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Joint Transmission with Imperfect Partial Channel State Information

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***Abstract*—The knowledge of the impact of imperfect channel state information (CSI) on data transmission techniques is helpful to improve the performance of wireless communication systems. In this paper, based on the proposed cooperative downlink (DL) transmission scheme applying adaptive scheduling of mobile stations (MSs), significant channel selection, and joint transmission (JT) with partial CSI, i.e., JT considering only part of the useful channels and the interference channels, a novel performance assessment is performed taking imperfectness of the CSI into consideration. The performance degradation caused by the imperfectness of the CSI which is used in the adaptive scheduling, the significant channel selection and the JT with partial CSI is investigated. The question about how much CSI should be taken into consideration as a function of the extent of imperfectness of the CSI in order to achieve optimum system performance is answered based on numerical results.**

I. INTRODUCTION

Multiuser mobile radio cellular systems considering all the antennas of the base stations (BSs) on one side and all the antennas of the MSs on the other side together can be considered as multiuser multiple-input multiple-output (MIMO) systems for which remarkable capacity potentials have been predicted in [1]. The performance of conventional cellular systems is mainly limited by interferences [2]. In order to achieve higher spectral efficiency in the DL of multiuser mobile radio cellular systems, we can apply JT at the transmitter side at the BSs to reduce the inter-cell interferences [3]–[8]. For example, applying the zero forcing (ZF) algorithm [9] in a purely interference limited cellular system with full CSI and full cooperation of all BSs, we can cancel all the inter-cell interference and achieve the optimum system performance [3]. However, in a realistic cellular system covering a large area containing a huge number of cells, applying full CSI of the whole system in JT is almost infeasible because the implementation complexity is quite high. In order to reduce the implementation complexity, JT with partial CSI following different strategies has recently been proposed under the names distributed antenna system (DAS), group cell architecture, and service area (SA) architecture [8], [10], [11]. In the present paper, we propose a selection scheme for the significant channels in the form of the significant useful channels and the significant interference channels for each MS. The dynamically selected significant CSI, i.e., the channel coefficients corresponding to the selected significant channels, will be applied in the JT with partial CSI. An iterative algorithm with partial CSI following the ideas of the iterative ZF algorithm with full CSI is proposed for JT. Additionally, in order to further improve the system performance, adaptive scheduling techniques can be added to our system concept before the significant channel selection and the JT with partial CSI to select the active MSs for the individual subcarriers according to a criterion such as the channel gain or the signal-to-noise-ratio (SNR) [12].

Considering the ability to track the CSI, in realistic cellular systems usually only imperfect CSI is available to the proposed cooperative DL transmission scheme. The influence of imperfect CSI has been paid more and more attention by researchers in the recent years [13]–[16]. However, these previous works only focus on the impact of imperfect CSI on JT with full CSI. The impact of imperfect CSI on JT with partial CSI has rarely been mentioned in the literature, and the present paper will contribute to this point. We will investigate the performance degradation caused by the imperfect CSI used in the adaptive scheduling, the significant channel selection, and the JT with partial CSI, respectively. Based on the numerical results, we will discuss how much CSI should be taken into consideration as a function of the extent of imperfectness of the CSI. Namely, we will investigate whether it is worth applying the adaptive scheduling or not by comparing the performance applying adaptive scheduling with that applying random scheduling. We will determine which transmission strategy with partial CSI is a more suitable choice considering their sensitivity to the imperfectness of the CSI, e.g., JT considering only the intra-cell useful CSI which is identical to the intracell matched filtering (MF) or JT considering the significant CSI corresponding to the significant useful channels and the significant interference channels for each MS. Furthermore, in the case of JT with significant CSI we will have a look at how many significant useful channels and significant interference channels should be considered to obtain optimum system performance as a function of the extent of imperfectness of the CSI.

The remainder of this paper is organized as follows. Based on the system model considering imperfect CSI in Section II, the cooperative DL transmission scheme including adaptive scheduling, the significant channel selection and the JT with partial CSI is described in Section III. A novel performance assessment of JT with imperfect partial CSI is performed based on numerical results in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODEL

In this paper, multiuser data transmission in the DL of a multicell cellular system is considered. Applying the orthogonal frequency division multiplexing (OFDM) transmission technique [17], all the intra-cell interference can be avoided and it is sufficient to consider a single subcarrier. Each cell contains one BS equipped with multiple antennas and one active MS equipped with a single antenna in the considered subcarrier and time slot. The active MS in each cell can be selected randomly or adaptively from N_{M} MSs in each cell, and this will be discussed in more detail in Section III. In the investigated reference scenario, we assume that for the number K of cells, the total number K_{B} of BSs, the total number K_{M} of MSs, the total number K_{A} of BS antennas, and the number N_{A} of antennas at each BS,

$$K = K_{\mathrm{M}} = K_{\mathrm{B}} = K_{\mathrm{A}}/N_{\mathrm{A}} \tag{1}$$

holds. With the transmitted vector $\underline{\mathbf{s}}$, the received vector $\underline{\mathbf{e}}$, the noise vector $\underline{\mathbf{n}}$ and the DL channel matrix including the channel transfer functions

$$\underline{\mathbf{H}} = \begin{pmatrix} \underline{H}^{(1,1)} & \dots & \underline{H}^{(1,K_{\mathrm{A}})} \\ \vdots & & \vdots \\ \underline{H}^{(K_{\mathrm{M}},1)} & \dots & \underline{H}^{(K_{\mathrm{M}},K_{\mathrm{A}})} \end{pmatrix}, \tag{2}$$

the system model is described by

$$\underline{\mathbf{e}} = \underline{\mathbf{H}} \cdot \underline{\mathbf{s}} + \underline{\mathbf{n}} \ . \tag{3}$$

The estimated data vector $\hat{\underline{\mathbf{d}}}$ is equal to the received vector $\underline{\mathbf{e}}$ if no post-processing is applied in the receivers at the MSs. We apply JT in the transmitters at the BSs to obtain the transmitted vector $\underline{\mathbf{s}}$ from the data vector $\underline{\mathbf{d}}$. The elements of the data vector are assumed to be independent and identically distributed (i.i.d.) with the transmitted energy per data symbol being denoted by E_{d}. The elements of the noise vector $\underline{\mathbf{n}}$ are assumed to be independent and identically Gaussian distributed with variance $\sigma_{\mathrm{N}}^2/2$ of real and imaginary parts.

In the case of imperfect CSI, with the channel-error matrix $\underline{\mathbf{E}}$ the estimated channel matrix

$$\hat{\underline{\mathbf{H}}} = \underline{\mathbf{H}} + \underline{\mathbf{E}} \tag{4}$$

is used at the transmitter side in the cooperative DL transmission scheme. We assume the elements of $\underline{\mathbf{E}}$ are independent and identically Gaussian distributed with variance $\sigma_{\mathrm{E}}^2/2$ of real and imaginary parts.

III. COOPERATIVE DL TRANSMISSION SCHEME

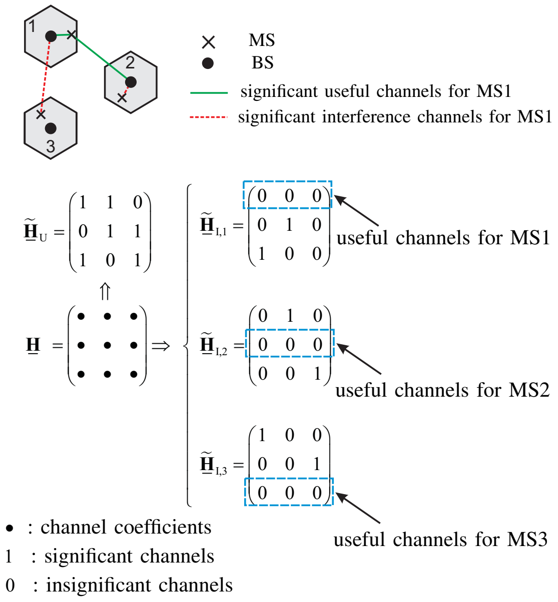
A. Adaptive MS scheduling

As described in the system model, in the considered single subcarrier and time slot only one out of several MSs in each cell is served by the BSs. The active MS can be adaptively selected according to different criteria such as the instantaneous signal-to-noise-ratio (SNR) [12], signal-to-noise-plus-interference-ratio (SNIR), and channel gain. A practical approach for MS scheduling with moderate computational complexity is proposed in this paper. Assuming the MSs in each cell have the same average noise power and leaving the consideration of the inter-cell interference to the proposed powerful interference cancellation technique in JT, we take the channel gain corresponding to the channel between each MS and the BS in the same cell at the considered subcarrier as the criterion to perform the adaptive MS scheduling. Since multiple antennas are considered at each BS, the MS having the maximum sum of the channel gains corresponding to all the channels between this MS and all the BS antennas in the cell will be chosen to be served in the considered subcarrier and time slot. However, when the available CSI is imperfect, the results of scheduling depending on the channel gain calculated from imperfect CSI can be different from the results in the case of perfect CSI.

B. Significant channel selection

In order to apply JT more efficiently with reduced computational load and moderate implementation complexity, we propose JT with partial CSI considering only the significant channels for each MS. In the selection scheme of the significant channels, for each MS k_{M} we select the significant useful channels over which we can generate significant useful contributions to the received signal for this MS, and the significant interference channels over which we will cause significant interference to other MSs when transmitting the data symbol for the considered MS k_{M}. Assuming that perfect CSI is included in the available channel matrix $\underline{\mathbf{H}}$, through the significant channel selection we obtain the significant useful channel indicator matrix $\underline{\widetilde{\mathbf{H}}}_{\mathrm{U}}$ for all the K_{M} MSs and the individual MS specific significant interference channel indicator matrices $\underline{\widetilde{\mathbf{H}}}_{\mathrm{I},k_{\mathrm{M}}}$ for each MS k_{M}. These indicator matrices include “1”s indicating significant channels and “0”s indicating insignificant channels.

There are various mathematical criteria to determine the significant channels in the form of the significant useful channels and the significant interference channels based on the available channel coefficients. A suitable approach for the selection of significant useful channels is to perform a channel energy comparison in each row of $\underline{\mathbf{H}}$ corresponding to each individual MS. For each MS k_{M}, a channel with the channel coefficient $\underline{H}^{(k_{\mathrm{M}},k_{\mathrm{A}})}$ is selected as a significant useful channel if the channel energy $\left(\underline{H}^{(k_{\mathrm{M}},k_{\mathrm{A}})^*}\underline{H}^{(k_{\mathrm{M}},k_{\mathrm{A}})}\right)$ covers a significant portion of the sum of all channel energies for one MS $\sum_{k_{\mathrm{A}}}\left(\underline{H}^{(k_{\mathrm{M}},k_{\mathrm{A}})^*}\underline{H}^{(k_{\mathrm{M}},k_{\mathrm{A}})}\right)$. The selected significant useful channels for each MS k_{M} are indicated by “1”s in the corresponding k_{M}-th row of $\underline{\widetilde{\mathbf{H}}}_{\mathrm{U}}$, and the left positions of $\underline{\widetilde{\mathbf{H}}}_{\mathrm{U}}$ are occupied by “0”s indicating insignificant useful channels. Therefore, a single channel indicator matrix $\underline{\widetilde{\mathbf{H}}}_{\mathrm{U}}$ is sufficient to represent the significant useful channels for all the MSs. Except the useful channels of MS k_{M}, any channel out of the channels corresponding to channel coefficients in all the other rows of $\underline{\mathbf{H}}$ could be selected as a significant interference channel. Among these channels, any selected significant interference channel for one MS could be considered as an insignificant interference channel for another MS. So it is reasonable to use individual MS specific significant interference channel indicator matrices $\underline{\widetilde{\mathbf{H}}}_{\mathrm{I},k_{\mathrm{M}}}$ to represent the significant interference channels for the individual MSs k_{M}.



$$\widetilde{\underline{\mathbf{H}}}_\mathrm{U}=\begin{pmatrix}1&1&0\\0&1&1\\1&0&1\end{pmatrix}\Uparrow\quad \underline{\mathbf{H}}=\begin{pmatrix}\bullet&\bullet&\bullet\\\bullet&\bullet&\bullet\\\bullet&\bullet&\bullet\end{pmatrix}\Rightarrow\begin{cases}\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},1}=\begin{pmatrix}0&0&0\\0&1&0\\1&0&0\end{pmatrix}\\ \widetilde{\underline{\mathbf{H}}}_{\mathrm{I},2}=\begin{pmatrix}0&1&0\\0&0&0\\0&0&1\end{pmatrix}\\ \widetilde{\underline{\mathbf{H}}}_{\mathrm{I},3}=\begin{pmatrix}1&0&0\\0&0&1\\0&0&0\end{pmatrix}\end{cases}$$

Fig. 1. Example for significant channel selection and matrix formalism

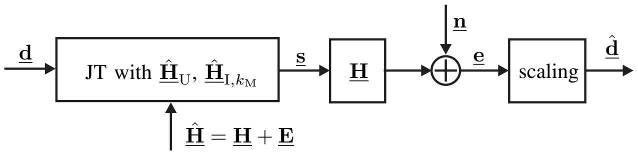


Fig. 2. Data transmission based on JT

During the selection of significant interference channels for each MS k_M, firstly we assign "0"s to the k_M-th row of $\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}$ since the corresponding channels of these elements are even not interference channels for MS k_M. Then based on the left channel coefficients in $\underline{\mathbf{H}}$, we can determine the significant interference channels and insignificant ones by comparing the channel weighting factor magnitude of the interference as one of the various selection algorithms. A channel with the channel coefficient $\underline{H}^{(k'_\mathrm{M},k_\mathrm{A})}$ is selected as a significant interference channel if the channel weighting factor magnitude $\left|\underline{H}^{(k'_\mathrm{M},k_\mathrm{A})}\underline{H}_\mathrm{U}^{(k_\mathrm{M},k_\mathrm{A})^*}\right|$ corresponding to the scaling of the interference in matched filtering covers a significant portion of the sum of the channel weighting factor magnitudes $\sum_{k'_\mathrm{M}}\sum_{\substack{\text{considered BS}\\ \text{antennas } k_\mathrm{A}}}\left|\underline{H}^{(k'_\mathrm{M},k_\mathrm{A})}\underline{H}_\mathrm{U}^{(k_\mathrm{M},k_\mathrm{A})^*}\right|$ for all the interferences caused by MS k_M. An example of the significant channel selection in a 3-cell scenario is shown in Fig. 1.

Based on perfect CSI in the channel matrix $\underline{\mathbf{H}}$, we can perform an optimum significant channel selection and obtain the significant useful channels and the significant interference channels for each MS. In realistic cellular systems, the impact of the imperfectness of the CSI has to be considered. Based on the imperfect estimate $\hat{\underline{\mathbf{H}}}$ of the channel matrix $\underline{\mathbf{H}}$, we can only perform a suboptimum selection of the significant channels, and therefore it is possible that some selected significant channels are not significant in reality. Although the significant useful channel indicator matrix $\widetilde{\underline{\mathbf{H}}}_\mathrm{U}$ and the individual MS specific significant interference channel indicator matrices $\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}$ could be different for different inputs of the selection scheme, i.e., the channel matrix $\underline{\mathbf{H}}$ or the estimated channel matrix $\hat{\underline{\mathbf{H}}}$, the selection scheme itself is unmodified in realistic systems.

C. JT with partial CSI

As shown in Fig. 2, the estimated significant useful channel matrix $\hat{\underline{\mathbf{H}}}_\mathrm{U}$ and the MS specific significant interference channel matrices $\hat{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}$ will be applied in the JT with partial CSI. Based on the above introduced significant useful channel indicator matrix $\widetilde{\underline{\mathbf{H}}}_\mathrm{U}$ and the individual MS specific significant interference channel indicator matrices $\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}$, from the imperfect estimate $\hat{\underline{\mathbf{H}}}$ considering the channel error matrix $\underline{\mathbf{E}}$ as described in (4), we obtain

$$\hat{\underline{\mathbf{H}}}_\mathrm{U}=\hat{\underline{\mathbf{H}}}\odot\widetilde{\underline{\mathbf{H}}}_\mathrm{U}=\underline{\mathbf{H}}\odot\widetilde{\underline{\mathbf{H}}}_\mathrm{U}+\underline{\mathbf{E}}\odot\widetilde{\underline{\mathbf{H}}}_\mathrm{U}=\underline{\mathbf{H}}_\mathrm{U}+\underline{\mathbf{E}}_\mathrm{U} \tag{5}$$

and

$$\hat{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}=\hat{\underline{\mathbf{H}}}\odot\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}=\underline{\mathbf{H}}\odot\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}+\underline{\mathbf{E}}\odot\widetilde{\underline{\mathbf{H}}}_{\mathrm{I},k_\mathrm{M}}=\underline{\mathbf{H}}_{\mathrm{I},k_\mathrm{M}}+\underline{\mathbf{E}}_{\mathrm{I},k_\mathrm{M}}\ , \tag{6}$$

where the operator $\odot$ denotes element-wise multiplication. The selected significant useful channel matrix $\underline{\mathbf{H}}_\mathrm{U}$ and the selected MS specific significant interference channel matrices $\underline{\mathbf{H}}_{\mathrm{I},k_\mathrm{M}}$ include the perfect significant channel coefficients from the channel matrix $\underline{\mathbf{H}}$ and "0"s corresponding to insignificant channels. The significant useful channel error matrix $\underline{\mathbf{E}}_\mathrm{U}$ and the MS specific significant interference channel error matrices $\underline{\mathbf{E}}_{\mathrm{I},k_\mathrm{M}}$ include the independent and identically Gaussian-distributed channel errors from $\underline{\mathbf{E}}$ with variance $\sigma_\mathrm{E}^2/2$ of real and imaginary parts and "0"s corresponding to insignificant channels.

An iterative algorithm with the selected significant CSI is proposed as a practical solution in JT following the ideas of iterative ZF algorithm with full CSI. With the estimated channel energy scaling matrix

$$\hat{\mathbf{G}}=\operatorname{diag}\left(\hat{\underline{\mathbf{H}}}_\mathrm{U}\hat{\underline{\mathbf{H}}}_\mathrm{U}^{*\mathrm{T}}\right) \tag{7}$$

and the estimated channel correlation matrix

$$\hat{\underline{\mathbf{R}}}=\left(\ \hat{\underline{\mathbf{H}}}_{\mathrm{I},1}\left[\hat{\underline{\mathbf{H}}}_\mathrm{U}^{*\mathrm{T}}\right]_1,\ldots,\hat{\underline{\mathbf{H}}}_{\mathrm{I},K_\mathrm{M}}\left[\hat{\underline{\mathbf{H}}}_\mathrm{U}^{*\mathrm{T}}\right]_{K_\mathrm{M}}\ \right)\ , \tag{8}$$

we obtain the predistorted data vector $\underline{\mathbf{t}}(i)$ in the i-th iteration and the transmitted vector $\underline{\mathbf{s}}$ as

$$\underline{\mathbf{t}}(i)=\hat{\mathbf{G}}^{-1}\cdot\left(\underline{\mathbf{d}}-\overline{\operatorname{diag}}\left(\hat{\underline{\mathbf{R}}}\right)\cdot\underline{\mathbf{t}}(i-1)\right) \tag{9}$$

$$\underline{\mathbf{s}}=\hat{\underline{\mathbf{H}}}_\mathrm{U}^{*\mathrm{T}}\cdot\underline{\mathbf{t}}\ , \tag{10}$$

where the matrix operator $[\cdot]_{k_\mathrm{M}}$ returns the k_M-th column of its argument as a column vector, and $\overline{\operatorname{diag}}(\cdot)$ returns a matrix containing the offdigonal elements of its argument. This iterative ZF algorithm with significant CSI can be implemented by distributed signal processing. For each MS, the signal processing is performed at its neighbouring BSs corresponding to its significant useful channels. At each BS, only local significant CSI is required and no central unit of system is needed [7].

To adjust the transmitted energy, the scaling matrix

$$\hat{\mathbf{F}}=\left(\operatorname{diag}\left(\left(\hat{\mathbf{G}}+\overline{\operatorname{diag}}\left(\hat{\underline{\mathbf{R}}}^{*\mathrm{T}}\right)\right)^{-1}\hat{\underline{\mathbf{H}}}_\mathrm{U}\hat{\underline{\mathbf{H}}}_\mathrm{U}^{*\mathrm{T}}\left(\hat{\mathbf{G}}+\overline{\operatorname{diag}}\left(\hat{\underline{\mathbf{R}}}\right)\right)^{-1}\right)\right)^{-\frac{1}{2}} \tag{11}$$

is considered. The limiting value of the estimated data vector in the iterative algorithm is obtained as

$$\underline{\hat{\mathbf{d}}} = \hat{\mathbf{F}}^{-1}\left(\underline{\mathbf{H}}\,\underline{\hat{\mathbf{H}}}_{\mathrm{U}}^{*\mathrm{T}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}\right)\right)^{-1}\hat{\mathbf{F}}\cdot\underline{\mathbf{d}}+\underline{\mathbf{n}}\right)\ . \quad (12)$$

The corresponding SNIR, i.e.,

$$\gamma^{(k_{\mathrm{M}})} = S^{(k_{\mathrm{M}})}/(I^{(k_{\mathrm{M}})}+N^{(k_{\mathrm{M}})}), \quad (13)$$

of a certain MS k_{M} is obtained with

$$S^{(k_{\mathrm{M}})} = E_{\mathrm{d}}\left[\mathrm{diag}\left(\hat{\mathbf{F}}^{-1}\underline{\mathbf{H}}\,\underline{\hat{\mathbf{H}}}_{\mathrm{U}}^{*\mathrm{T}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}\right)\right)^{-1}\hat{\mathbf{F}}\right)\right.$$

$$\left.\cdot\ \mathrm{diag}\left(\hat{\mathbf{F}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}^{*\mathrm{T}}\right)\right)^{-1}\underline{\hat{\mathbf{H}}}_{\mathrm{U}}\underline{\mathbf{H}}^{*\mathrm{T}}\hat{\mathbf{F}}^{-1}\right)\right]_{k_{\mathrm{M}},k_{\mathrm{M}}}, \quad (14)$$

$$I^{(k_{\mathrm{M}})} = E_{\mathrm{d}}\left[\overline{\mathrm{diag}}\left(\hat{\mathbf{F}}^{-1}\underline{\mathbf{H}}\,\underline{\hat{\mathbf{H}}}_{\mathrm{U}}^{*\mathrm{T}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}\right)\right)^{-1}\hat{\mathbf{F}}\right)\right.$$

$$\left.\cdot\ \overline{\mathrm{diag}}\left(\hat{\mathbf{F}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}^{*\mathrm{T}}\right)\right)^{-1}\underline{\hat{\mathbf{H}}}_{\mathrm{U}}\underline{\mathbf{H}}^{*\mathrm{T}}\hat{\mathbf{F}}^{-1}\right)\right]_{k_{\mathrm{M}},k_{\mathrm{M}}}, \quad (15)$$

$$N^{(k_{\mathrm{M}})} = \sigma^2\left[\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}^{*\mathrm{T}}\right)\right)^{-1}\underline{\hat{\mathbf{H}}}_{\mathrm{U}}\underline{\hat{\mathbf{H}}}_{\mathrm{U}}^{*\mathrm{T}}\left(\hat{\mathbf{G}}+\overline{\mathrm{diag}}\left(\underline{\hat{\mathbf{R}}}\right)\right)^{-1}\right]_{k_{\mathrm{M}},k_{\mathrm{M}}}. \quad (16)$$

The above described iterative ZF algorithm is derived from the iterative interference cancellation algorithm with perfect full CSI of the whole system. With appropriately selected significant channels, it is expected that we can still obtain good system performance with partial significant CSI. However, if the partial CSI is imperfect, some system performance degradation is inevitable and will be investigated in Section IV.

IV. NUMERICAL RESULTS

As mentioned above, in realistic cellular systems imperfect CSI is applied in the proposed cooperative DL transmission scheme including adaptive MS scheduling, significant channel selection and JT with partial CSI. In order to investigate the impact of the imperfectness of CSI on the cooperative transmission scheme, some numerical results are provided to assess the system performance.

As shown in Fig. 3, we consider a realistic cellular system with 19 cells including a center cell and 2 tiers of cells around the center cell as the reference scenario. Rayleigh fading channels and a path loss with attenuation exponent $\alpha = 3$ with respect to the distance are considered. In this paper, we investigate the case that the system has strong inter-cell interference, i.e., the MSs are located on circles touching the boundaries of the hexagonal cells. Obviously, if good system performance applying our proposal can be obtained in this case, even better system performance can be expected in the general case that MSs are randomly distributed in each cell since in the general case inherently less inter-cell interference exists in the cellular system. Assuming $N_{\mathrm{M}} = 8$ MSs uniformly distributed on a circle in each cell as shown in Fig. 3, only one MS is selected at each time instant in the considered single subcarrier by the scheduler. We assume each BS is equipped with 3 antennas and each MS is equipped with a single antenna. According to the system model described in Section II, the whole system can be considered as a MIMO system with $K_{\mathrm{A}} = 19 \times 3$ BS antennas and $K_{\mathrm{M}} = 19$ MS antennas. Then JT considering N_{u} significant useful channels and N_{i} significant interference channels for each MS, which is denoted by JT $(N_{\mathrm{u}}, N_{\mathrm{i}})$, is performed with imperfect CSI. In this paper, we will investigate the system performance of the MS in the center cell, i.e., MS $k_{\mathrm{M}} = 1$, when applying JT with imperfect significant CSI to all the MSs in the system. With a constant transmitted energy $E_{\mathrm{s}} = E_{\mathrm{d}} = 1$, the average received useful energy of MS 1 when applying MF is $E_{\mathrm{MF}} = \mathrm{E}\{\sum_{k_{\mathrm{A}}} \underline{H}^{(1,k_{\mathrm{A}})}\underline{H}^{(1,k_{\mathrm{A}})^*}\}$. In the simulations, we assume the ratio of the average received useful energy to the noise variance σ_{N}^2 to be $10\log_{10}\{\gamma_{\mathrm{N}}\} = 10\log_{10}\{E_{\mathrm{MF}}/\sigma_{\mathrm{N}}^2\} = 20\mathrm{dB}$. Similarly, we use the ratio $10\log_{10}\{\gamma_{\mathrm{E}}\} = 10\log_{10}\{E_{\mathrm{MF}}/\sigma_{\mathrm{E}}^2\}$ of the average received useful energy to the variance of channel estimate error σ_{E}^2 to indicate the extent of the imperfectness of CSI.

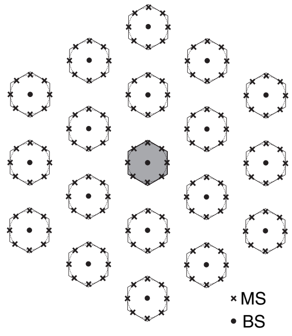


Fig. 3. 19-cell cellular system

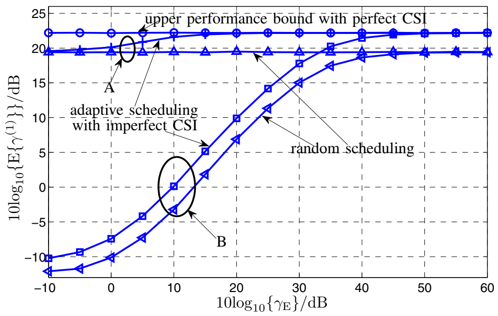


Fig. 4. Average SNIR $\mathrm{E}\{\gamma^{(1)}\}$ as a function of γ_{E}, investigation of the impact of imperfect CSI on adaptive scheduling, applying JT(57, 1026), $10\log_{10}\{\gamma_{\mathrm{N}}\} = 20\mathrm{dB}$, A: significant channel selection and JT are based on perfect CSI, B: significant channel selection and JT are based on imperfect CSI.

Firstly, we investigate the impact of imperfect CSI on the adaptive MS scheduling based on the numerical results in Fig. 4. When we assume that the significant channel selection and JT are based on perfect CSI, we can clearly see the performance degradation caused by imperfect CSI used in the adaptive scheduling. With increasing imperfectness of the CSI, i.e., decreasing γ_{E}, the system performance when applying adaptive scheduling approaches that of applying random scheduling. Under the realistic assumption that the significant channel selection and the JT with partial CSI are based on imperfect CSI, the system performance sharply decreases when the extent of imperfectness of CSI increases.

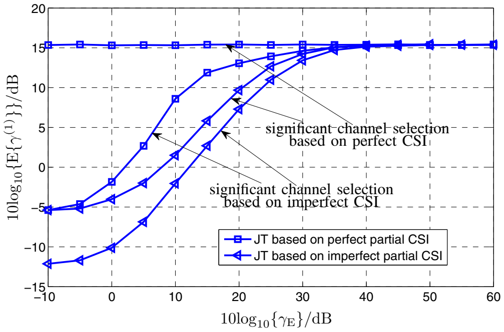


Fig. 5. Average SNIR $\mathrm{E}\{\gamma^{(1)}\}$ as a function of γ_{E}, investigation of the impact of imperfect CSI on significant channel selection and JT with partial CSI, applying JT(4, 10), $10\log_{10}\{\gamma_{\mathrm{N}}\} = 20\mathrm{dB}$.

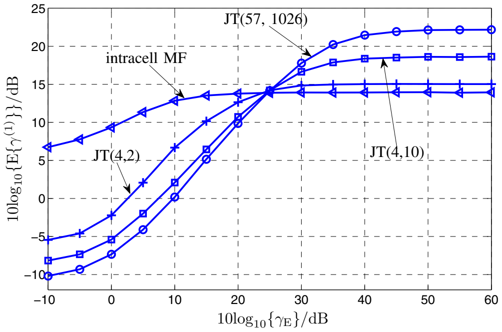


Fig. 6. Average SNIR $\mathrm{E}\{\gamma^{(1)}\}$ as a function of γ_{E} considering imperfect CSI in the whole cooperative transmission scheme including adaptive scheduling, investigation of the impact of imperfect CSI on JT with different numbers of significant channels selected following strategies, $10\log_{10}\{\gamma_{\mathrm{N}}\} = 20\mathrm{dB}$.

The performance degradation caused by imperfect CSI used in the significant channel selection and JT is much larger than the performance degradation caused by replacing adaptive scheduling with random scheduling. In a word, when the extent of imperfectness of CSI is large, it is not worth much applying adaptive scheduling in our JT scheme. Secondly, considering random scheduling, we investigate the impact of imperfect CSI on the significant channel selection and the JT with partial CSI. As shown in Fig. 5, using the performance in the unrealistic case that perfect CSI is used throughout the whole cooperative transmission scheme as reference, we can see the performance degradation caused by imperfect CSI used in the significant channel selection and the JT with partial CSI respectively. Finally, we consider imperfect CSI in the whole JT scheme, i.e., adaptive scheduling, significant channel selection, and JT with partial CSI. It is shown in Fig. 6 that when the available CSI is imperfect the answer to the question how many significant useful channels and significant interference channels should be considered to obtain the optimum system performance depends on the extent of the imperfectness of CSI. $\mathrm{JT}(57, 1026)$, which is identical to full ZF JT, is not always the best choice anymore. The simple intracell MF can be more robust when the extent of imperfectness is large. Other possible numbers of significant channels can also be chosen in realistic systems according to their level of knowledge of the available CSI and other system parameters such as the background noise variance.

V. CONCLUSIONS

In this paper, a novel assessment of the impact of imperfect CSI is performed based on a practical transmission scheme, i.e., the cooperative DL transmission scheme with partial CSI including adaptive scheduling, significant channel selection and JT with partial CSI. Generally, it can be concluded that the larger the imperfectness of CSI is, the less CSI should be considered in JT to obtain the optimum system performance.

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