Interference Cancellation with Beamforming and Power Control in Cooperative Networks

Mongkol Somrobru

Abstract— **The interference cancellation (IC) technique for cooperative networks is investigated, if the relay and the destination are disturbed by the co-channel interference (CCI) from neighborhood system. In order to solve such interference problem, the beamforming algorithm with the appropriate weight estimation of the array smart antenna at the source (S), the power control technique at interfering source and signal combining algorithms at the destination (D). The maximum ratio combining (MRC) and the cooperative maximum ration combining (C-MRC) are used to combine the received signals arrived at D. We can also control the transmitted power at the source from interfering system, and maintain nearly the diversity gain compare with CCI and no CCI. Therefore, the proposed scheme achieves the maximum diversity gain and lower probability of error in comparison with the conventional decode-and-forward protocol (DF). And it is able to provide the power control strategy from interfering source to the relay and the destination nodes in order to achieve the minimum symbol error rate (SER) based on the experimental results from computer simulations.**

Keywords- Beamforming; Cooperative Network; Diversity Gain; Interference Cancellation; Power Control

I. INTRODUCTION

The required for higher data rate 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 modern 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 [1]. 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. 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 behavior. 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, the interference cancellation (IC) [9,10] 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

DOI: 10.5176/2251-3043_4.4.338

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 [11].

The main contribution of this paper is as follows, the interference cancellation with the array smart antenna by beamforming algorithm is investigated. In addition, the system performance can be enhanced by adopting the power control at the source of 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 algorithm, power control strategy and signal combining techniques were investigated. In Section IV, the simulation results are shown and discussed, and the conclusion is given in Section V.

II. SYSTEM MODEL

First, in this section, let us introduce the system and received signal models 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_{SD}). 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_{SR}) and between R and D (h_{RD}) are also flat Rayleigh fading coefficient. In addition, the noise signal is modeled as an additive white Gaussian noise (AWGN) in this system. We also 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.

A. Received Signal Model

Second, 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,

$$\mathbf{y}_{SD} = \sqrt{P_1} h_{SD} \mathbf{u}_{SD} s + InF_D + \mathbf{n}_{SD} \tag{1}$$

where P_1 denotes the transmit power of S, h_{SD} denotes the channel state information (CSI) of the S-D link, s denotes the transmitted symbol, u denotes a M-row array vector of the smart antenna system with M being a number of antenna elements, $InF_D = \sqrt{P_i} h_i u_i$ denotes the interference signal at D and $\mathbf{n}_{SD}$ denote the AWGN with zero-mean and variance N_0. In addition, $\mathbf{u}_{SD} = [u_{11}, u_{12}, ..., u_{1M}]^T$ where $u_{1m} = e^{-j\beta m \Delta x \cos\phi_1}$ denotes the m$^{\text{th}}$ 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.

At the destination node, the received signal vectors in (1) was weighted by the M-row weight vectors $\mathbf{w}_{SD}$, respectively, as follows,

$$r_{SD} = \mathbf{w}_{SD}^H \mathbf{y}_{SD} \tag{2}$$

The received signal vector at R can be described by,

$$\mathbf{y}_{SR} = \sqrt{P_1} h_{SR} \mathbf{u}_{SR} s + InF_R + \mathbf{n}_{SR} \tag{3}$$

where P_1 denotes the transmit power of S, h_{SR} denotes the CSI of the S-R link, s denotes the transmitted symbol, $\mathbf{u}_{SR}$ denotes a M-row array vector of the smart antenna system with M being a number of antenna elements, InF_R denotes the interference signal at R and $\mathbf{n}_{SR}$ denote the AWGN with zero-mean and variance N_0 . At the relay node, the received signal vectors in (2) was weighted by the M-row weight vectors $\mathbf{w}_{SR}$ as follows,

$$r_{SR} = \mathbf{w}_{SR}^H \mathbf{y}_{SR} \tag{4}$$

$\mathbf{w}_{SR}$ is weight vector at the relay node, $(\cdot)^H$ denotes the complex-conjugate transpose. In phase 2, R decodes, encodes and retransmits the received signal in (3) with a proper gain P_2 to the destination node. The received signal at D is given by

$$y_{RD} = \sqrt{P_2} h_{RD} \tilde{s} + n_{RD} \tag{5}$$

where P_2 denotes the transmit power of R, and h_{RD} denotes the CSI of R-D link, $\tilde{s}$ denotes the transmitted from decoded symbol and n_{RD} denotes the AWGN with zero-mean and variance N_0 .

III. THE PROPOSED TECHNIQUES

A. Beamforming Method

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

$$\mathbf{y}_P^I = \sqrt{P_1} h_{SD}^I \mathbf{u}_{SD} s_P + \mathbf{n}_{SD}^I \tag{6}$$

where h_{SD}^I denotes the CSI of the S-D link, and $\mathbf{n}_{SD}^I$ 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,

$$\mathbf{y}_P^{II} = \sqrt{P_1} h_{SR}^{II} \mathbf{u}_{SR} s_P + \mathbf{n}_{SR}^{II} \tag{7}$$

where h_{SR}^{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_{SD}^{I} and h_{SR}^{II} are modeled as zero-mean, complex Gaussian random variables, $\mathbf{n}_{SD}^{I}$ and $\mathbf{n}_{SR}^{II}$ are modeled the AWGN with zero-mean with a variance N_0 and employ least mean squares (LMS) algorithm [12, 13], for adaptively updating the weight vector, $\mathbf{w}_{SD}$ and $\mathbf{w}_{SR}$ described as follows,

$$\mathbf{w}(0)=0 \tag{8}$$

$$e(i)=d(i)-\mathbf{w}^{H}(i)\mathbf{y}_{P} \tag{9}$$

$$\mathbf{w}(i+1)=\mathbf{w}(i)+\mu\mathbf{y}_{P}e^{*}(i) \tag{10}$$

where i denotes the iteration index, $d(i)$ = 1 denotes the desired response that is a unit energy, μ denotes the step size, $(\cdot)^{*}$ denotes the complex-conjugate, and $(\cdot)^{H}$ denotes the complex-conjugate transpose. Specifically, $\mathbf{y}_{P}^{I}$ is used for obtaining $\mathbf{w}_{SD}$ and, $\mathbf{y}_{P}^{II}$ is used for obtaining $\mathbf{w}_{SR}$.

B. Power Control Strategy

In the section, we described the power control (PC) strategy. Let us assume the source is disturbed by CCI from neighborhood system and investigate the system with one source, one relay and one destination which is defined as "Primary system" and the neighborhood system; we define as "Interfering system". Figure 1 show the primary system which R and D are disturbed by CCI from neighborhood systems.

We proposed the weighting adaptive, $k_{P_{1_i}}$ which is based on the primary system and channel estimation [16] based on the interfering system, which can be taken to control the transmission power of source at the interfering system (P_{PC_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 as the channel quality threshold compared with instantaneous of them was shown in Figure 2. Power control at the source can follows as

$$k_{P_{PC_i}} = 1,\ \left|h_{s_i,r_i}\right| \le \left|h_{th}\right| \tag{9}$$

$$k_{P_{PCi}} = 1-\left|h_{s_i,r_i}\right|+\text{mean}\left(\left|h_{s_i,r_i}\right|\right),\ \left|h_{s_i,r_i}\right| > \left|h_{th}\right| \tag{10}$$

$$P_{PC_i} = k_{P_{PC_i}} P_{1_i} \tag{11}$$

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 symbol each n^{th} ,and $k_{P_{PC_i}}$ is weighting adaptive.

A. Signal Combining Techniques

We can summarized the received signals in phase 1 and 2 by using a maximum ratio combining (MRC)[14] and a cooperative maximum ratio combining (C-MRC) [8].

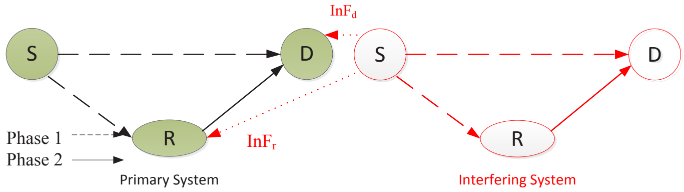

Figure 1. System model in decode-and-forward (DF) protocol with interference at R and D by interfering system

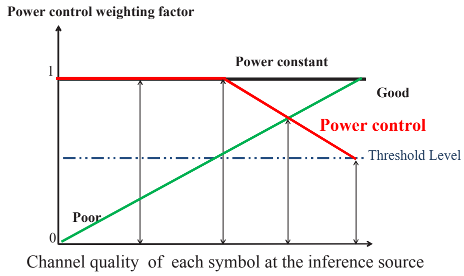

Figure 2. Power control strategy

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

$$x_{MRC} = q_1 r_{SD} + q_2 y_{RD} \tag{14}$$

where

$$q_1 = \sqrt{P_1}h_{SD}^{*}\cdot\frac{\left(\mathbf{w}_{SD}^{H}\cdot\mathbf{u}_{SD}\right)^{*}}{\sqrt{P_i h_i s_i}+\left\|\mathbf{w}_{SD}\right\|^{2}N_0} \tag{15}$$

and

$$q_2 = \frac{\sqrt{P_2}}{\sqrt{P_{ii}h_{ii}s_{ii}}+N_0}h_{RD} \tag{16}$$

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

$$x_{C-MRC} = q_1 r_{SD} + \left(\gamma_{\min}/\gamma_{r,d}\right)q_2 y_{RD} \tag{17}$$

where $\gamma_{\min}=\min(\gamma_{SD},\gamma_{RD})$ with $\gamma_{SR}:=\left|h_{SR}\right|^{2}P_1/N_0$ and $\gamma_{RD}:=\left|h_{RD}\right|^{2}P_2/N_0$ are instantaneous signal-to-noise-ratio (SNR) of the S-R and R-D links, respectively.

B. 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, we can calculate the average SINR for (2) as follows,

$$SINR_{SD} = \frac{P_1\left|h_{SD}\right|^{2}\left\|\mathbf{u}_{SD}^{H}\mathbf{w}_{SD}\right\|^{2}}{\sqrt{P_i h_i s_i}+N_0\left\|\mathbf{w}_{SD}\right\|^{2}} \tag{18}$$

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

$$SINR_{RD} = \frac{P_2 |h_{RD}|^2}{\sqrt{P_{ii}} h_{ii} s_{ii} + N_0} \tag{19}$$

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]:

$$\gamma_{total}^{MRC} = \gamma_{SD} + \gamma_{RD} \tag{20}$$

where γ_{total}^{MRC} is the total SINR, γ_{SD} is the SINR in the S-D link, and γ_{RD} is the SINR in the R-D link, which can be expressed as

$$\gamma_{total}^{MRC} = \frac{P_1 |h_{SD}|^2 \left\|\mathbf{u}_{SD}^H \mathbf{w}_{SD}\right\|^2}{\sqrt{P_i} h_i s_i + N_0 \left\|\mathbf{w}_{SD}\right\|^2} + \frac{P_2 |h_{RD}|^2}{\sqrt{P_{ii}} h_{ii} s_{ii} + N_0} \tag{21}$$

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,

$$\gamma_{total}^{C-MRC} = \frac{P_1 |h_{SD}|^2 \left\|\mathbf{u}_{SD}^H \mathbf{w}_{SD}\right\|^2}{\sqrt{P_i} h_i s_i + N_0 \left\|\mathbf{w}_{SD}\right\|^2} + g \frac{P_2 |h_{RD}|^2}{\sqrt{P_{ii}} h_{ii} s_{ii} + N_0} \tag{22}$$

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

IV. SIMMULATION RESULTS

A. Simulation Parameters

In this section, the simulation is conducted under slowly varying Rayleigh flat fading channel. In addition, Jake's model [15] is employed with a normalize Doppler shift of 5,000 Hz. 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 = 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. We define $(\sigma_{SD}, \sigma_{SR}, \sigma_{RD} = 1,1,1)$ 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**.** And apply the array smart antenna with 4 elements (M=4) 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)

Figure 3 presents the curves of simulated SER versus SINR performance comparison of the decode and with various values of the interference signal with MRC at 1watt, 0.75 watt, 0.5 watt and no CCI at R and D. The DF 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 4 presents the curves of simulated SER performance comparison of the proposed BF algorithm with MRC when the interference signal is 1 watt at R and D. At the SINR = 15 dB, the proposed BF algorithm has SER about 10^{-3} but the conventional DF has SER about 10^{-1} because of the effect of the BF algorithm with the weight estimation array smart antenna.

Figure 5 shows that the curves of simulated SER performance comparison of the proposed power control strategy with MRC when the interference signal is 1 watt at R and D. At SER = 10^{-1}, the proposed power control strategy has SER better than the conventional DF about 3 dB because of the effect from the weighting of the proposed power control strategy.

Figure 6 shows that, the curves of simulated SER performance comparison of the proposed BF algorithm and power control strategy with MRC when the interference signal is 1 watt at R and D. At the SINR = 15 dB, the proposed BF algorithm and power control strategy has SER about 10^{-3} but the conventional DF has SER about 10^{-1} because of the effect of the BF algorithm with the weight estimation array smart antenna and the weighting of the proposed power control strategy.

Figure 7 presents the curves of simulated SER comparison of the proposed IC with MRC when the interference signal is 1watt at R and D. The results show that the proposed IC with MRC yields the lower probability of error than the conventional DF protocol.

2) Cooperative maximum ratio combining(C-MRC)

Figure 8 presents the curves of simulated SER versus SINR performance comparison of the DF with various values of the interference signal with C-MRC at 1 watt, 0.75 watt, 0.5 watt, no CCI and no CCI with MRC at R and D. The DF C-MRC system with CCI is 1 watt, 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 9 shows that the curves of simulated SER performance comparison of the proposed beamforming algorithm with MRC and C-MRC. At the SINR is 20 dB, the proposed BF algorithm C-MRC systems has SER of 10^{-5}, the proposed BF algorithm MRC systems has SER of 10^{-3} but the conventional DF had SER about 10^{-1} because of the effect from the BF algorithm with the weight estimation of array smart antenna and the weighted of received signal from the relay.

Figure 10 presents the curves of simulated SER performance comparison of the proposed power control strategy with MRC and C-MRC when the interference signal is 1 watt at R and D. At SER=10^{-1}, the proposed power control strategy C-MRC system has the SINR better than the conventional C-MRC about 3 dB. And the high SINR regimes, the proposed power control strategy C-MRC system has SER less than the proposed power control strategy MRC system because of the effect of the weighted of received signal at the relay and the weighting of the proposed power control strategy.

Figure 11 shows that the curves of simulated SER performance comparison of the proposed BF algorithm and power control strategy with MRC and C-MRC when the interference signal is 1watt at R and D. At the SINR = 15 dB, the proposed power control strategy BF DF C-MRC systems had SER about closely 10^{-4} but the conventional DF C-MRC had SER about 10^{-1} because of the effect from the BF algorithm with the weight estimation array smart antenna, the weighting of the proposed strategy, and the weighted of received signal from the relay.

Figure 12 presents the curves of simulated SER comparison of the proposed IC with MRC and C-MRC when the interference signal is 1 watt at R and D. The results show that the proposed IC 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 DF C-MRC yields the lower probability of error than MRC because the power of source can robust the interference signals from neighborhood systems, at high SINR. The weighted of received signal from the relay is no effect.

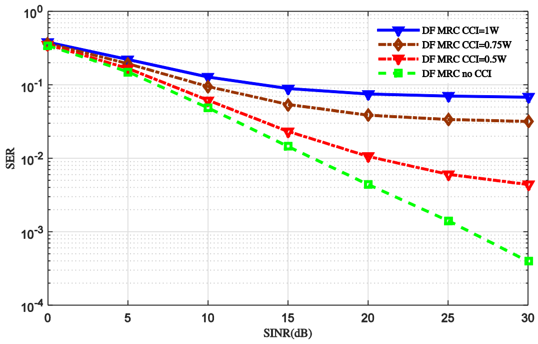

Figure 3. SER comparison of the various values of interference with MRC

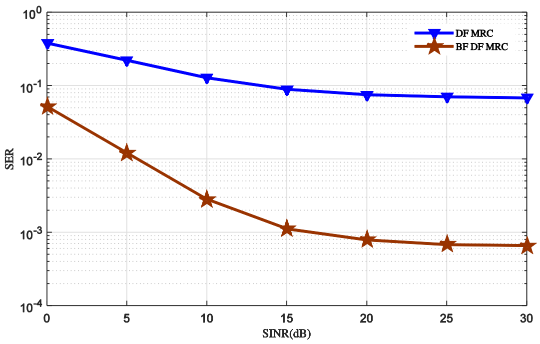

Figure 4. SER comparison of the proposed BF with MRC

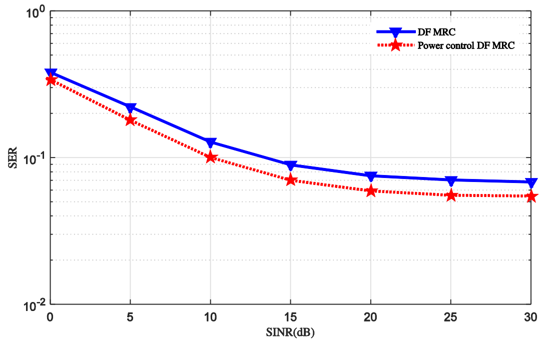

Figure 5. SER comparison of the proposed power control with MRC

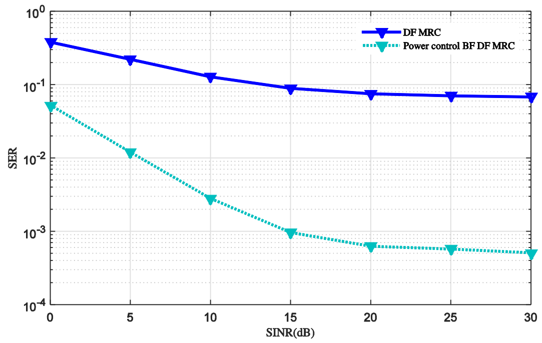

Figure 6. SER comparison of the proposed BF and power control with MRC

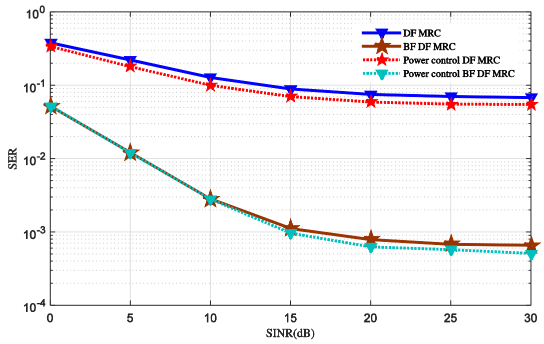

Figure 7. SER comparison of the proposed IC with MRC

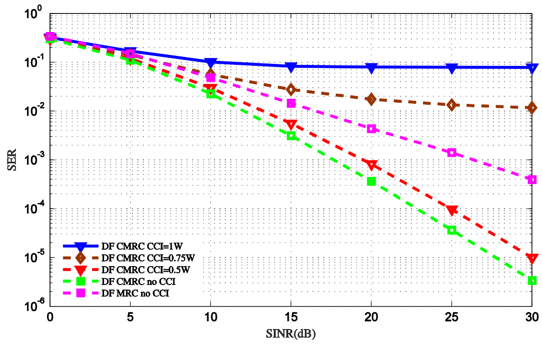

Figure 8. SER comparison of the various values of interference with MRC and C-MRC

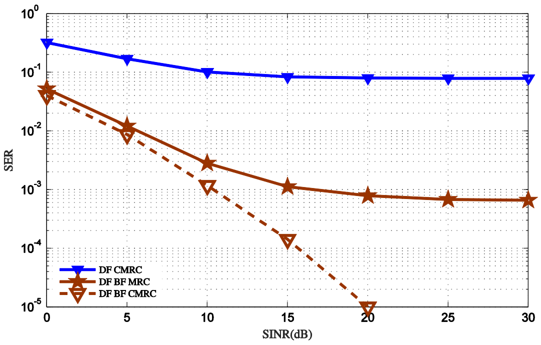

Figure 9. SER comparison of the proposed BF with MRC and C-MRC

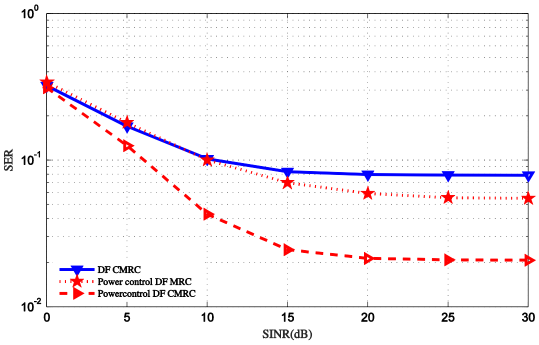

Figure 10. SER comparison of the proposed PC with MRC and C-MRC

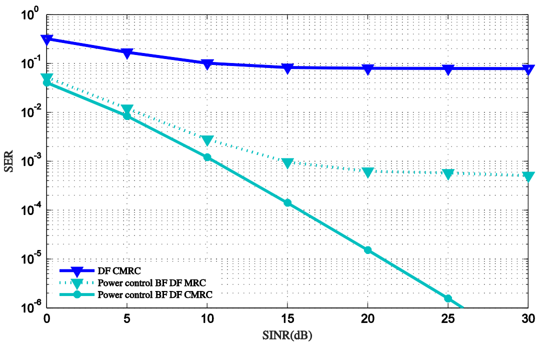

Figure 11. SER comparison of the BF and PC with MRC and C-MRC

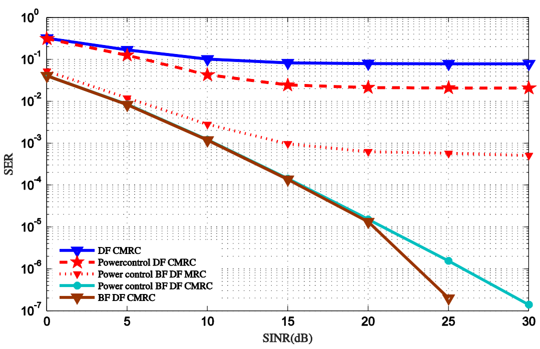

Figure 12. SER comparison of the proposed IC with MRC and C-MRC

V. CONCLUSION

In this paper, we have proposed the BF algorithm with the weight estimation of the array smart antenna at S, the power control strategy from S of interfering system with signal combining technique at D 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 with C-MRC yields the lower probability of error than MRC because effect from 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 at high SINR the power of source can robust the interference signals from neighborhood system. The weighted of received signal from the relay had no effect in this scenario.

REFERENCES

[1] M. K. Simon and M. S. Alouini, *Digital Communication Over Fading Channels*, John Wiley & Sons, New York, 2005.

[2] J. G. Proakis, M. Salehi, *Digital Communications*, McGraw-Hill, 5th edition (international), 2008.

[3] J. N. Laneman, D. N. C. Tse, and G. W.Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” IEEE Transactions on Information Theory, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.

[4] J. N. Laneman and G. W.Wornell, “Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks,” *IEEE Transactions on information theory*, vol. 49, no. 10, pp. 2415–2525, Oct. 2003.

[5] A. Ribeiro, X. Cai, and G. B. Giannakis, “Symbol error probabilities for general cooperative links”, *IEEE Transactions on Wireless Communication*, vol. 4, no. 3, pp. 1264–1273, May 2005.

[6] W. Mo and Z. Wang, “Average symbol error probability and outage probability analysis for general cooperative diversity system at high signal to noise ratio,” *IEEE Conference on Information Science System*, Princeton, New Jersey, pp. 1443–1448, Mar. 2004.

[7] J. Adeane, M. R. D. Rodrigues, and I. J. Wassell, “Characterisation of the performance of cooperative networks in Rician fading channels,” *International Conference on Telecommunication*, Cape Town, South Africa, May 2005.

[8] T. Wang et al., “High performance cooperative demodulation with decode and forward relays,” *IEEE Transactions on Wireless Communication*, vol. 55, no. 7, pp. 1427-1438, Jul. 2007.

[9] L. Li, Y. Jing, and H. Jafarkhani, “Interference cancellation at the relay for multi-user wireless cooperative networks,” *IEEE Transactions Wireless Communication*, vol. 10, no. 3, pp. 930–939, Mar. 2011.

[10] S. Fazeli-Dehkordy, S. Shahbazpanahi, and S. Gazor, “Multiple peer-to-peer communications using a network of relays,” *IEEE Transactions Signal Process*, vol. 57, no. 8, pp. 3053–3062, Aug. 2009.

[11] B. Guo et al., “Energy-Efficient Topology Management With Interference Cancellation in Cooperative Wireless Ad Hoc Networks,” *IEEE Transactions on Network and Service Management*, vol. 11, no. 3, pp.405-415, Sep. 2014.

[12] C. Charoenphap, C. Pirak, “Performance enhancement for cooperative communications using smart antenna systems, *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology* (ECTI-CON2008), pp.557-560, May 2008.

[13] J. C. Liberti, and T. S. Rappaport, *Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications*, Prentice Hall, 1999, ch 4.

[14] D.G. Brennan, “Linear Diversity Combining techniques,” *Proceedings of the IEEE*, vol.91, No.2, pp.331-356, Feb. 2003.

[15] W. C. Jakes, *Microwave Mobile Communications*, IEEE Press New York, 1994.

[16] M. Somrobru, C. Pirak and G. Ascheid, "On the performance of channel estimation in cooperative wireless communications," *Asia-Pacific Conference on Communications (APCC 2014),* pp.397-400, Oct. 2014.

AUTHOR'S PROFILE

Mongkol Somrobru received his Bachelor degree in Telecommunication Engineering from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 1999. Master degree in Telecommunications Engineering from Asian Institute of Technology, Pathumthani, Thailand in 2005. Currently, he is a Ph.D. candidate in communication engineering of The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, Thailand. His current research interests include wireless communication, channel estimation, cooperative communication and statistical signal processing.