Research Article

Collaborative Relay Beamforming Based on Minimum Power for M2M Devices in Multicell Systems

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Recently, machine-to-machine (M2M) communication has been studied in the single cell system. However, in the multicell system multiple M2M type devices at the edge of a cell may suffer from the strong interference that consists of the intercell interference from other cells and the intracell interference from other M2M devices in the local cell. In this paper, we study the relay beamforming strategy to guarantee the quality of service (QoS) requirements of the multiple destination devices in multicell systems. We minimize the transmit power of the base stations (BSs) and relays to save the power of M2M devices, while guaranteeing the receive signal-to-interference-and-noise ratio (SINR) of the destination devices. The main contribution of this paper is that we propose an iterative algorithm to jointly optimize the BS and relay beamforming weights with minimizing the BS and relay power under the receive SINR constraints in the perfect channel state information (CSI). Using the semidefinite relaxation (SDR) technology, the optimization problems for the BS and relay beamforming weights can be effectively solved. In addition, we also discuss the issue of imperfect CSI in practice. Simulation results validate our theoretical analysis and demonstrate that our proposed iterative scheme can achieve near-optimal performance within a few iterations.

1. Introduction

Recently, machine-to-machine (M2M) communication has been studied by many standards as the European Telecommunications Standards Institute (ETSI) [1] and 3rd Generation Partnership Project (3GPP) [2, 3]. Machine-type communication devices, such as smart meters, automotive applications, and smart phones, can communicate in M2M systems, which do not necessarily need human intervention [4]. According to the 3GPP standards, the base station (BS) can be used to manage the M2M devices and many BSs can divide the M2M devices into multiple cells [5]. The M2M devices communicate with each other through the BS in the cell system [6].

To offer the high data rate for the M2M systems, multiple-input multiple-output (MIMO) antenna systems can increase the channel capacity for given transmit power and bandwidth in previous studies [7]. However, the performance of MIMO systems may degrade due to correlated signals among antennas and cannot offer high coverage in large areas for M2M devices. Recently, many literatures research on the relay devices to guarantee the quality of service (QoS) requirements of the destination devices [8]. The BS transmit signals to the destination devices with the help of one or more relay devices in wireless M2M networks in Figure 1.

In general, there are three types of relay schemes, including the amplify-and-forward (AF) [9], decode-and-forward (DF) [10], and compress-and-forward (CF) [11] schemes. In the AF scheme, relay devices receive the signals transmitted from the source and forward the amplified signals to the destinations. In the DF scheme, relay devices decode and reencoded the received signals to the destinations. In the CF scheme, relay devices send quantized and compressed signals to the destinations. Among them the AF scheme is the most attractive for the M2M relay communication due to its low implementation complexity. With the aid of channel state information (CSI), relay devices can be designed to work collaboratively to guarantee the QoS requirements by forming a virtual beamforming system [12, 13].
Most existing contexts have studied relay beamforming strategies in a single cell. Relay strategies in sensor networks with minimum mean square error (MMSE) performance are designed in [8], which is subject to local and global relay power constraints, respectively. Elkheir et al. [14] presented an M2M relay communication scheme, which is subject to the total relay power under specific performance constraints and the individual power of each relay. Wang et al. [15] proposed the iterative strategies to jointly optimize the source antenna selection and the collaborative relay beamforming weights in wireless M2M networks. Li et al. [16] proposed two algorithms with random user scheduling and greedy user scheduling in maximizing the achievable user number by dynamical power assignment in the cellular system. Chen et al. [17] considered signal transmission with the aid of multiple half-duplex single-antenna relay nodes using the AF strategy for a multiuser wireless M2M communication system and proposed two suboptimal relay beamforming schemes that only require local CSI to minimize mean square error (MSE) for all the users with nonorthogonal channels. Zheng et al. proposed the relay beamforming schemes that achieve maximum the received signal-to-noise ratio (SNR) for a single destination under both total and individual power constraints with the aid of perfect CSI [18] and imperfect CSI [19]. In addition, Choi investigated the distributed beamforming for AF relay nodes when a consensus algorithm was employed for cooperative beamforming in [20] and the minimum mean square error (MMSE) criteria were used in [21]. Nguyen et al. studied the relay beamforming schemes to minimize the total relay power in a multiple AF relay network with multiple source-destination pairs under the signal-to-interference-and-noise ratio (SINR) [22] and SNR requirement [23] at each destination, respectively. However, in the multicell system destination devices at the edge of a cell may suffer from the high signal attenuation, as well as the strong interference that consists of the intercell interference from other cells and the intracell interference from other M2M devices in the local cell. In such a case, coordination multiccell processing of the BSs and relay devices in adjacent cells is needed to cope with the severe intercell and intracell interference [24, 25].

In this paper, we study the collaborative relay beamforming for multiple M2M destination devices which suffered intercell and intracell interference in the multicell systems. The relay devices can coordinately form virtual beams to transmit beamforming signals from a BS towards multiple destination devices in the AF scheme. Due to the power limitation of the M2M devices, we optimize the BS and relay beamforming weight with minimizing the BS and relay power to guarantee the receive SINR for multiple destination devices with the aid of perfect CSI. We propose an iterative scheme to jointly optimize the BS and relay beamforming weights to deal with the severe intercell and intracell interference for multiple destination devices in the multicell system. Using the semidefinite relaxation (SDR) technique [26], we show that the optimization problems for the BS and relay beamforming weights can be converted into semidefinite programming (SDP) problems, which can be effectively solved by interior-point methods.

The rest of this paper is organized as follows. In Section 2, we describe a multicell system model with multiple destination devices in each cell which suffered from the intercell and intracell interference. Sections 3 and 4 optimize the BS and relay beamforming weights to minimize the BS and relay power under the receive SINR constraints, respectively. Then, we propose an iterative scheme to jointly optimize the BS and relay beamforming weights to deal with the severe intercell and intracell interference for multiple destination devices in Section 5. Simulation results are presented and discussed in Section 6. The issue of imperfect CSI is discussed in Section 7. Finally, conclusions are drawn in Section 8.

Notation. Vectors are written in boldface lowercase letters, for example, \( \mathbf{x} \), while matrices are denoted by boldface uppercase letters for example, \( \mathbf{X} \). \( \text{Tr}(\mathbf{S}) \) represents the trace of a matrix \( \mathbf{S} \), and \( \text{diag}(s_1, s_2, \ldots, s_k) \) denotes a diagonal square matrix with \( s_1, s_2, \ldots, s_k \) as the diagonal elements. The superscripts \(^*\), \(^T\), and \(^H\) stand for the conjugate, transposition, and Hermitian of a complex vector or matrix, respectively. \( \mathbb{E}[z] \) calculates the expectation of a random entity \( z \), while \(|z|\) takes the modulus of a complex number \( z \). \( \mathbf{A} \succeq \mathbf{0} \) means that \( \mathbf{A} \) is a hermitian semidefinite matrix and \( \mathbf{0} \) means the upper bound of the computational complexity. In addition, the real and complex number fields are denoted by \( \mathbb{R} \) and \( \mathbb{C} \), respectively.

2. System Model

In this section, we describe a multicell system with \( L \) separate cells. In each cell, there are one BS with \( D_b \) antennas, \( M \) single-antenna AF relay devices, and \( K \) destination M2M devices, where \( K \leq D_b \), \( K > D_b \), and \( K \geq D_b \) respectively.
diversity among destinations [27]. The M2M devices may not only suffer the inter-cell interference from other cells, but also suffer the intracell interference from other M2M devices in the local cell. The system model of the 1th cell is shown in Figure 2. We assume that the L cells operate on the same frequency band over independent flat fading channels. Since we focus on the performance enhancement at the edge of a cell, we do not consider the direct link between the BS and destination M2M devices. The k destination devices receive the interfering signal from the relay devices of the lth cell, which is denoted by \( r_{l,m} \) in Figure 2.

In Figure 2, we consider the two-step AF relay protocol. In the first step, the lth BS broadcasts the K destinations’ signal \( s_{l,k} \), \( k = 1, 2, \ldots, K \), to the relay devices using beamforming vectors in the lth cell. We assume that destinations’ signals are independent with \( E[s_{l,k}] = 0 \) and \( E[|s_{l,k}|^2] = P_{l,k} \). In the second step, the mth relay devices forward the received signals \( r_{l,m} \) to the destinations with certain AF weights of the coordinated relay beamforming. These relay forwarded signals are the ICI for the other users in adjacent cells.

Thus, during the first step, the relay device \( m \) in the lth cell receives the signal \( r_{l,m} \), which can be given by

\[
    r_{l,m} = \mathbf{g}_{l,m} \sum_{k=1}^{K} w_{l,k} s_{l,k} + u_{l,m} \tag{1}
\]

where \( \mathbf{g}_{l,m} \) is the channel coefficient row vector from the lth BS to the mth relay and \( u_{l,m} \) is the background noise at the lth BS. The interfering signal from the relay devices of the lth cell is expressed as

\[
    \sum_{k=1}^{K} w_{l,k} s_{l,k} = \frac{P_{l,k}}{\text{SINR}_{l,k}} \xi_{l,m} \tag{2}
\]

where \( \xi_{l,m} \) is the complex-valued weight at the mth relay in the lth cell. Thus, the received signal at the kth destination in the lth cell is shown in (3) at the bottom of the page, where \( h_{l'}\rightarrow_{l,m,k} \) is the channel coefficient from the mth relay in the \( l' \)th cell to the kth destination in the lth cell and \( n_{l,k} \) is the background noise at the kth destination in the lth cell with zero-mean and variance of \( N_{l,k} \).

Note that \( \sum_{m=1}^{M} h_{l'}\rightarrow_{l,m,k} v_{l,m} e_{l,m} \xi_{l,m} \) is the intercell interfering signals from the relay devices of the other cells and \( \sum_{m=1}^{M} h_{l'}\rightarrow_{l,m,k} v_{l,m} e_{l,m} w_{l,k} s_{l,k} \) is the intracell interfering signals from other destination devices in the local cell. Thus, the received SINR at the kth destination in the lth cell is given by

\[
    \text{SINR}_{l,k} = \frac{P_{l,k}^{s}}{P_{l,k}^{\text{inter}} + P_{l,k}^{\text{intra}} + P_{l,k}^{n}} \tag{4}
\]

where \( P_{l,k}^{s} \) is desired signal power at the kth destination in the lth cell,

\[
    P_{l,k}^{s} = \sum_{m=1}^{M} h_{l'}\rightarrow_{l,m,k} v_{l,m} e_{l,m} w_{l,k} \tag{5}
\]

\( P_{l,k}^{\text{inter}} \) is the inter-cell interfering power from the relay devices of the other cells,

\[
    P_{l,k}^{\text{inter}} = \sum_{k' \neq k}^{K} \sum_{m=1}^{M} P_{l,k'} \sum_{m=1}^{M} h_{l'}\rightarrow_{l,m,k} v_{l,m} e_{l,m} w_{l,k'} \tag{6}
\]

\( P_{l,k}^{\text{intra}} \) is the intracell interfering power from other destination devices in the local cell,

\[
    P_{l,k}^{\text{intra}} = \sum_{m=1}^{M} h_{l'}\rightarrow_{l,m,k} v_{l,m} e_{l,m} w_{l,k} \tag{7}
\]

and \( P_{l,k}^{n} \) is the noise power at the kth user in the lth cell,

\[
    P_{l,k}^{n} = \sum_{m=1}^{M} |h_{l'}\rightarrow_{l,m,k}|^2 |v_{l,m}|^2 N_{l,m} + \sum_{l' = 1 \land l' \neq l}^{L} \sum_{m=1}^{M} |h_{l'}\rightarrow_{l,m,k}|^2 |v_{l',m}|^2 N_{l',m} + N_{l,k} \tag{8}
\]

3. Minimum BS Power with SINR Constraints

In this section, we optimize the BS beamforming vectors to minimize the BS power in the multicell system under the destinations’ SINR constraints. The lth BS total transmit power is

\[
    P_{l}^{\text{B}} = \sum_{k=1}^{K} P_{l,k} w_{l,k}^* \tag{9}
\]
First step Second step

Thus, we can formulate the problem as

\[
\min_{\mathbf{w}_l, k} \sum_{l=1}^{L} p_l \mathbf{w}_l^H \mathbf{A}_l \mathbf{w}_l
\]

subject to \( \text{SINR}_{l,k} \geq \Gamma_{l,k} \),

\[ l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K, \]

\( \text{SINR}_{l,k} = p_{l,k} \mathbf{w}_l^H \mathbf{A}_l \mathbf{w}_l \)

\[ \times \left( \sum_{k' \neq k}^{K} p_{l,k'} \mathbf{w}_l^H \mathbf{A}_l \mathbf{w}_{l,k'} + \frac{1}{\Gamma_{l,k}} \right) \]

\[ + \sum_{l' \neq l}^{L} \sum_{k'=1}^{K} p_{l',k'} \mathbf{w}_{l',k'}^H \mathbf{A}_{l'} \mathbf{w}_{l',k'} + P_n \] \[ \mathbf{w}_l, k \] is not convex. Thus, Problem (13) cannot be solved.

min \( \mathbf{w}_l, k \) subject to \( \mathbf{w}_l, k \geq 0 \),

\[ \frac{p_{l,k}}{\Gamma_{l,k}} \mathbf{w}_l^H \mathbf{A}_l \mathbf{w}_l \]

\[ - \sum_{l'=1}^{L} \sum_{k'=1}^{K} p_{l',k'} \mathbf{w}_{l',k'}^H \mathbf{A}_{l'} \mathbf{w}_{l',k'} \geq P_n \]

\[ l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K. \]

Using \( \mathbf{w}_{l,k} = u_{l,k} \mathbf{w}_{l,k}^H \), Problem (12) can be represented into

min \( \mathbf{w}_{l,k} \) subject to \( \mathbf{w}_{l,k} \geq 0 \), \( \text{rank} (\mathbf{w}_{l,k}) = 1 \),

\[ \frac{p_{l,k}}{\Gamma_{l,k}} \mathbf{w}_{l,k}^H \mathbf{A}_{l} \mathbf{w}_{l,k} \]

\[ - \sum_{l'=1}^{L} \sum_{k'=1}^{K} p_{l',k'} \mathbf{w}_{l',k'}^H \mathbf{A}_{l'} \mathbf{w}_{l',k'} \geq P_n \]

\[ l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K. \]

The SDP problem in (14) can be solved by using interior-point methods. According to [28], the computational complexity of Problem (14) is \( O((LK)^3D^2 \log(1/\sigma)) \), where \( \sigma \) is the solution accuracy of interior-point methods.

The solution of Problem (14) provides a lower bound on the objective function in the original problem (13) due to excluding the rank-one constraint. However, in our extensive simulations, we have never observed that the optimal solution of Problem (14) has a rank higher than one. Thus, the original problem in (13) can be optimally solved. The similar observation was also reported in [29] to design the optimal beamforming schemes. For the cases where the solution of Problem (14) has a rank higher than one, several randomization techniques [30] can be used to provide a good approximate solution \( \mathbf{W}_{l,k} \) for Problem (13) from the optimal solution \( \mathbf{W}_{l,k} \) of Problem (14).
4. Minimum Relay Power with SINR Constraints

In this section, we optimize the relay beamforming weights to minimize the relay power with guaranteeing the receive SINR in the multicell system. Due to the power limitation of the M2M relay devices, the relay power is important to be minimized. The total relay power in the $l$th cell is given by

$$P^l = \sum_{m=1}^{M} E \left[ |x_{l,m}|^2 \right]$$

$$= \sum_{m=1}^{M} E \left[ |r_{l,m}|^2 \right]$$

$$= \sum_{m=1}^{M} \left( \sum_{k=1}^{K} P_{l,k} |g_{l,m} w_{l,k}|^2 + N_{l,m} \right)$$

$$= v_i^H E v_i,$$

where

$$v_i = [v_{l,1}, v_{l,2}, \ldots, v_{l,m}]^T,$$

$$E_l = \text{diag} \left( \sum_{k=1}^{K} P_{l,k} |g_{l,1} w_{l,k}|^2 + N_{l,1}, \ldots, \sum_{k=1}^{K} P_{l,k} |g_{l,M} w_{l,k}|^2 + N_{l,M} \right).$$

Thus, we can formulate the optimization problem as

$$\min_{v_i} \sum_{l=1}^{L} P^l$$

subject to SINR$_{l,k} \geq \Gamma_{l,k},$

$$l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K,$$

SINR$_{l,k} = P_{l,k} |b_{l^{-1},l,k}^T v_l|^2$

$$\times \left( \sum_{k=1}^{K} P_{l,k} |b_{l^{-1},l,k}^T v_l|^2 \right)$$

$$+ \sum_{l' \neq l} \sum_{k'=1}^{K} P_{l',k'} |b_{l^{-1},l,k'}^T v_l|^2$$

$$+ \sum_{l'=1}^{L} v_{l'}^H H_{l^{-1},l,k} v_{l'} + N_{l,k})^{-1}.$$

The receive SINR at the $k$th destination in (4) can be rewritten as (18), where

$$b_{l^{-1},l,k} = [h_{l^{-1},l,k} g_{l,1} w_{l,k}, \ldots, h_{l^{-1},l,m,k} g_{l,M} w_{l,k}]^T,$$

$$b_{l^{-1},l,k'} = [h_{l^{-1},l,k} g_{l,1} w_{l,k'}, \ldots, h_{l^{-1},l,m,k} g_{l,M} w_{l,k'}]^T,$$

$$H_{l^{-1},l,k} = \text{diag} \left( |h_{l^{-1},l,k_1}|^2 N_{l,1}, \ldots, |h_{l^{-1},l,m,k}|^2 N_{l,M} \right).$$

Therefore, problem (17) can be formulated as

$$\min_{v_i} \sum_{l=1}^{L} v_i^H E v_i$$

subject to

$$\left( \frac{P_{l,k}}{\gamma_{l,k}} + P_{l,k} \right) |b_{l^{-1},l,k}^T v_l|^2$$

$$- \sum_{l'=1}^{L} v_{l'}^H H_{l^{-1},l,k} v_{l'} \geq N_{l,k},$$

$$l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K.$$

Using $V_l = v_i v_i^H$ and $B_{l^{-1},l,k} = P_{l,k} b_{l^{-1},l,k} b_{l^{-1},l,k}^H$, problem (20) can be changed into the matrix form

$$\min_{V_l} \sum_{l=1}^{L} \text{Tr} (E_l V_l)$$

subject to $V_l \succeq 0, \quad \text{rank} (V_l) = 1,$

$$\left( \frac{1}{\gamma_{l,k}} + 1 \right) \text{Tr} (B_{l^{-1},l,k} V_l)$$

$$- \sum_{l'=1}^{L} \text{Tr} (H_{l^{-1},l,k} V_{l'}) \geq N_{l,k},$$

$$l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K,$$

where $V_l \succeq 0$ means that $V_l$ is a Hermitian semidefinite matrix. Note that the rank constraint $\text{rank} (V_l) = 1$ comes from $V_l = V_i V_i^H$, which is not convex. Thus, Problem (21) is not convex. We use the SDR technique to relax the nonconvex problem (21) into the following SDP problem [26]:

$$\min_{V_l} \sum_{l=1}^{L} \text{Tr} (E_l V_l)$$

subject to $V_l \succeq 0,$

$$\left( \frac{1}{\gamma_{l,k}} + 1 \right) \text{Tr} (B_{l^{-1},l,k} V_l)$$

$$- \sum_{l'=1}^{L} \text{Tr} (H_{l^{-1},l,k} V_{l'}) \geq N_{l,k},$$

$$l = 1, 2, \ldots, L, \quad k = 1, 2, \ldots, K.$$
Using the interior-point methods, we can solve the SDP problem (22). As shown in Section 3, the computational complexity of Problem (22) is $O((LK)^3 M^{3.5} \log(1/\sigma))$, where $\sigma$ is the solution accuracy of interior-point methods.

In our extensive simulations, we also have never observed that the optimal solution of Problem (22) has a rank higher than one. This means that the optimal solution of Problem (22) is also optimal for the original problem in (17). If the solution of Problem (22) has a rank higher than one, we can also use the randomization techniques [30] to provide a good approximate solution $\mathbf{V}_l$ for Problem (21) from the optimal solution $\mathbf{V}_l$ of Problem (22).

5. Iterative Algorithm

Based on the previous results, we propose an iterative scheme (see Algorithm 1) to jointly optimize the BS and relay beamforming weights to minimize the BS and relay power with guaranteeing the receive SINR in the multicell system. This proposed algorithm firstly optimizes the BS beamforming vector according to the current relay beamforming vector. Then the relay beamforming vector is optimized on the basis of the current BS beamforming vector. Circulate the above two steps, until the total relay power is sufficiently close to a fixed point or the iteration number exceeds a predetermined number. The details of Algorithm 1 is in the following.

According to [28], the computational complexity of Algorithm 1 is $O((LK)^3 (M^{3.5} + D^{3.5}) \log(1/\sigma))$. Since the BS and relay power are minimized at Step 3 and Step 9, after a few iterations from Step 2 to Step 16, our algorithm can obtain near-optimal performance, which can be confirmed by simulation results in Section 6.

6. Simulation Results

In this section, we present simulation results to validate the performance of our proposed iterative scheme for multiple destination M2M devices in a multicell system. It is assumed that the flat-fading channel coefficients $g_{lm}$, $h_{l,m,k}$, $l = 1, 2, \ldots, L$, $m = 1, 2, \ldots, M$, and $k = 1, 2, \ldots, K$, are independent Rayleigh random variables with mean zero and unit variance. For convenience, it is assumed that the noise at all the devices, including relays and destinations, has the same power spectral density; that is, $N_{l,m} = N_{l,k} = N_0$, $l = 1, 2, \ldots, L$, $m = 1, 2, \ldots, M$, and $k = 1, 2, \ldots, K$. The BS transmission SNR is set to $P_l/N_0 = 10$ (dB), which is the same for all the BSs to each destination in the multicell system. In the simulations, we assume that all destination devices have the same SINR constraint; that is, $\gamma_{l,k} = \gamma_0$, $l = 1, 2, \ldots, L$, and $k = 1, 2, \ldots, K$. We use CVX [31] to numerically solve the SDP problems.
4 iterations the proposed scheme can obtain near-optimal performance.

In Figure 4, we compare our proposed algorithm with the relay beamforming algorithm in [32]. Note that Ubaidulla and Chockalingam [32] only consider the single-user case in a single cell system (without considering the intercell interference). The scheme in [32] can be seen as a special case of our proposed scheme. For convenience, we assume that there are $L = 3$ BSs with $D_l = 8$ antennas, $M = 20$ relays, and $K = 1$ destination device in each cell of Figure 4. We choose the same channel conditions as in [32] to run the simulations for our proposed iterative scheme with 4 iterations. Note that Ubaidulla et al.[32] denoted $\delta_\alpha$ and $\delta_\beta$ as the error norm bounds to determine the level of additive CSI error in the channel from the BS to the relay devices and from the relay nodes to the destination device, respectively. $\delta_\alpha = \delta_\beta = 0$ represents that each device, including relay and destination, knows the perfect CSI in the system. The results in Figure 4 indicate that the total relay power consumption of both the algorithms increases as the receive SINR constraint increases. However, the total relay power consumption of our proposed scheme is more than that of the proposed algorithm in [32]. The reason is that in our proposed algorithm the relay power consumption needs to overcome the inter-cell interference in order to improve the performance of the destination device in the multicell system.

Figure 5 shows the total relay power of our proposed iterative algorithm to jointly optimize the BS and relay beamforming weights for multiple destinations in various scenarios of multicell systems. We simulate three scenarios of multicell systems, where $(L, D_l, M, K) = (2, 4, 6, 2), (3, 8, 8, 3), (3, 10, 15, 3)$. We run simulations for the proposed iterative scheme with 4 iterations. Note that when the number of destinations and cells increases, the intercell and intracell interference will become severer. We need to increase the transmission power of BSs and relays to reach the receive SINR constraints. The simulation results in Figure 5 show that we can increase the number of antennas or...
relays to cope with the severer interference under the same power constraint. As such, the performance in the case of $(L, D_l, M, K) = (3, 10, 15, 3)$ is close to that in the case of $(L, D_l, M, K) = (2, 4, 6, 2)$, as the number of antennas and relays is increased.

7. Discussion

In the above results, the perfect CSI at relay and destination devices is essential for our proposed iterative algorithm. Thus, the perfect CSI from the BSs to relays and from relays to the destinations needs to feedback to the central processor calculating the BS and relay beamforming weights. This becomes a drawback of the proposed relay-aided transmission schemes in practice wireless M2M networks, which will decrease frequency efficiency and could be costly if the number of relays and users is large. If the channel estimate error exists or the capacity of feedback channel is limited, the central processor only knows the imperfect CSI. In order to overcome this problem in practice, Huang et al. [33] considered the orthogonal beamforming systems with limited feedback under the per user unitary and rate control (PU2RC) technology, where the beamforming weights are selected from a codebook of multiple orthonormal bases in the multiuser system. The concept of the PU2RC technology has been included in the LTE standard. We can use the PU2RC technology to our collaborative relay beamforming algorithm for wireless M2M devices in multicell systems to deal with the problem of the imperfect CSI, where the BS and relay beamforming weights can be selected from a codebook in the central processor.

As the relay devices are distributed, we can use the distributed relay beamforming strategies as in [18, 19] to reduce the CSI feedback to deal with the issue of imperfect CSI in practice. It is assumed that each relay device can learn the local CSI from the source by training and from destinations by feedback, respectively, and measure its noise level. Note that Zheng et al. [18, 19] proposed a distributed implementation algorithm with local CSI under SNR constraints based on the Karush-Kuhn-Tucker (KKT) analysis. Another distributed algorithm was proposed in [21, 34], which used MMSE criterion to construct distributed relay beamforming strategies. However, they focused on the distributed beamforming schemes for the single cell system. Choi [21] investigated the distributed beamforming strategies for the single destination in the multiple relay system and Verdu [34] developed the distributed beamforming strategies into the scenario of multiple destinations. The distributed algorithm for multiple destinations in the multicell system will be investigated in our future work.

8. Conclusion

In this paper, we proposed an iterative scheme to jointly optimize the BS and relay beamforming weights under the receive SINR constraints to cope with the strong inter-cell and intracell interference in the multicell systems. We minimized the BS and relay beamforming power, while guaranteeing the receive SINR for the multiple destination devices by using the SDR technology. We showed that the optimization problems for BS and relay beamforming weights can be converted into SDP problems, which can be effectively solved by interior-point methods. Simulation results demonstrated that our proposed iterative scheme can achieve near-optimal performance with only 4 iterations.

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