

Interference Cancellation Using Joint Beamforming and Power Control Techniques in Cooperative Networks

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Abstract—In this paper, the interference cancellation (IC) techniques are studied for cooperative networks with the interference source if the destination is disturbed by the co-channel interference (CCI). In order to solve such interference problem, the beamforming techniques with the appropriate weight estimation for array antenna at the source will be employed. We can also control the transmitted power at the interference source, and maintain nearly the diversity gain compare with the existing decode and forward protocol. The system performance can be enhanced by adopting the power control strategy at the interference source by channel quality criterion and signal combining techniques. The maximum ratio combining (MRC) and the cooperative maximum ratio combining (C-MRC) are used to combine the received signals arrived at the destination to achieve the minimum probability of error based on the experimental results from simulations. The results show proposed IC C-MRC systems had the lower probability of error than MRC because effect from the weighted of received signal from the relay because of the effect of three weighted factors: the BF algorithm for the weighted estimation for the array antenna, the weighting factor of the proposed power control strategy, and the weighted of received signal from the relay.

Keywords— Beamforming, Cooperative Maximum Ratio Combining (C-MRC), Diversity Gain, Interference Cancellation, Power Control

I. INTRODUCTION

The required for speed and quality in wireless communication is continuously dramatic increase. Recently, cooperative wireless communication has received tremendous interests as an untapped means for improving the performance of information transmission operating over the challenged wireless medium. Cooperative communication has emerged as a new paradigm of diversity to emulate the strategies designed for multiple antenna systems, since a wireless mobile device may not be able to support multiple transmit antennas due to size, cost, or hardware limitations. By employing the broadcast nature of the wireless channel, cooperative communication allows single-antenna radios to share their antennas to form a virtual antenna array, and offers significant performance enhancements. In wireless network systems, the transmitted signals via radio wave propagation through

wireless channels, is a complicated phenomenon characterized by various effects such as, multipath fading and shadowing. An accurate mathematical description of this phenomenon is either unknown or too complex for compatible communication systems analysis [1]. To reduce such effects, the diversity can be used by transferring the different samples of the same signal over essentially independent channels [2]. There are different approaches to implement the diversity in a wireless transmission. One of the most important diversity is a spatial diversity. Spatial diversity has been studied intensively in the context of peer-to-peer communications, especially for a multiple-input multiple-output (MIMO) system.

In [3,4], the authors proposed different cooperative diversity protocols and analyzed their performance in terms of an outage behaviour. The terms called, decode-and-forward (DF) and amplify-and-forward (AF) have been presented. In DF, each relay receives and decodes the signal transmitted by the source, and then it forwards the decoded signal to the destination which combines these entire duplicate in a usual way. AF is a simpler technique, in which the relay amplifies the received signal and then forwards it to the destination. Although the noise is amplified along with the signal in this technique, it still gains the spatial diversity by transmitting the signal over two spatially independent channels.

The performance analysis for general AF has been shown in [5], such it is that shown that full diversity is achievable with AF. In [6] for the source to the relay links, a weighted superposition of the source and relay signals arriving at the destination can be combined using maximum-ratio-combining (MRC), which also collects the maximum available diversity order. With DF relays, MRC does not offer a full diversity [7]. To the best of our knowledge, no efficient demodulation technique is available, which is at an affordable complexity that can provably collect full diversity, regardless of the constellation, when using the most practical relay strategy as DF. The combining technique, namely a cooperative maximum ratio combining (C-MRC), is proposed to improve from the diversity gain limitation of the classical DF [8].

In classical cooperative communications, the main focus is to improve the capacity performance of single source destination pair through single or multiple relays. Recently, with development of parallel cooperative transmissions

between multiple source-destination pairs, interference cancellation (IC) [9-11] has been proposed to further improve the capacity performance. Different from the traditional approaches of separating concurrent transmissions, multiple source-destination pairs can now transmit simultaneously by cancelling the cross-user interference among them. In IC cooperative communications, relays cooperatively amplify and rotate the received combined signals from multiple-sources in such a way that only the desired signals are left at destinations. In other words, with the help of multiple cooperative relays and advanced signal processing technologies, cross-user interference is cancelled out. On the other hand, rising energy costs and increasingly rigid environmental standards have led to an emerging trend of addressing energy efficiency issue of wireless communication systems. Therefore, in addition to capacity, energy efficiency is also an important factor in network design [12].

In [13] the authors proposed nonlinear beamforming based on the method of radial basis functions (RBF) to combine with constant modulus algorithm (CAM) for interference cancellation. In [14,15] the authors proposed use power control technique for uplink in CDMA systems. Given the advantages of interference cancellation, it can be applied to cooperative communications for performance enhancement with beamforming, power control strategy and signal combining techniques.

The main contribution of this paper is as follows, the interference cancellation with array smart antenna by beamforming technique is investigated. In addition, the system performance can be enhanced by adopting the power control at neighborhood cooperative system and signal combining techniques.

The rest of this paper is organized as follows. Section II describes the mathematical model of system and received signal. In Section III, the proposed beamforming techniques, power control strategy and signal combining techniques were investigated. In Section IV, the simulation results are shown, and the finally conclusions are given in Section V.

II. SYSTEM MODEL

In this section, we introduce the system model and received signal model for cooperative wireless communications. The cooperative communication system is shown in Figure 1, in which a source node (S) and a destination node (D) communicate over wireless channels with a slow-flat Rayleigh fading coefficient ($h_{s,d}$). A relaying node (R) is also able to receive the signal from source node, and it is willing to cooperate and relay the signal to the destination. The channel coefficients between S and R ($h_{s,r}$) and between R and D ($h_{r,d}$) are also flat Rayleigh fading coefficient. In addition, the noise signal is modeled as an additive white Gaussian noise (AWGN) in this system. We employ a time division multiple access (TDMA) as a channel access method for sharing medium networks and an M-ary phase shift keying (MPSK) is used as a digital modulation scheme for signal transmission.

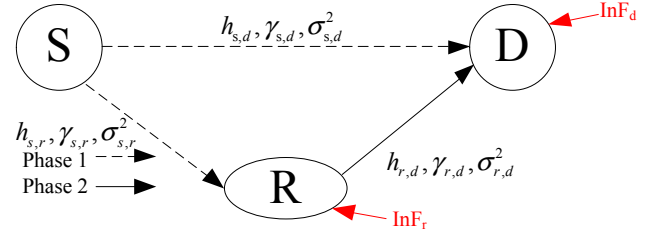


Figure 1. System model in decode-and-forward (DF) protocol with interference at R and D

A. Received Signal Model

Let us present a received signal model. In phase 1, S broadcasts the modulated symbol to R and D. The received signal model at R and D can be written as, respectively [16],

$$y_{s,d} = \sqrt{P_1} h_{s,d} \mathbf{u}_{s,d} s + InF_d + \mathbf{n}_{s,d} \quad (1)$$

where P_1 signify the transmit power of S, $h_{s,d}$ signify the channel state information (CSI) of the S-D link, s signify the transmitted symbol, $\mathbf{u}_{s,d}$ signify a M-row array vector of the smart antenna system with M being a number of antenna elements, $InF_d = \sqrt{P_i} h_{i,d} s_i$ signify the interference signal at D and $\mathbf{n}_{s,d}$ denote the AWGN with zero-mean and variance N_0 .

In addition, $\mathbf{u}_{s,d} = [u_{11}, u_{12}, \dots, u_{1M}]^T$ where $u_{1m} = e^{-j\beta m \Delta x \cos \phi_1}$ signify a m^{th} array response with $\beta = 2\pi/\lambda$, λ being the wavelength of the carrier frequency, $\Delta x = \lambda/2$ being an antenna's element spacing, and ϕ_1 being the direction-of-arrival (DOA) of the transmitted signal in the S-D link in the azimuth plane given that the elevation plane is perpendicular to the direction of the impinging signal show as Figure 2. At D, the received signal vectors in (1) was weighted by the M-row weight vectors $\mathbf{w}_1$ as follows,

$$r_{s,d} = \mathbf{w}_1^H \mathbf{y}_{s,d} \quad (2)$$

The received signal vector at R can be described by,

$$y_{s,r} = \sqrt{P_1} h_{s,r} \mathbf{u}_{s,r} s + InF_r + \mathbf{n}_{s,r} \quad (3)$$

Where P_1 signify the transmit power of S, $h_{s,r}$ signify the CSI of the S-R link, s signify the transmitted symbol, $\mathbf{u}_{s,r}$ signify a M-row array vector of the smart antenna system with M being a number of antenna elements of the S-R link, $InF_r = \sqrt{P_{ii}} h_{ii} s_{ii}$ signify the interference signal at R and $\mathbf{n}_{s,r}$ denote the AWGN with zero-mean and variance N_0 . At the

relay node, the received signal vectors in (3) was weighted by the M-row weight vector $\mathbf{w}_2$ as follows,

$$r_{s,r} = \mathbf{w}_2^H \mathbf{y}_{s,r} \quad (4)$$

where $\mathbf{w}_2$ is weight vector to the relay node, $(\cdot)^H$ signify the complex-conjugate transpose

In phase 2, R decodes, encodes and retransmits the received signal in (4) with a proper gain P_2 to the destination node. The received signal at D is given by

$$y_{r,d} = \sqrt{P_2} h_{r,d} \tilde{r}_{s,r} + InF_d + n_{r,d} \quad (5)$$

where P_2 signify the transmit power of R, and $h_{r,d}$ signify the CSI of R-D link, $\tilde{r}_{s,r}$ signify the transmitted from decoded symbol, $InF_d = \sqrt{P_i} h_{i,s_i}$ signify the interference signal at D and $n_{r,d}$ signify the AWGN with zero-mean and variance N_0 .

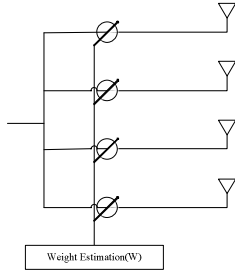


Figure 2. Array smart antenna with weight estimation (M=4)

III. PROPOSED METHODS

A. Beamforming method

We apply an algorithm, least mean squares (LMS) [17, 18], for adaptively updating the weight vector, $\mathbf{w}_1$ and $\mathbf{w}_2$ described as follows,

$$\mathbf{w}(0) = 0 \quad (6)$$

$$e(i) = d(i) - \mathbf{w}^H(i) \mathbf{y}_p \quad (7)$$

$$\mathbf{w}(i+1) = \mathbf{w}(i) + \mu \mathbf{y}_p e^*(i) \quad (8)$$

where i signify the iteration index, $d(i) = 1$ signify the desired response that is a unit energy, μ signify the step size parameter is the convergence factor which controls the rate of adaptation, $(\cdot)^*$ signify the complex-conjugate, and $(\cdot)^H$ signify the complex-conjugate transpose. Specifically, $\mathbf{y}_p^I$ is used for obtaining $\mathbf{w}_1$ and, $\mathbf{y}_p^{II}$ is used for obtaining $\mathbf{w}_2$ [17].

In order to obtain an optimal weight vectors, we send a pilot signal from S before the signal transmission in phase 1 to train the array antenna system to D and feedback data to S for obtaining and we also send a pilot signal to R to train the array

antenna system for obtaining and R feedback data to S. The pilot signal is simply a unit energy signal, $s_p = 1$. Hence, before the signal transmission in phase 1, the received signal at D during this training period is as follows,

$$\mathbf{y}_p^I = \sqrt{P_1} h_{s,d}^I \mathbf{u}_{s,d} s_p + \mathbf{n}_{s,d}^I \quad (9)$$

where $h_{s,d}^I$ denotes the CSI of the S-D link, and $\mathbf{n}_{s,d}^I$ denotes the M-row additive Gaussian noise vector. Similarly, before the signal transmission in phase 1, the received signal at R during this training period is as follows,

$$\mathbf{y}_p^{II} = \sqrt{P_1} h_{s,r}^{II} \mathbf{u}_{s,r} s_p + \mathbf{n}_{s,r}^{II} \quad (10)$$

where $h_{s,r}^{II}$ denote the CSI of the S-R link, and $\mathbf{n}_{s,r}^{II}$ denotes the M-row additive Gaussian noise vector. In addition, $h_{s,d}^I$ and $h_{s,r}^{II}$ are modeled as zero-mean, complex Gaussian random variables, $\mathbf{n}_{s,d}^I$ and $\mathbf{n}_{s,r}^{II}$ are modeled the AWGN with zero-mean with a variance N_0 .

B. Power control strategy

We assume with if the source is disturbed by the co-channel interference from neighbourhood systems. If we investigate the system with one source, one relay and one destination which is defined as “Primary system” and the neighbourhood system; we define as “Interfering system”. Figure 3 shows in the system model with two cooperative communications systems and Primary system which is interference from neighbourhood systems.

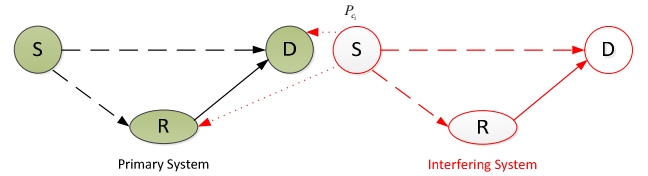


Figure 3. Cooperative communications systems with interference

We proposed the weight vector for smart antennas with beamforming which is based on the primary system and channel estimation [21] based on the interfering system, that can be taken to reduce the transmission power of source at the interfering system (P_{c_i}), which makes the interference that comes from the interfering system to interfere less with the primary system. In the interfering system will use the transmission power at the source following to the quality of channel, which is equal to mean of the CSI of the S-R link compared with instantaneous of them was shown in Figure 4. Power control at the source can follows as

$$w_{P_i} = 1, |h_{s_i, r_i}| \leq |h_{th}| \quad (11)$$

$$w_{P_i} = 1 - \left| h_{s_i, r_i} \right| + \text{mean} \left(\left| h_{s_i, r_i} \right| \right), \left| h_{s_i, r_i} \right| > \left| h_{th} \right| \quad (12)$$

$$P_{c_i} = w_{P_i} P_{l_i} \quad (13)$$

where $\text{mean} \left(\left| h_{s_i, r_i} \right| \right)$ is channel quality threshold (h_{th}), h_{s_i, r_i} is channel quality of each symbol at the inference source and w_{P_i} is weighting factor.

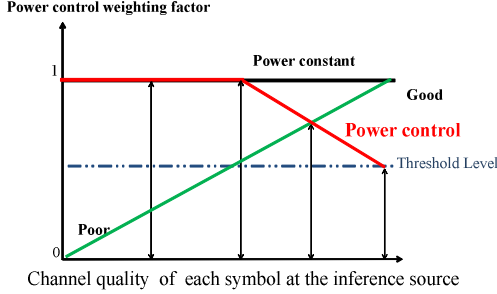


Figure 4. Power control strategy

C. Signal combining techniques

In this section, we summarized the received signals in phase 1 and phase 2 by using a maximum ratio combining (MRC) technique [16, 19] and a cooperative maximum ratio combining (C-MRC) technique [8].

1) Maximum ratio combining technique : We apply a maximum-ratio combining (MRC) to combine these weighted received signals as follows in decode-and-forward protocol,

$$z_{MRC} = a_1 r_{s,d} + a_2 y_{r,d} \quad (14)$$

where

$$a_1 = \sqrt{P_1} h_{s,d}^* \cdot \frac{(\mathbf{w}_{s,d}^H \cdot \mathbf{u}_{s,d})^*}{\sqrt{P_i h_i s_i + \|\mathbf{w}_{s,d}\|^2 N_0}} \quad (15)$$

and

$$a_2 = \frac{\sqrt{P_2}}{\sqrt{P_{ii} h_{ii} s_{ii} + N_0}} h_{r,d} \quad (16)$$

2) Cooperative maximum ratio combining technique :

And we apply a cooperative maximum ratio combining (C-MRC) to combine these weighted received signals as follows; the combined received signal at D is given by

$$z_{C-MRC} = a_1 r_{s,d} + (\gamma_{\min} / \gamma_{r,d}) a_2 r_{r,d} \quad (17)$$

where $\gamma_{\min} = \min(\gamma_{s,d}, \gamma_{r,d})$ with $\gamma_{s,r} := |h_{s,r}|^2 P_1 / N_0$ and

$\gamma_{r,d} := |h_{r,d}|^2 P_2 / N_0$ are instantaneous signal-to-noise-ratio

(SNR) of the S-R and R-D links, respectively.

D. Signal to interference plus noise ratio analysis

Here, let us investigate the signal to interference plus noise ratio (SINR) for the weighted received signals. In the S-D link $r_{s,d}$, we can calculate the average SINR for (2) as follows,

$$\text{SINR}_{s,d} = \frac{P_1 |h_{s,d}|^2 \|\mathbf{u}_{s,d}^H \mathbf{w}_{s,d}\|^2}{\sqrt{P_i h_i s_i + N_0} \|\mathbf{w}_{s,d}\|^2} \quad (18)$$

In the R-D link, we can calculate the average SINR for (5) as follows,

$$\text{SINR}_{r,d} = \frac{P_2 |h_{r,d}|^2}{\sqrt{P_{ii} h_{ii} s_{ii} + N_0}} \quad (19)$$

1) Maximum ratio combining (MRC): We also derive a closed-form expression of the total SINR resulted from such combining techniques. It could be shown that the output of the MRC detector at the destination can be expressed as follows [14,16]:

$$\gamma_{\text{total}}^{\text{MRC}} = \gamma_{s,d} + \gamma_{r,d} \quad (20)$$

where $\gamma_{\text{total}}^{\text{MRC}}$ is the total SINR, $\gamma_{s,d}$ is the SINR in the S-D link, and $\gamma_{r,d}$ is the SINR in the R-D link, which can be expressed as

$$\gamma_{\text{total}}^{\text{MRC}} = \frac{P_1 |h_{s,d}|^2 \|\mathbf{u}_{s,d}^H \mathbf{w}_{s,d}\|^2}{\sqrt{P_i h_i s_i + N_0} \|\mathbf{w}_{s,d}\|^2} + \frac{P_2 |h_{r,d}|^2}{\sqrt{P_{ii} h_{ii} s_{ii} + N_0}} \quad (21)$$

2) Cooperative maximum ratio combining C-MRC : And from (17) and (21), it will show that the output of the C-MRC detector at the D can be calculated as follows,

$$\gamma_{\text{total}}^{\text{C-MRC}} = \frac{P_1 |h_{s,d}|^2 \|\mathbf{u}_{s,d}^H \mathbf{w}_{s,d}\|^2}{\sqrt{P_i h_i s_i + N_0} \|\mathbf{w}_{s,d}\|^2} + g \frac{P_2 |h_{r,d}|^2}{\sqrt{P_{ii} h_{ii} s_{ii} + N_0}} \quad (22)$$

This fact results in the expression of $g = \gamma_{eq} / \gamma_{r,d}$, where $\gamma_{eq} = \min(\gamma_{s,d}, \gamma_{r,d})$ and $\gamma_{s,r}, \gamma_{r,d}$ are the instantaneous SINR between S-R and R-D links.

IV. SIMULATION RESULTS

A. Simulation parameters

In this section, the simulation is conducted under slowly varying Rayleigh flat fading channel. In addition, Jake's model [20] is employed with a normalized doppler shift of 5,000Hz. The digital modulation with QPSK constellation is employed. We will show the performance of the proposed methods through a computer simulation. We employ an equal power allocation for the source and relay nodes, i.e. $P_1 = P_2 = 1$ watt. The total transmit power is $P_{\text{total}} = 2$ watt. And the bandwidth efficiency is 1 bit/s/Hz. The variances of channel links will be varied to different values in order to examine the proposed system in various aspects.

In simulation results, we define $(\sigma_{s,d}, \sigma_{s,r}, \sigma_{r,d} = 1, 1, 1)$ as channel variances of the source (S)-to-destination (D), the source (S)-to-relay(R), and the relay (R)-to-destination (D) links, respectively. We apply the array smart antenna with 4 elements ($M=4$), the step size for the weight adaptation is $\mu = 0.1$ and beamforming's iterative loop = 100 rounds.

B. Simulation results

For a fair comparison, we illustrate the symbol error rate (SER) curves as function of SINR (dB).

1) Maximum ratio combining (MRC) technique

Figure 5 presents the curve of simulated SER versus SINR (dB) performance comparison of the decode and with various values of the interference signal with MRC at 1 watt, 0.75 watt, 0.5 watt and no CCI at R and D. The system with CCI is 1 watt, has the SINR difference in comparison with the no CCI system, about 7 dB at SER of 10^{-1} .

Figure 6 presents the curve of simulated SER comparison of the proposed IC system with MRC when the interference signal is 1 watt at R and D. The results show that the proposed IC system with MRC yields the lower probability of error than the conventional DF protocol.

2) Cooperative maximum ratio combining(C-MRC)

Figure 7 presents the curve of simulated SER versus SINR (dB) performance comparison with various values of the interference signal with C-MRC at 1, 0.75 and 0.5 watt, no CCI with MRC at R and D. The C-MRC system with CCI is 1W, have the SINR difference in comparison with the no CCI C-MRC system, about 5 dB at SER of 10^{-1} and the no CCI C-MRC system compare with the no CCI MRC, about 5 dB at SER of 10^{-2} . Because of the effect of weighted received signal from the relay help to higher gain the performance of the system.

Figure 8 presents the proposed IC systems with MRC and C-MRC when the interference signal is 1 watt at R and D. The results show that the proposed IC system with C-MRC yields the lower probability of error than MRC because of the effect of the weighted of received signal from the relay. But the high SINR regimes at SINR=20 dB, the proposed BF C-MRC yields the lower probability of error than MRC because the power of source can robust the interference signals from neighbourhood systems, at high SINR. The weighted of received signal from the relay is no effect.

V. CONCLUSIONS

In this paper, we have proposed the BF algorithm with the weighted estimation for array antenna at the source, the power control strategy from the interference source with signal combining technique at the destination with MRC and C-MRC. We can summarize, those had affect higher gain to enhance the performance of the system. The results show that the proposed IC systems with C-MRC yields the lower probability of error than MRC because effect from the weight

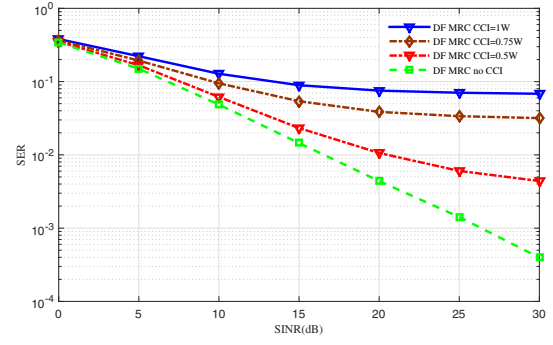


Figure 5. SER comparison of the DF system with various values of interference with MRC

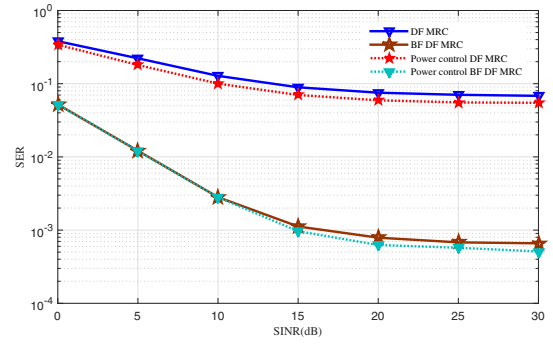


Figure 6. SER comparison of the proposed system with MRC

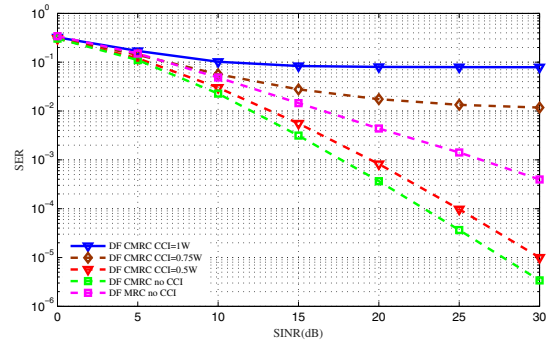


Figure 7. SER comparison of the DF system with various values of interference with MRC and C-MRC

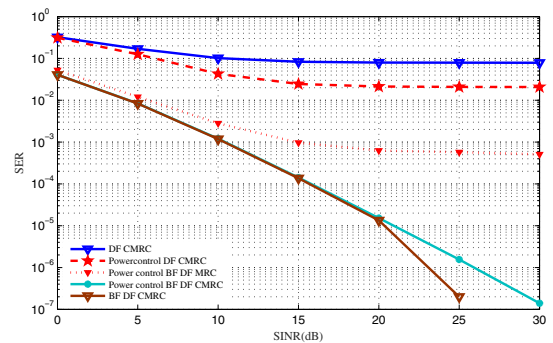


Figure 8. SER of the proposed systems with MRC and C-MRC

of received signal from the relay. But the high SINR regimes at SINR=10 dB the proposed IC C-MRC yields the lower probability of error than MRC because at high SINR the power of source can robust the interference signals from the interference source. The results show proposed IC C-MRC systems had the lower probability of error than MRC because effect from the weighted of received signal from the relay because of the effect of three weighted factor: 1.the BF algorithm for the weighted estimation for the array antenna, 2. the weighting factor of the proposed power control strategy, and 3.the weighted of received signal from the relay.

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