Distributed Beam Forming Techniques for Dual-hop Decode-and-Forward based Cooperative Relay Networks

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Abstract—**In this paper, it has been proved that the transmission rate can be increased substantially by alleviating co-channel interference by use of beamforming techniques at relay stations. In this setup, the downlink transmission segment is taken into consideration from the Base Station (BS) to two Mobile Stations (MS). The data is transmitted concurrently through two Relay Stations (RS) using the same frequency channel. It is assumed that the RSs use decode-and-forward (DF) strategy. In this technique of beamforming, pre-coding vectors are used at the RS to alleviate co-channel interferences. Due to this strategy, each user will be able to get its own data sans interference. Two pre-coding techniques which incarnate two different transmission protocols have been proposed. Simulations results show that such type of schemas outperforms their counterpart brethren schemas.**

Keywords—Beamforming; base station; decode and forward; mobile station; relay station

I. INTRODUCTION

To acquire a higher data rate, MIMO techniques are widely used in most current wireless communication systems. The channel coding or forward error correction (FEC) scheme is an important part of MIMO communication systems if one targets high QoS for mobile users. It is essential to exploit high-performance FEC methods to achieve the performance gains in MIMO based communication systems. The FEC methods like turbo codes and LDPC codes [1-4] promises to come close to the Shannon capacity limit. The harsh channel conditions demand to use FEC schemes with iterative decoding to achieve the performance goals. Turbo codes are one of the coding schemes that are based on the concept of iterative decoding [1-4].

The relay is considered a useful technique to receive, process and retransmit signals in a wireless network. Currently, many wireless systems are using relaying techniques. By use of relays, an extension of coverage areas or hotspot capacity enhancement can be achieved. Initially, the idea of cooperative transmission was presented in [4]. The author in [5] present a cooperative system by sharing the wireless communication network by two users transmitting coherently using the same codebook. The authors proved that due to this set up the capacity region is increased. A zero force multiuser relaying system having multiple nodes both at source and destination was introduced in [6] and [7], where the channel is orthogonalized between the source and destination pairs by a relay gain allocation. A good variety of relaying protocols has been discussed in [8]. The DF protocol has been found to have numerous advantages as compared to another type of relaying protocols [9].

In this paper, a novel technique of Cooperative Relay (CR) having multiple decode and forward (DF) relays is presented. The focus is made only on downlink transmission. The relays are installed on such a position where the establishment of a healthy link-budget to the BS is ensured. It is supposed that each relay has channel information about the second hop transmission. But this information is limited about the characteristics of their own channel. The information of the channel is gained by the uplink transmission between the mobiles and the relays or by users' feedback. In the second hop, the channel information of their own makes the RS able to reckon pre-coding vectors to annul co-channel interference (CCI) [10-12]. The cancellation or alleviation of CCI is very helpful to get architecture of the receiver for MS.

In this paper, in addition of CCI cancellation, Maximum Ratio Combining (MRC) [13] and Space-Time Codes (STC) [14-18] are also used so that a good diversity gain can be achieved at Mobile Stations. While transmitting cooperatively to the MS, the relays are synchronized to its maximum level. The MRC relay scheme has phase synchronization amongst the transmitting relays. The high degree of synchronization amongst RS is relaxed at the cost of performance degradation by utilization of STC relaying technique. In both scenarios, it has been seen that when transmit is made concurrently to the consumers with the same frequency channel, a superior multiplexing gain is obtained as compared to transmit to the diverse user(s) using disparate channel(s). The simulation results confirmed that the proposed protocols/schemes are more efficient. Particularly the ameliorated transmission rates of both schemes are worth to explore.

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The paper has been organized as follows; the system model is discussed in Section II. MRC-relay is elaborated in Section III whereas Section IV discusses the Space-Time-relay protocols. The simulation results are presented in Section V, and the conclusion is given in Section VI.

II. System Model

The model shown in Fig. 1 is considered. The proposed model comprises a single BS, two MSs and two DF relays. Because of the enormous distance between them, it is assumed that the BS does not have a direct connection with MS.

The relays are fixed at such positions where healthy link-budget from the relays to the base stations is established. Initially, it is supposed that each MS is equipped with a single antenna. The numbers of antennas at BS are presented by B, at RS by R and at MS by 1and it is assumed that $B \geq R > 1$. Further, it is assumed that the transmission scheme based on OFDM to ensure that the channel between each pair of transmitting and receiving antenna is not frequency selective. The channels between BS and RS are represented by $\boldsymbol{H}_i \in \mathbb{C}^{R \times B}$ with i =1, 2. The second hop channel between RSi and MSj is represented by $\boldsymbol{h}_{i,j} \in \mathbb{C}^R$, with $(i, j) \in \{1,2\}^2$. Furthermore, it is assumed that the channel between the nodes is *i.i.d* block fading. Every relay has channel information only about the second hop, *i.e.* RS_1 and RS_2 know only about $\boldsymbol{h}_{1,1}^H$ and $\boldsymbol{h}_{2,1}^H$, and $\boldsymbol{h}_{1,2}^H$ and $\boldsymbol{h}_{2,2}^H$, respectively. ($\boldsymbol{h}_{1,1}^H, \boldsymbol{h}_{2,2}^H$) represents direct link channel whereas ($\boldsymbol{h}_{1,2}^H, \boldsymbol{h}_{2,1}^H$) represents the cross-link channel. The power constraint at BS is represented by P_{BS} and at RS by P_{RS}. Moreover, Additive White Gaussian Noise (AWGN) is assumed on each link having variance σ_{RS}^2 at RS stations and σ_{MS}^2 at MS station.

The proposed model is a half-duplex relay. The data is transmitted to MS in two phases. In the first phase, the BS transmits the data to two RSs, which is referred to as a broadcast scenario. In the second stage, both relays simultaneously transmit to MS_1 and MS_2 using the same channels. In the proposed scheme, due to the cancellation of CCI, the MS merely receive its own data. In the next section, the cancellation of CCI is done by use of pre-coding vectors will be discussed.

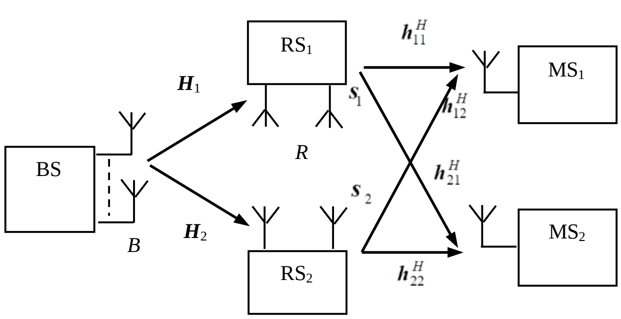

Fig. 1. System Model.

III. Maximum Ratio Combining Relay

One of the main purposes of Maximum Ratio Combining relay is to improve the diversity gain by using the cross-link channel. In order to provide additional array gain, the MRC also synchronizes the phase of each user's signal at the receiver. The symbols which are supposed to transmit to MS1 and MS2 are represented by s1 and s2. Primordially, the Base Station transmits the data symbol $\boldsymbol{S} \in$ CB to two relays with $\boldsymbol{s} = (s_1, s_2)$. Since both relays receive the same information, so it is the multicast scenario. Since it is required that both relays may decode the data perfectly received from BS, so in second hop the maximum transmission rate can be achieved as:

$$R_1 = \max_{\Gamma} \min \times \left\{ \log_2 \det(\boldsymbol{I}_R + \frac{1}{\sigma_{RS}^2}.\boldsymbol{H}_1.\boldsymbol{\Delta}.\boldsymbol{H}_1^H) , \log_2 \det(\boldsymbol{I}_R + \frac{1}{\sigma_{RS}^2}.\boldsymbol{H}_2.\boldsymbol{\Delta}.\boldsymbol{H}_2^H) \right\} \tag{1}$$

with: $\mathrm{tr}(\boldsymbol{\Delta}) = \mathrm{tr}(\boldsymbol{s}.\boldsymbol{s}^H) = P_{BS}$.

When the data received from BS is decoded by the RS, then in the second phase the transmitted signal vectors from RS1 and RS2 is written as:

$$\boldsymbol{x}_1 = s_1.\boldsymbol{v}_1 + s_2.\boldsymbol{v}_2 \tag{2}$$

and

$$\boldsymbol{x}_2 = s_1.\boldsymbol{v}_3 + s_2.\boldsymbol{v}_4 \tag{3}$$

with $\boldsymbol{v}_k \in$ CR (k = 1,2,3,4) are the pre-coding vectors having the condition that $\mathrm{tr}(\boldsymbol{v}_k.\boldsymbol{v}_k^H) = 1$ in order to satisfy the transmit power constraints. The pre-coding vectors also have to fulfill the condition given below in (4) and (5):

$$\boldsymbol{h}_{2,1}^H.\boldsymbol{v}_1 = 0 \qquad \boldsymbol{h}_{1,1}^H.\boldsymbol{v}_2 = 0 \tag{4}$$

and

$$\boldsymbol{h}_{2,2}^H.\boldsymbol{v}_3 = 0 \qquad \boldsymbol{h}_{1,2}^H.\boldsymbol{v}_4 = 0 \tag{5}$$

Actually, the pre-coding vectors lay in the null space of the corresponding channel. This type of pre-coding vectors is easily formed at RSs because of a large number of antennas while it is comparatively difficult at MSs due low number of antennas. The dimension of kernel space of $\boldsymbol{h}_{i,j}^H$ is never null for independent and identical distribution AWGN channel $\forall (i, j) \in \{1,2\}$. By use of these pre-coding vectors, the CCI is annulled and only the specific users receive the transmitted data symbols.

Considering expressions (2) to (5), the received signal at MS1 and MS2 is written as:

$$y_1 = (\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1 + \boldsymbol{h}_{1,2}^H.\boldsymbol{v}_3)\, s_1 + n_1 \tag{6}$$

and

$$y_2 = (\boldsymbol{h}_{1,2}^H.\boldsymbol{v}_2 + \boldsymbol{h}_{2,2}^H.\boldsymbol{v}_4)\, s_2 + n_2 \tag{7}$$

where n_1 represents AWGN at MS1 and n_2 the noise at MS2. To satisfy the power constraint, the equation $E\left(s_1.s_1^* + s_2.s_2^*\right) = P_{RS}$ is taken into consideration.

As it is known that each MS has only a single receiving antenna, hence in (6) and (7) the quantities $\boldsymbol{h}_{i,j}^H.\boldsymbol{v}_k (i,j) \in \{1,2\}^2$ and $k = 1,2,3,4$ are complex scalar numbers. For any pre-coding vector $\boldsymbol{v}_k$ which satisfies equations (2) to (5), the other pre-coding vector $\boldsymbol{v}_k.e^{j.\varphi}$ is also an expedient pre-coding vector. Hence the pre-coding vectors are chosen in such a way that the term $\boldsymbol{h}_{i,j}^H.\boldsymbol{v}_k$ in (6) and (7) have zero phases all over, *i.e.*

$$\angle(\boldsymbol{h}_{1,1}^H\boldsymbol{v}_1) = \angle(\boldsymbol{h}_{1,2}^H\boldsymbol{v}_3) = \angle(\boldsymbol{h}_{1,2}^H\boldsymbol{v}_2) = \angle(\boldsymbol{h}_{2,2}^H\boldsymbol{v}_4) = 0 \tag{8}$$

It is easy to calculate all these pre-coding vectors. For example, if $\boldsymbol{v}_1^0$ is found in the null space of $\boldsymbol{h}_{21}^H$, the final pre-coding vector at RS1 can be computed as:

$$\boldsymbol{v}_1 = \boldsymbol{v}_1^0.\frac{\left(\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1^0\right)^*}{\left|\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1^0\right|} \tag{9}$$

It is seen that the pre-coding vector in (9) is unique and is independent of the selection of $\boldsymbol{v}_1^0$. By selecting the pre-coding vector $\boldsymbol{v}_1$, the commensurate model of channel model between RS1 and MS1 is given by:

$$\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1 = \boldsymbol{h}_{1,1}^H\boldsymbol{v}_1^0.\frac{\left(\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1^0\right)^*}{\left|\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1^0\right|} = \left|\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1^0\right| = \left|\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1\right| \tag{10}$$

From the above equation, it is obvious that the term $\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1$ is a non-negative real number. Following the same procedure, the rest of the pre-coding vectors can be derived. Similarly, the SNR at MS1 and MS2 is computed as:

$$\mathrm{SNR}_{1,\mathrm{MRC}} = \frac{\left(\left|\boldsymbol{h}_{1,1}^H.\boldsymbol{v}_1\right| + \left|\boldsymbol{h}_{1,2}^H.\boldsymbol{v}_3\right|\right)^2.E\left(s_1.s_1^*\right)}{\sigma_{\mathrm{MS}}^2} \tag{11}$$

and

$$\mathrm{SNR}_{2,\mathrm{MRC}} = \frac{\left(\left|\boldsymbol{h}_{2,1}^H.\boldsymbol{v}_1\right| + \left|\boldsymbol{h}_{2,2}^H.\boldsymbol{v}_4\right|\right)^2 E\left(s_2.s_2^*\right)}{\sigma_{\mathrm{MS}}^2} \tag{12}$$

The maximum achievable rate in the second hop is:

$$R_{2,\mathrm{MRC}} = \log_2\left(1+\mathrm{SNR}_{1,\mathrm{MRC}}\right) + \log_2\left(1+\mathrm{SNR}_{2,\mathrm{MRC}}\right) \tag{13}$$

and the overall transmission rate is given by:

$$R_{\mathrm{MRC}} = \frac{1}{2}.\min\left(R_1, R_{2,\mathrm{MRC}}\right) \tag{14}$$

For analyzing the signal's diversity order, Rayleigh fading channel $\boldsymbol{h}_{i,j} \cong \mathrm{XN}\,(0,\sigma_{i,j}^2.\boldsymbol{I}_R)$, $(i,j) \in \{1,2\}$ is assumed, where $\sigma_{i,j}^2$ is the variance of the channel. The relationship $\mathrm{tr}(\boldsymbol{v}_k.\boldsymbol{v}_k^H) = 1$, for $k \in [1,4]$, shows that $\boldsymbol{h}_{i,j}^{\boldsymbol{H}}\boldsymbol{v}_k$ is the linear combination of the complex random normal variable. Due to this isotropic property of complex normal random vectors (9), the term $\boldsymbol{h}_{i,j}^{\boldsymbol{H}}\boldsymbol{v}_k$ is also a normal random variable with variance $\sigma_{i,j}^2$.

It is observed that second-order diversity can be obtained by the Cooperative Maximum Ratio Combining (CMRC) transmission strategy subject to the condition that the cross-link and direct link are equally robust. Secondly, at the receiver end, the received signals from different relays coherently add up if they have the same phase. In other words, a management to get additional array gain is made. However, for alignment of the phases of different signals, the relays are to be synchronized. It means that a global phase reference for the relay nodes has to be taken into account. The CMRC scheme deals two users at the same time providing maximum transmission rate to each user. This achievement is possible sans additional resources or channel knowledge.

IV. Cooperative Space-Time (CSR) Relay

Like the CMRC transmission technique, the CST Relay by dint of channel knowledge in the second hop cancels CCI occurring to the MS from the RS side. Additionally, CST Relaying technique is also used to cater to optimal diversity at MS. In such a scenario, it necessary to synchronize the symbol level between relays.

The symbols which are supposed to transmit from BS to MS1 and from BS to MS2 are represented by two successive time slots $x_1^{(1)}$, $x_1^{(2)}$, and $x_2^{(1)}$, $x_2^{(2)}$ respectively. In the initial phase of the transmission, the BS sends the data to two relays in two successive time slots. In initial hop, the rate of expression all the time shall remain the same as that of Eq. (1).

When decoding of all the four symbols by two relays is finished than in the second phase they start retransmitting to two end users. The phase-II transmission is made in two consecutive time slots.

Equation (15) and (16) denotes the transmitted signals respectively by RS1 and RS2 during the first time slot.

$$\boldsymbol{x}_1^{(1)} = s_1^{(1)}.\boldsymbol{v}_1 + s_2^{(1)}.\boldsymbol{v}_2 \tag{15}$$

and

$$\boldsymbol{x}_2^{(1)} = s_1^{(2)}.\boldsymbol{v}_3 + s_2^{(2)}.\boldsymbol{v}_4 \tag{16}$$

where $v_k \in$CR (k = 1, 2, 3, 4) denote the pre-coding vectors. They satisfy the condition mentioned in (4), (5) and $tr(v_k.v_k^H)=1$.

Equation (17) and (18) denotes the transmitted signals respectively by RS1 and RS2 during the second time slot.

$$x_1^{(2)} = (-s_1^{(2)})^*.v_1 + (-s_2^{(2)})^*.v_2 \tag{17}$$

and

$$x_2^{(1)} = (s_1^{(1)})^*.v_3 + (s_2^{(1)})^*.v_4. \tag{18}$$

Because of the cancellation of multiuser interference by the pre-coding vector, the received signal at MS1 and MS2 is written as:

$$y_1 = \begin{bmatrix} h_{1,1}^H.v_1 & h_{1,2}^H.v_3 \\ \left(h_{1,2}^H.v_3\right)^* & -\left(h_{1,1}^H.v_1\right)^* \end{bmatrix}.s_1 + n_1 \tag{19}$$

and

$$y_2 = \begin{bmatrix} h_{2,1}^H.v_2 & h_{2,2}^H.v_4 \\ \left(h_{2,2}^H.v_4\right)^* & -\left(h_{2,1}^H.v_2\right)^* \end{bmatrix}.s_2 + n_2 \tag{20}$$

where $y_i = [y_i^{(1)}, (y_i^{(2)})^*]^T$, i =1,2 is referred to as the vector of the signal received at MSi, whereas $s_i = [s_i^{(1)}, s_i^{(2)}]^T$ is known as the vector of the transmitted signal, and $n_i = [n_i^{(1)}, (n_i^{(2)})^*]^T$ represents the vector of noise at MS_i.

Taking into consideration this new approach of CR and following the basic decoding scheme of *Alamouti* code, the SNR received at MS1 and MS2 for each symbol is expressed as:

$$\mathrm{SNR}_{1,\mathrm{STC}} = \frac{\left(\left| h_{11}^H.v_1 \right|^2 + \left| h_{12}^H.v_3 \right|^2\right) \mathrm{E}\left(s_1^{(1)}.\left(s_1^{(1)}\right)^*\right)}{\sigma_{\mathrm{MS}}^2} \tag{21}$$

and

$$\mathrm{SNR}_{2,\mathrm{STC}} = \frac{\left(\left| h_{21}^H.v_2 \right|^2 + \left| h_{22}^H.v_4 \right|^2\right) \mathrm{E}\left((s_2^{(1)}.\left(s_2^{(1)}\right)^*\right)}{\sigma_{\mathrm{MS}}^2} \tag{22}$$

where $\mathrm{E}\left(s_1^{(1)}.\left(s_1^{(1)}\right)\right) + \mathrm{E}\left(s_2^{(1)}.\left(s_2^{(1)}\right)^*\right) = P_{\mathrm{RS}}$. Here, it is assumed that $s_i^{(1)}$ and $s_i^{(2)}$ is equated in power, $i-1, 2$. In the second hop, the optimal rate of transmission at each time slot is given by:

$$R_{2,\mathrm{STC}} = \log_2\left(1+\mathrm{SNR}_{1,\mathrm{STC}}\right) + \log_2\left(1+\mathrm{SNR}_{2,\mathrm{STC}}\right) \tag{23}$$

and the overall transmission rate of two hops is given by

$$R_{\mathrm{STC}} = \frac{1}{2}\min\left(R_1, R_{2,\mathrm{STC}}\right) \tag{24}$$

For transmission over the second hop, a Rayleigh fading channel is considered, $h_{i,j}^H v_k$ is a Gaussian random variable. From Eq. (21) and (22) it is seen that the received signal will be of second-order diversity having no array gain. If it is compared with the CMRC relay, one can see that the only difference is the synchronization of symbols between the relays, which is not difficult to implement as compared to phase synchronization. The cooperative space-time relay obtains maximum rate sans additional bandwidth and channel knowledge.

V. Simulation Results

For performance evaluation, the two proposed relay schemes are compared and simulated with some latest CR schemes available in the literature. For this, the following three types of CR techniques are considered.

A. Zero-Forcing (ZF)

During the second hop, RS_1 transmits the data of MS_1 and RS_2 transmits the data of MS_2. To counter the CCI to the cross-link, each relay uses a pre-coding vector. The pre-coding vectors v_1 and v_4 are chosen according to (4) and (5). In the second hop, the transmitted signal by the relays is denoted as:

$$x_1 = s_1.v_1, \quad x_2 = s_2.v_4 \tag{25}$$

where $E\left(s_1.s_1^*\right) = E\left(s_2.s_2^*\right) = P_{RS}$.

B. Beamforming (BF_1) Case-I

In this scenario, the relay station RS1 transmits data to MS1 and the relay station RS2 to MS2. The beamforming vectors RS1 and RS2 are employed on the transmitter side and are chosen as:

$$v_1 = \frac{h_{11}}{\|h_{11}\|}, \quad v_2 = \frac{h_{22}}{\|h_{22}\|} \tag{26}$$

and RS_1 and RS_2 transmit:

$$x_1 = s_1.v_1, \quad x_2 = s_2.v_2 \tag{27}$$

where $E\left(s_1.s_1^*\right) = E\left(s_2.s_2^*\right) = P_{RS}$. In this scenario, the data along with interferences is received by each user.

C. Beamforming (BF_2) Case-II

In this scheme, RS_1 and RS_2 transmit to MS1 and MS_2 in time t_1 and t_2, respectively. At time t_1, both the relay stations RS_1 and RS_2 transmit data to MS_1 and at time t_2 to MS_2. While transmitting the data to end users at time t1 and t2, both the relays RS_1 and RS_2 go on beamforming. The channels are orthogonal, so there shall be no CCI at the MS receivers.

Fig. 2 shows the transmission schemes amongst different schemes. To have an equitable comparison between diverse transmission scenarios, first, it is required to normalize the rate to a number of the channel used by each relay. The performance of the proposed CMRC, STC and CR are simulated by comparing them with three other schemas discussed above. It is assumed that the channels both at first and second hops are independent and identical distribution

Rayleigh fading channel. Further, it is assumed that $\boldsymbol{h}_{i,j} \cong \mathcal{CN}\ (0, \sigma_{i,j}^2 . \boldsymbol{I}_R)$ for $(i, j) \in \{1, 2\}$, where $\sigma_{i,j}^2$ is a variance of the channel. The direct link (DL) is defined as:

$$SNR_{\mathrm{DL}} = \frac{P_{\mathrm{RS}} . \sigma_{i,i}^2}{\sigma_{\mathrm{MS}}^2} \tag{28}$$

and mathematically the cross-link SNRs may be written as:

$$SNR_{\mathrm{CL}} = \frac{P_{\mathrm{RS}} . \sigma_{i,j}^2}{\sigma_{\mathrm{MS}}^2}, \qquad (i, j) \in \{1, 2\},\ i \neq j \tag{29}$$

Fig. 3 illustrates the average transmission rate of the proposed schemas. For simulation purpose, the SNR of the cross link as 20 (in the first hop) and 10dB (in the second hop) is considered, whereas the SNR of cross-link has been set to vary from zero to 10dB. In first hop, the cross-link SNR is taken as 20dB. Results show that whenever the cross-link is meager, then transmission may be done by beamforming.

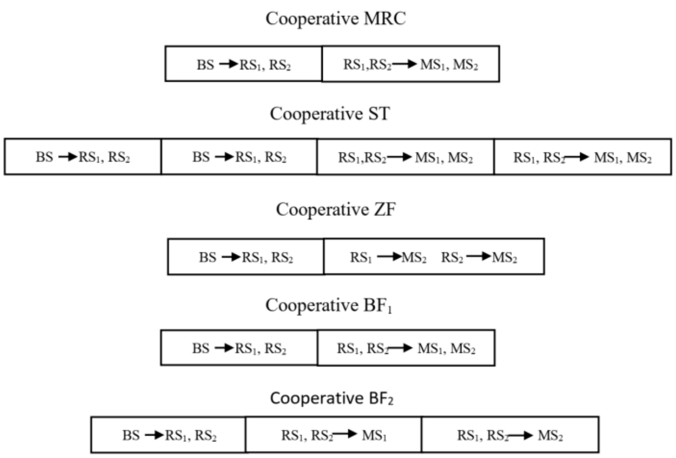

Fig. 2. Relay Protocols Transmission Schemes.

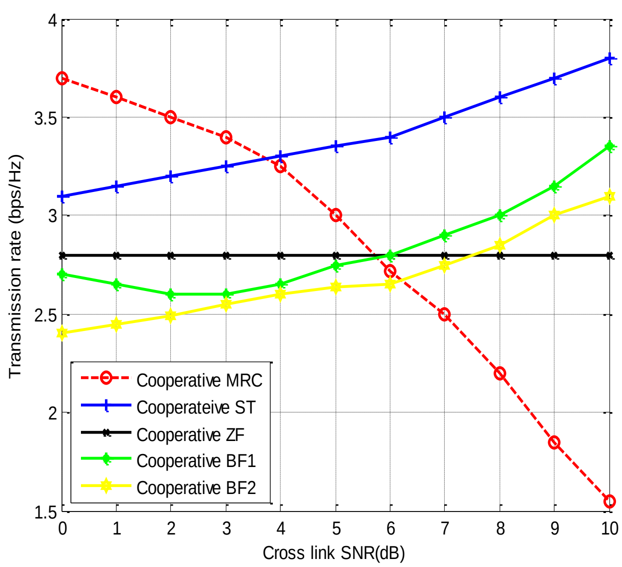

Fig. 3. Transmission Rates vs Cross-Link SNR of some Cooperative Schemes.

It can be proved that the interferences induced in the receiver are weak. Hence in such a scenario, combating to annul the cross-link interference is not incumbent rather it may devour a freedom of one spatial degree at the transmitter.

On the other hand, when the cross-link appears to be stronger, then the cross-talk interference at the receiver may cause critical degradation of performance if interference is not countered. From results, it is seen that the new proposed CMRC schemes outperform others if the cross-link SNR is greater than 4 dB. Whenever cross link-SNR is greater than 7 dB, then the CST scenario gains better transmission rate as compare to ZF, BF_1, and BF_2. Hence it is concluded that whenever the direct link and cross-link come closer to each other, then the new proposed cooperative approaches perform well.

Fig. 4 depicts a scenario presenting the average transmission rate between the cross and direct-links when they are equally powerful. Because of the same multiplexing gain, the average rate of transmission of the expounded schemas and the ZF cooperative relaying strategies resemble to each other. Its mean, the relay nodes transmit to all users in same time and frequency. Whereas in the case of BF_2, the relay nodes transmit to all users using different channels, and as a result loses the multiplexing gain. This scene is observed in the given figure from the narrow slope of BF_2 cooperative relay. In this proposal, where one mobile user is equipped with two relays, hence the received signals get maximum diversity and higher array gains. This tells us the reasons that why BF_2 cooperative relays offer higher transmission rates at lower SNRs.

The impact of noisy channel estimates is considered over the whole system performance. In fact, in this proposed scheme, the purpose of the provision of channel information about the second hop is to suppress the interferences. In this case, it is worth to investigate the impact of imperfect channel information. So, here it is supposed that the relays have noisy channel and hence $\tilde{\boldsymbol{h}}_{i,j}$ is used instead of $\boldsymbol{h}_{i,j}$.

$$\tilde{\boldsymbol{h}}_{i,j} = \boldsymbol{h}_{i,j} + \hat{\boldsymbol{h}}_{i,j} \quad i, j = 1, 2 \tag{30}$$

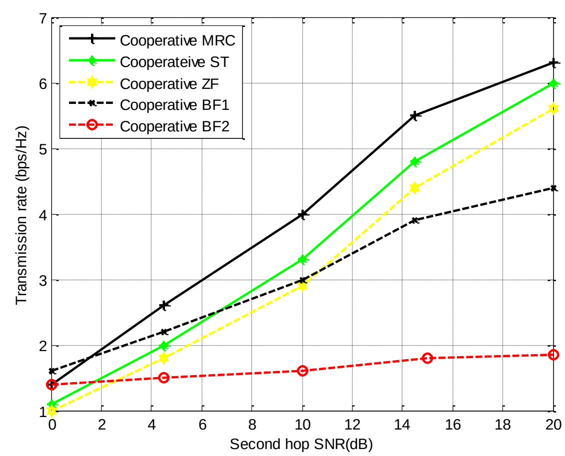

Fig. 4. Transmission Rates vs SNR in the Second Hop of different CR Schemes (1st hop SNR=20 dB, 2nd hop Direct Link SNR=10 dB).

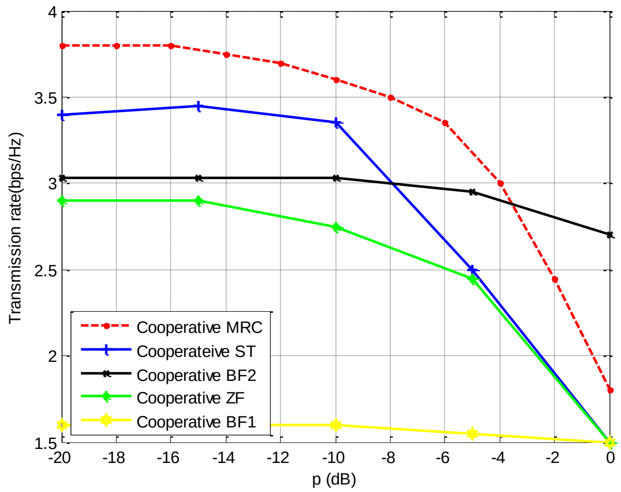

Fig. 5. Transmission Rate of difference Schemes vs the Erroneous Channel State Information at Relays.

Each entry of $\hat{h}_{i,j}$ is modeled as *i.i.d* circularly symmetric zero mean complex normal random variable $\boldsymbol{h}_{i,j} \cong \mathcal{CN}\ (0, \sigma^2_{i,j}.\boldsymbol{I}_R)$. To quantify the estimation accuracy the parameter $\rho = \hat{\sigma}^2_{i,j} / \sigma^2_{i,j}$ is used. Simulation results are given in Fig. 5.

It is known that a set up having interference cancellation capability may also be sophisticated to erroneous channel estimates. The BF2 cooperative relay scheme is unsusceptible to erroneous channel information by virtue of its characteristics that the relay nodes provide services to users through diverse channels. Even in worst in the case where the channel information is not perfect, the relay does not cause interference to other subscribers.

VI. Conclusions

Two novel CR technique using Decode and Forward strategy is proposed. The proposed techniques have the property that exchange of transmission data or knowledge of channel is not required by the relays and the signal received at each MS is free of interference. In term of spectral efficiency, the CMRC technique outdoes others at the cost of the high level of synchronization between different relaying stations. In case of synchronization problem, some type of cooperative space-timing technique is preferred. When the cross-link is powerful, then the both schemes surmount the conventional ZF and beamforming relay techniques.

The decode and forward strategy is lethargic as compared to other protocols explored in literature. Future work may be extended to use other protocols by countering the emerging problems. The use of spectrum may also be enhanced in future works.

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