

Performance Analysis of Modified STBC Scheme for Cooperative MIMO Communications

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ABSTRACT

The cooperative MIMO communications is a new challenge to provide more reliable transmissions from the collaboration between users. Mostly, the MIMO employment is performed by using a simple diversity scheme. However, there are many MIMO schemes that can be implemented in practice. This paper proposes the modified STBC scheme for cooperative MIMO communications. Also the performance analysis of the proposed system in term of the data error rate and the outage probability is originally presented. The simulation results indicate that the proposed system can offer a better bit error rate and improve the outage probability than the diversity scheme.

Keywords: Decode and Forward, Outage Probability, Cooperative MIMO Communications

1. INTRODUCTION

Currently, the communication technology has a huge impact in everyday life. Among those technologies, wireless communication system is the most influent form of communications. They are commonly used due to the ease of installation but they need to be developed effectively to get a higher data transmission, a freedom of movement and a quality of communication that is reliable in providing a good service. In order to support the requirements of multimedia data communication in the future, the MIMO (Multiple Input Multiple Output) technique has been introduced for wireless communication system [1-5]. This technique can support the need of high transmission data of multimedia communication in the future since the system can increase the channels of communication and send data in the parallel channels. However, the MIMO operation requires multiple antennas at both transmitter and receiver which are not practical for mobile devices. In this light, the new challenge to increase the channels of communication as well as MIMO wireless communication system but no need to increase the number of antennas at the

transmitter and the receiver is presented and called as cooperative MIMO communications [6-10]. This technique depends on the conditionally transmitted data by allowing users in system to help each other to send their data like MIMO technique. This operation is performed as a virtual MIMO system. This technique can increase more channel diversity and can reduce the bit error rate (BER) of the system. However, the problem of fading in the channel due to noise of the signal sent by the delay and reflected in multipath of the channel resulted in signal distortion. From these problems the authors have aware of the needs for communications to respond the demands of users increasing for the improved performance of communication system.

In the past few years, a cooperative communication has been a very active research field. Extensive researches have focused on the physical layer aspects of cooperative communications [11-15]. Therefore, there are many developments of research in cooperative wireless communication systems in literature. The cooperative communications have categorized into two main protocols used in the relay node consisting of Amplify-and-Forward (AF) and Decode-and-Forward (DF) [6,16]. Recently, the researches in [17-19] proposed the transmission technique in type of forwarding data information for cooperative communications. The researchers in [20-21] have developed the system to propose the amplify-and-forward protocol using the transmission of data in distributed and forwarding data information to obtain in MIMO channels for data transmission. However, the positions of the relay in cooperative communication system are varied in practice so the relay selection is very important issue for the cooperative MIMO communication. In [22], the authors point out that relay selection in cooperative communication depends on power transmission, distance and condition of channel. The solution of methods to choose relay is proposed by using the estimated channel and the coefficients of the signal in each path. In [23], it shows the method to select relay from consideration of signal-to-noise ratio throughout the path from the transmitter to the receiver.

However, in literatures the process of relay cooperation is done by forwarding and repeating the signal symbols on the allocated time slot. In this paper, the authors propose the utility of relay by cre-

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ating the process of sending symbols based on STBC mode so called as modified STBC mode. By changing the symbols sent from source to relay ($S_1 \rightarrow S_1^*$ and $S_2^* \rightarrow \tilde{S}_2$) the destination can be easily detected as a typical STBC mode. The proposed cooperative MIMO technique is introduced to improve the system performance of wireless communication networks. The modified STBC scheme is selected to implement the virtual MIMO transmitter. By using the neighbouring antennas, the overall system can be operated as MIMO communication. It is interesting to see the improvement of using the proposed concept in wireless communication networks. In case of relay selection in literatures the process of relay cooperation is done by considering channel information [24] and signal-to-noise ratio throughout the path from the transmitter to the receiver [25]. This paper also proposes the performance analysis of modified STBC scheme for cooperative MIMO communications in term of the data error rate and the outage probability. The remainder of the paper is as follows. Section II describes the details of the cooperative MIMO communications. In Section III explains the technique of modified STBC code scheme with cooperative MIMO communications. The outage probability analysis of the cooperative MIMO communications is presented in Section IV. Simulation results are presented in Section V and the paper is concluded in Section VI.

2. COOPERATIVE MIMO COMMUNICATIONS

Since the mobile communications is considered in this paper, hence all wireless devices are assumed with only single antenna. They are connected to a base station which is assumed to be located at the center of a cell. The authors consider a system model as depicted in Fig. 1, where source node and relay nodes have only single antenna and destination node (base station) has two antennas. The cooperative system is in the manner that source node S transmits information to a destination node D with the help of the best-selected relay node R_i . The channels considered in this system model are assumed to undergo AWGN, multipath, and slow fading. Source and relay nodes must know Channel State Information (CSI) between source and relay as well as between relay and destination, respectively.

In general, wireless devices must have two transmitting antennas in order to apply 2×2 Alamouti STBC MIMO systems. Although Ho-Jung An et. al. [26] applied precoding scheme with the STBC symbols to employ STBC with single antenna, but it costs a significant delay and suffers from AF protocol. In this paper, the authors propose a technique to transmit virtual STBC symbols in order to apply with a single antenna system. The source node and relay node virtually offer the multiple antennas for the cooperation of transmitted symbols at the same

STBC schemes to the destination. The proposed system works as given in the following steps.

The first step is shown in Fig. 1 (a). The source node makes agreement with the destination node to transmit and receive by using the cooperative MIMO technique. The source node then finds relay nodes by sending the invitation message to all potential relay nodes. The available relay nodes will send the confirmation message to cooperate with source node and destination node. At this point, source node, relay node and destination node are now ready to operate the system with cooperative MIMO technique.

The second step is the pre-transmitting process shown in Fig. 1 (b). The source node transmits symbols to relay node. When the relay node obtains symbols from source node, then the relay node will adjust or reformat symbols in the form of STBC coding schemes. In the proposed scheme, the relay node is not necessary to modify anything with the received data. By using the conventional method for relay node, then it can retransmit any received data to destination. This step is based on the perfect synchronization between source node and relay node and also including with the perfect knowledge of coding sequences. In addition, the transmission in this step requires a less power than the other steps because only the enough power in transmission range between source and relay is required.

For the third step, it can be shown in Fig. 1(c). The source node and relay node transmit simultaneously the coding symbols to the destination node. The destination node receives all signals from both source node and relay node by multiple receiving antennas. This process is as same as the normal MIMO system because the destination node can virtually see the received signals coming from multiple-antennas source.

3. MODIFIED STBC SCHEME FOR COOPERATIVE MIMO TECHNIQUE

Transmission models in the cooperative MIMO communication systems are presented in this paper. The system consists of source, relay and destination nodes. Source node transmits data signals to relay node and destination node. The relay node transmits the signal received from the source node to the destination node. Destination node receives signals information from relay node and source node. The destination node will decode information signals based on CSI of both relay and source nodes. By using transmission models in the cooperative MIMO communications, the system will forward the information signal from the relay node to the destination node using DF protocol through Rayleigh fading channels. The authors consider the total transmitted power from all transmitting antenna. The sum of output power of the source node and the relay node is obtained with $P_T = P_s + P_r$ where P_T is the total power in the

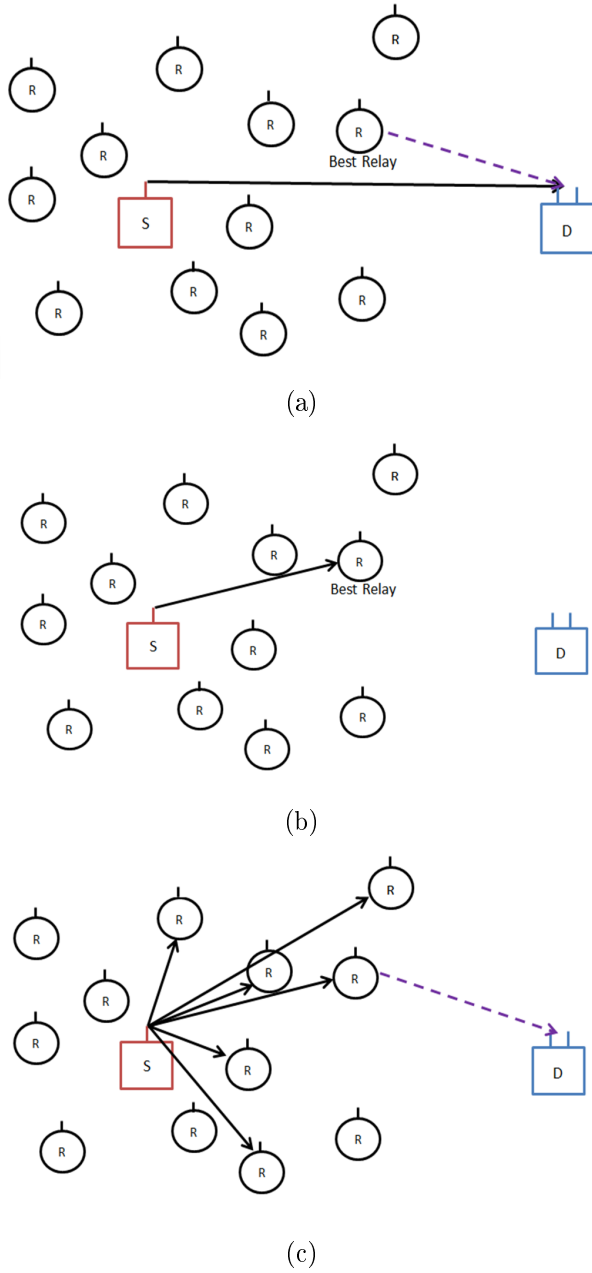


Fig.1: (a): The First Step of Cooperative MIMO Communications. (b): The Second Step of Cooperative MIMO Communications. (c): The Third Step of Cooperative MIMO Communications.

system.

In general, the cooperative MIMO communications have many transmission models. However, in this paper the authors consider the STBC MIMO scheme in comparing the conventional (diversity) MIMO scheme. According to the channel using TDD (Time Division Duplex), basically the form of transmission models in the cooperative communication system is shown in Fig. 2.

In Fig. 2, source node sends information to relay node which will forward this information to the

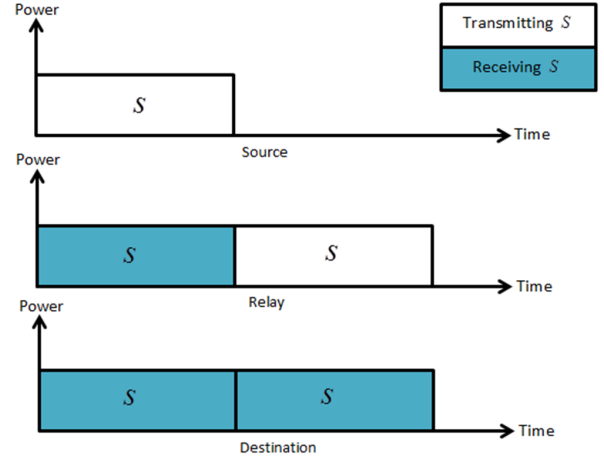


Fig.2: Transmitting/Receiving Symbols of Source Node, Relay Node and Destination Node for Cooperative Communication.

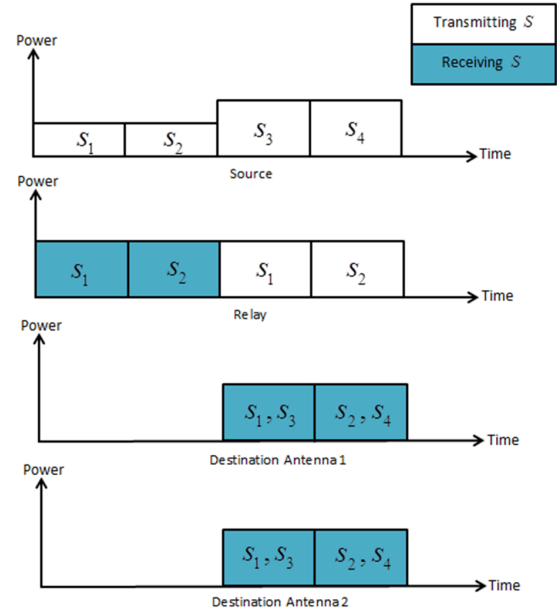


Fig.3: Transmitting/Receiving Symbols of Source Node, Relay Node and Destination Node for Cooperative MIMO Communication (Diversity Scheme).

destination for later decoding the information. This method is utilization of diversity techniques which makes the higher performance of the cooperative communication system.

The transmission scenario for the cooperative MIMO communication system is shown in Fig. 3. As seen in this figure, source node sends information to relay node with utilization of TDD techniques. The relay node receives information from source node and then relay node will forward to destination in the next time slot. This method is the utilization of combination between diversity technique and MIMO

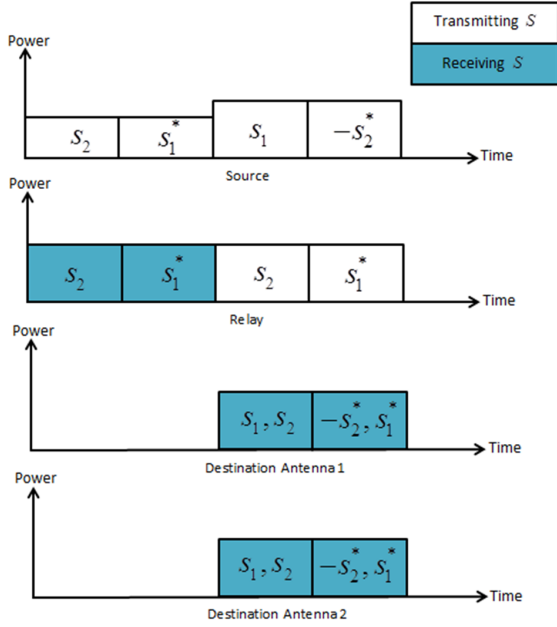


Fig.4: Transmitting/Receiving Symbols of Source Node, Relay Node and Destination Node for Cooperative MIMO Communication using Modified STBC Scheme.

technique which makes the better performance of the cooperative MIMO communication system.

For the proposed cooperative MIMO system called as modified STBC scheme, it is shown in Fig. 4. The process of STBC system [27] encodes the input data symbols into both spatial and time domains. However, in cooperative MIMO system, the spatial domain splits data into multiple users. Hence, the method to set a block coding schemes is a necessary part to be designed. In this paper, the authors propose the sequence of transmitting symbols by modifying STBC scheme for cooperative MIMO users in wireless communications as shown in Fig. 4.

In Fig. 4, the overall data symbols are occurred within four symbol periods in order to perform one STBC block. The first two periods are the time of exchanging data symbols between source and relay. This is referred to the second step in the previous section. In this interval, the destination cannot obtain any data symbols from source because the transmitting power between source and relay is very little in comparing with the transmitting power between destination and source.

The time periods of the first symbol and the second symbol shown in Fig. 4 is the time that source node sends signals to the relay node. The received signal at relay node is expressed by

$$y_r = \sqrt{P_s} h_{s,r} s + n_{s,r} \quad \text{When, } s = s_2, s_1^* \quad (1)$$

By assuming that both periods experience the

same fading, then

$$y_r^{(1)} = \sqrt{P_s} h_{s,r} s_2 + n_{s,r} \quad (2)$$

$$y_r^{(2)} = \sqrt{P_s} h_{s,r} s_1^* + n_{s,r} \quad (3)$$

Where $h_{s,r}$ is the wireless channel from source node to relay node, $n_{s,r} \sim CN(0, \sigma_r^2)$ is complex AWGN including the effect of interference signal, P_s and s are the source node transmission power and transmission of symbols, respectively.

The signals at relay node have to go through the process that the relay node can receive signals for forwarding symbols. The two estimated symbols, \tilde{s}_1 and \tilde{s}_2 , can be calculated by.

$$\tilde{s}_1 = h_{s,r} y_r^* \quad (4)$$

$$\tilde{s}_2 = h_{s,r}^* y_r \quad (5)$$

The time periods of the third symbol and the fourth symbol are the STBC MIMO transmission. The authors consider one source node, one relay node and one destination node. Then, the received signals of both antennas at the destination node can be expressed by equation (6) to equation (9)

$$y_{d1}^{(1)} = \sqrt{P_s} h_{s,d1} s_1 + \sqrt{P_r} h_{r,d1} s_{2r} + n_{s,r,d1}^{(1)} \quad (6)$$

$$y_{d1}^{(2)} = -\sqrt{P_s} h_{s,d1} s_2^* + \sqrt{P_r} h_{r,d1} s_{1r}^* + n_{s,r,d1}^{(2)} \quad (7)$$

Where $h_{s,d1}$ and $h_{r,d1}$ are the wireless channel from source node to destination node at the first antenna and the wireless channel from relay node to destination node at the first antenna, $n_{s,r,d1}^{(1)} \sim CN(0, \sigma_d^2)$ and $n_{s,r,d1}^{(2)} \sim CN(0, \sigma_d^2)$ are complex AWGN including the effect of interference signals at the first antenna, P_s and P_r is the transmission power of source node and relay node, respectively.

Considering the second antenna at destination node, the received signals are expressed by

$$y_{d2}^{(1)} = \sqrt{P_s} h_{s,d2} s_1 + \sqrt{P_r} h_{r,d2} s_{2r} + n_{s,r,d2}^{(1)} \quad (8)$$

$$y_{d2}^{(2)} = -\sqrt{P_s} h_{s,d2} s_2^* + \sqrt{P_r} h_{r,d2} s_{1r}^* + n_{s,r,d2}^{(2)} \quad (9)$$

Where $h_{s,d2}$ and $h_{r,d2}$ are the wireless channel from source node to destination node at the second antenna and the wireless channel from relay node to destination node at the second antenna, $n_{s,r,d2}^{(1)} \sim CN(0, \sigma_d^2)$ and $n_{s,r,d2}^{(2)} \sim CN(0, \sigma_d^2)$ are complex AWGN including the effect of interference signals at the second antenna.

Note that $s_1 = s_{1r}$ and $s_2 = s_{2r}$ because the link between relay node and source node in the second step mentioned earlier has the effects of fading channel as well. This might cause the uncertainty of symbol realization on relay node. However, most of the works in this area assume that relay node can perfectly retrieve all received symbols.

Then, at the destination, the process of extracting the data symbols from incoming signals is the same as described by normal STBC scheme. The two estimated symbols, \tilde{s}_1 and \tilde{s}_2 , from the first antenna are calculated by.

$$\tilde{s}_1 = h_{s,d1}^* y_{d1}^{(1)} + h_{r,d1} \left(y_{d1}^{(2)} \right)^* + h_{s,d2}^* y_{d2}^{(1)} + h_{r,d2} \left(y_{d2}^{(2)} \right)^* \quad (10)$$

$$\tilde{s}_2 = h_{r,d1} y_{d1}^{(1)} - h_{s,d1} \left(y_{d1}^{(2)} \right)^* + h_{r,d2} y_{d2}^{(1)} - h_{s,d2} \left(y_{d2}^{(2)} \right)^* \quad (11)$$

4. ANALYSIS OF OUTAGE PROBABILITY

In this section, the outage probability of the proposed system is derived. The outage capacity is another popular performance index for communication techniques in fading channels. This outage is the situation that the message cannot be reliably decoded at the destination node. From an information theoretic standpoint, given the transmission rate R and the channel realization h , it can be said that the outage occurs if the channel capacity is less than the transmission rate, i.e., $\log_2(1 + \text{SNR} |h|^2) < R$. Hence, the outage probability under the channel realization h can be expressed as the function of the transmission rate as given below [28].

$$P_{out}(R) \triangleq \Pr \left(\log_2(1 + \text{SNR} |h|^2) < R \right) = \Pr \left(\text{SNR} |h|^2 < 2^R - 1 \right) \quad (12)$$

The ε -outage capacity is then defined as the maximum transmission rate that can be achieved over the fading channel such that the outage probability is smaller than ε , i.e.,

$$C_\varepsilon = \arg \max_{\{R: P_{out}(R) \leq \varepsilon\}} P_{out}(R) \quad (13)$$

Where $\varepsilon \in [0, 1]$ is a constant threshold.

The outage probability can be calculated by using the probability density function of the channel coefficient or the received SNR. For example, in the Rayleigh channel where the envelope of channel coefficient is Rayleigh distribution and the received SNR, $\text{SNR} |h|^2$ is exponentially distributed with mean $\text{SNR} \sigma_h^2$, the outage probability of the Rayleigh channel given the transmission rate R is expressed by

$$P_{out}(R) = \Pr \left(\text{SNR} |h|^2 < 2^R - 1 \right) = 1 - \exp \left(-\frac{2^R - 1}{\text{SNR} \sigma_h^2} \right) \quad (14)$$

Where P_{out} denotes the outage probability of the system that the destination performs detection based only on the received signals from the relay node. This

scheme is identical to the conventional transmissions. In order to successfully transmit a codeword over both s-r and r-d links in this case, the rate of the codeword must be bounded by the capacity of both links by.

$$2R \leq \min \left\{ \log_2 \left(1 + \text{SNR}_{s,r} |h_{s,r}|^2 \right), \log_2 \left(1 + \text{SNR}_d \|H\|_F^2 \right) \right\} \quad (15)$$

Hence, the average end-to-end achievable rate is given by

$$C = \frac{1}{2} \min \left\{ \log_2 \left(1 + \text{SNR}_{s,r} |h_{s,r}|^2 \right), \log_2 \left(1 + \text{SNR}_d \|H\|_F^2 \right) \right\} \quad (16)$$

Following (14), yields

$$P_{out} = \Pr \left(\frac{1}{2} \min \left\{ \log_2(1 + \gamma_{s,r}), \log_2(1 + \gamma_d) \right\} < R \right) \quad (17)$$

Where C is the channel capacity and $\|H\|_F^2$ represents the squared Frobenius norm of the matrix H . The above formula can be further rewritten as,

$$\begin{aligned} P_{out} &= \Pr \left(\frac{1}{2} \log_2(1 + \gamma_{s,r}) < R \right) \\ &\quad + \Pr \left(\frac{1}{2} \log_2(1 + \gamma_{s,r}) \geq R \right) \\ &\quad \times \Pr \left(\frac{1}{2} \log_2(1 + \gamma_d) < R \right) \\ &= \Pr(\gamma_{s,r} < 2^{2R} - 1) \\ &\quad + \Pr(\gamma_{s,r} \geq 2^{2R} - 1) \\ &\quad \times \Pr(\gamma_d < 2^{2R} - 1) \end{aligned} \quad (18)$$

In the Rayleigh fading scenario, the $\gamma_{s,r}$ and γ_d are exponentially distributed with mean $\gamma_{s,r} = \text{SNR}_{s,r} |h_{s,r}|^2$ and $\gamma_d = \text{SNR}_d \|H\|_F^2$. Hence, we have

$$\begin{aligned} P_{out} &= 1 - \exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} \right) \\ &\quad + \exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} \right) \\ &\quad \times \left(1 - \exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_d} \right) \right) \\ &= 1 - \exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} \right) \\ &\quad + \left[\exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} \right) \right. \\ &\quad \left. - \exp \left(-\frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} - \frac{2^{2R} - 1}{\bar{\gamma}_d} \right) \right] \end{aligned} \quad (19)$$

Given, $e^{-x} \approx 1 - x$, then

$$P_{out} = 1 - \left(1 - \frac{2^{2R} - 1}{\bar{\gamma}_{s,r}}\right) + \left(1 - \frac{2^{2R} - 1}{\bar{\gamma}_{s,r}}\right) - \left(1 - \frac{2^{2R} - 1}{\bar{\gamma}_{s,r}} - \frac{2^{2R} - 1}{\bar{\gamma}_d}\right) \quad (20)$$

Consider the total power constraint by $P_s + P_r = P_T$ the authors can set $P_s = \beta P_T$ and $P_r = (1 - \beta) P_T$, for some $0 \leq \beta \leq 1$, and $n_{s,r}^2 = n_d^2 = n_T^2$. Then, the outage probability can be approximated as.

$$\begin{aligned} P_{out} &= \frac{2^{2R} - 1}{\text{SNR}} \left(\frac{1}{\beta \|H\|_F^2} + \frac{1}{(1 - \beta) \|H\|_F^2} \right) \\ &\quad + \frac{2^{2R} - 1}{\text{SNR}} \left(\frac{1}{(1 - \beta) h_{s,r}^2} \right) \\ &= \frac{2^{2R} - 1}{\text{SNR}} \left(\frac{1}{\beta \|H\|_F^2} + \frac{1}{(1 - \beta) \|H\|_F^2} \right) \\ &\quad + \frac{1}{(1 - \beta) h_{s,r}^2} \end{aligned} \quad (21)$$

5. SIMULATION RESULTS

In this section, the fading channels are generated by Rayleigh distribution including with the complex additive white Gaussian noise (AWGN). The data symbols are randomly generated and modulated by BPSK modulation. The estimated channels are assumed to be perfect which means that the destination is also assumed with the full knowledge of channel information. The cooperative MIMO technique in wireless communication networks is assumed with the perfect synchronization of timing symbols. This assumption is possible for wireless communication networks because the wireless devices always adjust the time slot to base station from time to time. The ML decision is also assumed to be employed at the destination.

In fact, the selection scheme from literature as well as our proposed scheme add more complexities to the actual implementation of wireless communication in terms of overhead transmission and delay processing time. However, the selection schemes can offer a higher capacity, more energy saving and a lower outage probability. These benefits are valuable enough to be the significant factors for considering the trade-offs to implement the proposed scheme in practice.

Firstly, in order to investigate the system performance of using cooperative MIMO technique, the system model in simulation is consisted of 1 source with one antenna, 1 relay with one antenna and 1 destination with two antennas. Three transmission schemes are compared here including cooperative diversity, cooperative MIMO and proposed method shown in Fig. 5. The cooperative diversity utilizes the advantage of diversity technique in receiver without MIMO

technique. The cooperative MIMO is the cooperative system with MIMO technique but without modifying STBC scheme. Next, in order to investigate the system performance in term of outage probability, the results of two systems including with cooperative diversity [16] and proposed method are shown in Fig. 6 and Fig. 7. Also, the channel is generated by Rayleigh fading.

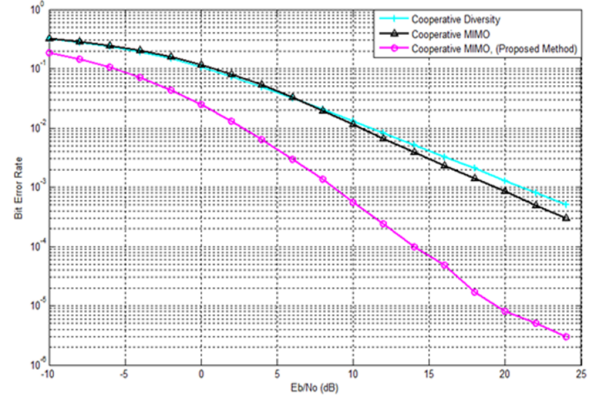


Fig.5: BER Comparison between the Proposed Method and Others.

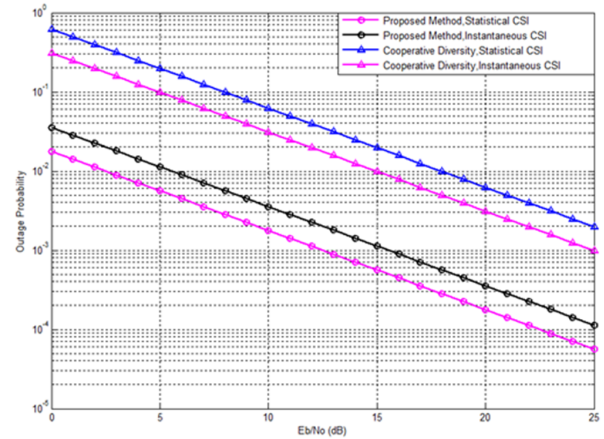


Fig.6: Outage Probability Performance Comparison between the Proposed Method and Diversity Scheme.

As seen in Fig. 5, there is no result of the method without modifying STBC scheme because it will provide the same result as the cooperative diversity communications. The results indicate that the cooperative MIMO transmission with proposed method provides the lowest BER. Also seen in Fig. 5, for 10^{-3} BER, the E_b/N_0 at 8.5 can be achieved by using the proposed method while it must be attained at about 19 dB and 21 dB by using cooperative MIMO method and cooperative diversity method, respectively. The more benefits are obtained when E_b/N_0 is higher. This is to confirm the success of the proposed method to implement for wireless communications.

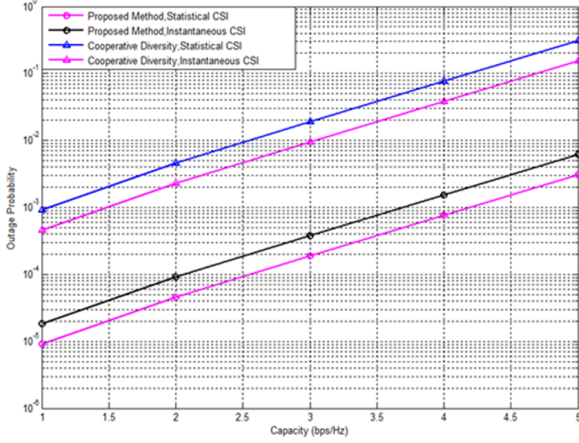


Fig.7: Outage Probability versus Spectral Efficiency.

In Fig. 6, the results indicate that the system performance in term of outage probability of the proposed method provides the lowest outage probability. Also seen in Fig. 6, for $10^{-3} P_{out}$, the E_b/N_0 at 10 dB in statistical CSI and the E_b/N_0 at 10 dB in instantaneous CSI can be achieved by using the proposed method while it must be attained at 25 dB in statistical CSI and more than 25 dB in instantaneous CSI by using cooperative diversity method. In Fig. 7, the results indicate that the system performance in term of outage probability versus spectral efficiency of the proposed method provides the lowest outage probability. Also seen in Fig. 7, for $10^{-3} P_{out}$, the 1 bps/Hz in statistical CSI and the 1.6 bps/Hz in instantaneous CSI can be achieved by using the proposed method while it must be attained at 3.8 bps/Hz in statistical CSI and more than 4.3 bps/Hz in instantaneous CSI by using cooperative diversity method. Considering fair-basis criteria of outage probability comparison, the proposed scheme is still able to provide the higher performance than the other.

Fig. 8 presents the outage probability versus distance between source node and relay node. The results indicate that the system performance in term of outage probability of the proposed method provides the lowest outage probability for any distances between source node and relay node. Fig. 9 shows the outage probability versus the allocation of transmitted power. This investigation is on the balance of the transmission power between source node and relay node. The transmitted power can be changed by the allocation of power factor. The results indicate that there is an optimal power allocation to minimize the outage probability. Hence, this might be useful to further investigate the efficiency of energy consumption.

6. CONCLUSIONS

In this paper, the performance analysis of cooperative MIMO technique using modified STBC scheme

is presented to apply on wireless communications. It is based on the modification of STBC scheme for DF protocol. The outage probability and BER performances are investigated. The results conclude that the proposed system can offer a better BER and a lower outage probability than other methods.

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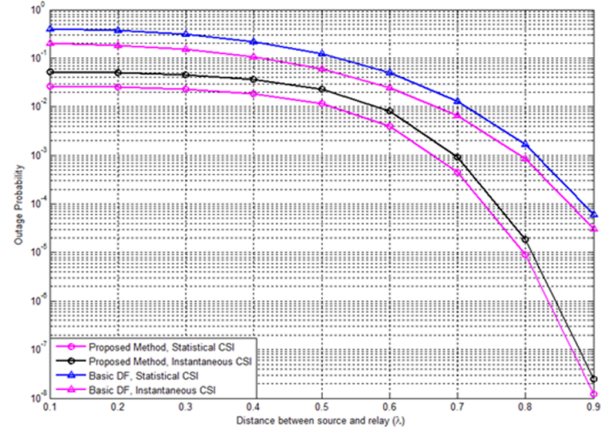


Fig.8: Outage Probability versus Distance between Source Node and Relay Node.

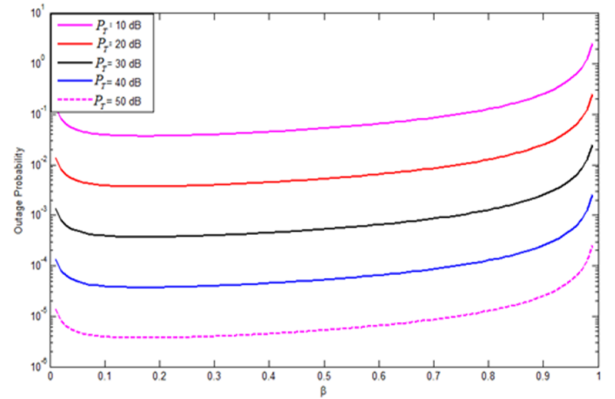


Fig.9: Outage Probability versus the Allocation of Transmitted Power.

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