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Power Allocation for Two Source Destination Pair Cooperative Communication System under The Outage Probability Constraint

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ABSTRACT: To achieve the multiuser diversity and cooperative diversity, a two source destination pair is considered for cooperative communication system. Hybrid Decode Amplify Forward (HDAF) Relaying Protocol improves the system performance by combining the merits of both Amplify Forward (AF) and Decode Forward (DF) protocols is used. The fast and efficient Parallel Shift Water Filling (SPWF) algorithm can minimize the total power, based on the outage probability constraint. In the conventional algorithms, the solution is obtained by an iterative binary searching and Lagrange Multiplier searching process. In contrast, PSWF Algorithm removes the iterative searching process. It executes the PSWF only once, and then directly calculates the final solution with the parallel shift property as an enabling mechanism. Numerical analysis is used to compare the various relaying protocols based on outage probability and Bit Error Rate.

KEYWORDS: Cooperative communication system, HDAF Relaying Protocol, Outage Probability, PSWF Power Allocation.

I. INTRODUCTION

In mobile terminals, it is difficult to support multiple antennas due its limitations in size, cost, complexity, etc. The alternative approach to achieve spatial and cooperative diversity without multiple antennas is the cooperative communication system [1]. Spatial diversity is that several antenna elements separated in space. Cooperative diversity is that several cooperative multiple antenna elements separated in space. Advantages of Cooperative communication system are ease of implementation, good scalability, increased connectivity, better coverage, reduced operating power level etc. Cooperative communication system consists of three nodes, a) Source, which transmits the signal, b) Relay, which forwards its signal to destination by some relaying protocols, c) Destination, receives the signal from relay and source.

Amplify and forward relay will amplify its signal and forward it to the destination. But the demerit here is the amplification of noise [2]. Decode and Forward relay will regenerate the original signal and passes the clean set of signals to destination. It provides clean data extraction. But the demerit of this is if the relay wrongly decodes the signal, the performance of the system is degraded [3]. These observations motivate a new signal forwarding scheme that combines the benefits from AF and DF, this scheme is called Hybrid Decode Amplify Forward (HDAF) relaying. The intuition behind this protocol is that, if the relay cannot decode the signal correctly or the link between the relay and source is not good enough, then the relay will amplify the signal and forward the amplified signal to destination.

II. RELATED WORK

The relay will forward the reliable information to the destination by performing soft decoding and forward the reliable information to destination [4]. The Symbol Error Probability (SEP) of HDAF cooperative system has been analyzed [5]. HDAF protocol is the best relaying protocol when the quality of relay destination link is better than source relay [6]. The expressions for outage probability and Bit Error Rate (BER) have been derived [7]. In [8] and [9], the scheme requires many relay nodes to forward the received signal to destination and it degrades the spectral efficiency.

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In recent years, there is an increasing interest in investigating the relaying in MIMO networks, which improves the achievable rate in shared spectrum multiple access wireless networks [10]. MIMO achieves the cooperative diversity, with the support of multiple relays [11]. The result of using multiple relay schemes is very low spectral efficiency and high complexity. To reduce the spectral efficiency loss and high complexity, decrease the number of relays. Hence, the two source destination pair relay network is modelled [12]. Therefore, each source destination pair can achieve the cooperative diversity, where another source will act as the relay.

Beyond these considerations, to improve the performance of cooperative communication system due to limited transmission power, the most important design consideration is the power allocation. Various power allocation schemes are proposed to maximize the minimum SNR, to minimize the maximum transmit power and to maximize the network throughput [13]. The Water Filling power allocation algorithm using iterative binary searching process has been proposed to optimize the total power [14]. Each iterations are computationally efficient and guarantees to a local optimum. But this computational process makes it as a complex algorithm. Hence, a new power allocation algorithm called Parallel Shift Water Filling power allocation algorithm has been proposed to remove the iterative binary searching process [15]. It executes the Parallel Shift Water Filling only once, and then directly calculates the final solution with the parallelshift property as an enabling mechanism. Outage probability and power allocation for AF relaying with channel estimation errors has been investigated and it shows that significant power saving can be obtained [16].

The main objective is the power allocation for a HDAF relaying using PSWF algorithm under the outage probability constraint. The design considerations are summarized as follows.

1. The simple two source destination pair cooperative network is modeled, which can achieve high cooperative diversity in high SNR region and also reduce the spectral efficiency loss and high complexity over multiple relays in MIMO system. It achieves both cooperative diversity and multiuser diversity and reduces the total power.
2. The HDAF relaying protocol can improve system performance especially at higher SNR regions. By comparing the threshold SNR and SNR of source relay link, either AF or DF protocol will be chosen and then the signal will be forwarded to the destination.
3. The fast and efficient Parallel Shift Water Filling algorithm can minimize the total power, based on the outage probability constraint.

III. SYSTEM MODEL

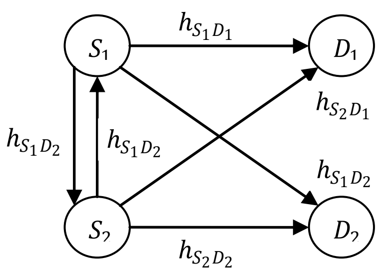

Fig. 1. Model of two source destination pair cooperative communication system

Consider the two source destination pair cooperative communication wireless network in Fig. 1, in which source nodes S_1 and S_2 transmit the data to destination nodes D_1 and D_2, respectively. A higher level network protocol has allocated bandwidth to two terminals for transmission to their intended destinations or next hops, such as, in a cellular network, S_1 and S_2 are respectively handsets and $D_1 = D_2$ correspond to the base station. As another consideration, in wireless local area network, D_1 and D_2 correspond to ad hoc configuration. Here, we assume all the channels as quasi static Rayleigh distribution. The Additive White Gaussian Noise (AWGN) with complex Gaussian components with zero mean and variance N_0 is represented at each receiver.

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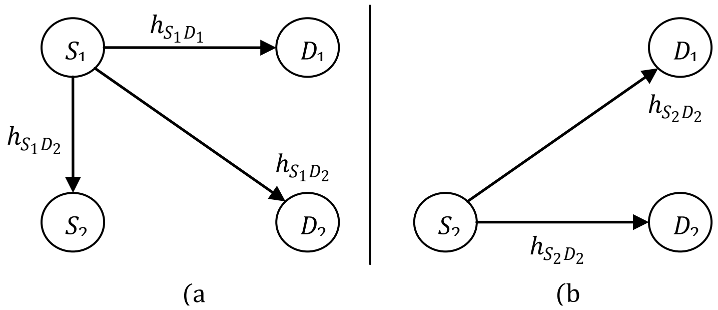

Fig. 2. Case 1. S_1 acts as a "source" and S_2 acts as a "relay". (a) First Phase, (b) Second Phase

In Fig. 2, case 1 is illustrated. In that, S_1 acts as a "source" and S_2 acts as a "relay". It consists of two phases. In first phase, S_1 transmits the information to destinations D_1 and D_2 and also to relay S_2. The relay will amplify or decode the information according to the SNR condition in source relay link. At lower SNR the relay will amplify the received information and at higher SNR the relay will decode the received information. Then in second phase, S_2 will forward the amplified or decoded symbols to both of the destinations D_1 and D_2. Then at both destinations Maximum Ratio Combining (MRC) technique will be applied to combine the direct signal and the relayed signal.

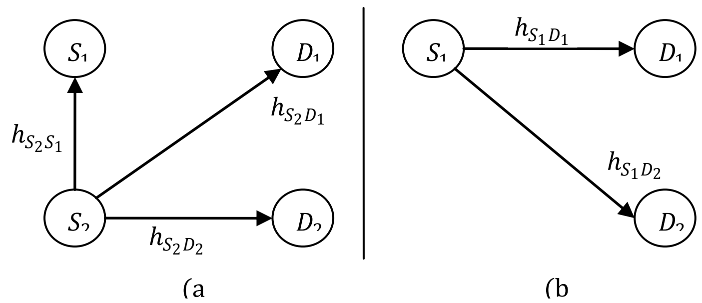

Fig. 3. Case 2. S_2 acts as a "source" and S_1 acts as a "relay". (a) First Phase, (b) Second Phase

In Fig. 3, case 2 is illustrated. In that, S_2 acts as a "source" and S_1 acts as a "relay". It also consists of two phases. In first phase, S_2 transmits the information to destinations D_1 and D_2 and to the relay S_1. The relay will amplify or decode the information according totheSNRconditioninsourcerelay link. At lower SNR the relay will amplify the received information and at higher SNR the relay will decode the received information. Then in second phase, S_1 will forward the amplified or decoded symbols to both of the destinations D_1 and D_2. Then at both destinations MRC technique will be applied to combine the direct signal and the relayed signal.

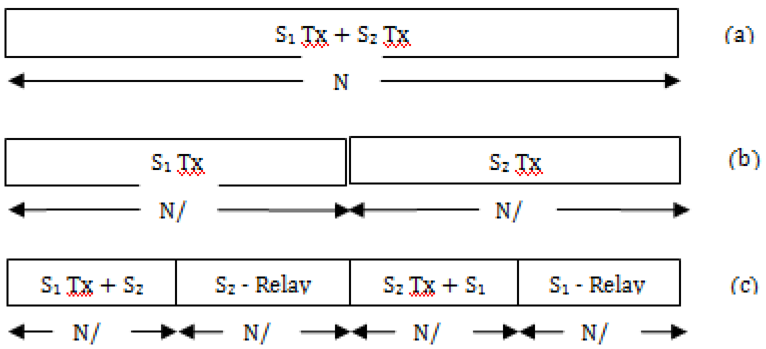

Fig. 4. (a) Direct Transmission, (b) Orthogonal direct transmission (ODT), (c) Orthogonal cooperative transmission (OCT)

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Some level of synchronization between the terminals is required for cooperative diversity to be effective. Consider the scenario in Fig. 4,in which the terminals are block, carrier and symbol synchronous. Given some form of network block synchronization, carrier and symbol synchronization for the network can build upon the same between the individual transmitters and receivers. It focuses on half duplex communication that lends itself more easily to practical implementation. Thus, for half duplex operation, each channel is divided into orthogonal sub channels.

A. *Channel Models*

Under the above orthogonality constraints, the channel models are characterized using a frequency division notation. During the transmission sources S_1 and S_2 broadcast their messages to each other and to the destinations D_1 and D_2 respectively. A baseband equivalent discrete time channel model considers N consecutive uses of the channel, where N is larger.For Orthogonal Direct Transmission (ODT), the received signal to the destination directly from source is

$$y_{SD}[n] = \sqrt{(p_S)} * h_{SD} * x[n] + N_{SD}[n] \quad (1)$$

for n = 1,…,N/2, wherep_S is the source transmitted power, h_{SD} is the Rayleigh coefficient of source to destination link, $x[n]$ is the source transmitted signal, $N_{SD}[n]$ is the AWGN coefficient of source to destination link and $y_{SD}[n]$ is the destination received signal. The other terminal transmits for n = N/2 + 1,…,N, as depicted in Fig. 4(b). Thus, each source utilizes only half of the available degrees of freedom of the channel.

For cooperative diversity, the cooperative transmission is divided into two phases. During the first phase of the block, the sources S_1 or S_2transmit the signal with the transmission power p_S and the relay and destination received signals respectively are

$$y_{SR}[n] = \sqrt{(p_S)} * h_{SR} * x[n] + N_{SR}[n] \quad (2)$$

$$y_{SD}[n] = \sqrt{(p_S)} * h_{SD} * x[n] + N_{SD}[n] \quad (3)$$

for n = 1,…,N/4, where $x[n]$ is the source transmitted signal,h_{SR} is the Rayleigh coefficient of source to relay link, $N_{SR}[n]$ is the AWGN coefficient of source to relay link, $y_{SR}[n]$ and $y_{RD}[n]$ are the relay and destination received signals respectively.

During the second phase, the relay will forward the information using HDAF relaying protocol. The received signal is

$$y_{RD}[n] = \sqrt{(p_S)} * h_{RD} * \ddot{x}[n] + N_{RD}[n] \quad (4)$$

for n =N/4 + 1,…,N/2, where $\acute{x}[n]$ is the relay transmitted signal,h_{RD} is the Rayleigh coefficient of relay to destination link, $N_{RD}[n]$ is the AWGN coefficient of relay to destination link and $y_{RD}[n]$ is the destinationreceived signal. Note that only half the degrees of freedom are allocated to each source terminal for transmission to its destination and a quarter of the degrees of freedom are available for communication to its relay, as depicted in Fig. 4(c).

IV. PARAMETERS

The two important parameters are SNR and spectral efficiency. These parameters are defines in terms of standard parameters in the continuous time channel. In continuous time channel the transmit power is P_c joules per second, the discrete power can be P = $2P_c$/W J/2D. The channel model is parameterized by the SNR random variables as

$$\gamma_{SD} = \frac{p_S |h_{SD}|^2}{N_0} \quad (5)$$

$$\gamma_{SR} = \frac{p_S |h_{SR}|^2}{N_0} \quad (6)$$

$$\gamma_{RD} = \frac{p_S |h_{RD}|^2}{N_0} \quad (7)$$

where γ_{SD} , γ_{SR} and γ_{RD} are the SNR values of source to destination link, source to relay link and relay to destination link respectively. The value of SNR is varying from low to high. Increasing the source relay SNR proportionally to

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increases in the source destination SNR leads to the full diversity benefits of the cooperative protocols. In addition to SNR, transmission schemes are further parameterized by the rate *r*bits per second,

$$R = 2r / Wb / s / Hz \tag{8}$$

The rate normalized by the number of degrees of freedom utilized by each terminal, not by the total number of degrees of freedom in the channel.

V. COOPERATIVE DIVERSITY PROTOCOL

If γ_{SR} is less than the SNR threshold γ_{th}, then the relay will choose AF in order to avoid error propagation. Otherwise, DF is chosen to avoid noise amplification. Defining Z represents,

$$Z = \begin{cases} 1, \gamma_{SR} < \gamma_{th} \\ 0, \gamma_{SR} \geq \gamma_{th} \end{cases} \tag{9}$$

If AF relaying protocol is adopted, the destination received signal is given by

$$y_{RD}^{AF}[n] = \beta * h_{RD} * y_{SR}[n] + N_{RD}[n] \tag{10}$$

where β is the amplification factor and it can be given as

$$\beta = \sqrt{\frac{p_S}{p_S |h_{RD}|^2 + N_0}} \tag{11}$$

where N_0 is the variance of AWGN channel.
If the relay adopts DF relaying protocol, the destination received signal is given by

$$y_{RD}^{DF}[n] = \sqrt{(p_S)} * h_{RD} * \hat{x}[n] + N_{RD}[n] \tag{12}$$

where $\hat{x}[n]$ is the decoded signal at the relay. At the end of the second phase, the destinations combine the received information at two phases with MRC technique.

VI. OUTAGE PROBABILITY ANALYSIS AND POWER ALLOCATION ALGORITHM

1. *Outage Probability Analysis*

In cooperative system, outage occurs at the destination when the mutual information from source to the destination fails to achieve the target rate. This section focuses on the exact outage probability of adaptive HDAF relaying. The performance of HDAF protocol and derive closed form expressions of outage probability in high SNR regions are characterized. For the achievable rate R, *Pr[I<R]* denotes outage probability.

A. Orthogonal Direct Transmission

The source transmits the signal over quasi static Rayleigh fading channels. The maximum average mutual information between the input and output is given by

$$I = \log(1 + \gamma_{SD}) \tag{13}$$

as a function of the fading coefficient h_{SD}. The outage event for spectral efficiency R is given by $I < R$.
The outage probability is expressed as follows:

$$P_{ODT}^{out} = \Pr\{\log(1 + \gamma_{SD}) < R\} = \frac{(2^R - 1) N_0}{p_S} \tag{14}$$

B. *Orthogonal Cooperative Transmission*

a) *Amplify and Forward:* In AF the maximum average mutual information between the input and outputis given by

$$I_{AF} = \frac{1}{2} \log(1 + \gamma_{SD} + f(\gamma_{SR}, \gamma_{RD})) \tag{15}$$

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The Outage event for spectral efficiency R is given by $I_{AF} < R$ and is equivalent to

$$P_{OCT_{AF}}^{out} = \Pr\left(I_{AF} < R\right) = \left(\frac{1}{2\Omega_{SR}^{2}} \frac{\Omega_{SR}^{2}+\Omega_{RD}^{2}}{\Omega_{SR}^{2}\Omega_{RD}^{2}}\right)\left(\frac{\left(2^{2R}-1\right)N_0}{p_S}\right)^2 \quad (16)$$

b) *Decode and Forward:* To analyze DF transmission, examination of symbol by symbol decoding at the relay becomes involved because it depends upon the particular coding and modulation choices. The maximum average mutual information for input and output is given by

$$I_{DF} = \frac{1}{2}\min\left\{\log\left(1+\gamma_{SR}\right), \log\left(1+\gamma_{SD}+\gamma_{RD}\right)\right\} \quad (17)$$

The outage event for spectral efficiency R is given by $I_{DF} < R$ and is equivalent to

$$P_{OCT_{DF}}^{out} = \frac{1}{\Omega_{SR}} \frac{\left(2^{2R}-1\right)N_0}{p_S} \quad (18)$$

c) *Hybrid Decode Amplify Forward:* The maximal average mutual information between the input and output is given by

$$I = \frac{1}{2}\log\left(1+\gamma_{SD}+\gamma_Z\right) (19)$$

The outage probability is given as

$$P_{OCT_{HDAF}}^{out} = \Pr\left\{\frac{1}{2}\log\left(1+\gamma_{SD}+\gamma_Z\right) < R\right\} \quad (20)$$

In order to calculate P_{OCT}^{out},the cumulative distribution function (CDF) of γ_Z is given by

$$F_{\gamma z}\left(g(R)\right) = \begin{cases} g(R)N_0\left(\frac{1}{p_S\Omega_{SR}} + \frac{1}{p_S\Omega_{RD}}\right), \gamma_{th} \le g(R) \\ \frac{2\gamma_{th}N_0 - g(R)N_0}{p_S\Omega_{SR}} + \frac{g(R)N_0}{p_S\Omega_{RD}}, \gamma_{th} > g(R) \end{cases} \quad (21)$$

where $g(R) = 2^{2R} - 1$

The outage probability (16) can be rewritten as

$$P_{OCT_{HDAF}}^{out} = \Pr\left\{\gamma_{SD} + \gamma_Z < g(R)\right\} = \int_0^{g(R)} \Pr\left\{\gamma_Z < g(R) - \gamma_{SD}\right\}\left(\gamma_{SD}\right) d\gamma_{SD} \; (22)$$

Changing the variable $\gamma' = 1 - \gamma_{SD}/g(R)$, we obtain

$$P_{OCT_{HDAF}}^{out} = \frac{g(R)N_0}{p_S\Omega_{SR}} \int_0^{g(R)} \Pr\left\{\gamma_Z < g(R)\gamma'\right\} * \exp\left(-\frac{N_0 g(R)(1-\gamma')}{p_S\Omega_{SR}}\right) d\gamma' \; (23)$$

At high SNR, all the relays can decode the sources' messages. At high SNR region, the outage probability can be simplified as

$$P_{OCT}^{out} = \frac{g(R)N_0}{p_S\Omega_{SR}} \int_0^1 F_{\gamma z}\left(g(R)\gamma'\right) d\gamma' = \begin{cases} \frac{\left|g(R)N_0\right|^2}{2p_S\Omega_{SD}}\left(\frac{1}{p_S\Omega_{SR}} + \frac{1}{p_S\Omega_{RD}}\right), \gamma_{th} \le g(R) \\ \frac{g(R)N_0{}^2}{2p_S\Omega_{SD}}\left(\frac{2\gamma_{th} - g(R)}{p_S\Omega_{SR}} + \frac{g(R)}{p_S\Omega_{RD}}\right), \gamma_{th} > g(R) \end{cases} \quad (24)$$

2. Power Allocation Algorithm

At any given time instant, a single source experiencing deep fades will then have to expend large amount of power in order to meet the quality ofservice constraints. The proposed cooperative scheme can achieve MUD and cooperative diversity that reduces the probability of deep fades, thus reducing the total power. In this section, the objective of power allocation is to minimize the total power while satisfying the outage probability constraint. Assuming the transmit power in each sub channel is *Pn*, the maximum rate of reliable communication using the Rayleigh channel model is

$$C = \sum_{n=0}^{N-1} \log\left(1 + \frac{P_n |h_{SD}|^2}{N_0}\right) bit/symbols \tag{25}$$

where N_0 is the variance of Additive White Gaussian Noise. Therefore the power allocation can be chosen so as to minimize the rate in (21).

The power allocation, thus, is the solution to the optimization problem:

$$C_N := \max_{P_0,\ldots,P_{N-1}} \sum_{n=0}^{N-1} \log\left(1 + \frac{P_n |h_{SD}|^2}{N_0}\right) \tag{26}$$

Subject to

$$\sum_{n=0}^{N\text{-}1} P_n = P_{total}\ P_n \geq 0, n = 0, \ldots, N-1 \tag{27}$$

The objective function (25) is convex in the powers and this optimization problem can be solved by the Lagrangian method. Consider the expression

$$L(\lambda, P_0, \ldots, P_{N-1}) := \sum_{n=0}^{N-1} \log\left(1 + \frac{P_n |h_{SD}|^2}{N_0}\right) - \lambda \sum_{n=0}^{N-1} P_n \tag{28}$$

where λ is the Lagrange multiplier. The Kuhn-Tucker condition for the optimal solution is

$$\begin{cases} \dfrac{\partial L}{\partial P_n} = 0 if P_n > 0 \\ \dfrac{\partial L}{\partial P_n} \leq 0 if P_n = 0 \end{cases} \tag{29}$$

Define $x^+ := \max(x, 0)$. The power allocation can be expressed as

$$P_n^+ = \left(\frac{1}{\lambda} - \frac{N_0}{|h_{SD}|^2}\right)^+ \tag{30}$$

which is the optimal solution if the Lagrange multiplier λ satisfies the condition

$$\sum_{n=0}^{N-1} \left(\frac{1}{\lambda} - \frac{N_0}{|h_{SD}|^2}\right)^+ = P_{total} \tag{31}$$

The inverse of the Lagrange multiplier can be regarded as a water level. Generally, the water level can be found by the binary search method.

VII. SIMULATION RESULTS

In this section, the performance of various relaying protocols through numerical simulation results is evaluated. Numerical simulations have been performed over quasi static Rayleigh fading channels with AWGN. Note that P_s transmission power in all numerical simulations.

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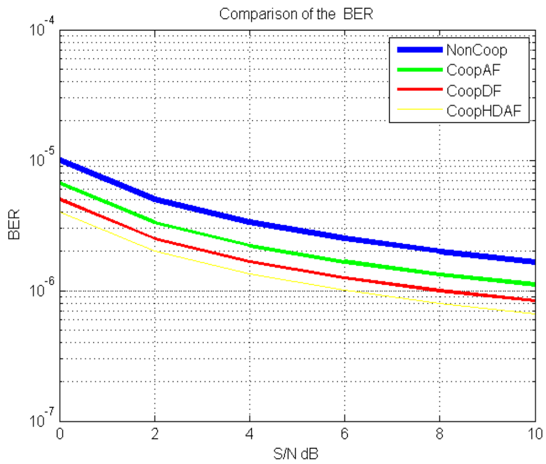

Fig. 5. SNR threshold verses Bit error rate (BER) under different transmission protocols.

Fig. 5 plots the Bit Error Rate (BER) versus various SNR thresholds under different transmission protocols. It compares the three relaying protocols with the non cooperative communication system. In the case of direct transmission, the BER value is in the range of 10^{-5}. It is shown that BER decreases as threshold SNR increase. As expected, there is a tradeoff between BER and threshold SNR. The numerical simulation results of the BER are 0.1664 e-5 at $\gamma_{th} = 6$ for Non cooperative system and 0.5740 e-6 at $\gamma_{th} = 6$ for HDAF cooperative system. The BER of Non cooperative system is much higher than the HDAF cooperative system under the same condition.

TABLE 1
BIT ERROR RATE COMPARISON OF NON COOPERATIVE SYSTEM AND RELAYING SYSTEMS

SNR Threshold	Non Coop system	AF Relaying system	DF Relaying system	HDAF Relaying system
2	0.5004e-5	0.3338e-5	0.2505 e-5	0.1335 e-5
4	0.2504e-5	0.1665 e-5	0.1247 e-5	0.7970 e-6
6	0.1664e-5	0.1112 e-5	0.8350 e-6	0.5740 e-6
8	0.1248e-5	0.8310 e-6	0.6240 e-6	0.4990 e-6
10	0.1000e-5	0.6680 e-6	0.4000 e-6	0.3500 e-6

The numerical values in the Fig. 5 of three different relaying protocols are tabulated in TABLE 1. It shows the BER and SNR values for various relaying protocols. As stated before, the BER value is decreasing as threshold SNR increases. In the numerical simulation results the BER values are 0.1 e-5, 0.6680 e-6, 0.4000 e-6 and 0.3500 e-6 for Non Cooperative system, AF, DF and HDAF at $\gamma_{th} = 10$ respectively. It is shown that HDAF relaying system performs better than other two protocols.

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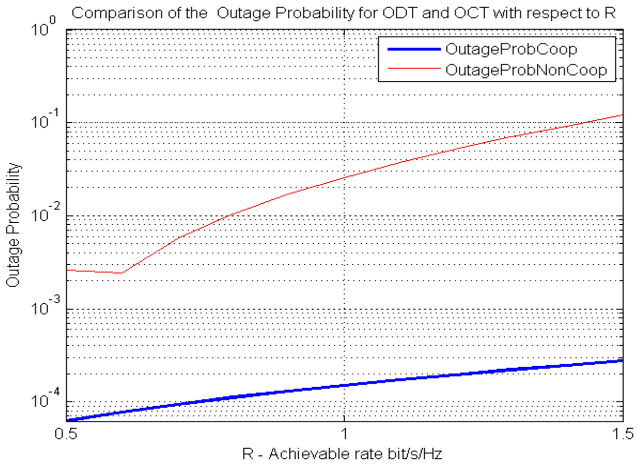

Fig. 6. Achievable rate (R) verses Outage probability under different transmission protocols.

Fig. 6 presents outage probability versus available rate in two cases: $\gamma_{th} \leq g(R)$ (ODT) and $\gamma_{th} > g(R)$ (OCT). The numerical simulation results of outage probability are 0.0152, 0.143, and 0.6942 at R = 0.5, 1, and 1.5 for Non cooperative communication system. The numerical simulation results of outage probability are 0.13e-3, 0.3183e-3, and 0.5737e-3 at R = 0.5, 1, and 1.5 for HDAF Cooperative communication system. Hence, it is observed that MUD gain and diversity gain can be obtained in the form of improved outage performance.

VIII. CONCLUSION AND FUTURE WORK

A two source destination pair cooperative communication system was developed and derived closed form expressions of outage probability associated with Amplify and forward, Decode and Forward and HDAF protocols are analyzed. Based on outage probability constraint, water filling power allocation minimizes the outage probability was discussed. Numerical results offer important analytical tools and fully exploit the potential of HDAF based multiple source destination pairs.

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