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Uplink Throughput of Multi-cell Processing with HDAF Cooperation Between Mobiles

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***Abstract*—Joint decoding at base stations combined with cooperative transmission is investigated to improve the uplink throughput of current cellular systems over fading channels. In this paper, we consider amplify-and-forward (AF), decode-and-forward (DF) and hybrid decode-amplify-forward (HDAF) cooperation schemes between relay stations. We analyze the throughput of direct transmission (DT), AF, DF, and HDAF both in single-cell and multi-cell respectively. A linear mesh network is considered where a single mobile terminal for each cell communicates with a local base station via a dedicated relay, which can be AF, DF, or HDAF. All of the base stations in the mesh network decode the received signals cooperatively.**

***Keywords*—Cooperation, amplify-and-forward (AF), decode-and-forward (DF), hybrid decode-amplify-forward (HDAF).**

I. INTRODUCTION

Multi-cell processing, referred as joint decoding at base stations, is considered to be an important method towards providing higher data rates and improving robustness to channel impairments in wireless systems. Cooperative transmission between relay stations is a promising paradigm for next generation communication systems [1]. Simeone *et al* have studied system performance of the relay stations with AF and DF cooperation between mobile terminals respectively [1] [2].

In each cell, there are three nodes, i.e. mobile terminal (MT), relay station (RS) and base station (BS) constituting a cooperative diversity system which is a promising solution for high data-rate coverage required in future cellular and ad-hoc wireless communication systems. There are two main advantages of this relaying technology: the low transmit power requirements and the spatial diversity that can mitigate fading [3-6]. The protocols have been applied on different relaying modes as amplify-and-forward (i.e., non-regenerative relays) [5] and decode-and-forward (i.e., regenerative relays) [6].

Basically, mesh networks prescribe the combination of communication via direct transmission to base stations and via multi-hop transmission through relay nodes [7]. In this paper, we study the case of two-hop mesh network for its simplicity.

In multi-cell processing system, the BSs are all connected via optical fiber backbone with high capacity and low latency, allowing a reliably fast exchanged of information among them. Recently, there has been considerable interest in further enhancing the performance of cellular or mesh networks. It endows the system with a central processor that is able to pool the signals received by the BSs and performs joint processing [7-9], which can improve the performance of the mesh networks.

There exists transmission between MTs and RSs in adjacent cells that is different from [1]. In most situation, the RSs do not always decode the signals correctly. If RSs decode wrong and forward the decoding signal, which has bad effects on system performance. So we consider the RSs in each cell decode and forward the signals transmitted by the mobile terminals when the signals are decoded correctly by the RSs. Otherwise, the RSs amplify and forward the received signals. We compare the system performance of DT, AF, DF and HDAF. Simulation results demonstrates that the system performance of HDAF is between AF and DF.

Throughout this paper, $E[\cdot]$, $(\cdot)^T$, $(\cdot)^H$ denote the expectation, the transpose matrix, the conjugate transpose matrix.

The rest of the paper is organized as follows. The system model is given in section II. The concept of single cell processing appears in section III. Multi-cell processing is addressed in section IV. Some practical concerns are discussed and numerical results are provided in section V. Finally, section VI contains some concluding remarks.

II. SYSTEM AND CHANNEL MODEL

This paper considers a linear Wyner's cellular model [7] [8] with well-known multiple-access technique, i.e., time-division multiple-access (TDMA) in uplink system. We assume one MT is active in each cell and each active MT not only communicates with the same BS directly but also via a dedicated RS to arrive at BS. The RSs in cellular network can receive signals transmitted by the MTs in the same cell as well as the adjacent cells. So BSs receive signals transmitted by MTs and RSs from intra-cell and neighboring cell described in Fig. 1 as sketched in Fig. 2 [7]. For simplicity, there is only one omnidirectional antenna with MT, RS and BS in each cell.

In cellular system, the number of cells in linear array indexed by N, with interference between neighboring cells. The BSs are denoted as $\{B_j\}_{j=1}^{N}$, the source MTs, one for each cell, are referred to as $\{T_j\}_{j=1}^{N}$, and the RSs as $\{R_j\}_{j=1}^{N}$.

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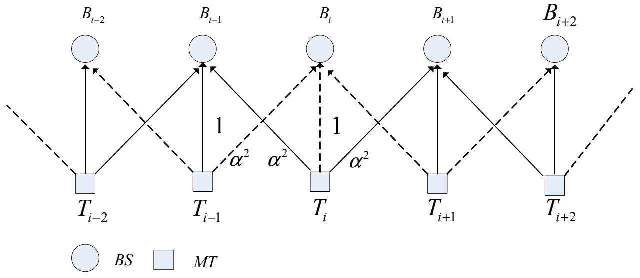

Fig. 1. A linear variant of Wyner's model of a cellular system.

However, all of the results in this paper can be extended to the case of multiple antennas at MTs, RSs and BSs.

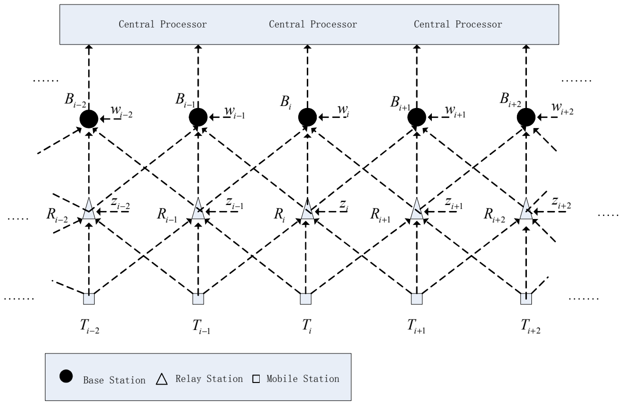

Fig. 2. A schematic model of the linear two-hop mesh work.

We assume the MTs are at the border of the cells, which is of concern in mesh networks. The fading channel gains are identified by their subscripts, e.g., $h_{R_iB_j}$ is the channel between RS R_i and BS B_j. A narrow-band flat-fading channel is considered and a low mobility environment is assumed, such that the channel remains constant within several frames. These gains are assumed to be independent identical ergodic complex circularly symmetric Gaussian processes (i.i.d Rayleigh fading).

According to AF and DF protocols , in the first time slot, the MTs transmit the signals to the RSs and BSs, while in the second time slot, the RSs transmit the signals or decoding signals received in first time slot to the BSs.

Moreover, we focus on Rayleigh fading channels and assume homogeneous conditions for the channel power gains so that the intra-cell and inter-cell direct transmission channel gains are 1 and α^2 respectively. Inter-cell MT-to-RS (first hop) and RS-to-BS (second hop) power gains are β^2 and δ^2 respectively, and similarly, the inter-cell power gains between adjacent cells are σ^2 and α^2 for the first and second hop.

In the paper, we assume there exists no relevant channel power gain between RSs in adjacent cells and the RSs are working with full duplex transmission [10]. By using the Maximum Ration Combination (MRC) technique, the BS combines the received signal from the RSs in the second time slot and the received signal from the source MT in the first time slot. Multi-cell processing considers the interference from adjacent cells as useful signals that can improve the system performance, while the interference from the adjacent cells are considered noise in single cell multiple-access.

III. SINGLE CELL PROCESSING

In this section, we discuss the baseline scenarios where no cooperation takes place. First we analyze the direct transmission (DT) and the limitation of the HDAF (AF and DF). Then we analyze the HDAF.

A. Direct Transmission (DT)

As shown in Fig. 1, direct transmission between MTs and BSs independently processes the received signal i.e., no cooperation between BS is employed. The received signal in each time by the BS B_i is given as

$$y_{B_i} = h_{T_iB_i}x_i + w_i + n_i \tag{1}$$

with x_i denoting the signal transmitted by the MT T_i, which is assumed to adopt Gaussian codebook with power $E\left[|x_i|^2\right] = E_s$. Moreover, we think all MTs $\{T_i\}_{i=1}^N$ transmit signals with the same power, i.e., $E_1 = \cdots = E_N = E_s$. The additive Gaussian thermal noise has power $E\left[|n_i|^2\right] = N_0$. The remaining term

$$w_i = h_{T_{i-1}B_i}x_{i-1} + h_{T_{i+1}B_i}x_{i+1} \tag{2}$$

accounts for inter-cell interference. In this scenario, the interference term w_i is regarded as additive Gaussian noise with power: $E\left[|w_i|^2\right] = E_s\left(\left|h_{T_{i-1}B_i}\right|^2 + \left|h_{T_{i+1}B_i}\right|^2\right)$. We assume the BS has knowledge of the channel gains $h_{T_{i\pm j}B_i}\,(j = 0, \pm 1)$ and the interference power $E\left[|w_i|^2\right]$, so the per-cell achievable ergodic sum-rate measured in $bit/s/Hz$ reads

$$R_{SC-DT} = E_h\left[\log_2\left(1 + SNR\frac{\left|h_{T_iB_i}\right|^2}{1 + W_i}\right)\right] \tag{3}$$

with $E_h[\cdot]$ denoting the ensemble average with respect to the fading channel gains, and the signal-to-noise ratio (SNR) is $SNR = E_s/N_0$ and $W_i = \frac{E\left[|w_i|^2\right]}{N_0}$.

B. Amplify-and-Froward (AF) Transmission

As shown in Fig. 2, cooperation between RSs is assumed to adopt AF protocol. In the first time slot, each active MT T_i broadcasts signal to both RS R_i and the BS B_i. The signal received by MT B_i is (1), whereas the RS R_i receives

$$y_{R_i} = h_{T_iR_i}x_i + w_{R_i} + n_{R_i} \tag{4}$$

The Gaussian thermal noise in RS R_i has the power $E\left[|n_{R_i}|^2\right] = N_0$.

$$w_{R_i} = h_{T_{i-1}R_i}x_{i-1} + h_{T_{i+1}R_i}x_{i+1} \tag{5}$$

accounts for inter-cell interference. From [1], we can get that the RS scales the received signal y_{R_i} in order to keep the average transmitted energy per symbol equal to E_s,

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and then forwards the resulting symbol, i.e., $g_{R_i} y_{R_i} = g_{R_i} h_{T_{i-1}R_i} x_{i-1} + g_{R_i} h_{T_i R_i} x_i + g_{R_i} h_{T_{i+1}R_i} x_{i+1} + g_{R_i} z_i$, with $E\left(\left|g_{R_i} y_{R_i}\right|^2\right) = E_s$, so we can get

$$g_{R_i}^2 = \frac{SNR}{SNR \cdot \sum\limits_{j=-1}^{1} \left|h_{T_{i+j}R_i}\right|^2 + 1} \tag{6}$$

Secondly, the signal received at the second time slot by the BS can be written as

$$y_{B_i}^{'} = h_{T_i B_i}^{'} x_i + w_i^{'} + n_{B_i}^{'} + n_{B_i} \tag{7}$$

with $h_{T_i B_i}^{'}$ denoting the equivalent channel gains that accounts for the useful signal paths from two adjacent cells T_{i-1}, T_{i+1} and the in-cell MT T_i to BS B_i. $w_i^{'} = \left(h_{T_{i-1}B_i}^{'} x_{i-1} + h_{T_{i+1}B_i}^{'} x_{i+1} + h_{T_{i-2}B_i}^{'} x_{i-2} + h_{T_{i+2}B_i}^{'} x_{i+2}\right)$ is the interference from adjacent cells and $n_{B_i}^{'}$ for equivalent noise. n_{B_i} denotes the thermal noise at BS B_i, assumed to be independent of the noise n_{R_i} in the first time slot but has the same power $E\left(\left|n_{B_i}\right|^2\right) = N_0$. The equivalent channel gains of $h_{T_i B_i}^{'}, h_{T_{i-1}B_i}^{'}, h_{T_{i+1}B_i}^{'}, h_{T_{i-2}B_i}^{'}, h_{T_{i+2}B_i}^{'}$, and equivalent noise $n_{B_i}^{'}$ are following by (8) (9) and (10):

$$\begin{aligned} h_{T_i B_i}^{'} &= h_{T_i R_{i-1}} g_{R_{i-1}} h_{R_{i-1}B_i} + h_{T_i R_i} g_{R_i} h_{R_i B_i} \\ &\quad + h_{T_i R_{i+1}} g_{R_{i+1}} h_{R_{i+1}B_i} \end{aligned} \tag{8}$$

$$h_{T_{i-1}B_i}^{'} = h_{T_{i-1}R_{i-1}} g_{R_{i-1}} h_{R_{i-1}B_i} + h_{T_{i-1}R_i} g_{R_i} h_{R_i B_i} \tag{9a}$$

$$h_{T_{i+1}B_i}^{'} = h_{T_{i+1}R_i} g_{R_i} h_{R_i B_i} + h_{T_{i+1}R_{i+1}} g_{R_{i+1}} h_{R_{i+1}B_i} \tag{9b}$$

$$h_{T_{i-2}B_i}^{'} = h_{T_{i-2}R_{i-1}} g_{R_{i-1}} h_{R_{i-1}B_i} \tag{9c}$$

$$h_{T_{i+2}B_i}^{'} = h_{T_{i+2}R_{i+1}} g_{R_{i+1}} h_{R_{i+1}B_i} \tag{9d}$$

$$\begin{aligned} n_{B_i}^{'} = & g_{R_{i-1}} h_{R_{i-1}B_i} n_{R_{i-1}} + g_{R_i} h_{R_i B_i} n_{R_i} \\ & + g_{R_{i+1}} h_{R_{i+1}B_i} n_{R_{i+1}} \end{aligned} \tag{10}$$

The noise power in the second time slot ia written as

$$\begin{aligned} & E\left[\left(w_i^{'} + n_{B_i}^{'} + n_{B_i}\right)\left(w_i^{'} + n_{B_i}^{'} + n_{B_i}\right)^H\right] \\ & = N_0\left(W_i^{'} + N_{B_i}^{'} + 1\right) \end{aligned} \tag{11}$$

where $W_i^{'} = E\left[\left|w_i^{'}\right|^2\right] \Big/ N_0$ and $N_{B_i}^{'} = E\left[\left|n_{B_i}^{'}\right|^2\right] \Big/ N_0$.

The equivalent additive Gaussian noise at the BS in the two slots is correlated as $\rho = \frac{E\left[(w_i + n_i)\left(w_i^{'} + n_{B_i}^{'} + n_{B_i}\right)^H\right]}{N_0}$.

We assume that the BSs are able to know the full channel state information (CSI), so that we can get the ergodic per-cell achievable sum-rate in BS B_i

$$\begin{aligned} & R_{SC-AF} = \frac{1}{2} \cdot \\ & E_h\left[\log_2\left(1 + SNR\left[\begin{array}{cc} h_{T_i B_i}^{*} & h_{T_i B_i}^{'*} \end{array}\right] Q^{-1}\left[\begin{array}{c} h_{T_i B_i} \\ h_{T_i B_i}^{'} \end{array}\right]\right)\right] \end{aligned} \tag{12}$$

with $Q = \left[\begin{array}{cc} 1 + W_i & \rho \\ \rho^H & 1 + W_i^{'} + N_{B_i}^{'} \end{array}\right]$.

C. Decode-and-Forward (DF) Transmission

Similar to AF, cooperation between MT T_i and RS R_i is assumed to follow DF protocol. In the first time slot, each active MT T_i broadcasts signal to both RS R_i and BS B_i. The signal received by B_i is (1), while the RS R_i is (4).

The signal received by the BS B_i in the second time slot is

$$y_{B_i}^{''} = h_{R_i B_i} x_i + w_i^{''} + n_i^{''} \tag{13}$$

with $n_i^{''}$ denoting thermal noise at B_i, assumed to be independent of the noise in the first time slot and with the power $E\left[\left|n_i^{''}\right|^2\right] = N_0$. The remaining term

$$w_i^{''} = h_{R_{i-1}B_i} x_{i-1} + h_{R_{i+1}B_i} x_{i+1} \tag{14}$$

accounts for inter-cell interference from two adjacent cells.

Same as AF transmission, the interference term $w_i^{''}$ is considered to be additive Gaussian noise with power$W_i^{''} = E\left[\left|w_i^{''}\right|^2\right] \Big/ N_0$

The equivalent additive Gaussian noise at the BS B_i in the two slots is correlated as $\rho^{'} = \frac{E\left[(w_i + n_i)\left(w_i^{''} + n_i^{''}\right)^H\right]}{N_0}$.

We also assume the BSs are able to know the full CSI, so that we can get the ergodic per-cell achievable sum-rate in BS B_i

$$\begin{aligned} & R_{SC-DF} = \frac{1}{2} \cdot \\ & E_h\left[\log_2\left(1 + SNR\left[\begin{array}{cc} h_{T_i B_i}^{*} & h_{R_i B_i}^{*} \end{array}\right] M^{-1}\left[\begin{array}{c} h_{T_i B_i} \\ h_{R_i B_i} \end{array}\right]\right)\right] \end{aligned} \tag{15}$$

with $M = \left[\begin{array}{cc} 1 + W_i & \rho^{'} \\ \rho^{'H} & 1 + W_i^{''} \end{array}\right]$.

D. Hybrid Decode-Amplify-Forward (HDAF) Transmission

In some cases, the DF relay transmission can impair the system performance if the relay decodes the received signals incorrectly but forwards to the BS. In this section, we put forward the HDAF transmission to solve this problem. If the RS in the cell decodes the received signals correctly, the RS will adopt DF protocol, otherwise, the RS adopts AF protocol. In most case, the RS in the multi-cell processing network is the combination of AF and DF, so the performance in Section IV-B and IV-C is the lower bound and upper bound of HDAF.

In the first time slot, the MTs broadcast signals to the RSs and BSs, which is the same as Section III-B and III-C in the first hop.

In the second time slot, the BSs receive the signals from RSs assumed to be AF or DF protocol. The BS B_i is affected by RS R_{i-1}, R_i, R_{i+1}, so the signal received by BS B_i is the combination of AF and DF in RS R_{i-1}, R_i, R_{i+1}. Flowchart of this scenario is shown in Fig. 3:

The signal received by the BS B_i in the second time slot is

$$y_{B_i}^{'''} = h_{T_i B_i}^{'''} x + w_i^{'''} + n_i^{'''} \tag{16}$$

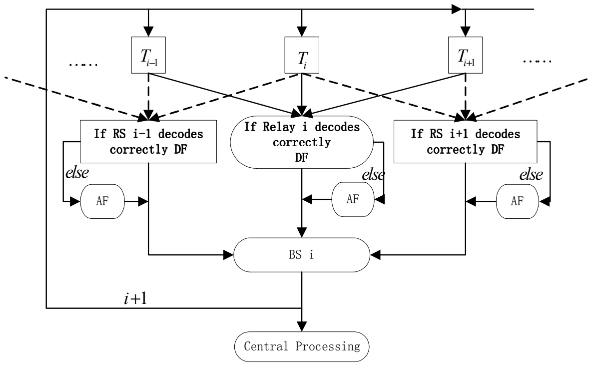

Fig. 3. HDAF Transmission Flowchart.

The equivalent channel $h^{'''}_{T_iB_i}$, noise $n^{'''}_i$ and interference $w^{'''}_i$ are determined by the combination of AF and DF in RS R_{i-1}, R_i, R_{i+1}.

Similar to AF transmission, the interference term $w^{'''}_i$ is considered to be additive Gaussian noise with power $W^{'''}_i = \frac{E\left[\left|w^{'''}_i\right|^2\right]}{N_0}$, the noise power is $N^{'''}_i = \frac{E\left[\left|n^{'''}_i\right|^2\right]}{N_0}$, the equivalent additive Gaussian noise at the BS in the two slots is correlated as $\rho^{''} = \frac{E\left[(w_i+n_i)\left(w^{'''}_i+n^{'''}_i\right)^H\right]}{N_0}$.

We also assume the BSs are able to know the full CSI, so that we can get the ergodic per-cell achievable sum-rate in BS B_i

$$R_{SC-DF} = \frac{1}{2}\cdot E_h\left[\log_2\left(1+SNR\left[\begin{array}{cc} h^*_{T_iB_i} & h^{'''*}_{T_iB_i}\end{array}\right]L^{-1}\left[\begin{array}{c} h_{T_iB_i} \\ h^{'''}_{T_iB_i}\end{array}\right]\right)\right] \tag{17}$$

with $L = \left[\begin{array}{cc} 1+W_i & \rho^{''} \\ \rho^{''H} & 1+W^{'''}_i \end{array}\right]$.

IV. JOINT MULTI-CELL PROCESSING AT THE BSS

In this section, we assume the signals received at all BSs are jointly decoded by an optimal central receiver, which is connected to the BSs via a high-speed optical fiber backbone, so that information can be broadcasted reliably and fast to all the BSs in the network, in order to detect the transmitted vector $\mathbf{x} = [x_1 \cdots x_N]^T$.

A. Direct Transmission (DT)

However, differently from Section III-A, here the BSs jointly decode the signals $\{x_i\}_{i=1}^N$ transmitted by all active MTs. Therefore, the contribution from the other cells to the BS, accounted by the term w_i (2), is now considered as useful signal instead of as an additional nuisance [2]. Accordingly, by gathering the signals received by all N BSs (1) into $N \times 1$ the vector $\mathbf{y} = [y_1 \cdots y_N]^T$, the signal model becomes [2]

$$\mathbf{y} = \mathbf{H}_{TB}\mathbf{x} + \mathbf{N} \tag{18}$$

where the transmitted vector is $\mathbf{x} = [x_1 \cdots x_N]^T$ and the additive noise $\mathbf{N} = [n_1 \cdots n_N]^T$. The power of vector $\mathbf{x}$ and $\mathbf{N}$ are $E\left[\mathbf{x}\mathbf{x}^H\right] = E_s \cdot \mathbf{I}_N$ and $E\left[\mathbf{N}\mathbf{N}^H\right] = N_0 {\cdot} \mathbf{I}_N$ respectively. Assuming the BSs are aware of the channel matrix $\mathbf{H}_{TB}$, the per-cell achievable sum-rate is

$$R_{MC-DT} = \frac{1}{N}E_h\left[\log_2\left|\mathbf{I}_N + SNR\cdot\mathbf{H}_{TB}\mathbf{H}^H_{TB}\right|\right] \tag{19}$$

B. Amplify-and-Forward (AF) Transmission

Based on the analysis of Section III-B, the distinctive feature is that, differently from the single cell processing, inter-cell interference terms are treated as useful signals, as explained above in the context of direct transmission. The signal received at the BS in the first time slot can be written as (18) for AF protocol.

In the second time slot, the interference term $w^{'}_i$ is treated as useful signal for decoding. So the $N \times 1$ receiving signal vector is

$$\mathbf{y}^{'}_B = \mathbf{H}^{'}_{TB}\cdot\mathbf{x} + \mathbf{N}^{'}_{\mathbf{B}} + \mathbf{N}_{\mathbf{B}} \tag{20}$$

the elements of matrix $\mathbf{H}^{'}_{TB}$ can be computed by (8) (9). The noise terms are $\mathbf{N}^{'}_B = \left[n^{'}_{B_1}\cdots n^{'}_{B_N}\right]^T$ and $\mathbf{N}_B = [n_{B_1}\cdots n_{B_N}]^T$. The correlation matrix of the equivalent additive Gaussian noise is $E\left[\left(\mathbf{N}^{'}_B+\mathbf{N}_B\right)\left(\mathbf{N}^{'}_B+\mathbf{N}_B\right)^H\right] = N_0\mathbf{R}_{\mathbf{N}^{'}_B} + N_0\mathbf{I}_N$, where $\mathbf{R}_{\mathbf{N}^{'}_{\mathbf{B}}}$ is a pentadiagonal Toeplitz correlation matrix with $\left[\mathbf{R}_{\mathbf{N}^{'}_B}\right]_{i,i+j} = \frac{E\left[\mathbf{N}^{'}_B\mathbf{N}^{'H}_B\right]_{i,i+j}}{N_0} = \frac{E\left[n^{'}_{B_i}n^{'*}_{B_{i+j}}\right]}{N_0}$:

$$\left[\mathbf{R}_{\mathbf{N}^{'}_B}\right]_{i,i+j} = \begin{cases} \sum\limits_{k=-1}^{1} g^2_{R_{i+k}}\left|h_{R_{i+k}B_i}\right|^2 & j=0 \\ g^2_{R_i}h_{R_iB_i}h^*_{R_iB_{i\pm1}} + g^2_{R_{i\pm1}}h_{R_{i\pm1}B_i}h^*_{R_{i\pm1}B_{i\pm1}} & j=\pm1 \\ g^2_{R_{i\pm1}}h_{R_{i\pm1}B_i}h^*_{R_{i\pm1}B_{i\pm2}} & j=\pm2 \\ 0 & otherwise \end{cases} \tag{21}$$

In the two time slots, the same as [1] [2], recalling that the BSs jointly decode the transmitted signal vector based on both the signal received in the first time slot (18) and the second time slot (20) and the full channel state information is assumed at the BSs, the achievable per-cell sum-rate is

$$R_{MC-AF} = \frac{1}{2N}\cdot E_h\left[\log_2\left|\mathbf{I}_{2N} + SNR\left[\begin{array}{c}\mathbf{H}_{TB}\\ \mathbf{H}^{'}_{TB}\end{array}\right]^H\mathbf{Q}^{-1}\left[\begin{array}{c}\mathbf{H}_{TB}\\ \mathbf{H}^{'}_{TB}\end{array}\right]\right|\right] \tag{22}$$

with $\mathbf{Q} = \left[\begin{array}{cc}\mathbf{I}_N & \mathbf{0}_N \\ \mathbf{0}_N & \mathbf{I}_N + \mathbf{R}_{\mathbf{N}^{'}_B}\end{array}\right]$.

C. *Decode-and-Forward (DF) Transmission*

The same as Section IV-A and IV-B, the signal received at the BS in the first time slot can be written as (18) for DF protocol.

In the second time slot, the signal received by the BS is (13) that, similarly to (18) and (20), can be expressed according to a matricial formulation by defining the $N \times 1$ vector

$$\mathbf{y}_B^{''} = \mathbf{H}_{RB}^{'}\mathbf{x} + \mathbf{n}^{''} \tag{23}$$

Recalling that the BSs jointly decode the transmitted signal vector based on both the signal received in the first time slot (18) and the second time slot (23), while the full CSI is assumed at the BSs, the achievable per-cell sum-rate is

$$R_{MC-DF} = \frac{1}{2N} \cdot E_h\left[\log_2\left|\mathbf{I}_{2N} + SNR\begin{bmatrix}\mathbf{H}_{TB}\\ \mathbf{H}_{RB}^{'}\end{bmatrix}^H \mathbf{M}^{-1}\begin{bmatrix}\mathbf{H}_{TB}\\ \mathbf{H}_{RB}^{'}\end{bmatrix}\right|\right] \tag{24}$$

with $\mathbf{M} = \begin{bmatrix}\mathbf{I}_N & \mathbf{0}\\ \mathbf{0} & \mathbf{I}_N\end{bmatrix}$.

D. *Hybrid Decode-Amplify-Forward (HDAF) Transmission*

Similar to Section IV-A and IV-B, the signal received at the BS B_i in the first time slot can be written as (18) for HDAF protocol.

In the second time slot, the signal received by the BS is (16) that, similarly to (18) (20) (23), it can be expressed according to a matricial formulation by defining the $N \times 1$ vector

$$\mathbf{y}_B^{'''} = \mathbf{H}_{TB}^{'''}\mathbf{x} + \mathbf{N}^{'''} \tag{25}$$

Similarly to AF and DF transmission, the achievable per-cell sum-rate is

$$R_{MC-HDAF} = \frac{1}{2N} \cdot E_h\left[\log_2\left|\mathbf{I}_{2N} + SNR\begin{bmatrix}\mathbf{H}_{TB}\\ \mathbf{H}_{TB}^{'''}\end{bmatrix}^H \mathbf{L}^{-1}\begin{bmatrix}\mathbf{H}_{TB}\\ \mathbf{H}_{TB}^{'''}\end{bmatrix}\right|\right] \tag{26}$$

with $\mathbf{L} = \begin{bmatrix}\mathbf{I}_N & \mathbf{0}_N\\ \mathbf{0}_N & \frac{E\left(\mathbf{N}^{'''}\mathbf{N}^{'''H}\right)}{N_0}\end{bmatrix}$.

V. SIMULATION RESULTS AND DISCUSSION

Some results are presented in order to demonstrate the analysis reasonable in the previous sections. To get a better insight into the performance of the scenarios in the paper but without loss of generality, we specialize the results of the previous section to be a simple geometric model. The RS R_i is assumed for simplicity to be on a line that connects the active MT T_i to the BS B_i at a normalized distance from MT T_i equal to $0 \leq d \leq 1$, where $1-d$ is the normalized distance from RS R_i to the BS B_i.

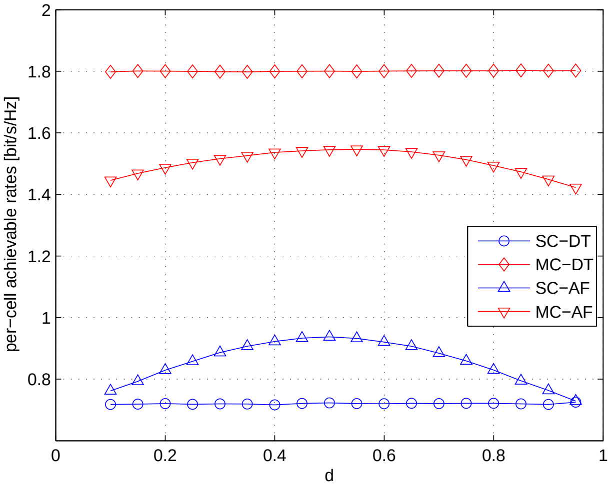

Fig. 4. Ergodic capacity of DT and AF for single-cell and multi-cell processing versus the normalized distance d (SNR = 3dB, $\alpha^2 = -3$dB, $\sigma^2 = -3$dB, $\gamma = 3$).

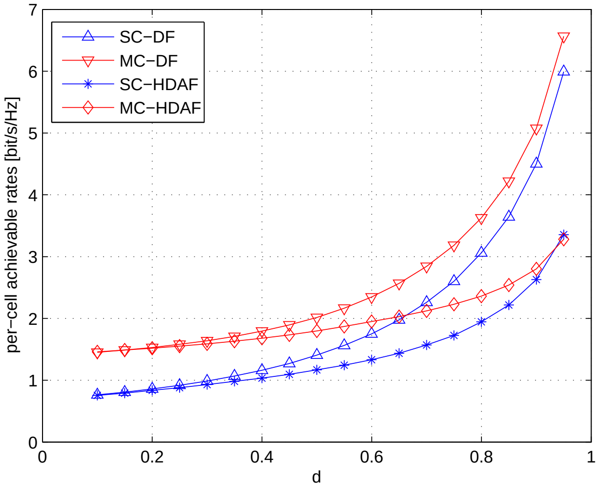

Fig. 5. Ergodic capacity of DF and HDAF for single-cell and multi-cell processing versus the normalized distance d (SNR = 3dB, $\alpha^2 = -3$dB, $\sigma^2 = -3$dB, $\gamma = 3$).

The average channel gain is defined by d and by the path loss exponent γ ($\gamma > 1$ and integer for simplicity) as $\alpha^2 = \frac{1}{d^{\gamma}}$, $\delta^2 = \frac{1}{(1-d)^{\gamma}}$.

Fig. 4 and Fig. 5 compare the per-cell rates of direct transmission in DT, AF, DF and HDAF in single cell and multi-cell processing versus normalized distance d for $N = 10$, $SNR = 3$dB, $\alpha^2 = -3$dB, $\sigma^2 = -3$dB, $\gamma = 3$, respectively. It can be seen from Fig. 4 that, notwithstanding single cell or multi-cell processing, the maximum sum-rate is for a range of d around 0.5 in AF transmission but it has no effect on DT that is true from the former assumption. From Fig. 5 we can see that in DF and HDAF transmission, the sum-rate is monotone increase with respect to distance d.

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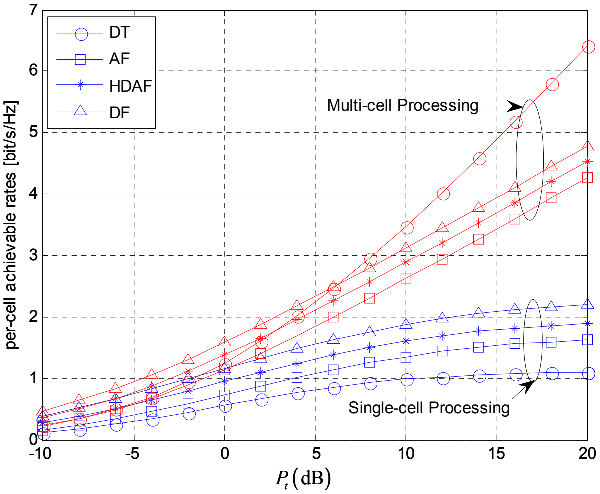

Fig. 6. Ergodic capacity of different schemes with or without cooperation between MTs and BSs versus SNR ($\alpha^2 = -3$dB, $\sigma^2 = -3$dB, d=0.5, $\gamma = 3$).

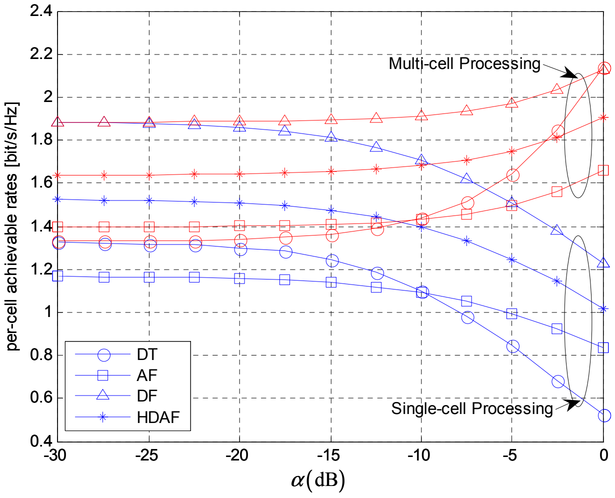

Fig. 7. Ergodic capacity of different schemes for single-cell and multi-cell processing versus α (SNR=3dB, $\delta^2 = -3$dB, d=0.5, $\gamma = 3$).

Cooperation between BSs treat the inter-cell interference as useful signals while the inter-cell interference is considered to be noise in single-cell processing, so it can improve the system performance. From Fig. 6, we can see that the multi-cell processing outperforms single-cell processing for rates about 2.0 bit/s/Hz. As shown in Fig. 6, AF and DF is the two limitation of HDAF, the results demonstrate the assumption at the beginning is true.

From Fig. 7, we can get that α has different effects on single-cell and multi-cell processing in this paper. As α increasing, the system performance becomes better in joint multi-cell processing, on the contrary, the system performance becomes bad in single-cell processing, the conclusion is the same as [1].

VI. CONCLUSIONS

In this paper, we study DT, AF transmission, DFtransmission and HDAF transmission in single-cell processing and multi-cell processing. We consider TDMA system for simplicity analysis. Through analysis, we get the multi-cell processing has better performance than the single-cell processing, so joint multi-cell processing is a effective technology to cancel interference and has a promising prospect in future wireless communication systems. We only analyze the one dimensional model in this paper, in practice, the planar model is commonly used, which is a hot point in future study.

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