SER OF OSTBC WITH DECODE-AMPLIFY AND FORWARD FOR COOPERATIVE COMMUNICATIONS

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Abstract: *The innovation of Wireless communication has been developed very fast in order to improve the performance of communication systems. Especially, a concept of Multiple Input Multiple Output (MIMO) is purposed to fulfill a high data rate service such as high quality video conference. However, a limitation in size and power of mobile device in the latest version of cellular system i.e. third Generation (3G) and fourth Generation (4G) causes difficulty to implement MIMO on mobile unit. Hence, Cooperative communication has been created to operate as a virtual MIMO in modern wireless communication. The objective of this paper, the performance analysis of Hybrid Decode-Amplify and Forward (HDAF) Cooperative communication using Orthogonal Space-Time Block Code (OSTBC) is derived in term of Symbol Error Rate (SER) against Signal-to-Noise Ratio (SNR) when the system applies different type of modulation techniques. Additionally, the error performance is derived base on Moment Generating Function (MGF) of the Rayleigh fading channel. We only focus on the downlink direction. Assuming that multiple antennas can be equipped into a transmitter which operates as base station in cellular system, mobile unit can be equipped with only single antenna due to the size limitation which operates as relays and destination. Moreover, the receiver uses Maximum Ratio Combining (MRC) to receive the transmitted signal.*

Key words: *orthogonal space-time block code, symbol error rate, cooperative communication, moment generating function, relaying protocol*

1. Introduction

Wireless communications have been proposed and adapted very fast in the last few decades. In present time, it was found that, new generation of wireless communications such as third generation (3G) and fourth generation (4G) can support high data rate communications and are widely used in the communication field. However, these services are not enough to fulfill ever increasing human demands due to some limitations. The limitations are caused by many parameters such as transmission power, size of mobile device, multi-path fading and noise which degrades the performance of data transmission among users. Therefore, if these limitations can be mitigated, the performance will be improved.

Multiple-Input Multiple-Output (MIMO) communications have been proposed to overcome the limitations. MIMO exploits the idea of multiple antennas at both the transmitter and the receiver ends. When compared to the conventional Single-Input Single Output (SISO) communications, MIMO gives a better performance. For example, increasing the number of antennas at both sides can enhance the spectrum efficiency of the system [1][2]. Moreover, Maximum Ratio Combining (MRC) at the receiver can mitigate multipath fading by exploiting the Channel State Information (CSI). However, transmitter diversity is quite difficult to implement in mobile communications due to the complexity [3] with transmission in uplink mode. Therefore, Orthogonal Space-Time Block Coding (OSTBC) has been proposed as an attractive solution for MIMO systems to combat channel fading [4]. However, setting up more than one antenna on a single mobile device is impractical because of its small size, as well as the requirements of the extension of the coverage area. Therefore, Cooperative communications have been created. These systems use nodes to help other nodes receive a signal from transmitter or vice versa. The helping nodes are called relays. This kind of communication method gets rid of equipping multiple antennas on a mobile device by operating as virtual MIMO which can not only achieve a high data rate transmission but also increase the coverage area between the transmitter and the receiver [5],[6]. There are a few conventional protocols that can be used in a relay system, for example Amplify-Forward relay (AF), Decode-Forward relay (DF) and Compress-Forward relay (CF) etc. Moreover, some recent papers presented studies about applying OSTBC to Cooperative communications instead of conventional channel block coding. The result shows that OSTBC can improve the performance of Cooperative communications [7]-[10]. Recently, another type of relay system, that is Hybrid Decode-Amplify Forward (HDAF) relay, which has combined the advantages from the aforementioned AF and DF relay systems, has been investigated [11]. These papers state that a hybrid protocol can improve the performance of Cooperative communications. For mobile communications such as the standard 3G or 4G, it is possible to equip multiple antennas on the base stations, but it is very difficult to set up multiple antennas on the mobile device which operates as a relay station, hence the performance of the OSTBC will decrease dramatically because there is only one antenna on the mobile unit.

In this paper, we investigate the SER performance of OSTBC applies to single relay in cooperative communication system with hybrid decode-amplify and forward protocol. The rest of this paper is organized as follows. In section 2, the system model of cooperative communication with single relay is described. Then the performance analysis including pdf, end-to-end SNR, moment generating functions and symbol error rate are analysed in section 3. Section 4 presents the numerical results and discussion. Finally, we summarize our conclusion in section 5.

2. System Model

The source is equipped with multiple transmit antennas, corresponding to base station of cellular system as shown in Figure 1. Whereas the relay and the destination are equipped with only single antenna caused by a size limitation of a mobile device. The whole transmission is completed in two phases; In the first phase, the source broadcasts signal to the relay and the destination by adopting OSTBC, while the relay and the destination are silent to listen; In the another phase, the relay retransmit the signal to destination while the source and the destination are silent. In this phase, the relay will perform as DF mode or AF mode, depends on threshold value and signal strength. If the signal strength is higher than some specific threshold value and the relay decode the signal correctly, the relay will perform re-encoding and transmitting the signal to the destination. If the signal strength is lower that the threshold value due to fading channel, the relay will amplify the received signal with some gain and forward it to the destination. The destination combines the signal from two phases by using MRC.

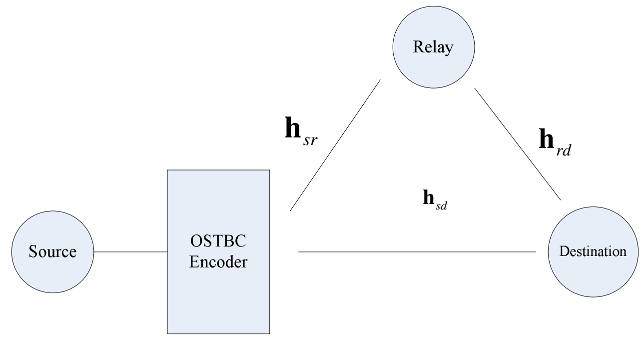

Fig. 1. System model of OSTBC with single relay under Cooperative communication with multiple antennas at transmitter.

3. Performance Analysis

In the first phase, the signal vectors are received at the relay, defined as $\mathbf{y}_r = \{y_{rk}\}_{K\times 1}$, and the received signal vectors at the destination are defined as $\mathbf{y}_d = \{y_{dk}\}_{K\times 1}$, are given by

$$\mathbf{y}_r = \mathbf{X}\mathbf{h}_{sr} + \mathbf{n}_{sr} \quad (1)$$

$$\mathbf{y}_d = \mathbf{X}\mathbf{h}_{sd} + \mathbf{n}_{sd} \quad (2)$$

respectively, where $\mathbf{X} = \{x_k\}_{K\times N_T}$ is the column orthogonal matrix signal transmitted from OSTBC encoder, each signal x_k are a linear combination of input information sequence $\{x_1, x_2, x_3, ..., x_L\}$ with its conjugate $\{x_1^*, x_2^*, x_3^*, ..., x_L^*\}$ and K is the block length of coded signal, $\mathbf{h}_{sr} = \{h_{sr}^i\}_{N_T\times 1}$ denoted the source-to-relay channel and $\mathbf{h}_{sd} = \{h_{sd}^i\}_{N_T\times 1}$ denoted the source-to-destination channel at $i = 1, 2, ..., N_T$ transmit antenna, $\mathbf{n}_{sr} = \{n_{sr}^k\}_{K\times 1}$ and $\mathbf{n}_{sd} = \{n_{sd}^k\}_{K\times 1}$ are Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 vectors at a receiver of the relay and the destination respectively. In this paper, channels are assumed to be flat-fading spatially uncorrelated Rayleigh fading channels and the large scale fading will not be considered for simple tractability.

In the second phase, it depends on an operation of the relay node during the second hop transmission as mentioned above. Therefore, the received signal vectors at the destination can be defined i.e., $\mathbf{y}^{DF} = \{y_k\}_{K\times 1}$ and $\mathbf{y}^{AF} = \{y_k\}_{K\times 1}$ for DF and AF mode, respectively, are given by

$$\mathbf{y}^{DF} = \mathbf{X}\mathbf{h}_{rd} + \mathbf{n}_{rd} \quad (3)$$

$$\mathbf{y}^{AF} = G\mathbf{y}_r\mathbf{h}_{rd} + \mathbf{n}_{rd} \quad (4)$$

where $\mathbf{h}_{rd}$ represent the relay-to-destination channel coefficient and $\mathbf{n}_{rd} = \{n_{rd}^k\}_{K\times 1}$ are zero mean AWGN vector with variance σ^2 per dimension. For the AF mode, G is an amplifying parameter chosen as

$$G = \sqrt{\frac{1}{\|\mathbf{h}_{sr}\|_F^2 + \sigma^2}} \quad (5)$$

where $\|.\|_F^2$ denotes the squared Frobenius norm. In case of the DF mode, the information will be retransmitted to the destination during the second phase if the relay correctly decodes received signal. Therefore, the SNR (γ_{DF}) at the destination is given by

$$\gamma_{DF} = \gamma_{sd} + \gamma_{rd1} \quad (6)$$

where γ_{sd} and γ_{rd1} are the SNR of source-to-destination and relay-to-destination path, respectively.

In case of the AF mode, the information will be forwarded to the destination by amplifying the received signal with the gain G. Then, the SNR (γ_{AF}) at the destination when the relay operates as AF mode is given by

$$\gamma_{AF} = \gamma_{sd} + \gamma_{rd2} \quad (7)$$

where γ_{rd2} is the SNR of relay-to-destination path when the relay performs as AF mode. The received SNR per symbol from direct source-to-destination transmission is given by [7]

$$\gamma_{sd} = \frac{P_s\|h_{sd}\|_F^2}{\sigma^2 N_T R} = \frac{\bar{\gamma}}{N_T}\|h_{sd}\|_F^2 \quad (8)$$

where P_s is the transmit energy at the source, R is the code rate of OSTBC and $\bar{\gamma} = \frac{P_s}{\sigma^2 R}$ is the average SNR. For received SNR per symbol from relay-to-destination path when the relay operates as DF is given by

$$\gamma_{rd1} = \frac{P_s}{2\sigma^2 R_s} \quad (9)$$

where R_s is symbol rate at the relay broadcast phase. Similarly, when apply the squaring method to decode OSTBCs expressed in [12] and some mathematic manipulation [7], the received SNR per symbol at the destination from AF relay mode is given as follow

$$\gamma_{rd2} = \frac{P_s}{R}.\frac{1}{N_T}.\frac{\frac{\|h_{sr}\|_F^2|h_{rd}|^2}{\sigma^2}}{\frac{|h_{rd}|^2}{\sigma^2} + \frac{1}{\sigma^2 G^2}} \quad (10)$$

The PDF statistic SNR value of system will be firstly provided in order to derive SER for the OSTBC transmission with cooperative diversity. Then, Moment Generating Function (MGF) will be expressed to simplify the performance analysis of SER. For the PDF of SNR at direct source-to-destination transmission, SNR in (8) follows the chi-square distribution of $2N_T$ degree of freedom [7], Therefore its PDF can be expressed as

$$p_{\gamma_{sd}}(\gamma) = \frac{N_T^{N_T}\gamma^{N_T-1}}{(N_T-1)!\bar{\gamma}^{N_T}}e^{-\frac{\gamma}{\bar{\gamma}}N_T} \quad (11)$$

From (9), the signal is propagated through the Rayleigh flat fading channel. Then PDF of average SNR per symbols is given by

$$p_{\gamma_{rd1}}(\gamma) = \frac{1}{\bar{\gamma}}e^{-\frac{\gamma}{\bar{\gamma}}} \quad (12)$$

For the CDF of SNR for OSTBC transmission in cooperative AF relay mode with multiple antennas can be expressed as [7]

$$P_{\gamma_{rd2}}(\gamma) = 1 - \frac{2}{(N_T-1)!\bar{\gamma}^{N_T}}e^{-\frac{2\gamma N_T}{\bar{\gamma}}}\sum_{n=0}^{N_T-1}C_{N_{T-1}}^n(N_T\gamma)^{N_T-n-1}(N_T^2\gamma^2+N_T\gamma)^{\frac{n+1}{2}} \times K_{n+1}\left(\frac{2\sqrt{N_T^2\gamma^2+N_T\gamma}}{\bar{\gamma}}\right) \quad (13)$$

where $C_N^n = \frac{n!}{(N-n)!n!}$ and $K_n(.)$ present the *nth*-order modified Bessel function of second kind.
Then, by taking the first derivative of (.11) respect to γ with the help of [7], the PDF of SNR for AF mode can be given by

$$P_{\gamma_{rd2}}(\gamma) = \frac{2}{(N_T-1)!\bar{\gamma}^{N_T}}e^{-\frac{2\gamma N_T}{\bar{\gamma}}}\sum_{n=0}^{N_T-1}C_{N_{T-1}}^n(N_T\gamma)^{N_T-n-1}(N_T^2\gamma^2+N_T\gamma)^{\frac{n+1}{2}}\left(\frac{2N_T}{\bar{\gamma}} - N_T + n + 1\right)$$

$$\times K_{n+1}\left(\frac{2\sqrt{N_T^2\gamma^2+N_T\gamma}}{\bar{\gamma}}\right)+\frac{1}{\sqrt{N_T^2\gamma^2+N_T\gamma}}$$

$$\times(2N_T^2\gamma+N_T)\frac{\gamma}{\bar{\gamma}}K_n\left(\frac{2\sqrt{N_T^2\gamma^2+N_T\gamma}}{\bar{\gamma}}\right) \quad (14)$$

By applying the well-know MGF approach [13], the MGF of γ_{sd},γ_{rd1} and γ_{rd2} can be expressed as follow;

$$\Phi_{\gamma sd}(s) = \int_0^\infty p_{\gamma sd}(\gamma)e^{-s\gamma}d\gamma = \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(s+\frac{N_T}{\bar{\gamma}}\right)^{-N_T} \quad (15)$$

$$\Phi_{\gamma rd1}(s) = \frac{1}{1+\bar{\gamma}s} \quad (16)$$

$$\Phi_{\gamma rd2}(s) = \frac{\sqrt{\pi}}{(N_T-1)!}A^{N_T+1}\left[\sum_{n=0}^{N_T}B_nA^{n+1}\frac{\Gamma(N_T+n+2)\Gamma(N_T-n)}{\Gamma(N_T+1.5)}C_1 -2D_nA^n\frac{\Gamma(N_T+n+1)\Gamma(N_T-n-1)}{\Gamma(N_T+0.5)}C_2 +\frac{\Gamma^2(N_T+1)}{\Gamma(N_T+1.5)}C_3 +A^{N_T}\frac{\Gamma(2N_T+1)\Gamma(1)}{\Gamma(N_T+1.5)}C_4\right] \quad (17)$$

where

$$A = \frac{4N_T}{4N_T+s\bar{\gamma}},\quad B_n = \frac{(N_T-1)!}{(N_T-n-1)!n!}+\frac{(N_T-1)!}{(N_T-n-2)!(n+1)!}$$

$$C_1 = F(N_T+n+2,n+1.5;N_T+1.5;E) \quad (18)$$

$$C_2 = F(N_T+n+1,n+1.5;N_T+0.5;E) \quad (19)$$

$$C_3 = F(N_T+1,0.5;N_T+1.5;E) \quad (20)$$

$$C_4 = F(2N_T+1,0.5;N_T+1.5;E) \quad (21)$$

$$D_n = (N_T-n-1)\frac{(N_T-1)!}{(N_T-n-1)!n!} \quad (22)$$

and $E = \frac{\bar{\gamma}s}{4N_T+\bar{\gamma}s}$. $F(a,b;c;z)$ and $\Gamma(.)$ are denoted the Gauss's hypergeometric function and the Gamma function, respectively.

Denoting P_c is the probability that the relay correctly decodes the symbol when the source uses M-PSK modulation scheme to transmit information, given by

$$P_c = 1-\frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}}\frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(\frac{g}{(\sin\theta)^2}+\frac{N_T}{\bar{\gamma}}\right)^{-N_T}d\theta \quad (23)$$

where $g = \left(\sin\frac{\pi}{M}\right)^2$.

For the HDAF relay protocol, the relay operates as DF mode when it correctly decodes the signal from the source. On the other hand, it operates as AF mode when the signal cannot be correctly decoded. Hence, the average SER of HADF protocol using OSTBC with arbitrary number of transmit antenna can be expressed as

$$P_s(E) = \frac{P_c}{\pi}\int_0^{(M-1)\frac{\pi}{M}}\Phi_{\gamma sd}\left(\frac{g}{(\sin\theta)^2}\right)\Phi_{\gamma rd1}\left(\frac{g}{(\sin\theta)^2}\right)d\theta + \frac{1-P_c}{\pi}\int_0^{(M-1)\frac{\pi}{M}}\Phi_{sd}\left(\frac{g}{(\sin\theta)^2}\right)\Phi\gamma_{rd2}\left(\frac{g}{(\sin\theta)^2}\right)d\theta \quad (24)$$

Moreover, the unified MGF-based approach method of Digital communication [11] over fading channels can be applied to calculate the performance of different kind of modulations. Hence, the SER of a wide variety of M-ary modulations can be obtained.

4. Simualtion Results

In this part, the numerical results are be presented and considered in order to prove the performance analysis of SER derived in the previous section. This thesis is interested in multiple antenna at the transmitter and single antenna at the relay and receiver due to a size and power constraint on a mobile device. The varied number of transmit antennas and modulation schemes will be shown to consider an impact on SER of the system. All curves and figures are plotted by SER against an average SNR.

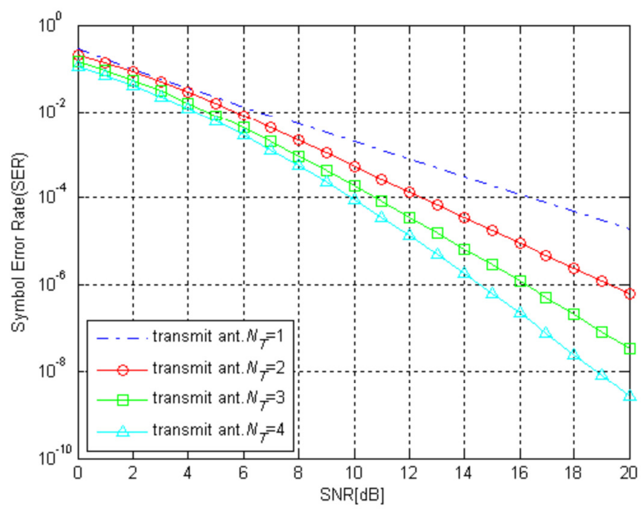

Fig.2. SER versus SNR in comparison of cooperative relay system using BPSK modulation scheme with different number of transmit antennas.

In figure 2, the SER performance of the BPSK modulation scheme using different number of transmit antenna are shown. It is clear that four transmit antenna give a better result when compared to two, three or a conventional single transmit antenna of HDAF relay protocol. From the curve, it can be seen that four transmit antennas improve the performance of the system at a high SNR level. Therefore, the performance can be improved if an antenna at the transmitter is increased.

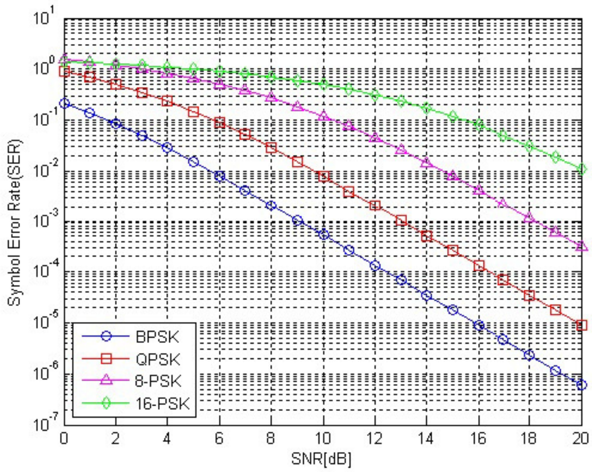

Fig. 3. SER versus SNR in comparison of cooperative relay system using different kinds of M-ary phase shift keying with two transmit antennas.

In figure 3 the performance of SER against SNR is plotted. Assuming the transmitter is fixed with two antennas but it uses the different kind of MPSK to transmit the signal. It is evident from figure 3 that as the higher order of modulations are more, the more power are needed in order to keep the same value of probability of symbol error.

In figure 4, Performance of SER versus SNR is plotted. Assume there are two transmit antennas using three different 4-ary modulation schemes to transmit signal to the receiver. It is obvious that QPSK gives a better result than the others. This is because 4-AM and QAM are the modulation techniques which use different power level to transmit data while QPSK uses constant power to transmit data.

5. **Conclusion**

The performance of Orthogonal Space time Block code with two hops Hybrid Decode Amplify and Forward relay network using multiple transmit antennas but single antenna at relay and destination node are examined. The result show the performance when apply different transmit antenna and modulation scheme to transmit a signal through the flat fading Rayleigh channel. According to the previous

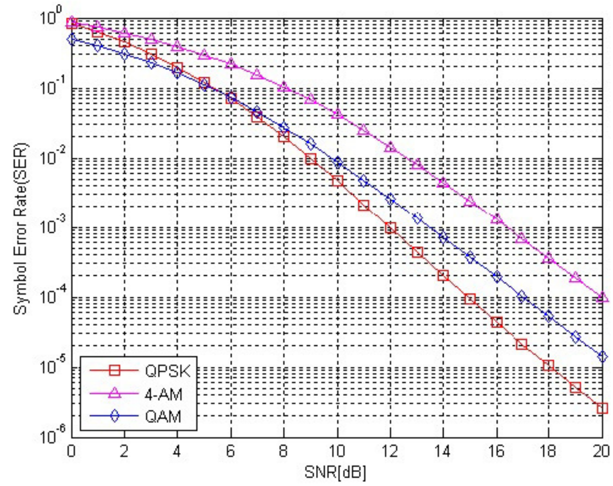

Fig. 4. SER versus SNR in comparison of cooperative relay system using different kinds of M-ary modulation scheme with two transmit antennas.

section, the performance of the system first is calculated from the PDF of SNR and derived to average SER. Then, SER of two relay systems that is DF and AF are combined together in order to derive SER of HDAF. The result is represent by the figures plotted SER versus SNR. It is shown that increasing a number of transmit antennas can improve the performance of overall system. However, increasing a number of antennas also need more power when uses higher modulation scheme to transmit a signal especially in amplitude modulation techniques.

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