Distributed MIMO for Cellular Networks with Multihop Transmission Protocols

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***Abstract*— We consider the downlink in a MIMO cellular network utilizing two-hop transmission protocols with fixed infrastructure relay stations to enhance coverage and data rates in a cell. We investigate the potential of relaying protocols in the case when a mobile station is in the communication range of two relays but not in the range of the base station. Since the relays are mounted at fixed positions we assume that the base station has knowledge about the channels to the relays which enables spatial precoding of the transmit data. We show that in the first hop the use of MIMO broadcast coding techniques, where the base station transmits only a subset of the data which is intended for the mobile station to each relay, has a superior performance compared to a MIMO multicast, where the whole data is transmitted to both relays.**

I. Introduction

Node cooperation strategies have received a lot of attention in the research community over the last years. Important contributions to this field have been presented in [1]–[7]. The major focus is thereby on half-duplex cooperative relaying strategies since multihop communication is an efficient means to enhance the communication range of a transmitter.

Future cellular networks will operate at higher carrier frequencies than today's 2G and 3G systems. On the one hand this makes multiple antennas even at small mobile devices possible, on the other hand path loss is considerably increased which in turn increases the number of required base stations (BS) to achieve full coverage. Simple dedicated infrastructure relay stations (RS), which do not have a wired connection to the backbone, can be utilized to reduce the required BS density [8]. These RSs are placed intentionally around a BS (e.g., mounted on lamp posts) and have sufficient power supply. To achieve a full coverage the single coverage areas of the RSs have to overlap (see Fig. 1). This enables cooperative relaying strategies to serve mobile stations (MS) within these overlapping zones by multiple relays. These cooperative relaying strategies vary from simple relay selection to distributed space-time coding and distributed spatial multiplexing.

In this work we investigate the scenario where two RSs are used for a downlink connection to the MS. Special emphasis is on the data transmission from the BS to both RSs. Since the RSs are placed intentionally at fixed places it is reasonable to assume channel state information (CSI) at the BS. Both ends, BS and RSs, provide multiple antennas what therefore leads to a multiuser MIMO broadcast scenario [9]. This multiuser MIMO scenario can be utilized by two different approaches which are studied in this work. The first approach is that the BS transmits the full data which is intended for the MS to each RS. Since the RSs receive the same message we refer to this case as *multicast broadcasting* approach. In the second hop both RSs use a common space-time code to transmit the data to the MS. This approach is the apparent extension of the protocols of [2] to the case of multiple antenna nodes. The second approach is that the data which is intended for the MS is divided in two parts. The BS then transmits only one part of the data to each RS. We refer to this case as *unicast broadcasting* approach. This approach is theoretically described by the MIMO broadcast channel (BC) [10]. In the second hop the RSs have to cooperate with respect to a MIMO multiple access channel (MAC) and its corresponding rate region [11], [12].

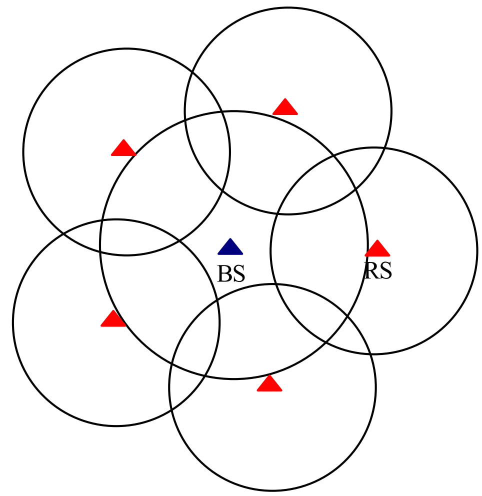

Fig. 1. Single cell of cellular network with multiple RS to enhance coverage. Coverage areas overlap each other.

It has recently been shown that the capacity of the MIMO BC can be achieved by the use of dirty paper coding (DPC) [10], [13]–[16]. DPC is based on the fact that a channel in which the transmitter knows the interference in advance has the same capacity as a channel without the interference [17]. However, the drawback of DPC is that it is difficult to implement in realistic systems. Therefore, several suboptimal schemes for the MIMO BC have been proposed. One straightforward approach is to invert the equivalent MIMO channel between the transmitter and all receivers. The drawback of this channel inversion is the requirement for suppression of

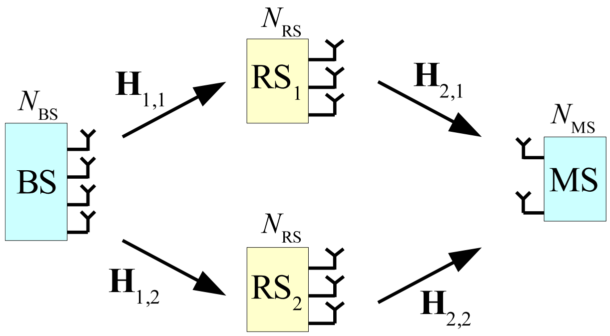

Fig. 2. System model with one BS, two RSs, and one MS.

all interference at the receive antennas. An approach which allows residual interference is presented in [18]. Both schemes are introduced for receivers with only one antenna. In [19] the zero-forcing approach is generalized to receivers with multiple antennas. The equivalent MIMO channel between transmitter and all receivers is only block-diagonalized rather than inverted completely. This is achieved by projecting the transmit signals of each user on the null space of the interfering channels. We refer to this block diagonalization approach as Block-Zero Forcing (Block-ZF).

In the following we show that the use of MIMO BC precoding techniques in the first hop leads to a reduction in transmit power at the BS to achieve the same overall data rate between BS and MS as with the multicast broadcasting approach. Furthermore, we show that the cooperation between the two RSs achieves higher data rates than pure relaying with only one RS.

II. Scenario and System Model

We consider a cellular downlink scenario where a BS with N_{BS} antennas serves a MS with N_{MS} antennas. The MS is in communication range of $N_{\mathrm{r}} = 2$ RSs which are both equipped with N_{RS} antennas but not in the communication range of the BS. We require less antennas at each RS as at the BS, i.e., $N_{\mathrm{RS}} < N_{\mathrm{BS}}$. We consider i.i.d. block fading channels between all nodes which are assumed to be frequency flat for simplicity reasons. Extending the presented analysis to the case of frequency selective fading channels is straightforward, e.g., by assuming OFDM modulation. The channel matrix between BS and RS i, where $i \in \{1, 2\}$, is denoted by $\mathbf{H}_{1,i} \in \mathbb{C}^{N_{\mathrm{RS}} \times N_{\mathrm{BS}}}$, whereas the channel matrix between RS i and MS is denoted by $\mathbf{H}_{2,i} \in \mathbb{C}^{N_{\mathrm{MS}} \times N_{\mathrm{RS}}}$. Note that we assume that the BS has knowledge of $\mathbf{H}_{1,1}$ and $\mathbf{H}_{1,2}$ which is a reasonable assumption because of the fixed RS positions. The MS usually has higher mobility. Therefore we assume that the RSs have no knowledge about the channel to the MS. The transmit power of the BS and RS i are denoted by P_{BS} and $P_{\mathrm{RS}}^{(i)}$. We assume circular symmetric complex Gaussian noise contributions with zero mean at the nodes whereby the noise variances of each RS and the MS are given by σ^2_{RS} and σ^2_{MS}, respectively.

III. Approach A: Multicast Broadcasting

The first approach applies the space-time coded cooperation protocol of [2] to the case of multiple antenna nodes. In this scheme the BS performs multicast broadcasting in the first hop, i.e., it transmits the same data $\mathbf{x} \in \mathbb{C}^{N_{\mathrm{BS}}}$ to both RSs. The supported rate between BS and RS i is given by

$$I_{1,i}^{(\mathrm{mc})} = \log_2 \left| \mathbf{I}_{N_{\mathrm{RS}}} + \frac{1}{\sigma^2_{\mathrm{RS}}} \mathbf{H}_{1,i} \mathbf{\Gamma} \mathbf{H}_{1,i}^{\dagger} \right|, \qquad (1)$$

where $\mathrm{tr}\left(\mathbf{\Gamma}\right) = \mathrm{tr}\left(\mathrm{E}\left\{\mathbf{x}\mathbf{x}^{\dagger}\right\}\right) = P_{\mathrm{BS}}$. Since we require both relays to decode the full message the rate of the BS in the first can maximally be the minimum of both supported rates, i.e., $\min\left\{I_{1,1}^{(\mathrm{mc})}; I_{1,2}^{(\mathrm{mc})}\right\}$. Note that the existing literature on the optimization of $\mathbf{\Gamma}$ is limited to the case of single antenna receivers [20]. Since the optimization of $\mathbf{\Gamma}$ in the case of multiple receive antennas is out of the scope of this work we only consider spatially white transmit signals at the BS, i.e., $\mathbf{\Gamma} = P_{\mathrm{BS}}/N_{\mathrm{BS}} \cdot \mathbf{I}_{N_{\mathrm{BS}}}$. However, this is certainly suboptimal in the case of CSI at the BS.

In the second hop both RSs transmit a distributed space-time code with maximum rate

$$I_2^{(\mathrm{stc})} = \log_2 \left| \mathbf{I}_{N_{\mathrm{MS}}} + \frac{P_{\mathrm{RS}}^{(1)} \mathbf{H}_{2,1} \mathbf{H}_{2,1}^{\dagger} + P_{\mathrm{RS}}^{(2)} \mathbf{H}_{2,2} \mathbf{H}_{2,2}^{\dagger}}{N_{\mathrm{RS}} \sigma^2_{\mathrm{MS}}} \right|, \quad (2)$$

where we assume spatially white transmit signals at each RS because of the lack of CSI of the channel to the MS.

Since in this relaying protocol both RSs and the MS have to be able to decode the full data, the overall data rate over the two hops is given by the minimum of all supported rates, i.e.,

$$R^{(\mathrm{mc,stc})} = \frac{1}{2} \min\left\{I_{1,1}^{(\mathrm{mc})}; I_{1,2}^{(\mathrm{mc})}; I_2^{(\mathrm{stc})}\right\}. \qquad (3)$$

The factor $1/2$ thereby reflects the two orthogonal channel uses which are needed for the two-hop traffic pattern.

IV. Approach B: Unicast Broadcasting

In this approach the BS transmits only part of the data which is intended for the MS to each RS, i.e., it performs unicast broadcasting. Therefore, unlike the previous multicast approach the transmitted signal $\mathbf{x}$ is now a superposition of multiple signals designated for different RSs, i.e., $\mathbf{x} = \mathbf{x}_1 + \mathbf{x}_2$. In the following we derive the rate between BS and MS if the first hop is utilized by means of MIMO BC precoding techniques. For this BC precoding we study two possibilities. The first one is DPC [17] and the second one is Block-ZF [19].

A. First Hop: Broadcast Channel

1) Dirty Paper Coding: The goal of DPC is to choose the transmit signals $\mathbf{x}_1$ and $\mathbf{x}_2$ with covariance matrices $\mathbf{\Lambda}_1 = \mathrm{E}\left\{\mathbf{x}_1\mathbf{x}_1^{\dagger}\right\}$ and $\mathbf{\Lambda}_2 = \mathrm{E}\left\{\mathbf{x}_2\mathbf{x}_2^{\dagger}\right\}$ subject to the transmit power constraint $\sum_{k=1}^{2} \mathrm{tr}\left(\mathbf{\Lambda}_k\right) = P_{\mathrm{BS}}$ such that both RSs are able to decode their data. DPC makes use of the fact that the capacity of a channel where the transmitter has knowledge of the interference is as large as the capacity without interference [17]. This result can be applied to MIMO BC precoding at the BS when choosing codewords for both RSs. In DPC the BS first picks a codeword for one RS. Afterwards the BS chooses a codeword for the other RS under full awareness of the interference the codeword intended for the first RS causes at the second RS. From the receiver point of view this leads to the situation where the first RS sees the signal intended for the second RS as interference, but the second RS does not see any interference. Note that the ordering of this procedure certainly influences the supported rates at each RS since only the second RS can decode free of interference.

The achievable rates between the BS and the two RSs assuming DPC are given by

$$I_{1,i}^{(\mathrm{bc})} = \log_2 \frac{\left|\sigma_{\mathrm{RS}}^2 \mathbf{I}_{N_{\mathrm{RS}}} + \mathbf{H}_{1,i}\left(\mathbf{\Lambda}_i + \mathbf{\Lambda}_j\right)\mathbf{H}_{1,i}^{\dagger}\right|}{\left|\sigma_{\mathrm{RS}}^2 \mathbf{I}_{N_{\mathrm{RS}}} + \mathbf{H}_{1,i}\mathbf{\Lambda}_j \mathbf{H}_{1,i}^{\dagger}\right|}, \quad (4)$$

$$I_{1,j}^{(\mathrm{bc})} = \log_2 \left|\mathbf{I}_{N_{\mathrm{RS}}} + \frac{1}{\sigma_{\mathrm{RS}}^2}\mathbf{H}_{1,j}\mathbf{\Lambda}_j \mathbf{H}_{1,j}^{\dagger}\right|, \quad (5)$$

where $i, j \in \{1, 2\}$. The optimization of the covariance matrices $\mathbf{\Lambda}_k$ for each RS can be done via the dual MAC problem [15], [16]. The goal for this optimization can be either the sum-rate [21], symmetric rates [22], or the minimization of P_{BS} subject to individual rate constraints [23].

2) Block Zero Forcing: In the Block-ZF scheme the signals for each RS are linearly precoded by the matrix $\mathbf{W}_{1,j} \in \mathbb{C}^{N_{\mathrm{BS}} \times N_{\mathrm{s}}}$, where $j \neq i$ and $N_{\mathrm{s}} = N_{\mathrm{BS}} - N_{\mathrm{RS}}$. Let $\mathbf{s}_i \in \mathbb{C}^{N_{\mathrm{s}}}$ be the data the BS transmits to RS i. The resulting transmit signal at the BS is therefore

$$\mathbf{x} = \mathbf{x}_1 + \mathbf{x}_2 = \mathbf{W}_{1,2}\mathbf{s}_1 + \mathbf{W}_{1,1}\mathbf{s}_2. \quad (6)$$

The precoding matrix $\mathbf{W}_{1,j}$ is calculated by means of the *Block Diagonalization Algorithm* [19] such that it is orthogonal to the channel matrix $\mathbf{H}_{1,j}$. That is, $\mathbf{W}_{1,j}$ is defined by the null space of $\mathbf{H}_{1,j}$. Thus $\mathbf{s}_i$ will not be received at RS $j \neq i$. Since N_{RS} degrees of freedom are needed to null the interference to the other RS only N_{s} independent data streams can be transmitted to each RS. The precoding matrices are normalized to $\mathrm{tr}\left(\mathbf{W}_{1,j}\mathbf{W}_{1,j}^{H}\right) = 1$.

Since the RSs receive their signal interference free, the achievable rates between BS and the RSs can be expressed as

$$I_{1,1}^{(\mathrm{bc})} = \log_2 \left|\mathbf{I}_{N_{\mathrm{RS}}} + \frac{1}{\sigma_{\mathrm{RS}}^2}\mathbf{H}_{1,1}\mathbf{W}_{1,2}\mathbf{\Sigma}_1 \mathbf{W}_{1,2}^{\dagger}\mathbf{H}_{1,1}^{\dagger}\right|, \quad (7)$$

$$I_{1,2}^{(\mathrm{bc})} = \log_2 \left|\mathbf{I}_{N_{\mathrm{RS}}} + \frac{1}{\sigma_{\mathrm{RS}}^2}\mathbf{H}_{1,2}\mathbf{W}_{1,1}\mathbf{\Sigma}_2 \mathbf{W}_{1,1}^{\dagger}\mathbf{H}_{1,2}^{\dagger}\right|, \quad (8)$$

where $\mathbf{\Sigma}_i = \mathrm{E}\left\{\mathbf{s}_i \mathbf{s}_i^{\dagger}\right\}$ denotes the covariance matrix of the transmit signal to RS i with $\sum_{i=1}^{2} \mathrm{tr}\left(\mathbf{\Sigma}_i\right) = P_{\mathrm{BS}}$. These covariance matrices can be, e.g., optimized with respect to the individual rate constraints of the RSs in the second hop or with respect to the sum-rate of the first hop. Compared to DPC the optimization of $\mathbf{\Sigma}_i$ is pretty simple since the optimization problem is only coupled by the sum transmit power constraint at the BS.

B. Second Hop: Multiple Access Channel

In the second hop each RS has independent data to transmit to the MS. This situation is theoretically described by the MIMO MAC [11], [12]. As in Section III we consider the transmit signals at the RSs to be spatially white. In this case the rate region is the well known pentagon defined by the three equations

$$R_{2,1}^{(\mathrm{mac})} \leq I_{2,1}^{(\mathrm{mac})}, \quad (9)$$

$$R_{2,2}^{(\mathrm{mac})} \leq I_{2,2}^{(\mathrm{mac})}, \quad (10)$$

$$R_{2,1}^{(\mathrm{mac})} + R_{2,2}^{(\mathrm{mac})} \leq I_{2}^{(\mathrm{mac})}, \quad (11)$$

where

$$I_{2,i}^{(\mathrm{mac})} = \log_2 \left|\mathbf{I}_{N_{\mathrm{RS}}} + \frac{P_{\mathrm{RS}}^{(i)}}{N_{\mathrm{RS}}\sigma_{\mathrm{MS}}^2}\mathbf{H}_{2,i}\mathbf{H}_{2,i}^{\dagger}\right|, \quad (12)$$

with $i \in \{1, 2\}$ and

$$I_{2}^{(\mathrm{mac})} = \log_2 \left|\mathbf{I}_{N_{\mathrm{MS}}} + \frac{P_{\mathrm{RS}}^{(1)}\mathbf{H}_{2,1}\mathbf{H}_{2,1}^{\dagger} + P_{\mathrm{RS}}^{(2)}\mathbf{H}_{2,2}\mathbf{H}_{2,2}^{\dagger}}{N_{\mathrm{RS}}\sigma_{\mathrm{MS}}^2}\right|. \quad (13)$$

To maximize the transmission rate to the MS, the RSs have to choose their codebooks such that their rates add up to the sum-rate $I_2^{(\mathrm{mac})}$ by fulfilling the individual constraints (9) and (10), respectively.

Note that the rate region (9)–(11) only describes the situation of the second hop without regarding the first hop. Taking the first hop into account we have to add the constraints that the transmit rate of the RSs cannot be larger than the rate they have received from the BS, i.e.,

$$R_{2,1}^{(\mathrm{mac})} \leq I_{1,1}^{(\mathrm{bc})}, \quad (14)$$

$$R_{2,2}^{(\mathrm{mac})} \leq I_{1,2}^{(\mathrm{bc})}. \quad (15)$$

With this constraints, we can express the two-hop rate region for this approach as

$$R_{2,1}^{(\mathrm{mac})} \leq \min\left\{I_{1,1}^{(\mathrm{bc})}, I_{2,1}^{(\mathrm{mac})}\right\}, \quad (16)$$

$$R_{2,2}^{(\mathrm{mac})} \leq \min\left\{I_{1,2}^{(\mathrm{bc})}, I_{2,2}^{(\mathrm{mac})}\right\}, \quad (17)$$

$$R_{2,1}^{(\mathrm{mac})} + R_{2,2}^{(\mathrm{mac})} \leq I_{2}^{(\mathrm{mac})}. \quad (18)$$

The overall data rate between BS and MS is given by

$$R^{(\mathrm{bc,mac})} = \frac{1}{2}\min\left\{\sum_{i=1}^{2}\min\left\{I_{1,i}^{(\mathrm{bc})}; I_{2,i}^{(\mathrm{mac})}\right\}; I_{2}^{(\mathrm{mac})}\right\}, \quad (19)$$

where the sum in the minimum defines the sum-rate of the first hop given the individual rate constraints at each RS in the second hop.

V. Performance Results

In this section we present the performance of the presented cooperative relaying schemes by means of computer simulations. We compare the presented schemes to two reference schemes.

1) Reference I: RS Selection: In this reference scenario the MS is only served by one RS. Furthermore, only the BS→RS→MS route is selected which supports the higher rate between BS and MS. The overall rate is thus given by

$$R^{(\mathrm{sel})} = \frac{1}{2} \max_{i\in\{1,2\}} \min\left\{I_{1,i}^{(\mathrm{one})}; I_{2,i}^{(\mathrm{one})}\right\}, \tag{20}$$

where

$$I_{1,i}^{(\mathrm{one})} = \log_2 \left| \mathbf{I}_{N_{\mathrm{RS}}} + \frac{1}{\sigma_{\mathrm{RS}}^2} \mathbf{H}_{1,i} \mathbf{\Theta} \mathbf{H}_{1,i}^{\dagger} \right|, \tag{21}$$

$$I_{2,i}^{(\mathrm{one})} = \log_2 \left| \mathbf{I}_{N_{\mathrm{MS}}} + \frac{P_{\mathrm{RS}}^{(i)}}{N_{\mathrm{RS}}\sigma_{\mathrm{MS}}^2} \mathbf{H}_{2,i} \mathbf{H}_{2,i}^{\dagger} \right|, \tag{22}$$

are the supported rates of the two hops. The index $i \in \{1, 2\}$ denotes the BS→RS→MS routes. The covariance matrix $\mathbf{\Theta}$ is either chosen to be uniform in the case of no CSI at the BS (i.e., $\mathbf{\Theta} = P_{\mathrm{BS}}/N_{\mathrm{BS}} \cdot \mathbf{I}_{N_{\mathrm{BS}}}$) or optimized by the water-filling (WF) procedure [24] to maximize the rate within the first hop. Note that CSI about the second hop channels is necessary for the selection process.

2) Reference II: One RS: In this reference scenario the BS→RS→MS route assignment is fixed and not chosen adaptively as in the previous reference scenario. Assuming that, e.g., RS 1 serves the MS the overall rate is given by

$$R^{(\mathrm{one})} = \frac{1}{2} \min\left\{I_{1,1}^{(\mathrm{one})}; I_{2,1}^{(\mathrm{one})}\right\}, \tag{23}$$

where the covariance matrix $\mathbf{\Theta}$ is either uniform or optimized as for the previous reference scenario.

Simulation Setup: In the simulations we consider i.i.d. channel coefficients which are distributed as complex normal with zero mean and unit variance, i.e., $\mathcal{CN}(0, 1)$. For the relaying schemes where two RSs cooperate in the second hop we assume that both RSs have the same distance to the MS. Further, both RSs have the same transmit power, i.e.,

$$P_{\mathrm{RS}}^{(1)} = P_{\mathrm{RS}}^{(2)} = \frac{P_{\mathrm{RS,sum}}}{2}.$$

In the reference scenarios the transmit power is set to $P_{\mathrm{RS}}^{(i)} = P_{\mathrm{RS,sum}}$ since only one RS is active. Thus, we compare the schemes on basis of the same transmit power in the second hop. We define the SNR at the MS as

$$\mathrm{SNR}_{\mathrm{MS}} = \frac{P_{\mathrm{RS,sum}}}{\sigma_{\mathrm{MS}}^2}. \tag{24}$$

In the simulation we fixed $\mathrm{SNR}_{\mathrm{MS}}$ and varied transmit power at the BS P_{BS} with fixed σ_{RS}^2. We define the relative SNR at the RSs as

$$\mathrm{SNR}_{\mathrm{RS,rel}} = \frac{P_{\mathrm{BS}}/\sigma_{\mathrm{RS}}^2}{\mathrm{SNR}_{\mathrm{MS}}}. \tag{25}$$

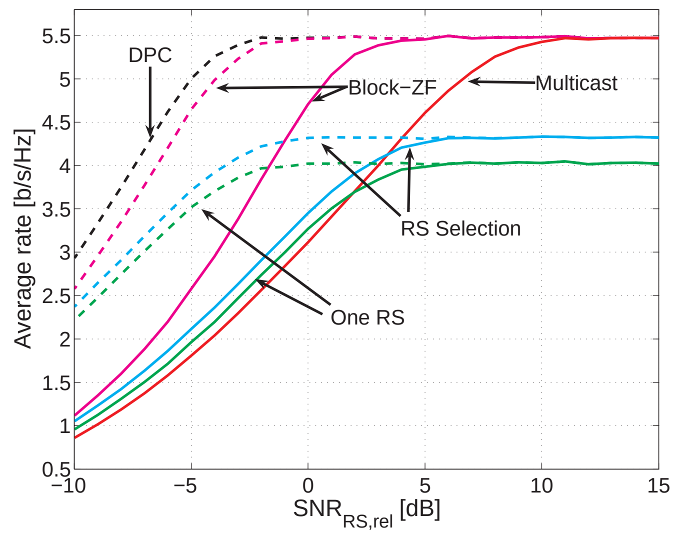

Fig. 3. Average rate versus the relative $\mathrm{SNR}_{\mathrm{RS}}$ for a system with $N_{\mathrm{BS}} = 8$, $N_{\mathrm{RS}} = 2$, and $N_{\mathrm{MS}} = 4$ antennas. $\mathrm{SNR}_{\mathrm{MS}} = 10$dB. Solid lines correspond to the cases where the covariance matrices are not optimized (i.e., weighted identity matrix), whereas dashed lines correspond to optimized covariance matrices.

In Fig. 3 the average rate is shown for a fixed $\mathrm{SNR}_{\mathrm{MS}} =$ 10dB versus $\mathrm{SNR}_{\mathrm{RS,rel}}$. We consider a system with $N_{\mathrm{BS}} = 8$, $N_{\mathrm{RS}} = 2$, and $N_{\mathrm{MS}} = 4$ antennas. It can be observed that all curves saturate in the high SNR regime. This is because of the fixed SNR in the second hop. Therefore the rate of the second hop is limited by this fixed SNR. Increasing the transmit power at the BS P_{BS} cannot improve the overall rate above the achievable rate of the second hop. It can be seen that the cooperation of two RSs leads to a considerable improvement in terms of rates between BS and MS compared to the case where only one RS is active. Compared to the RS selection scheme (Reference I) the gain in average rate is 1 b/s/Hz. This large gain comes from the fact that only with two RSs the full spatial multiplexing gain of 4 can be achieved. If the MS is only served by one RS the spatial multiplexing gain in the second hop is limited to 2. The gain of the unicast broadcasting approach (cf. Section IV) in terms of required transmit power at the BS compared to the multicast broadcasting approach (cf. Section III) is impressive. The curves show that DPC saturates with 12 dB less transmit power. Even the Block-ZF with spatially white input signals requires nearly 6 dB less transmit power.

In Fig. 4 the average rate is shown for a fixed $\mathrm{SNR}_{\mathrm{MS}} =$ 10dB versus $\mathrm{SNR}_{\mathrm{RS,rel}}$. We consider a system with $N_{\mathrm{BS}} = 8$, $N_{\mathrm{RS}} = 4$, and $N_{\mathrm{MS}} = 4$ antennas. It can be seen that the cooperation of two RSs still leads to higher rates between BS and MS compared to the case of one RS. However, the gain in average rate is decreased compared to Fig. 3 since now already one RS utilizes the full spatial multiplexing gain of 4 in the second hop. The reduction of transmit power at the BS of DPC compared to the multicast broadcasting approach is still around 5 dB.

Note that in the simulations only the case of equal distances

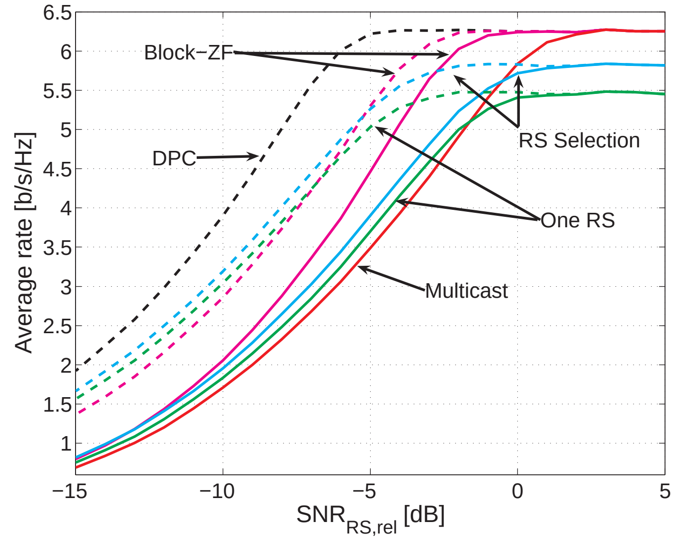

Fig. 4. Average rate versus the relative $\mathrm{SNR}_{\mathrm{RS}}$ for a system with $N_{\mathrm{BS}} = 8$, $N_{\mathrm{RS}} = 4$, and $N_{\mathrm{MS}} = 4$ antennas. $\mathrm{SNR}_{\mathrm{MS}} = 10\mathrm{dB}$. Solid lines correspond to the cases where the covariance matrices are not optimized (i.e., weighted identity matrix), whereas dashed lines correspond to optimized covariance matrices.

between the MS and the RSs is considered. Thus, both RSs contribute equally (at least in average) to the performance. In a more realistic scenario one would have to consider also different path loss or shadowing on both RS to MS links. It is likely that in this case the RS selection scheme works even better than the scheme presented in Section III and IV if no power allocation between both RSs is considered. However, RS selection requires CSI knowledge about the second hop.

VI. Conclusions

In this paper we presented relaying strategies for the downlink of a MIMO two-hop cellular network. We considered the case that a MS is in the communication range of two RSs but not in the range of the BS. The two RSs cooperate to serve the MS. We showed that by means of this cooperation higher data rates at the MS can be achieved compared to the single RS case. Furthermore we showed that by using MIMO BC precoding techniques the required transmit power at the BS can be minimized compared to schemes which do not use the knowledge about the channels between BS and RSs. This reduction in transmit power reduces the interference range of the BS and therefore helps to improve the frequency reuse distance within the cellular network.

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