Beamforming with Relays in Heterogeneous Networks Based on Correlation Knowledge

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***Abstract*—Considering a network with a frequency reuse one where intercell interference is a limiting factor, an unfair distribution of the signal-to-interference-plus-noise ratio (SINR) for different users results. A method to improve the SINR is fair multicell max–min beamforming (MBF). In addition to intercell interference, shadow fading is another performance limiting factor. Strongly shadowed users can decrease the performance of all jointly scheduled users if fairness is desired. To overcome this shadow fading effect, this paper investigates one-way half-duplex decode-and-forward relays in combination with MBF. The user is served only by the relay in the second hop and in the first hop only BS transmits the signal to the relay. In large networks, obtaining instantaneous channel state information (CSI) is difficult, therefore, the algorithm proposed in this paper is based on long-term CSI in the form of correlation knowledge. In addition to sum rate performance energy efficiency becomes a much more important issue. This paper proposes an algorithm which can achieve a higher performance as networks without relays with 20% reduced transmit power.**

***Index Terms*—Multiuser, max–min beamforming, decode-and-forward relays, long-term CSI**

I. Introduction

This paper investigates a multicell network with a frequency reuse factor of one. In such network, especially cell edge users are subject to intercell interference. An unfair distribution of the signal-to-interference-plus-noise-ratio (SINR) of all jointly served users can be the result. In addition to intercell interference, shadow fading is another performance limiting factor. Especially in networks where fairness is desired, strongly shadowed users can deteriorate the performance of all jointly active users. This paper combines two technologies to overcome the interference and shadow fading problem:

- Coordinated max–min beamforming (MBF) is a well known technique to deal with interference in a multiple input single output (MISO) channel. It results in a fair distribution of the SINR among the users. In some cases even a balanced SINR can be achieved.
- Relays are a well known solution to overcome the shadowing problem. Shadowed users can gain a larger spatial diversity or an improved received power of the desired signal due to reduced distance or by a line-of-sight (LOS) connection to a relay.

Scenario: The same multicell network architecture as in [1] is used in this paper. Each cell is equipped with one base station (BS) and two relay stations (RSs) arrays. Each BS has a height of 32 meters and the decode-and-forward half-duplex RSs have a height of 20 meters. Each station (BS or RS) consists of three sectors with a 120° antenna pattern. To guarantee a strong backbone (BS-RS) link, this paper considers a static LOS connection in a rooftop-to-rooftop scenario.

Related work: The information theoretical fundamentals of the relay channel were investigated in [2]. In the later work [3], space-time-diversity achieving half-duplex relay protocols called selective relaying or selection decode-and-forward (SDF) were investigated. In [3], the BS transmits to the RS and the user in the first hop. In the second hop the relay forwards the correctly decoded signal to the user. A diversity gain is achieved due to the relayed transmission. Another transmission scheme is presented in, e.g. [4]. In this article, the BS transmits in a first hop to the RSs. After decoding only the relays forward the signal to the user. The BS keeps silent. In both hops the precoding vectors are optimized. Zero-forcing beamforming was used to avoid mutual interference among the jointly transmitting RSs. However, this scenario is only limited to a single cell. An extension to a multicell scenario is presented in [5]. The authors propose different relay techniques (one-way and two-way relaying) to mitigate intercell interference in a multicell network.

Coordinated beamforming is useful for an interference mitigation. Different approaches have been investigated in the last decades. A low complexity method for the MBF problem is presented in [6], [7]. The authors propose a low complexity and optimal algorithm for the MBF problem where a maximized minimum SINR of all jointly served users given a total power constraint is desired. Later, the articles [8], [9], [10] extend the above mentioned techniques to a multicell scenario with general power constraints.

Beamforming as a promising technique to mitigate interference and can be combined with RSs which is a promising approach to achieve spatial diversity and to overcome the shadow fading effect. Combination of beamforming and relaying are presented in [11] and [1].

Contributions: The recent work [1] proposes a joint resource management and beamforming in a multicell network with RSs at the cell edge region. Decode-and-forward RSs are used, therefore, the beamforming problem is solved independently in the two hops. Using decode-and-forward relays, the total rate over the two hops is the minimum rate achieved in each hop. This paper extends the work of [1] with an additional SINR constraint to constrain the SINR of the second hop to the SINR of the first hop. The SINR of the second hop should be equal to the SINR of the first hop, otherwise power is wasted. Using this additional constraint, a reduction of the transmit

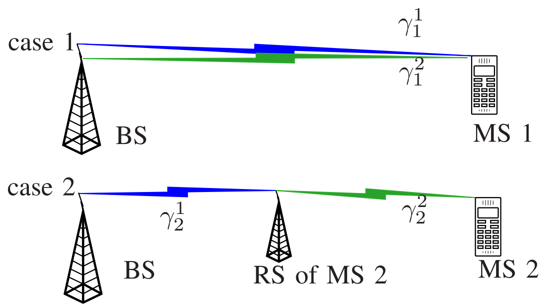

Fig. 1: Possible assignments of BSs and RSs to users (MSs), γ_m^t denotes the instantaneous SINR of the receiving station m in hop t.

power at the RSs is possible. Therefore, a new formulation of the optimization problem is introduced which also results in a low complexity algorithm.

Notation: Lower case and upper case boldface symbols denote vectors and matrices respectively. The nth element of a vector is denoted with $[\mathbf{a}]_n$. The element with indices n, m of a matrix $\mathbf{A}$ is denoted with $[\mathbf{A}]_{n,m}$. The conjugate transpose of a matrix $\mathbf{A}$ is denoted with $\mathbf{A}^H$. The conjugate of a scalar a is denoted with a^*. In $\mathbf{a}_k^t$, t and k denote indexes. The vector $\mathbf{1}$ denotes a vector where each element is a 1 and $\mathbf{I}$ denotes the identity matrix.

II. System Setup and Data Model

The Network layout is the same as in [1] and consists of $N_S = 63$ cooperative antenna arrays, $N_B = 21$ are BSs and $N_R = 42$ are RSs. Each cell has one BS and two RS antenna arrays with $N_A = 4$ antenna elements. Figure 1 illustrates the possible assignments of stations to users. The blue connection denotes the transmission of the first hop, the green connection is the transmission of the second hop. Three types of transmissions are considered in this paper:

1) Case 1 shows the conventional transmission scheme. The BS transmits the signal directly to the user without a RS. Mobile station (MS) 1 is served by a BS in two hops.
2) Case 2 corresponds to the approach presented in [1] and is a transmission of a BS via a RS to MS 2.

All assignments of users to BSs or RSs are based on local long-term CSI. This work considers a network where cases 1 and 2 can jointly occur. Figure 2 and Table I illustrate an example network consisting of two cells. The first column corresponds to hop 1. The second column gives the assignment of the second hop. In the first cell, BS 1 serves user MS 1 over two hops. In cell 2, BS 2 transmits to RS 3 in the first hop and then RS 3 forwards the decoded signal to MS 2. In the first hop, there is intercell interference among the BS-1-to-MS-1 and the BS-2-to-RS-3 link, while in the second hop, there is interference among the BS-1-to-MS-1 and the RS-3-to-MS-2 link.

This paper uses the same signal model as in [1] for the received signal at a RS in the first hop. In the first hop, the channel matrix $\mathbf{H}_{r(i),b}^H \in \mathbb{C}^{N_A \times N_A}$ denotes the MIMO channel between the RS $r(i)$ assigned to user i and the BS b. The transmit beamforming vectors at the BSs are denoted with

TABLE I: Assignment of stations to MSs and time division channel allocation

	1st hop	2nd hop
BS1 cell 1	MS1	MS1
RS1 cell 1		
RS2 cell 1		
BS2 cell 2	RS3	
RS3 cell 2		MS2
RS4 cell 2		

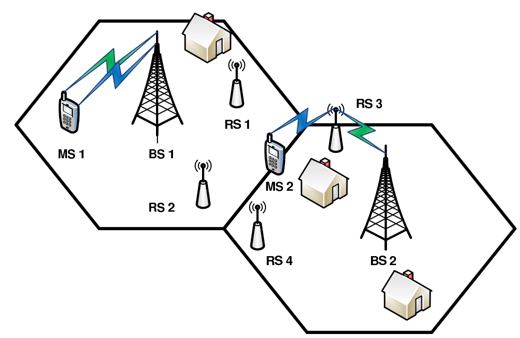

Fig. 2: Two cell example with 2 BSs, 4 RSs and 2 MSs.

$\boldsymbol{\omega}_{b(r(i))}$. The index $b(r(i))$ denotes the BS $b(r(i))$ serving RS $r(i)$ serving the user i. With the assumption of maximum ratio combing (MRC) $\mathbf{V}_{r(i)} = \boldsymbol{\omega}_{b(r(i))}^H \mathbf{H}_{r(i),b(r(i))}$ at the RSs, a RS serving user i receives the signal

$$g_{r(i),k}^1 = \mathbf{V}_{r(i)} \left(\mathbf{H}_{r(i),b(r(i))}^H \boldsymbol{\omega}_{b(r(i))} x_{r(i)} + \mathbf{f}_{r(i),k} + \mathbf{n}_{r(i)} \right) \tag{1}$$

where the interference signal of different BS-RS or BS-MS links is given by

$$\mathbf{f}_{i,k} = \sum_{\substack{b(l) \in \mathcal{B}_k^1, \\ b(l) \neq b(r(i))}} \mathbf{H}_{r(i),b(l)}^H \boldsymbol{\omega}_{b(l)} x_l. \tag{2}$$

The set of active BSs is given by $\mathcal{B}_k^t$, where $t \in \{1, 2\}$ is the index of the hop. The vector $\mathbf{n}_{r(i)}$ is the noise signal and the transmitted symbols are denoted with $x_{r(i)}$ with the assumptions $E\{|x_r|^2\} = 1$ and $E\{x_l x_k^*\} = 0$ if $k \neq l$.

A user i receives at a time instant k in hop $t \in \{1, 2\}$ the signal

$$g_{i,k}^t = \mathbf{h}_{i,s(i)}^H \boldsymbol{\omega}_{s(i)} x_i + \sum_{\substack{s(j) \in \mathcal{S}_k^t, \\ j \neq i, s(j) \neq s(i)}} \mathbf{h}_{i,s(j)}^H \boldsymbol{\omega}_{s(j)} x_j + n_i \tag{3}$$

where $\mathbf{h}_{i,s}$ is the channel vector from the station s serving the user i and $\boldsymbol{\omega}_s$ is the beamforming vector of station s. The set $\mathcal{S}_k^t$ denotes the set of active transmitting stations (BSs or RSs) in hop t of slot k. In the hop $t = 1$ only BSs $s \in \mathcal{B}_k^1$ serve users. A user i is served only by one station $s \in \mathcal{S}_k$ (BS or RS) in the second hop $t = 2$. The noise signal is given by n_i.

Using a decode-and-forward relay, the total achievable rate R_i a user i has over two hops, is given by [4], [5]:

$$R_i = \min\{R_{r(i)}^1, R_i^2\}. \tag{4}$$

Here $R_{r(i)}^1$ is the achievable rate the RS $r(i)$ serving user i achieves in the first hop with an SINR $\gamma_{r(i)}^1$:

$$R_{r(i)}^1 = \log_2(1 + \gamma_{r(i)}^1) \tag{5}$$

and

$$R_i^2 = \log_2(1+\gamma_i^2) \tag{6}$$

is the rate the user achieves in the second hop by a transmission of the RS $r(i)$ to user i. If user i is served by a BS directly, the user receives two different symbols and the rate is given by

$$R_i = R_i^1 + R_i^2. \tag{7}$$

A link over a RS causes, therefore, a capacity loss. All results in Section 4 with (5) and (6) are evaluated based on instantaneous CSI and based on the rates (4) or (7). However, network-wide optimization based on instantaneous CSI over both hops in all cells is difficult due to the fast fading. Two practically relevant assumption are made here:

- The optimization is done based on the long-term CSI in the form of spatial correlation matrices $\mathbf{R}_{m,s}$ [12] between a transmitting station s and a receiving station m. The result is the approximation of the SINRs $\gamma_{r(i)}^1$ or γ_i^2 by the mean SINR and given by:

$$\gamma_m^t \approx \bar{\gamma}_m^t(\mathbf{\Omega}_k^t) = \frac{(\boldsymbol{\omega}_{s(m)}^t)^H \mathbf{R}_{m,s(m)} \boldsymbol{\omega}_{s(m)}^t}{\sum_{\substack{l\in\mathcal{S}_k\\ l\neq s(l)}} (\boldsymbol{\omega}_{s(l)}^t)^H \mathbf{R}_{m,s(l)} \boldsymbol{\omega}_{s(l)}^t + \sigma_m^2}, \tag{8}$$

  where $\mathbf{\Omega}_k^t$ denotes the matrix consisting of all beamforming vectors $\boldsymbol{\omega}_s^t$ of hop t in slot k. The beamforming vectors for different scheduling decisions are computed by a central unit in advance and they can be reused as long as the channels are stationary.
- A rooftop-to-rooftop link is assumed in the first hop. A low complexity receiver technology is feasible at the RSs due to the static BS-RS link. This paper assumes a simple MRC based receiver based on local CSI at the RSs, which has low complexity. Furthermore, the first hop has a low fading, therefore long-term CSI in the form of spatial correlation knowledge is a good performance measure.

The rate, a receiving station achieves, can be approximated as in [13] by:

$$R_m^t = \mathrm{E}\{\log(1+\gamma_m^t)\} \approx \log(1+\bar{\gamma}_m^t(\mathbf{\Omega}_k^t)). \tag{9}$$

The optimization (in contrast to the results) is based on the mean SINR (8) and mean rates (9). A performance loss due to the not considered fading of the second hop is feasible, however, in multicell scenarios the global knowledge of the long-term CSI is easier to obtain.

III. Optimization Problem

This section presents a max–min fair optimization as an extension of a recent work [1] with a reduced overall transmit power. In this study an a priory assignment of either a BS (case 1) or a RS (case 2) to a user i, based on the best local long-term CSI, is made. To achieve fairness in a multicell network, it is desired to maximize the SINR of the weakest link. This problem is called MBF problem (MBP) [6], [10]. The two SINRs in the first and the second hop are decoupled if all transmitting stations are subject to a per-antenna array power constraint, therefore, the previous work [1] separates the beamforming problem in two sub-problems: The MBP in the first hop is:

$$\begin{aligned} \max_{\mathbf{\Omega}_k^1,\gamma} \quad & \gamma \\ \text{s.t.} \quad & \bar{\gamma}_i^1 \geq \gamma \ \ \forall i \in \mathcal{U}_k \cup \mathcal{R}_k \\ & (\boldsymbol{\omega}_b^1)^H \boldsymbol{\omega}_b^1 \leq P_b \quad \forall b \in \mathcal{B}_k^1, \end{aligned} \tag{10}$$

where $\mathcal{U}_k$ denotes the set of active users, $\mathcal{R}_k$ denotes the set of active RSs in slot k, and P_b denotes the allowed power of the beamforming vector. As in [1] the second hop is optimized by:

$$\begin{aligned} \max_{\mathbf{\Omega}_k^2,\gamma} \quad & \gamma \\ \text{s.t.} \quad & \bar{\gamma}_i^2 \geq \gamma \ \ \forall i \in \mathcal{U}_k \\ & (\boldsymbol{\omega}_s^2)^H \boldsymbol{\omega}_s^2 \leq P_s \quad \forall s \in \mathcal{B}_k^2 \cup \mathcal{R}_k. \end{aligned} \tag{11}$$

One further aspect in the network design is a reduced power consumption of the network. In a relay transmission with decode-and-forward relays no power is wasted if $\bar{\gamma}_{r(i)}^1 = \bar{\gamma}_i^2$

This idea results in additional constraints for the MBP of the second hop:

$$\begin{aligned} \max_{\mathbf{\Omega}_k^2,\gamma} \quad & \gamma \\ \text{s.t.} \quad & \bar{\gamma}_{r(i)}^1 \geq \bar{\gamma}_i^2 \geq \gamma \ \ \forall i \in \mathcal{U}_k \\ & (\boldsymbol{\omega}_s^2)^H \boldsymbol{\omega}_s^2 \leq P_s \quad \forall s \in \mathcal{B}_k^2 \cup \mathcal{R}_k. \end{aligned} \tag{12}$$

Here $\bar{\gamma}_{r(i)}^1$ is a parameter representing the mean SINR the RS achieves in the first hop. Hence, the optimized SINR $\bar{\gamma}_i^2$ is constrained by $\bar{\gamma}_{r(i)}^1 \geq \bar{\gamma}_i^2 \geq \gamma$. Another possibility would be an additional constraint of for the SINR of the first hop optimization (10) so that $\bar{\gamma}_{r(i)}^1 = \bar{\gamma}_i^2$. This will result in a similar problem.

If the user is served only by a BS $\bar{\gamma}_{r(i)}^1 = \infty$ there will be no constraint as in (11). The use of the mean SINR will result in a small performance loss due to the fading channels and the decode-and-forward protocol. The idea is here to limit the mean (spatial) SINR of the second hop the mean (spatial) SINR of the first hop. If there is, e.g., always a very low mean SINR in the first hop and a high mean SINR in the second hop, power will be wasted because the instantaneous SINR of the second hop is then often higher than the instantaneous SINR of the first hop. If instantaneous CSI is used for the optimization, power can be saved without performance loss.

The problem (11) is non-convex and difficult to solve. Therefore, this paper regards a different approach which can be solved by uplink-downlink duality:

$$\begin{aligned} d^D(\boldsymbol{\delta}) = \max_{\mathbf{\Omega}_k^2,\gamma} \quad & \gamma \\ \text{s.t.} \quad & \frac{\bar{\gamma}_i^2}{\delta_i} \geq \gamma \ \ \forall i \in \mathcal{U}_k \\ & (\boldsymbol{\omega}_s^2)^H \boldsymbol{\omega}_s^2 \leq P_s \quad \forall s \in \mathcal{B}_k^2 \cup \mathcal{R}_k. \end{aligned} \tag{13}$$

Here $\boldsymbol{\delta} = [\delta_1, \ldots, \delta_M]$ is a parameter vector which scales the SINRs of the problem (13). The objective function is now balancing the ratio $\bar{\gamma}_i^2/\delta_i$. To constrain the SINR of the second hop to the SINR of the first hop, the parameter δ_i is given by:

$$\frac{\bar{\gamma}_i^2}{\delta_i} = \bar{\gamma}_{r(i)}^1 \ \Leftrightarrow \ \delta_i = \frac{\bar{\gamma}_i^2}{\bar{\gamma}_{r(i)}^1}. \tag{14}$$

A low complexity algorithm for the MBP with general power constraints is proposed in [10]. It is based on the duality of an inner problem, which corresponds to a MBP with a weighted sum power constraint:

$$f^D(\boldsymbol{\delta}, \boldsymbol{\mu}) = \max_{\boldsymbol{\Omega}} \min_{i \in \mathcal{U}_k} \frac{\bar{\gamma}_i^2}{\delta_i} \tag{15}$$

$$\text{s.t.} \sum_{s \in \mathcal{B}_k^2 \cup \mathcal{R}_k} (\boldsymbol{\omega}_s^2)^H \mathbf{M}_s \boldsymbol{\omega}_s^2 \leq P. \tag{16}$$

The weighting factor $\mathbf{M}_s = \mu_s \mathbf{I}$ concatenated in a vector $\boldsymbol{\mu} = [\mu_1, \ldots, \mu_M]$ has to be determined to fulfill the per-antenna array power constraints. In [10], an update of the matrices $\mathbf{M}_s$ is presented such that the per-station power constraints are met. The total power of the inner problem is given by: $P = \boldsymbol{\mu}^T \boldsymbol{\rho}$, with $\boldsymbol{\rho} = [P_1, \ldots, P_M]^T$. With the uplink (UL) (receive) beamforming vectors of a station serving user i given by $\mathbf{v}_i$ and the UL powers $\boldsymbol{\lambda} = [\lambda_1, \ldots, \lambda_M]$, the dual UL SINR of the antenna array serving user i is given by:

$$\bar{\gamma}_i^{2,U} = \frac{\lambda_i \mathbf{v}_i^H \mathbf{R}_{i,s(i)} \mathbf{v}_i}{\mathbf{v}_i^H (\mathbf{M}_i + \sum_{\substack{l \in \mathcal{U}_k \\ l \neq s}} \lambda_l \mathbf{R}_{l,s(i)}) \mathbf{v}_i}. \tag{17}$$

Note: The beamforming problem is formulated for a unicast transmission. Hence, there is one beamforming vector per-station and user pair. Therefore, the sets $\mathcal{U}_k$ and $\mathcal{S}_k$ denote the same set of indexes. As in [10], the inner problem (15), (16), can be solved with the dual UL problem

$$f^U(\boldsymbol{\delta}, \boldsymbol{\mu}) = \max_{\boldsymbol{\lambda}, \mathbf{V}} \min_{i \in \mathcal{S}} \frac{\bar{\gamma}_i^{2,U}}{\delta_i} \tag{18}$$

$$\text{s.t. } \boldsymbol{\lambda}^T \cdot \mathbf{1} \leq P \quad \lambda_i \geq 0, \quad \forall\, i \in \mathcal{S}_k, \tag{19}$$

which achieves the same SINR as the DL problem with less complexity. As presented in [10], with an outer minimization over $\boldsymbol{\mu}$, the per-antenna array power constraints are met if a balanced SINR exists or if the network is interference coupled. The results are the optimized transmit beamforming vectors which achieve a balanced SINR with per-antenna array power constraints. The problems (13) and (11) are solved by the algorithm presented in [9], [10].

To determine the vector $\boldsymbol{\delta}$, the SINRs $\bar{\gamma}_{r(i)}^1$ and $\bar{\gamma}_i^2$ are required. The SINRs are computed by solving the problems (10) and (11). With $\bar{\gamma}_{r(i)}^1$ and $\bar{\gamma}_i^2$, the vector $\boldsymbol{\delta}$ can be computed according to

$$\delta_i = \begin{cases} \frac{\bar{\gamma}_i^2}{\bar{\gamma}_{r(i)}^1} & \text{if } \bar{\gamma}_{r(i)}^1 \leq \bar{\gamma}_i^2 \text{ and } i \text{ is served by a RS} \\ 1 & \text{otherwise.} \end{cases} \tag{20}$$

With $\boldsymbol{\delta}$, the problem (13) is solved and the result is a SINR $\bar{\gamma}_i^2$ which is limited to the SINR $\bar{\gamma}_{r(i)}^1$ of the first hop in the corresponding link. Alg. 1 presents the data flow.

IV. Numerical Results

Table II depicts the main simulation parameters. The Winner II channel model [14] creates the required channels. The rooftop-to-rooftop connection between a BS and a RS is simulated by the stationary B5a scenario of the Winner II model. This paper compares three approaches:

Algorithm 1 Optimization of (13)

Solve (10) $\rightarrow \bar{\gamma}_{r(i)}^1$ and $\mathbf{\Omega}_k^1$
Solve (11) $\rightarrow \bar{\gamma}_i^2$
With $\bar{\gamma}_{r(i)}^1$ and $\bar{\gamma}_i^2$ compute $\boldsymbol{\delta}$ according to (20)
With $\boldsymbol{\delta}$ solve (13) $\rightarrow \mathbf{\Omega}_k^2$
return $\mathbf{\Omega}_k^1$ and $\mathbf{\Omega}_k^2$

TABLE II: Simulation parameters

Number of users per user drop	60
Number of antenna array elements at BS	4
Number of antenna array elements at RS	4
Number of antenna array elements at MS	1
BS height	32 m
RS height	20 m
MS height	1.5 m
BS-RS channel	B5a (Winner II)
BS-MS channel	C1 (Winner II)
RS-MS channel	C1 (Winner II)

- A1: No RSs (case 1), only MBF at the BSs.
- A2: Case 1 and case 2 with consideration of the SINR of the first hop. Problem (13) is solved with a priory computation of $\boldsymbol{\delta}$ according to (20).
- A3: Case 1 and case 2 without consideration of the SINR of the first hop.

Figure 3 depicts the cumulative distribution function (CDF) of the individual achievable rates based on the instantaneous CSI per second hop of the different algorithms A1-A3. All algorithms using RSs (A2 and A3) outperform the conventional network (A1) without RSs. A2 reduces the transmit power of the second hop such that the mean SINR in both hops is equal. Therefore, a reduced instantaneous throughput in the second hop is the result. If instead of long-term CSI, instantaneous CSI is available for the optimization, A2 would achieve the same achievable rate as A3, while a reduced sum power can be achieved for A2. The individual throughput is not a good measure to compare the performance in a network. Therefore, Figure 4 depicts the sum rates of all algorithms in percentage compared to the conventional network A1. Algorithms A2 and A3 outperform A1. Algorithm A2 has a slightly lower achievable sum rate compared to A3 since long-term CSI is used for the computation of the beamformer.

Figure 5 shows the sum powers of all algorithms in percentage compared to A1. The sum power is the total transmit power of all stations over all slots. As expected, A2 with the consideration of the first hop has the lowest sum power and saves approximately 20% of the total power compared to A1, while it has a slightly higher sum rate. Finally, Figures 6 and 7 show the impact of heterogeneous power constraints, which usually occur in heterogeneous networks. Here different power constraints are used at the RSs and BSs. The power constraint at the RSs is reduced from $P_{rs} = P_{bs}$ to $P_{rs} = 1/4 P_{bs}$ and $P_{rs} = 1/16 P_{bs}$. It can be observed that in interference limited scenarios (with a low noise level) the impact of the power constraints is small. In noise limited scenarios (with a higher noise level), the lower power constraints at the RSs will result in a lower performance gain. The optimization is more

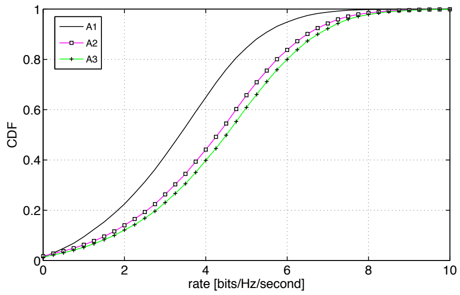

Fig. 3: CDF of the individual throughput per 2nd hop.

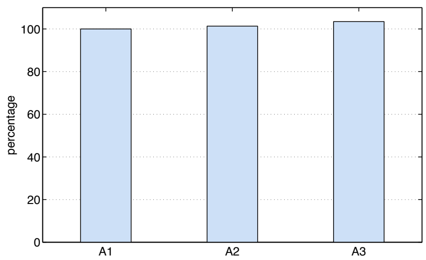

Fig. 4: Sum rates of all algorithms.

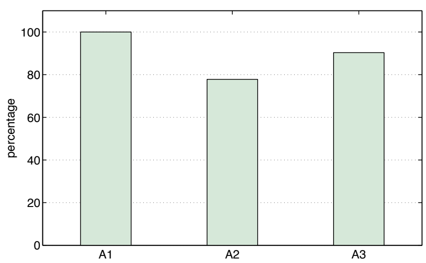

Fig. 5: Sum powers of all algorithms.

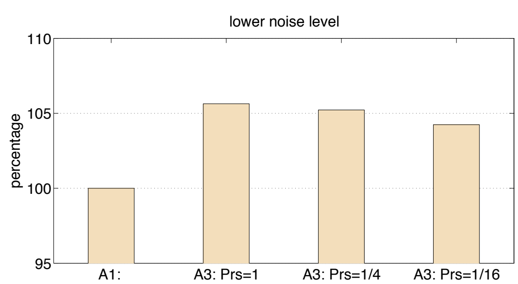

Fig. 6: Sum rate of the interference limited case for different power constraints at the RSs.

sensitive concerning low power constraints.

V. Conclusion

This paper proposes a multicell network with sectorized half-duplex decode-and-forward RSs. The presented Algorithm is based on long-term CSI and is able to achieve a higher sum rate if fairness is desired. An energy efficient scheme is proposed, which considers the rate of the first hop in the optimization of the second hop and needs 20% less transmit power as the conventional network with the same sum rate. Due to the fast computation of the beamforming weights

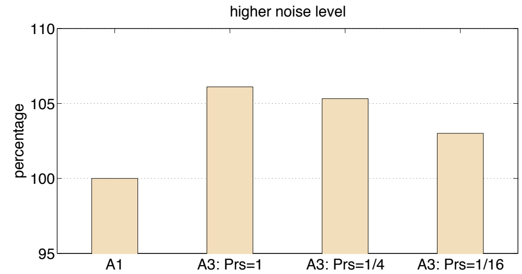

Fig. 7: Sum rate of the noise limited case for different power constraints at the RSs.

and the usage of long-term CSI, the algorithm is practically relevant in multicell networks. However, the use of long-term CSI will result in a small performance loss due to the decode-and-forward protocol in fading channels.

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Erratum: Beamforming with Relays in Heterogeneous Networks Based on Correlation Knowledge

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I. Correction

TABLE I
SIMULATION PARAMETERS

Number of users per user drop	60
Number of antenna array elements at BS	4
Number of antenna array elements at RS	4
Number of antenna array elements at MS	1
BS height	32 m
RS height	20 m
MS height	1.5 m
BS-RS channel	B5a (Winner II)
BS-MS channel	C1 (Winner II)
RS-MS channel	C1 (Winner II)

Table I depicts the corrected simulation parameters. The RSs have a hight of 20 meters instead of 10 meters and the BSs have a hight 32 meters instead of 30 meters of the version in IEEExplore.