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Linear Interference Pre-cancelation in Multiuser Cellular Relay System

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***Abstract*—A simple linear precoding scheme to cancel interference is proposed for downlimk multiuser cellular relay networks where the available information is asymmetric between the base station and the relay node. The interference signal from the relay is eliminated by linear pre-pocessing at the base station without any cooperation between the base station and the relay. In the information asymmetric environment, it is shown that the proposed scheme outperforms a time division multiple access (TDMA) scheme and approaches an ideal scheme based on dirty paper coding (DPC) in terms of capacity. An mathematical framework for the analysis of the proposed technique is also presented.**

I. INTRODUCTION

Recently using relays (RSs) in cellular systems has attracted much attentions since RSs are able to extend the coverage, increase transmit rates, and improve spectral efficiency with low cost and low transmit power. The fundamental role of relays in cellular systems is to forward data from a base station (BS) to mobile stations (MSs) via wireless channels, and vice versa. The pioneering studies of relay communications focused on point-to-point communications [1]-[5]. But recent studies have been extended to point-to-multipoint or multipoint-to-multipoint for multiple simultaneous users [6]-[11].

In the downlink multiuser cellular communications using relays, transmission occurs over two phases. A BS transfers its signal to a relay in the first phase. In the second phase, a BS and a RS simultaneously transmit signals for multiple users who are scheduled to be served by the BS or the RS. The RS forwards the received signal by a given relay protocol such as amplify-and-forward (AF) or decode-and-forward (DF). In the second phase, the achievable capacity is limited by mutual interference among users. The effect of interference becomes more severe as interference channel is stronger. In the downlink system, interference suppression at the receiver is not practical due to the complexity constraint of the mobile terminal, thus interference management should be dealt at the BS and the RSs. The orthogonal channelization such as time division multiple access(TDMA) is able to remove mutual interference. However, the spectral efficiency can rather be reduced by the costs for the orthogonalized channels, i.e., transmit duty cycle, etc.

To solve problem occurred by mutual interference without the costs for the orthogonalized channels, linear joint processing among the base station and relay nodes were investigated [12]-[14]. In [12] and [13], author built joint optimization problem to obtain linear precoding matrix and simplifyied parameters of the problem for information symmetric and asymmetric configuration. The optimal solution of the problem, however, is not obtained closed forms but obtained by numerical methods. In addition, conditions to solve problem includes impractical assumptions such as full or partial channel state information and power sharing among all nodes which are geographically separated.

The downlink multiuser communications in cellular relay systems typically have information asymmetric configurations that the available information at each node is asymmetric. That is, a BS knows the data for all users while a RS knows only the data for the user to be supported by the RS. In our paper, we further assume an ideal DF relay and no exchange of any channel state information between a BS and a RS since cooperation between geographically separated nodes is typically prohibited.

This paper proposes a simple linear interference pre-cancelation scheme for the downlink multiuser cellular relay systems. The pre-cancelation matrix is designed based on the desired and interference channel state information of the user served by BS. Specifically, in the second phase, the BS transmits not only data for MS served by the BS but also data for MS belonging to the the RS by aligning opposite direction to the interference signal from the RS. Consequently, interference signal is completely canceled out at the MS. Our analytical and numerical results show that the proposed interference pre-cancelation technique yields comparable performance to ideal DPC technique in the information asymmetric configuration.

The rest of this paper is organized as follows. In Section II, we present a system model we consider. The optimization problem in the given system is formulated in Section III. The proposed interference pre-cancelation scheme is introduced and analyzed in Section IV. Section V shows the capacity of the proposed scheme and compares it with other schemes. Finally, conclusions are drawn in Section VI.

II. SYSTEM MODEL

The downlink multiuser communications in a cellular relay system is considered. The MS_1 and MS_2 are served simultaneously by the BS and the RS respectively. Each node is

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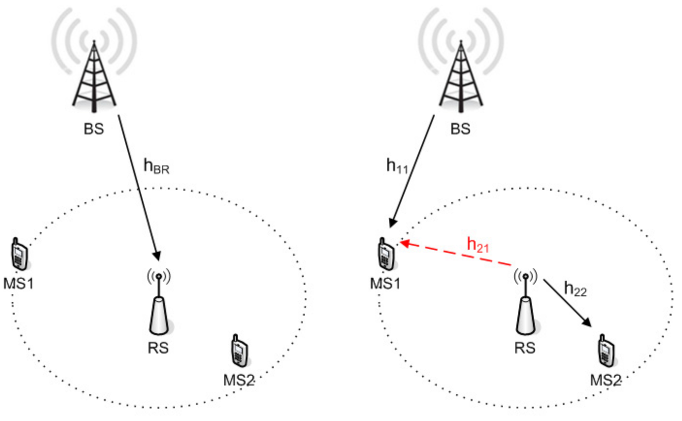

Phase 1: data relaying Phase 2: data transmission

Fig. 1. System model

assumed to have a single antenna. Fig. 1 shows our system model.

Since we assume a half-duplexing relay, the BS transfers the data s_2 for MS$_2$ to the RS in the first phase as shown in Fig. 1. We assume that there is no direct path between the BS and MS$_2$, which is typical in cellular relay systems. Although MS$_1$ also hears s_2, we do not consider interference suppression at the MS$_1$ such as successive interference cancelation (SIC) due to a complexity limitation at the mobile terminal. Then, the RS might be able to decode the data or fail to decode it depending on the channel condition of the BS to RS (B-R) link. In this paper, we assume that if channel condition of the B-R link cannot support desired data rate R, then the decoding is failed at the RS. At the first phase, the data relaying is not different from conventional relaying scheme and we will further focus on the interference pre-cancelation matrix design in the second phase.

In the second phase, both BS and RS simultaneously transmit data x_1 and x_2 after multiplying precoding vectors such as

$$x_1 = \mathbf{w}_1 \mathbf{s} \tag{1}$$

$$x_2 = \mathbf{w}_2 \mathbf{s} \tag{2}$$

where $\mathbf{w}_1 = [w_{11}\ w_{12}]$ and $\mathbf{w}_2 = [w_{21}\ w_{22}] \in \mathbb{C}^{1\times 2}$ are the precoding vectors at a BS and a RS, respectively. $\mathbf{s} = [s_1\ s_2]^T$ is the vector of the data symbols for MS$_1$ and MS$_2$. The superscript T denotes the vector transpose.

In Fig. 1, the channels with solid line and dotted line denote the desired channels and interference channels, respectively. The channel matrix of the entire network is given by

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{21} \\ 0 & h_{22} \end{bmatrix} \in \mathbb{C}^{2\times 2} \tag{3}$$

whose diagonal components h_{ii} stand for the desired channels and follow i.i.d. complex Gaussian distributions $\sim \mathcal{CN}(0, \sigma_{ii}^2)$. The off-diagonal components h_{ij} where $i \neq j$ denote interference channels and follow i.i.d. complex Gaussian distribution $\sim \mathcal{CN}(0, \sigma_{ij}^2)$. We assume that the average channel gain of interference channel is smaller than that of desired channel $\sigma_{ij}^2 \leq \sigma_{ii}^2$.

The received signal vector $\mathbf{y} = [y_1\ y_2]^T$ is given by

$$\mathbf{y} = \mathbf{HWs} + \mathbf{n} \tag{4}$$

where y_1 and y_2 are the received signal at MS$_1$ and MS$_2$, respectively, $\mathbf{W} = \left[\mathbf{w}_1^T\ \mathbf{w}_2^T\right]^T \in \mathbb{C}^{2\times 2}$ is the precoding matrix of the entire system, and $\mathbf{n} = [n_1\ n_2]^T \in \mathbb{C}^{2\times 1}$ is the additive complex Gaussian noise vector with zero mean and covariance matrix $\sigma_N^2 \mathbf{I}$. The transmitters are subject to individual power constraint P_1 and P_2 and $E[\mathbf{s}\mathbf{s}^T] = \mathbf{I}_{2\times 2}$. Therefore, the power constraints become

$$|w_{11}|^2 + |w_{12}|^2 \leq P_1 \tag{5}$$

$$|w_{21}|^2 + |w_{22}|^2 \leq P_2 \tag{6}$$

III. PROBLEM FORMULATION

To maximize achievable capacity at the second phase, the precoding matrix has to be jointly designed among the BS and the RS. The cooperative design of the precoding matrix, however, requires exchange of the full CSI and data of all MSs. Since the exchange of a large amount of CSI and data causes heavy burden and additional delay for the system, we need to design a precoding matrix in the inherent information asymmetric configuration without additional information exchange. The available information at the BS and the RS is again summarized as

1) The BS knows both s_1 and s_2 and CSI of MS$_1$.
2) The RS knows only s_2 (and CSI of MS$_2$).

Since the RS does not have any information on the data of MS$_1$ and no information exchange is allowed, the precoding matrix $\mathbf{W}$ has to be an asymmetric form such as

$$\mathbf{W} = \begin{bmatrix} w_{11} & w_{12} \\ 0 & w_{22} \end{bmatrix}. \tag{7}$$

Consequently, the linear joint precoder design problem reduces to an independent precoder design problem at the BS. Given the system model, the achievable capacities of MS$_1$ and MS$_2$ are given by

$$C_{MS_1} = \log_2\left(1 + \frac{|h_{11}w_{11}|^2}{\sigma_N^2 + |h_{11}w_{12} + h_{21}w_{22}|^2}\right), \tag{8}$$

$$C_{MS_2} = \log_2\left(1 + \frac{|h_{22}w_{22}|^2}{\sigma_N^2}\right). \tag{9}$$

The optimal precoder maximizing the system capacity is the solution of the following optimization problem:

$$\begin{aligned} \mathbf{W}_{opt} = \quad & \arg\max_{w_{11},\, w_{12}} \left(1 + \frac{|h_{11}w_{11}|^2}{\sigma_N^2 + |h_{11}w_{12} + h_{21}w_{22}|^2}\right) \\ & \cdot \left(1 + \frac{|h_{22}w_{22}|^2}{\sigma_N^2}\right) \end{aligned} \tag{10}$$

$$\text{s.t.} \quad |w_{11}|^2 + |w_{12}|^2 \le P_1, \\ |w_{22}|^2 \le P_2$$

IV. THE PROPOSED LINEAR INTERFERENCE PRE-CANCELATION SCHEME

The optimization problem in (10) is not only hard to obtain a closed form solution but also required sharing full CSI for MSs to solving problem. In this section, we propose a sub-optimal but much simpler interference pre-cancelation scheme which does not need to exchange CSI between the BS and the RS. Furthermore we derive analytical expression of ergodic capacity for proposed scheme.

A. Interference Pre-cancelation Matrix Design

If the RS does not have the data of MS$_1$, the RS cannot design a beneficial precoder for MS$_1$. So the RS transmits the data s_2 with pick power to maximize capacity of its serving user MS$_2$ and hence the precoding matrix becomes

$$\mathbf{W} = \begin{bmatrix} w_{11} & w_{12} \\ 0 & \sqrt{P_2} \end{bmatrix} \tag{11}$$

Now, we focus on the design of w_{11} and w_{12} to pre-cancel interference from the RS. Since the interference from the RS to MS$_1$ is given by $h_{21}\sqrt{P_2}s_2$ from (4) and (11), the BS steers the phase of w_{12}, θ to make s_2 from the BS oppositely align with s_2 from the RS:

$$\theta_{11} - \theta = \theta_{21} + \pi \tag{12}$$

where θ_{11} and θ_{21} are the phases of channel $h_{11} = |h_{11}|\angle\theta_{11}$ and $h_{21} = |h_{21}|\angle\theta_{21}$, respectively. To completely cancel the interference at the MS$_1$, the power portion α for w_2 is determined by

$$\alpha = \begin{cases} \frac{|h_{21}|^2 P_2}{|h_{11}|^2 P_1}, & \text{if } |h_{11}|^2 P_1 \ge |h_{21}|^2 P_2 \\ 0, & \text{otherwise} \end{cases} \tag{13}$$

where it should be noted that $0 \le \frac{|h_{21}|^2 P_2}{|h_{11}|^2 P_1} \le 1$. If the interference channel is stronger than the desired channel, we can not cancel the interference. Then, we set α to be 0 and do not manage interference for simplicity of the precoder. However, if the average channel gains of the desired channels are larger than those of the interference channels, which is typical in a fixed cellular relay networks, the strong interference case seldom occurs.

The complete interference pre-cancelation matrix is given by

$$\mathbf{W} = \begin{bmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{bmatrix} = \begin{bmatrix} \sqrt{(1-\alpha)P_1} & \sqrt{\alpha P_1} e^{-j\theta} \\ 0 & \sqrt{P_2} \end{bmatrix}. \tag{14}$$

If $|h_{11}|^2 P_1 \ge |h_{21}|^2 P_2$, the received SINRs of the proposed scheme are given by

$$SINR_{new,1} = \frac{(1-\alpha)P_1|h_{11}|^2}{\sigma_N^2}, \tag{15}$$

$$SINR_{new,2} = \frac{P_2|h_{22}|^2}{\sigma_N^2} \tag{16}$$

On the other hand, the received SINRs without precoding for interference management are given by

$$SINR_{no,1} = \frac{P_1|h_{11}|^2}{\sigma_N^2 + P_2|h_{21}|^2}, \tag{17}$$

$$SINR_{no,2} = \frac{P_2|h_{22}|^2}{\sigma_N^2}. \tag{18}$$

From (15) and (17), it is obvious that interference from the RS is completely removed at the MS$_1$ if the proposed linear precoding is applied. If the interference goes to 0, α approaches 0 and hence $SINR_{new,1}$ becomes the same as $SINR_{no,1}$. We note that proposed scheme guarantees at least same performance with no precoding scheme, and generally outperforms. At high SNR region which interference becomes dominant, $SINR_{no,1}$ could be saturated by interference from the RS. However, proposed scheme ensures interference free communication for all SNR region. This will be shown later by computer simulation.

B. Ergodic Capacity

We assume $P_1 = P_2 = P$ and transmit SNR $\rho = P/\sigma_N^2$ for simplicity. Then the capacity of the first phase is given by

$$C_1 = \log_2(1 + \rho|h_{BR}|^2). \tag{19}$$

If the RS fails to decode the data s_2 with probability $P_{Fail} = Pr\left[C_1 < R\right]$, the BS only transmits data s_1 to MS$_1$ in the second phase. Then, the capacity in the second phase is given by

$$C_{Fail} = \log_2(1 + \rho|h_{11}|^2). \tag{20}$$

If the RS succeeds in decoding s_2 in the first phase, the achievable rates by MS$_1$ and MS$_2$ in the second phase are divided into 2 cases: First case is when interference channel from the RS to MS$_1$ is stronger than desired channel with probability $Pr\left[|h_{11}|^2 < |h_{21}|^2\right]$. In this case, the BS cannot precancel interference due to peak power limitation, thus the BS and the RS transmit data simultaneously without any precoding. Second case is when the interference channel gain is smaller than the desired channel gain and this is occurred with probability $Pr\left[|h_{11}|^2 \ge |h_{21}|^2\right]$. In the second case, simultaneous transmission is performed with applying proposed precancelation scheme.

The capacity of MS$_i$ for different two cases are given by

$$C_{no,i} = \log_2(1 + SINR_{no,i}), \tag{21}$$

$$C_{new,i} = \log_2(1 + SINR_{new,i}), \tag{22}$$

respectively. From (21) and (22) the capacity of MS$_i$ in the second phase can be represented as

$$C_{2,i} = \begin{cases} C_{no,i}, & \text{if } |h_{11}|^2 < |h_{21}|^2 \\ C_{new,i}, & \text{if otherwise} \end{cases}. \tag{23}$$

The capacity of MS$_2$ who is served by relay is given by

$$C_{MS_2} = \min\{C_1, C_{2,2}\}. \tag{24}$$

Since the decoding threshold R is set to be greater than capacity of the second phase for MS$_2$, then the capacity of MS$_2$ is represented as $C_{MS_2} = C_{2,2}$. Therefore overall capacity of the system with proposed scheme is given by

$$C = \frac{P_{Fail}}{2} C_{Fail} + \frac{(1-P_{Fail})}{2}\left(C_{2,1} + C_{2,2}\right). \tag{25}$$

To derive ergodic capacity, we obtain average value for each component in (25). At first, the probability of decoding fail at the RS is represented as

$$P_{Fail} = Pr\left[C_1 < R\right] = 1 - \exp\left(-\frac{2^R - 1}{\rho\sigma_{BR}^2}\right). \tag{26}$$

Since channel gain $|h_{11}|^2$ follows an exponential distribution $\sim \chi^2(2)$ with mean $1/\sigma_{11}^2$, the average of C_{Fail} can be represented as

$$\mathbb{E}\left[C_{Fail}\right] = \int_0^\infty \log_2(1+x)\frac{1}{\rho\sigma_{11}^2} e^{-\frac{1}{\rho\sigma_{11}^2}x} dx. \tag{27}$$

The $SINR_{no,1}$ can be represented as

$$SINR_{no,1} = \frac{z}{1/\rho + y},$$

where z is an exponentially distributed random variable $\sim \chi^2(2)$ with mean σ_{11}^2, and y is an exponentially distributed random variable $\sim \chi^2(2)$ with mean σ_{21}^2. Using conditional probability, the pdf of $SINR_{no,1}$ is obtained by

$$\begin{aligned} f_{SINR_{no,1}}(x) &= \int_0^\infty f_{SINR_{no,1}|Y}(x|y) f_Y(y) dy \\ &= \frac{\frac{1}{\sigma_{21}^2} e^{-\frac{x}{\sigma_{11}^2\rho}}}{\left(\frac{x}{\sigma_{11}^2} + \frac{1}{\sigma_{21}^2}\right)^2}\left(\frac{1}{\sigma_{11}^2\rho}\left(\frac{x}{\sigma_{21}^2} + \frac{1}{\sigma_{11}^2}\right) + \frac{1}{\sigma_{21}^2}\right). \end{aligned} \tag{28}$$

The $SINR_{no,2}$ which is same as $SINR_{new,2}$ and the $SINR_{new,1}$ follow an exponential distribution $\sim \chi^2(2)$ with mean $1/\rho\sigma_{22}^2$ and $1/((1-\alpha)\rho\sigma_{11}^2)$ respectively. The probability density functions are given by

$$f_{SINR_{no,2}}(x) = f_{SINR_{new,2}}(x) = \frac{1}{\rho\sigma_{22}^2} e^{\frac{1}{\rho\sigma_{22}^2}x}, \tag{29}$$

$$f_{SINR_{new,1}}(x) = \frac{1}{(1-\alpha)\rho\sigma_{11}^2} e^{-\frac{1}{(1-\alpha)\rho\sigma_{11}^2}x}. \tag{30}$$

Using the total probability theorem, ergodic capacity of MS$_i$ in the second phase is given by

$$\begin{aligned} \mathbb{E}\left[C_{2,i}\right] &= Pr\left[|h_{11}|^2 < |h_{21}|^2\right]\mathbb{E}\left[C_{no,i}\right] \\ &+ Pr\left[|h_{11}|^2 \geq |h_{21}|^2\right]\mathbb{E}\left[C_{new,i}\right]. \end{aligned} \tag{31}$$

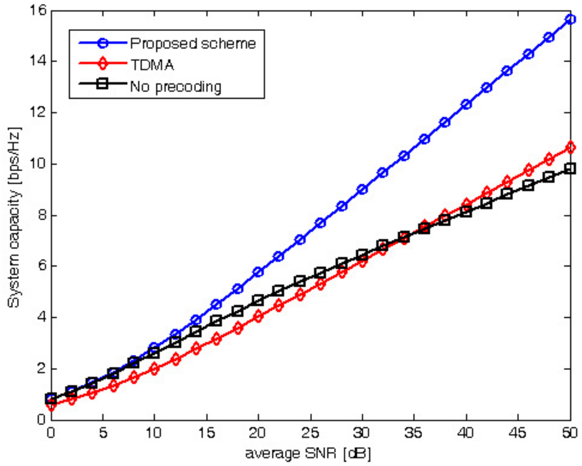

Fig. 2. System capacities in the second phase when $\sigma_{BR}^2 = 2$, $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.3$.

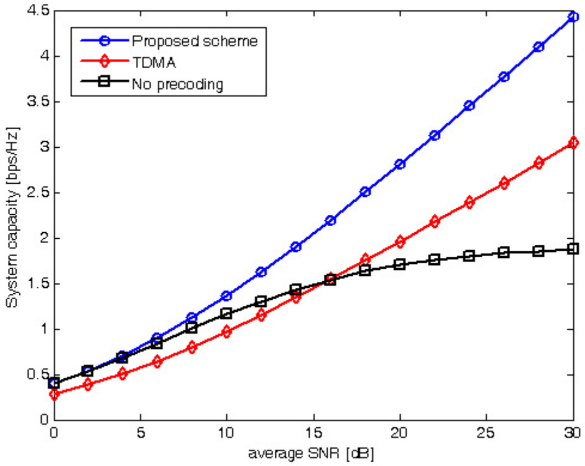

Fig. 3. Capacity for MS$_1$ in the second phase when $\sigma_{BR}^2 = 2$ and $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.3$.

Since probability of the event $|h_{11}|^2 < |h_{21}|^2$ is given by

$$Pr\left[|h_{11}|^2 < |h_{21}|^2\right] = \frac{\sigma_{21}^2}{(\sigma_{11}^2 + \sigma_{21}^2)}, \tag{32}$$

the average capacity of second phase for MS$_i$ is obtained by

$$\begin{aligned} \mathbb{E}\left[C_{2,i}\right] &= \tfrac{\sigma_{21}^2}{(\sigma_{11}^2+\sigma_{21}^2)}\int_0^\infty \log_2(1+x) f_{SINR_{no,i}}(x) dx \\ &+ \tfrac{\sigma_{11}^2}{(\sigma_{11}^2+\sigma_{21}^2)}\int_0^\infty \log_2(1+x) f_{SINR_{new,i}}(x) dx \end{aligned} \tag{33}$$

Finally, ergodic capacity with proposed interference pre-cancelation scheme is obtain by

$$\mathbb{E}[C] = \frac{P_{Fail}}{2}\mathbb{E}\left[C_{Fail}\right] + \frac{(1-P_{Fail})}{2}\left(\mathbb{E}\left[C_{2,1}\right] + \mathbb{E}\left[C_{2,2}\right]\right) \tag{34}$$

V. NUMERICAL RESULTS

In this section, we evaluate achievable capacity in the second phase by computer simulations and compare it with those of other conventional schemes.

A. *Conventional Schemes*

For comparison, we consider the following systems

- No precoding: the BS and the RS do not cooperate. So the precoding matrix is given by $\mathbf{W}_{no} = \mathbf{I}_{2\times 2}$. The received SINRs of the MSs are given in (17) and (18).
- TDMA: the transmission of the BS and the RS is orthogonalized by time. They alternately transmit signals to remove the mutual interference.

Fig. 2 shows the system capacities according to the average SNR in the second phase when $\sigma_{BR}^2 = 2$, $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.3$. The proposed scheme outperforms conventional schemes in all SNR regime. At the high SNR regime, the performance of no precoding is degraded because the capacity of MS$_1$ is saturated by interference from the RS. On the other hand, the capacity of the TDMA scheme is lower than that of no precoding case due to time duty cycle at the low SNR regime. To show effect of proposed scheme more clearly, we plot the capacity of MS$_1$ in the second phase in Fig. 3. We note that proposed scheme yields enhanced performance compared to conventional schemes through all SNR regime from Fig. 3. Opposed to that the capacity of no precoding is saturated due to interference from the RS at high SNR regime, the capacity of proposed scheme glows linearly as increasing average SNR.

The results for stronger interference channel are presented in Fig. 4 and 5, where the average gain of the interference channel σ_{ij}^2 is 0.5. The trends are similar to Fig. 2 and Fig. 3, but the capacity of no precoding is degraded faster than weaker interference environment, thus the crossing point between no precoding and the TDMA presents at smaller SNR value. The proposed scheme always achieves higher capacity than both conventional schemes in all SNR regime.

B. *An Ideal Scheme Based on DPC*

For further comparison, we consider an ideal scheme based on dirty paper coding (DPC) for the information asymmetric configuration that a BS knows both data s_1 for MS$_1$ and s_2 and full CSI for the MS$_1$ (the BS-MS$_1$ link and the Relay-MS$_1$ link) while a RS only knows the data s_2 for MS$_2$.

Since the BS knows both s_1 and s_2 and has full information of desired channel and interference channel of MS$_1$, the BS is able to design codeword for MS$_1$ ideally which is not interfered by signal from the RS. Consequently, the interference is completely eliminated at MS$_1$ *without any power loss*. Correspondingly, the received SINR of MS$_1$ becomes

$$SINR_{DPC,1} = \frac{P_1|h_{11}|^2}{\sigma_N^2}. \tag{35}$$

From (15) and (35) we note that difference between the proposed linear processing and ideal DPC is power loss factor $(1-\alpha)$. The fact that the power loss is marginal will be demonstrated by following numerical results.

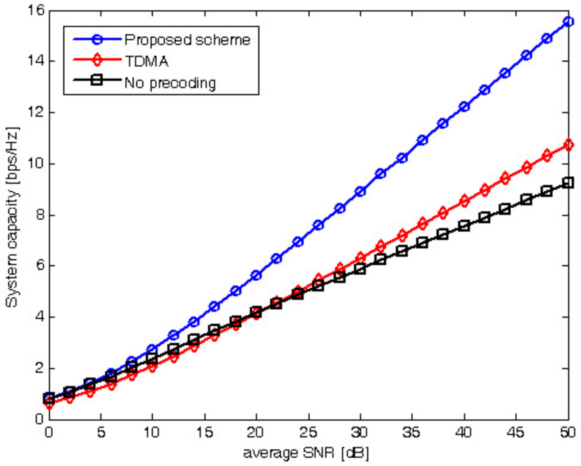

Fig. 4. System capacities in the second phase when $\sigma_{BR}^2 = 2$, $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.5$.

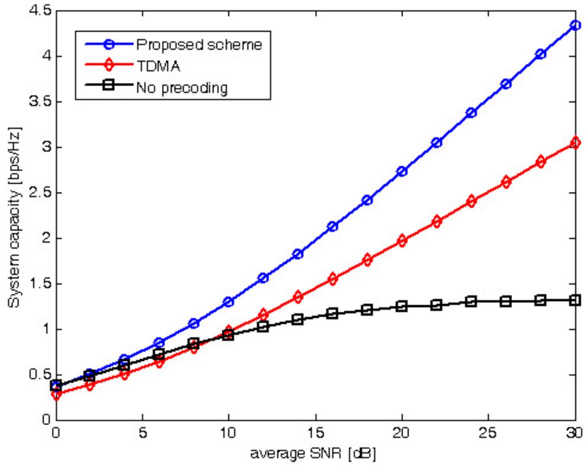

Fig. 5. Capacity for MS$_1$ in the second phase when $\sigma_{BR}^2 = 2$ and $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.5$.

Fig. 6 compares the system capacities of the proposed scheme and the ideal scheme based on DPC when $\sigma_{BR}^2 = 2$, $\sigma_{ii}^2 = 1$ and $\sigma_{i,j}^2 = 0.3$. Even though the proposed scheme is an suboptimal approach, it achieves comparable capacity to an ideal scheme using DPC which does not suffer from power loss for interference cancelation. A further comparison is given in Fig. 7 when $\sigma_{BR}^2 = 2$, $\sigma_{ii}^2 = 1$ and $\sigma_{i,j}^2 = 0.5$. In this figure, the capacity difference becomes larger compare to Fig. 6 due to the stronger interference channel but it is still marginal.

VI. CONCLUSION

In this paper, we propose a simple linear interference precancelation techniques and further derive analytical expression of the capacity for the downlink multiuser communications in a cellular relay system where the available information is asymmetric among the nodes. The BS transmits the data

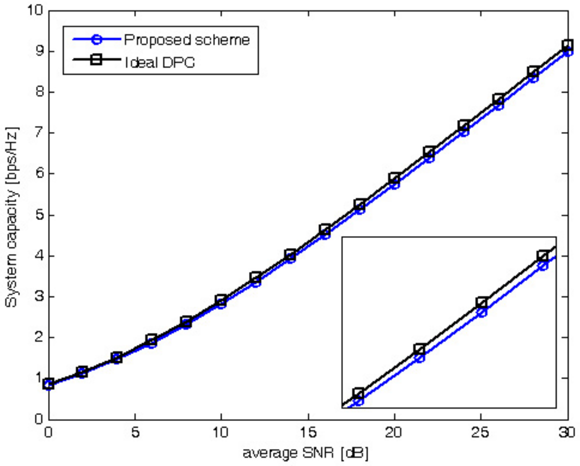

Fig. 6. System capacities in the second phase when $\sigma_{BR}^2 = 2$ and $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.3$.

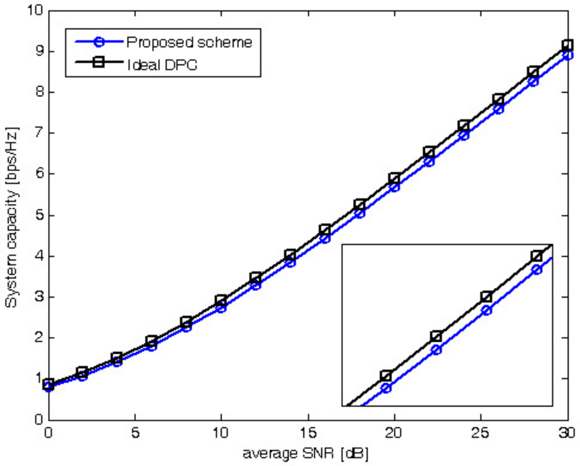

Fig. 7. System capacities in the second phase when $\sigma_{BR}^2 = 2$ and $\sigma_{ii}^2 = 1$ and $\sigma_{ij}^2 = 0.5$.

for the user belonging to the RS in addition to the data for the user served by the BS so that it is oppositely aligned with the interference signal from the BS and completely cancels out the interference. The simulation results have shown that the proposed interference pre-cancelation scheme yields enhanced performance compared to conventional schemes for the multiuser communications in a cellular relay system. The proposed scheme achieves comparable capacity to an ideal DPC scheme is also shown.

Future work may extend to multiple antenna BS and RS configuration and relay network includes direct link between the BS and MSs will be investigated.

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