)^{-1}$. This eliminates the inter-CA interference.

$$\mathbf{y} = \mathbf{H}_i\mathbf{C}^{CA_i}\mathbf{x} + \mathbf{n} = \mathbf{H}_i\mathbf{H}_i^{\dagger}\mathbf{x} + \mathbf{n} = \mathbf{x} + \mathbf{n} \tag{14}$$

which is equivalent to parallel AWGN transmission of data streams to different MTs.

5. PERFORMANCE EVALUATION

The concepts are investigated in a triple-sectored hexagonal cellular network with 19 BSs in total. The widely used extended spatial channel model (SCME) with urban macro scenario parameters is extended by the use of 3D antenna models with a downtilt angle of 10°. N_T MTs are assigned to each BS sector. The basic system settings are chosen according to [12].

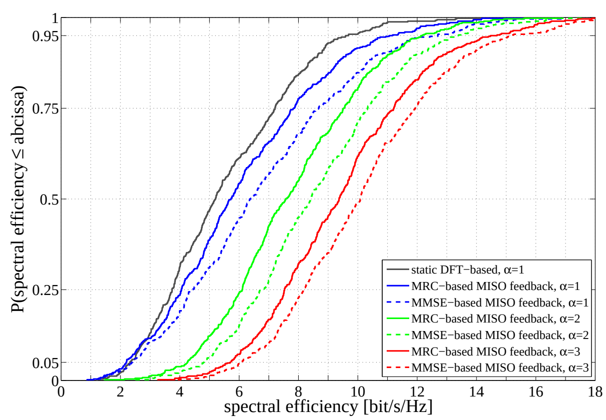

Figure 4: SCME based multi-cell results, variable cluster size α, spectral efficiency based on Shannon's formula

Fig. 4 depicts the achievable system throughput under consideration of the different feedback schemes for distributed interference management. The MMSE-based MISO feedback significantly outperforms the other concepts.

6. CONCLUSIONS

In our paper we proposed a collaborative antenna scheme for active interference management inside a so-called collaboration area (CA). Motivated from reducing the feedback channel load in the uplink we suggest a unified feedback scheme for distributed interference management in cellular systems. This concept combines an efficient pre-processing and selection of CSI data with the high probabilities of selecting SDMA in the multi-user MIMO downlink. The resulting MISO channel coefficients are reported to the serving BS and distributed among the BS within a CA. These decentralized nodes perform a joint pre-coder calculation in a parallel manner, reducing additional exchange of pre-coder weights and minimizing delay over the connecting link between BSs. A final coordinated and joint application of these pre-coder weights allows suppression of interference and coherent joint transmission of data-streams from distributed antennas within the CA. We point out that overall synchronization of data content and applied pre-coder weights is required. The suggested concepts nearly doubles the achievable system throughput for three collaborating sectors as compared to the static pre-coded case.

Acknowledgements

The authors are grateful for stimulating discussions with Malte Schellmann as well as for financial support from the German Ministry for Education and Research (BMBF) and NSN for financial support in the project ScaleNet.

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