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SER of OSTBC with Multiple Relays Using Hybrid Decode-Amplify and Forward For Cooperative Communications

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--***ABSTRACT***--
The improvement of wireless communication has been developed very fast in order to increase the performance of communication systems. Particularly, a concept of Multiple Input and Multiple Output (MIMO) is purposed to fulfill a high data rate service such as high quality video conference. The MIMO has some restriction i.e. size and power, so it is difficult to set up multiple antennas into a mobile device. To overcome this issue, cooperative communication is purposed to compensate the multiple antennas by using single relays to operate as virtual MIMO. In this paper, we apply multiple relays together with Orthogonal Space-Time Block Code (OSTBC) in cooperative communication under Hybrid Decode-Amplify and Forward (HDAF) relaying protocol. Furthermore, the error performance is derived base on Moment Generating Function (MGF) of the Rayleigh fading channel. We emphasize on the downlink direction. Optimal number of the relays to achieve the maximum performance will be calculated. Finally, the Symbol Error Rate (SER) of multiple relays using OSTBC with different types of modulation techniques is presented.
Keywords *- cooperative communication, Hybrid Decode-Amplify and Forward, moment generating function, multiple relays, orthogonal space-time block code, symbol error rate*

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I. INTRODUCTION

Cooperative communications for wireless networks have gained much interest due to its ability to mitigate fading in wireless network through achieving spatial diversity. It is closely related with multiple-input multiple-output (MIMO) systems, which has been widely employed to achieve a diversity gain, provide higher quality of service, power savings, extended coverage area, and improve reliability in bit error rate (BER). However, in some scenarios the wireless terminals may not be able to support multiple transmit antenna due to the hardware limitations. For example, the user terminals can be too small for implementing an antenna array. So in this case, it is possible to enable single antenna mobile in a multi-user environment to share their antennas and generate a virtual multiple-antenna transmitter that allows them to achieve transmit diversity. Cooperative communication protocols make use of the broadcast nature of wireless channel, where a number of relay nodes are assigned to help a source in forwarding its information to its destination, hence forming a virtual antenna array.

In [1]-[3], Laneman et al., proposed several different cooperative protocols for realizing cooperative diversity, including amplify-and-forward (AF), decode-and-forward (DF), adaptive relaying protocol (ARP), etc. Many researchers focused on the channel capacity, diversity gain, and outage behavior in different scenarios. In [4] and [5], the symbol error rate (SER) performance for DF cooperation was analyzed under Rayleigh fading channel. In [6] and [7], the authors analyze the SER performance over Nakagami fading channels for both AF and DF protocols, respectively. However, they all considered the classical three node model.

The design and performance analysis of multi-hop DF relaying with single-input single-output (SISO) in each hop has well studied [8-10]. In [10], an upper bound for error probability of the multi-hop system was investigated and it also introduced a concept of multi-hop diversity. Also in [11], the authors analyzed error probability performance for multi-hop DF relaying over Rayleigh fading channel under M-ary Quadrature Amplitude Modulation (M-QAM).

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 [12]. 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. Thus, to investigate how OSTBC applies to multiple relays in order to keep full diversity by utilizing the antenna of each relay unit as well as to have low complexity in channel coding are required to be studied. Furthermore, optimal number of relays is necessary to be considered due to the restriction in the amount of the relays in neighboring area.

The rest of this paper is organized as follows. In section II, the system model of cooperative communication with multiple relays is explained. Then the system analysis including pdf of end-to-end SNR, moment generating function (MGF) and symbol error rate are analyzed in section III. Section IV presents the numerical results. Finally, we provide our conclusion in section V.

II. SYSTEM MODEL

In this section, the system model of OSTBC cooperative HDAF multiple relays is examined in order to achieve a full diversity gain. For a transmission model, the source will transmit signal to the destination via a number of relays. Each relay will operate as either DF mode or AF mode depends on some threshold SNR value set on it. If the received signal is more than the threshold value that is the relay can decode the received signal correctly, the relay will forward the signal to the destination with re-encoding the signal. On the other hand, if the relay cannot decode the received signal or the received power is below the threshold level, the relay will amplify the received signal with particular gain and forward it to the destination without re-encoding the signal. In this part, it will be focus on how to combining DF protocol and AF protocol with multiple relays in order to get a better system performance. Furthermore, the performance gain of HDAF over DF and AF mode will be introduced to find optimal number of the relay in the system.

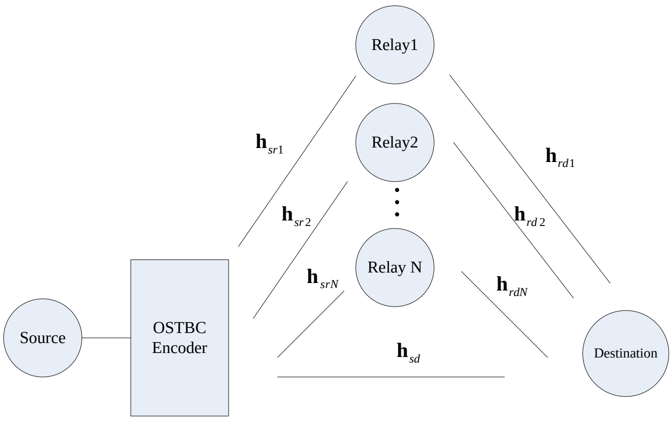

Figure 1. System model of OSTBC with Cooperative multiple relay with multiple antennas at transmitter.

From the figure 1, the source is equipped with multiple transmit antenna, while all relays and the destination are equipped with a single antenna. The source and the destination communicate over Rayleigh frequency flat fading channel. At the *N* number of relay node throughout the second hop transmission, for the relays which can correctly decode the signal, they will forward information to the destination. For the left of relays which cannot decode the signal, they will retransmit the signal to the destination with an amplifying gain *G*. Finally, the destination combines the signal from both *nth* number of relays and the source by using maximal ratio combining (MRC).

III. PERFORMANCE ANALYSIS

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

$$\mathbf{y}_{rn} = \mathbf{X}\mathbf{h}_{srn} + \mathbf{n}_{srn} \tag{1}$$

$$\mathbf{y}_d = \mathbf{X}\mathbf{h}_{sd} + \mathbf{n}_{sd}. \tag{2}$$

Thus, the received signal vectors at the destination can be defined i.e., $\mathbf{y}^{DF} = \{y_{rk}\}_{K\times 1}$ and $\mathbf{y}^{AF} = \{y_k\}_{K\times 1}$ for DF and AF mode, respectively, are given by

$$\mathbf{y}_{rn} = \mathbf{X}\mathbf{h}_{srn} + \mathbf{n}_{srn} \tag{3}$$

$$\mathbf{y}_{rn} = \mathbf{X}\mathbf{h}_{srn} + \mathbf{n}_{srn} \tag{4}$$

$\mathbf{X} = \{x_k\}_{K\times N_T}$ 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, $\mathbf{h}_{sd} = \{h_{sd}^i\}_{N_T\times 1}$ denoted the source-to-destination channel at $i = 1, 2, ..., N_T$ transmit antenna, and $\mathbf{n}_{sd} = \{n_{sd}^k\}_{K\times 1}$ is the Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 vectors at a receiver of the destination respectively. For $\mathbf{h}_{srn} = \{\mathrm{h}_{srn}^i\}_{N_T\times 1}$ denote the source-to-destination channel at $i = 1, 2, ..., N_T$ transmit antenna of each *nth* relay, $\mathbf{h}_{rdn}$ represents the relay-to-destination channel coefficient. $\mathbf{n}_{srn}$, $\mathbf{n}_{rdn}$ are AWGN vectors with zero mean and variance σ^2 between source-to-*nth* relay and *nth* relay-to- destination respectively. In this paper assumes that the channel of source-to-relay and relay-to-destination of each *nth* relay path are identical. $\mathbf{G}_n$ is an amplifying gain for each *nth* relay given as

$$\mathbf{G}_n = \sqrt{\frac{1}{\|h_{srn}\|_F^2 + \sigma^2}} \tag{5}$$

In case of the DF approach, if some relays correctly decode the received signal, they will retransmit the received signal to the destination during the second period. For the left of other relays which cannot decode the transmit signal from the source, they will remain silent. Therefore, the SNR (γ_{DF}) at the destination of DF mode is given by

$$\gamma_{DF} = \gamma_{sd} + \sum_{n=1}^{k} \gamma_{rdn1} \tag{6}$$

where γ_{rdn1} is SNR of the *nth* relay-to-destination path when the relay operate as DF mode. *k* is number of relays which can decode the received signal .

In case of AF approach, this means that all relays cannot decode the received signal correctly. They will forward the received signal to the destination by amplifying it with each their own gain (G_n) . The SNR of AF mode is given by

$$\gamma_{AF} = \gamma_{sd} + \sum_{n=1}^{k} \gamma_{rdn2} \tag{7}$$

where γ_{rdn2} is SNR of the *nth* relay-to-destination when all relays operate as AF mode. The moment generating function (MGF) of γ_{sd} and γ_{rd1} can be written as follow

$$\Phi_{\gamma sd}(s) = \int_0^\infty p_{\gamma sd}(\gamma) e^{-s\gamma} d\gamma = \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}} \left(s + \frac{N_T}{\bar{\gamma}} \right)^{-N_T} \tag{8}$$

$$\Phi_{\gamma rd1}(s) = \frac{1}{1 + \bar{\gamma} s} \tag{9}$$

The MGF of can be expressed by [12]

$$\Phi_{\gamma DF}(s) = \Phi_{\gamma sd}(s) \prod_{n=1}^{k} \Phi_{\gamma rdn1}(s) \tag{10}$$

By substituting (8) and (9) into (10) MGF of γ_{DF} is

$$\Phi_{\gamma DF}(s) = \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}} \frac{1}{\left(s+\frac{N_T}{\bar{\gamma}}\right)^{N_T}} \frac{1}{(1+\bar{\gamma}s)^k} \tag{11}$$

In the same direction as (11), MGF of γ_{AF} can be determined by [12]

$$\Phi_{\gamma AF}(s) = \Phi_{\gamma sd}(s)\prod_{n=1}^{N}\Phi_{\gamma rdn2}(s) \tag{12}$$

And

$$\Phi_{\gamma AF}(s) = \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}} \frac{1}{\left(s+\frac{N_T}{\bar{\gamma}}\right)^{N_T}} (\Phi_{\gamma rd2}(s))^N \tag{13}$$

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

$$P_c = 1-\frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(\frac{g}{(\sin\theta)^2}+\frac{N_T}{\bar{\gamma}}\right)^{-N_T} d\theta \tag{14}$$

where $g = \left(\sin\frac{\pi}{M}\right)^2$. As shown in (14) is the probability that each *nth* relay can decode the received signal in the first period. Assuming that source-to-*nth* relay path is identical. Hence, the probabilities (P_k^c) that *k* number of relays can decode the received signal and the other *N-k* relays cannot decode the signal are given by,

$$P_c = \left(1-\frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(\frac{g}{(\sin\theta)^2}+\frac{N_T}{\bar{\gamma}}\right)^{-N_T} d\theta\right)^k \times \left(\frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(\frac{g}{(\sin\theta)^2}+\frac{N_T}{\bar{\gamma}}\right)^{-N_T} d\theta\right)^{N-k} \tag{15}$$

P_0 is denoted as the probability that all relays fail in decoding the transmitted signal from the source, P_0 is given by

$$P_0 = \left(\frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\left(\frac{g}{(\sin\theta)^2}+\frac{N_T}{\bar{\gamma}}\right)^{-N_T} d\theta\right)^N \tag{16}$$

Therefore, HDAF protocol can be developed by a combination of DF and AF protocol. The SER of HDAF using M-PSK modulation scheme is given by

$$P_s(E) = \sum_{k=1}^{K}\binom{N}{k}\frac{P_k^c}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \Phi_{\gamma sd}\left(\frac{g}{(\sin\theta)^2}\right)\left(\Phi_{\gamma rd1}\left(\frac{g}{(\sin\theta)^2}\right)\right)^k$$
$$\times\left(\Phi_{\gamma rd2}\left(\frac{g}{(\sin\theta)^2}\right)\right)^{N-k} d\theta + \frac{P_0}{\pi}\int_0^{(M-1)\frac{\pi}{M}} \Phi_{\gamma sd}\left(\frac{g}{(\sin\theta)^2}\right)\left(\Phi_{\gamma rd2}\left(\frac{g}{(\sin\theta)^2}\right)\right) d\theta \tag{17}$$

For a performance of DF and AF protocol with multiple relays can be calculated in the same direction as (17) and defined as

$$P_{s,DF}(E) = \sum_{k=1}^{K}\binom{N}{k}\frac{P_k^c}{\pi}\int_0^{(M-1)\frac{\pi}{M}}\frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\frac{1}{\left(\frac{g}{(\sin\theta)^2}+\frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\right)^{N_T}}\frac{1}{\left(1+\bar{\gamma}\left(\frac{g}{(\sin\theta)^2}\right)\right)^{k}}d\theta+\frac{P_0}{\pi}\int_0^{\pi-\frac{\pi}{M}}\frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\frac{1}{\left(\frac{g}{(\sin\theta)^2}+\frac{N_T^{N_T}}{\bar{\gamma}^{N_T}}\right)^{N_T}}d\theta \quad (18)$$

$$P_{s,AF}(E) = \frac{1}{\pi}\int_0^{(M-1)\frac{\pi}{M}}\Phi_{\gamma sd}\left(\frac{g}{(\sin\theta)^2}\right)\left(\Phi_{\gamma rd2}\left(\frac{g}{(\sin\theta)^2}\right)\right)^{N}d\theta \quad (19)$$

IV. NUMERICAL RESULTS

In this section, numerical results of the SER performance with HDAF protocol using multiple antennas and multiple relays in the system are explained. Furthermore, this part also shows how a number of relays affect the relaying gain. All curve and graph of SER performance are plotted in term of symbol error rate (SER) against signal to noise ratio (SNR). The relaying gain is plot in term of relaying gain versus *N* numbers of relay in the system.

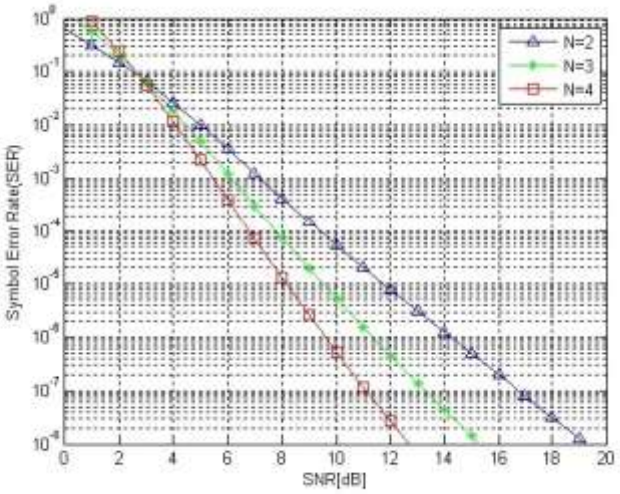

Figure 2. SER versus SNR in comparison of cooperative N number of relays system using BPSK modulation scheme with two transmit antennas.

In figure 2, the SER performance of OSTBC with HDAF cooperative communication with multiple relays is plotted against SNR. The source is equipped with two transmit antennas and use BPSK modulation scheme in transmission. It is obvious that increasing a number of relays can reduce the error probability. For example, four relays using less power than two relays at the same SNR of 10^{-4} .

In figure 3 shows the SER performance of OSTBC with HDAF cooperative communications using multiple relays. Assume that the source is equipped with three transmit antennas and using BPSK modulation scheme in transmission. It can be seen that a slope of four relays change more different than a slope of two and three relays. The difference of slope follows the fact that four relays give more diversity order than the others.

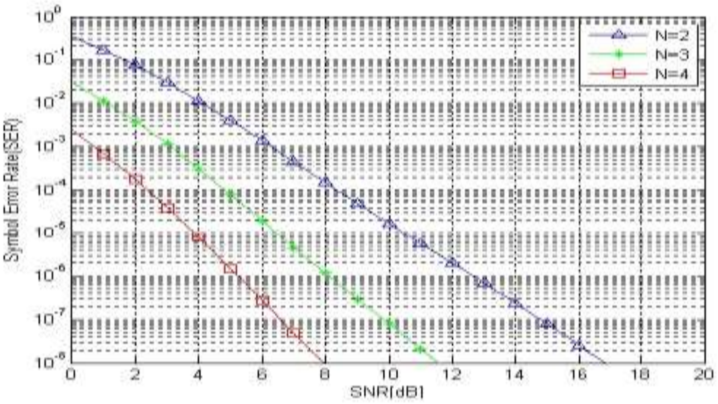

Figure 3. SER versus SNR of N relays system using BPSK modulation with three transmit antennas.

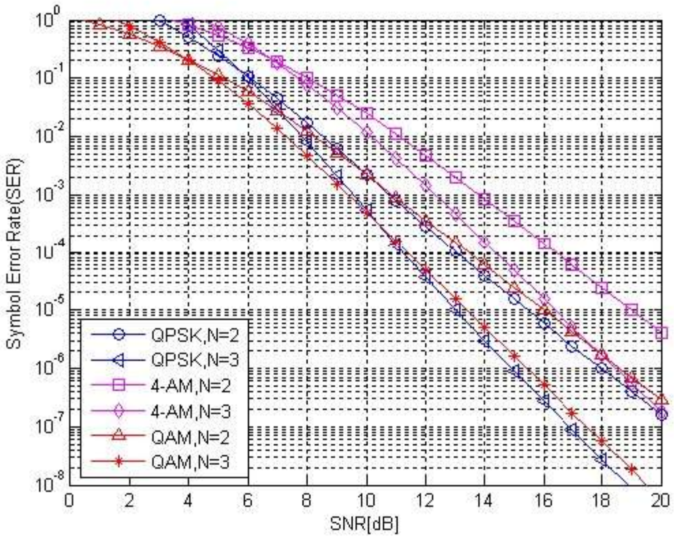

Figure 4. SER versus SNR in comparison of cooperative N number of relays system using different modulation scheme with two transmit antennas.

In figure 4 SER performance of OSTBC with HDAF cooperative multiple relays is plotted against SNR. It is assumed that two transmit antennas transmit the signal to different number of relays by using different modulation techniques. It is clear that both QPSK and QAM have a better result than 4-AM. A performance between QPSK and QAM has a bit different, but QPSK appear to be better in a high SNR regime. It is obvious that increasing a number of relays from two to three make the system get a better result in different kind of modulation techniques

V. CONCLUSION

In this paper, we study the performance analysis of HDAF cooperative communication using multiple antennas at transmitter with single antenna at the relay and receiver. The conclusion from the numerical analysis shows that the multiple antennas at the transmitter with only one antenna at the relay and the destination increase the performance of the system when compared to convention hybrid protocol. Furthermore, the multiple relay system is study. The result shows that the multiple relays improve the performance of HDAF considerably if a number of relays are increased. It is shown that the performance of multiple relays can be increased even though there is only one antenna at each relay and the destination.

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Biographies and Photographs

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