IJCTA, 10(9), 2017, pp. 427-435 ISSN: 0974-5572

Impact of Dual HOP Relaying on Asymmetric Fading Channels

P.B. Natarajan*, T. Pardhu and R. Karthik*****

ABSTRACT

Transmit diversity is created in the regular cooperative diversity (RCD) networks when the selected nodes assist the source by relaying its information signal to the destinationusing orthogonal channels to avoid co-channel interference. This decomposition is necessary because practical limitations in radio implementation prevent the relay from simultaneously transmitting and receiving on the same channel. K relays in RCD require K+1 channels which shows that as the number of relays increases the number of required channels increases linearly. This increase in channels gives fundamental drawback in all cooperative diversity networks. So if this problem is not addressed the cooperative diversity networks will lose attractiveness for high data rate, high efficiency communications. In this paper this problem is addressed tried to find a solution.The performance of the best-relay selection scheme will be examined in which only the "best" relay takes part in relaying, therefore only two channels take part in transmission regardless of the number of relays. The relay node that gives the highest signal-to-noise ratio (SNR) at the destination node is considered to be the best relay. A general mathematic probability model is presented and examined the performance of best-relay selection using amplify and forward (AF) scheme.

Index Terms: RCD, AF, SNR and Best Relay selection

1. INTRODUCTION

Transmit diversity is created in the regular cooperative diversity (RCD) networks when the selected nodes assist the source by relaying its information signal to the destination [20] using orthogonal channels to avoid co-channel interference. This decomposition is necessary because practical limitations in radio implementation prevent the relay from simultaneously transmitting and receiving on the same channel [3]. K relays in RCD require K+1 channels which shows that as the number of relays increases the number of required channels increases linearly. This increase in channels gives fundamental drawback in all cooperative diversity networks. So if this problem is not addressed the cooperative diversity networks will lose attractiveness for high data rate, high efficiency communications. In this paper this problem is addressed tried to find a solution.

The performance of the best-relay selection scheme will be examined in which only the "best" relay takes part in relaying, therefore only two channels take part in transmission regardless of the number of relays. The relay node that gives the highest signal-to-noise ratio (SNR) at the destination node is considered to be the best relay [4]. A general mathematic probability model is presented and examined the performance of best-relay selection using amplify and forward (AF) scheme. Particularly closed form expressions for the error probability, outage probability and the moments of the end to end SNR are presented over independent and non-identical Rayleigh fading channels

* Department of Electronics & Communication Engineering MLR Institute of Technology, Hyderabad, India

** Department of Electronics & Communication Engineering MLR Institute of Technology, Hyderabad, India, *Email: pthottempudi2020@gmail.com*

*** Department of Electronics & Communication Engineering MLR Institute of Technology, Hyderabad, India, *Email: karthik.r@mlrinstitutions.ac.in*

2. SYSTEM MODEL

Our system model is shown in Figure 1 which consist of source node 'S', destination node 'D' and a number of cooperating relay nodes $R_i\left(i=1,2....,M\right)$. 'S' communicates with 'D' directly over a channel having Rayleigh fading coefficient $h_{S,D}$. Also 'S' communicate with 'D' via set of K relays using amplify and forward (AF) protocol, our goal is to select one relay out of the set of K relays in order to retransmit source signal to destination. The Rayleigh fading channel coefficients between "S" and relay R_i are h_{S,R_i} and between relay R_i and 'D' are $h_{R_i,D}$. These all channel coefficients $h_{S,D}$ h_{S,R_i} and $h_{R_i,D}$ are considered mutually independent and non-identical

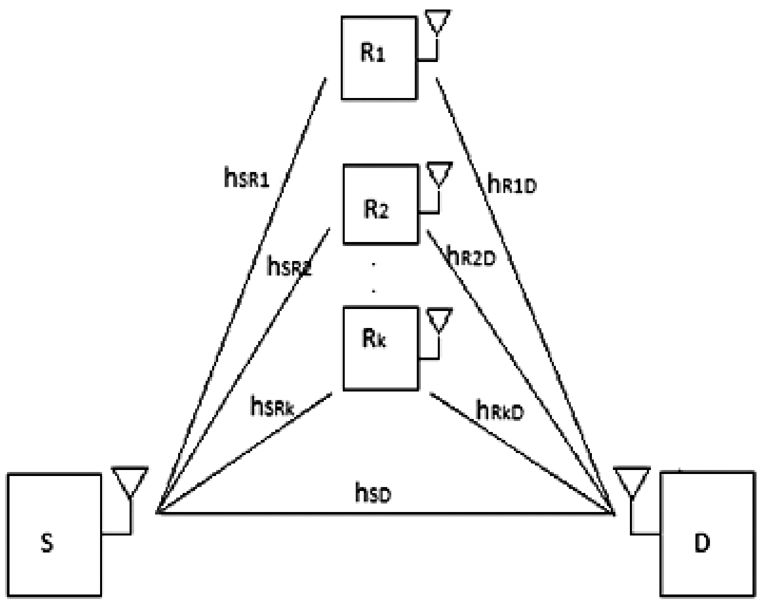

Figure 1: Opportunistic relaying system model

For indirect link AF protocol is used i.e. relays receive signal from 'S' amplify it and forward it to the 'D'. The relay gain equals $\dfrac{1}{\sqrt{h^2{}_{S,R_i}E_s+N_o}}$, E_s represents the transmitted signal energy of the source. The indirect link $S\rightarrow R_i\rightarrow D$ has the end-to-end SNR is given by [4]

$$\gamma_{S,R_i,D}=\frac{\gamma_{S,R_i}\cdot\gamma_{R_i,D}}{\gamma_{S,R_i}+\gamma_{R_i,D}+1} \tag{1}$$

Where $\gamma_{S,R_i}=\left|h_{S,R_i}\right|^2\dfrac{E_S}{N_O}$ and $\gamma_{R_i,D}=\left|h_{R_i,D}\right|^2\dfrac{E_S}{N_O}$ are the instantaneous SNRs between source 'S' and relay R_i and between relay R_i and destination 'D' respectively.

The relay which provides highest end-to-end SNR at receiver is selected for retransmitting source signal to destination. If maximum ratio combiner (MRC) technique at 'D' is used then the resultant SNR at 'D' can be written as [4]

$$\gamma_t = \gamma_{S,D} + \max_{i \in M} \left(\frac{\gamma_{SR_i} \gamma_{R_i D}}{\gamma_{S,R_i} + \gamma_{R_i,D} + 1} \right) \tag{2}$$

Where $\gamma_{S,D} = \left| h_{SD} \right|^2 \frac{E_S}{N_o}$ is the instantaneous SNR between source 'S' and destination 'D'.

Equation (1) is expressed in more manageable forms so that later on total SNR is used in calculating outage and error performance. To accomplish this, the tight upper bound for $\gamma_{S,R_i,D}$ can be written as [4]

$$\gamma_i = \gamma_{S,R_i,D} \leq \min\left(\gamma_{S,R_i}, \gamma_{R_i,D}\right) \tag{3}$$

The probability density function (PDF) of instantaneous SNR γ_i can be written in terms of average SNR from 'S' to Relay R_i $\bar{\gamma}_{S,R_i} = E\left(h_{S,R_i}{}^2 \right) \frac{E_S}{N_O}$ and from R_i to 'D' $\bar{\gamma}_{R_i,D} = E\left(h^2{}_{R_i,D} \right) \frac{E_s}{N_o}$ as where $\bar{\gamma}_i = \frac{\bar{\gamma}_{S,R_i} \bar{\gamma}_{R_i D}}{\bar{\gamma}_{S,R_i} + \bar{\gamma}_{R_i D}}$ using the value γ_i of in equation (2) the total SNR can be rewrite as

$$\gamma_t \leq \gamma_{S,D} + \gamma_b \tag{4}$$

This approximate end-to-end SNR is analytically more manageable and can be easily used in derivation of CDF, PDF and moment generating function (MGF) of the SNR. This approximation is enough accurate especially on medium and high SNR values.

2.1. Error Probability Analysis

In this section closed-form expressions for the error probability of the amplify-and-forward relaying over independent non-identical Rayleigh fading channels are presented. As MRC technique is assumed at destination „D" so error probability will only be calculated for coherent reception. In case of multi-channel coherent reception the error probability can be calculated by averaging the multi-channel conditional error probability over the joint random variables $\gamma_{S,D}$ γ_b which represents the SNR values of direct and indirect links.

$$P\left(e \middle| \gamma_{S,D}, \gamma_b\right) = A\, erfc\left(\sqrt{\beta\left(\gamma_{S,D} + \gamma_b\right)}\right) \tag{5}$$

Where $erfc(.)$, is an error function, which characterizes the error probability performance of digital signals in a way that is analytically more desirable for fading channel. In its general form it can be written as (equation 5).

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp\left(-t^2\right) dt$$

Alternatively, the classical mathematical error probability function often referred to as Gaussian probability integral [41] can be written as

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{\infty} \exp\left(\frac{x^2}{\sin^2(\theta)}\right) dt \tag{6}$$

Following (5.6) the error function in (5.5) can be written as

$$erfc\left(\sqrt{\beta\left(\gamma_{S,D} + \gamma_b\right)}\right) = \frac{2}{\sqrt{\pi}} \int_{x}^{\pi/2} \exp\left(\frac{-\beta\gamma_f}{\sin^2(\theta)}\right) \exp\left(\frac{-\beta\gamma_b}{\sin^2(\theta)}\right) \tag{7}$$

Substitute (7) into (5) we get,

$$P\left(e \middle| \gamma_{S,D}, \gamma_b\right) = \frac{2}{\sqrt{\pi}} \int_{x}^{\pi/2} \exp\left(\frac{-\beta\gamma_f}{\sin^2(\theta)}\right) \exp\left(\frac{-\beta\gamma_b}{\sin^2(\theta)}\right) d\theta \tag{8}$$

Also it is assumed that random variables $\gamma_{S,D}, \gamma_b$ are independent, the joint PDF $f_{\gamma S,D,\gamma_b}\left(\gamma_{S,D}, \gamma_b\right)$ can be written as $f_{\gamma S,D}\left(\gamma_{S,D}\right) f_{\gamma_b}\left(\gamma_b\right)$ Therefore the error probability can be written as

$$P(e) = \iint_{0} P\left(e \middle| \gamma_{S,D}, \gamma_b\right) f_{\gamma S,D}\left(\gamma_{S,D}\right) f_{\gamma_b}\left(\gamma_b\right) d\gamma_{S,D} d\gamma_b \tag{9}$$

Substitute (5.8) into (5.9), we get

$$P(e) = \iint_{0} \frac{2}{\pi} \int_{0}^{\pi/2} \exp\left(\frac{-\beta\gamma_f}{\sin^2\theta}\right) \exp\left(\frac{-\beta\gamma_b}{\sin^2\theta}\right) f_{\gamma S,D}\left(\gamma_{S,D}\right) f_{\gamma_b}\left(\gamma_b\right) d\gamma_{S,D} d\gamma_b \tag{10}$$

As the order of integration can be interchange [41] so the error probability in (10) can be written as

$$P(e) = \frac{2}{\pi} \int_{0}^{\pi/2} M_{\gamma S,D}\left(\frac{\beta}{\sin^2(\theta)}\right) M_{\gamma b}\left(\frac{\beta}{\sin^2(\theta)}\right) d\theta \tag{11}$$

Where

$$M_{\gamma_{S,D}} = \int_{0}^{\infty} f_{\gamma_{S,D}}\left(\gamma_{S,D}\right) \exp\left(-\gamma_{S,D}\right) d\gamma_{S,D}$$

$$M_{\gamma_b} = \int_{0}^{\infty} f_{\gamma_b}\left(\gamma_b\right) \exp\left(-\gamma_b\right) d\gamma_b$$

Represents the MGF of direct link SNR i.e. and via relay i.e $\gamma_{S,D}$, γ_b respectively. To find $P(e)$ we have to find PDF and then MGF of $\gamma_{S,D}$ & γ_b the PDF of $\gamma_{S,D}$ has an exponential distribution whose mean is represented by $\overline{\gamma}_{S,D}$ hence the MGF of $\gamma_{S,D}$ can be written as

$$M_{\gamma_{S,D}}(S) = \frac{1}{1 + S\overline{\gamma}_{S,D}} \tag{12}$$

To find the MGF of γ_b first the CDF and then the PDF is calculated the CDF of γ_b has the form,

$$F_{\gamma_b}(\gamma) = P(\gamma_b \le \gamma)$$

This can be written as

$$F_{\gamma_b}(\gamma) = \prod_{i=1}^{K}\left(1 - e^{-\gamma/\overline{\gamma}_i}\right) \tag{13}$$

By taking the derivative of (13) with respect to γ and after doing some manipulation the PDF γ_b of can be calculated,

$$F_{\gamma_b}(\gamma) = \sum_{n=1}^{K}(-1)^{n+1}\sum_{p_1=1}^{K-n+1}\sum_{p_2=p_1+1}^{K-n+1}.....\sum_{p_n=p_{n-1}+1}^{K-n+1}\times\prod_{i=1}^{K}\left(1-e^{-\gamma/\overline{\gamma}_i}\right)\sum_{j=1}^{n}\frac{1}{\overline{\gamma}_{p_j}} \tag{14}$$

With the help of PDF in (14) the MGF is calculated as,

$$M_{\gamma_b}(S) = \int_0^{\infty} e^{-S\gamma}\sum_{n=1}^{K}(-1)^{n+1}\sum_{p_1=1}^{K-n+1}\sum_{p_2=p_1+1}^{K-n+1}.....\sum_{p_n=p_{n-1}+1}^{K-n+1}\times\prod_{i=1}^{K}\left(1-e^{-\gamma/\overline{\gamma}_i}\right)\sum_{j=1}^{n}\frac{1}{\overline{\gamma}_{p_j}}d\gamma$$

$$M_{\gamma_b}(S) = \sum_{n=1}^{K}(-1)^{n+1}\sum_{p_1=1}^{K-n+1}\sum_{p_2=p_1+1}^{K-n+1}.....\sum_{p_n=p_{n-1}+1}^{K-n+1}\frac{\alpha}{S+\alpha} \tag{15}$$

Where

$$\alpha = \sum_{j=1}^{n}\frac{1}{\overline{\gamma}_{pj}}$$

Substituting (15) and (12) in (11) and evaluating its integral, the probability of error in closed form can be written as,

$$P(e) = \sum_{n=1}^{K}(-1)^{n+1}\sum_{p_1=1}^{K-n+1}\sum_{p_2=p_1+1}^{K-n+1}.....\sum_{p_n=p_{n-1}+1}^{K-n+1}\times\left[1-\frac{\frac{1}{\alpha}}{\frac{1}{\alpha}-\overline{\gamma}_{S,D}}\sqrt{\frac{\frac{\beta}{\alpha}}{1+\frac{1}{\alpha}}}+\frac{\overline{\gamma}_{S,D}}{\frac{1}{\alpha}-\overline{\gamma}_{S,D}}\sqrt{\frac{\beta\overline{\gamma}_{S,D}}{1+\overline{\gamma}_{S,D}}}\right] \tag{16}$$

2.2. Outage Probability

The outage probability is defined as the probability that the instantaneous total end-to-end SNR falls below a given required rate *R*. For opportunistic amplify and forward relaying with direct link using antennas selection, the outage probability for best antenna selection can be written as [4]

$$P_{out} = P_r(I \le R)$$

$$P_{out} = P_r\left(\frac{1}{2}\log_2\left(1+\gamma_{S,D}+\gamma_b\right) \le R\right)$$

$$P_{out} = P_r\left(\gamma_{S,D}+\gamma_b \le 2^{2R}-1\right)$$

It can be seen P_{out} is actually the CDF of γ_t, evaluated at $2^{2R}-1$, therefore

$$P_{out} = F_{\gamma_t}\left(2^{2R}-1\right) \tag{17}$$

The expression for outage probability in (17) can be easily rewritten for regular dual hop cooperative diversity network without best-relay selection scheme as

$$P_{out} = F_{\gamma_t}\left(2^{(K+1)R}-1\right) \tag{18}$$

This expression shows clearly that the outage probability for regular dual hop cooperative diversity network is greater than that of best-relay selection scheme for $K > 1$.

Where F_{γ_t} is the CDF of the total end-to-end SNR using the opportunistic relaying in cooperative diversity and can be found as follows [42]

$$F_{\gamma_t} = L^{-1}\left[\frac{M_{\gamma S,D}(S)M_{\gamma b}(S)}{S}\right]_{S=\gamma} \tag{19}$$

Where L^{-1} denotes the inverse Laplace transform, the inverse Laplace transform can be performed analytically and CDF of the total SNR can be written as (by doing some multiplication and partial fraction operations)

$$F_{\gamma_t} = \sum_{n=1}^{M}(-1)^{n+1}\sum_{k_1=1}^{M-n+1}\sum_{k_2=k_1+1}^{M-n+2}\cdots\sum_{k_n=k_{n-1}}^{M}\times\left[1-\frac{\frac{1}{\alpha}}{\frac{1}{\alpha}-\bar{\gamma}_{S,D}}e^{-\alpha\gamma}+\frac{\bar{\gamma}_{S,D}}{\frac{1}{\alpha}-\bar{\gamma}_{S,D}}e^{-\gamma/\bar{\gamma}_{S,D}}\right] \tag{20}$$

3. NUMERICAL RESULTS

In this section the dual-hop relay network under consideration is simulated in different scenarios. In all simulations, the channel coefficients, $h_1[k]$ and $h_2[k]$, are generated based onthe simulation method of [15]. This simulation method was developed to generate channel coefficients that are correlated in time. The amount of time-correlation is determined by the normalized Doppler frequency of the underlying channel, which is a function of the speed of the vehicle, carrier frequency and symbol duration. Obviously, for fixed carrier frequency and symbol duration, a higher vehicle speed leads to a larger Doppler frequency and less time-correlation.

Based on the normalized Doppler frequencies of the two channels, different cases can be considered. In Case I, it is assumed that all nodes are fixed or slowly moving so that both channels are slow-fading with the normalized Doppler values of f1 = 0.001 and f2 = 0.001. In Case II, it is assumed that the source is fast moving so that the SR channel is fast-fading with f_1 = .01. On the other hand, the relay and destination are fixed and the RD channel is slow-fading with f_2 =0.001. In Case III, it is assumed that both the source and the destination are fast moving so that both the SR and RD channels are fast fading with f1 =0 .02 and f2 =0 .01, respectively. In each case, information bits are differentially encoded with either BPSK (M = 2) or QPSK (M = 4) constellations.

Although an arbitrary power allocation between the source and the relay can be used, equal power allocation, namely $P_0 = P_1$, is assumed where P_1 is the relay power. The amplification factor at the relay is fixed to A = pP1/(P0 + N0) to normalize the average relay power to P1. At the destination, first, the two-symbol differential non-coherent detection is applied. The simulation is run for various values of the source power. The simulated BER values are computed for all cases and are plotted versus the source power in Figs. 1 and 2, for DBPSK and DQPSK, respectively.

For evaluating the theoretical BER values when the two symbol detection is applied, the value of _ is computed for each case. Also, {a = 0, b = √2}, {a = p2 – √2, b = p2 + √2}, are obtained for DBPSK and DQPSK, respectively [14]. The corresponding theoretical BER values and the error floors are computed from (18) and (20) and plotted in the figures with dashed and dotted lines, respectively.

As can be seen in Fig. 1, in case I, the BER is monotonically decreasing with (P0/N0) and it is consistent with the theoretical values in (18). However, the plot starts to flat out after (P0/N0) = 55 dB, which means that it reaches an error floor at very high SNR (which is practically insignificant). In Case II, which involves one fast-fading channel, this phenomenon starts earlier, around 35 dB, and leads to an error floor at 5 × 10–4, which can also be predicted from (20). The performance degradation is much more severe after 25 dB in Case III since both channels are fast-fading, which leads to an error floor at 3×10–3. Similar behaviours can be seen in Fig. 2 when using DQPSK modulation. As is clearly seen in both Figs. 1 and 2, the simulation results verify our theoretical evaluations.

Given the poor performance of the two-symbol detection in Cases II and III, MSDSD-DH algorithm is applied which takes a window of N = 10 symbols for detection. With known Doppler values of the channels, R_h and then L are computed. Then for N consecutive received symbols, the upper triangular matrix U is found and given to the MSDSD function described in [12] to recover (N – 1) transmitted symbols. The BER results of the MSDSD-DH algorithm are also plotted in Figures 2 and 3 with solid lines (different legends). Since, the best performance is achieved in the slow fading environment, the performance plot of Case I can be used as a benchmark to see the effectiveness of MSDSDDH. It can be

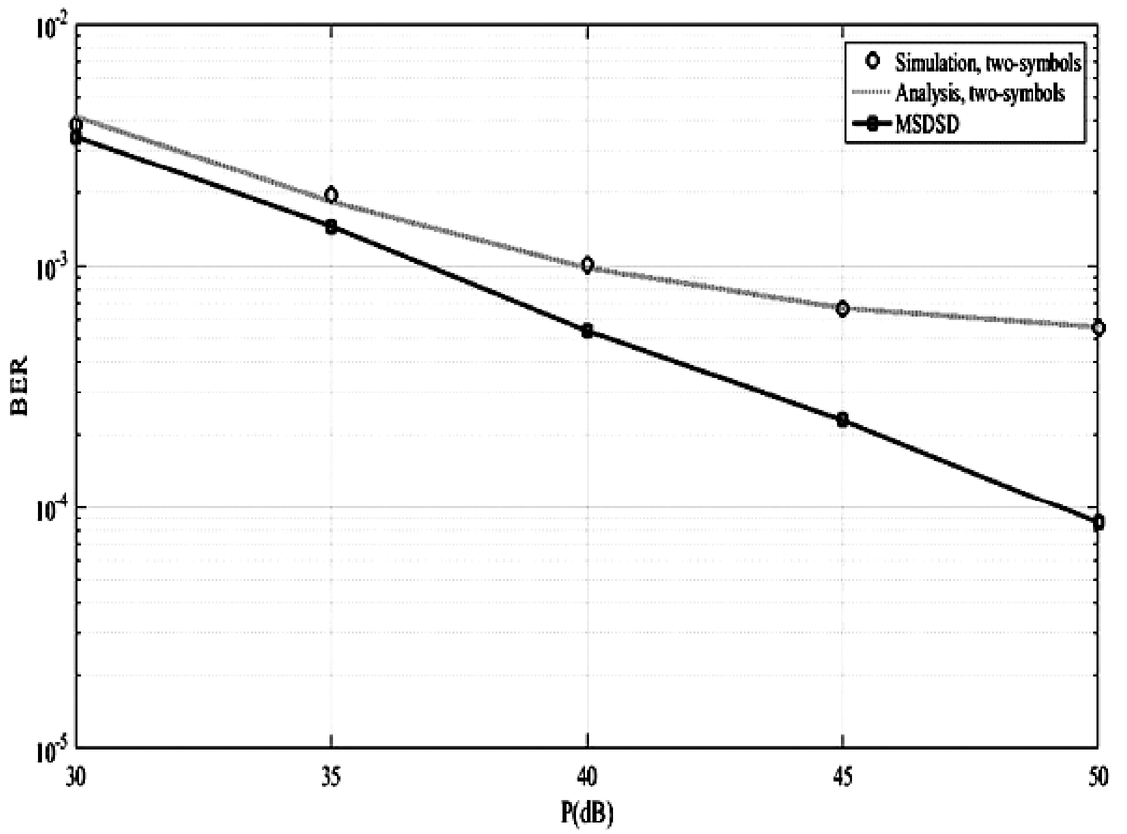

Figure 2: BER of a D-DH network in different fading cases using DBPSK and non-coherent detection with N = 2 and N = 10 symbols.

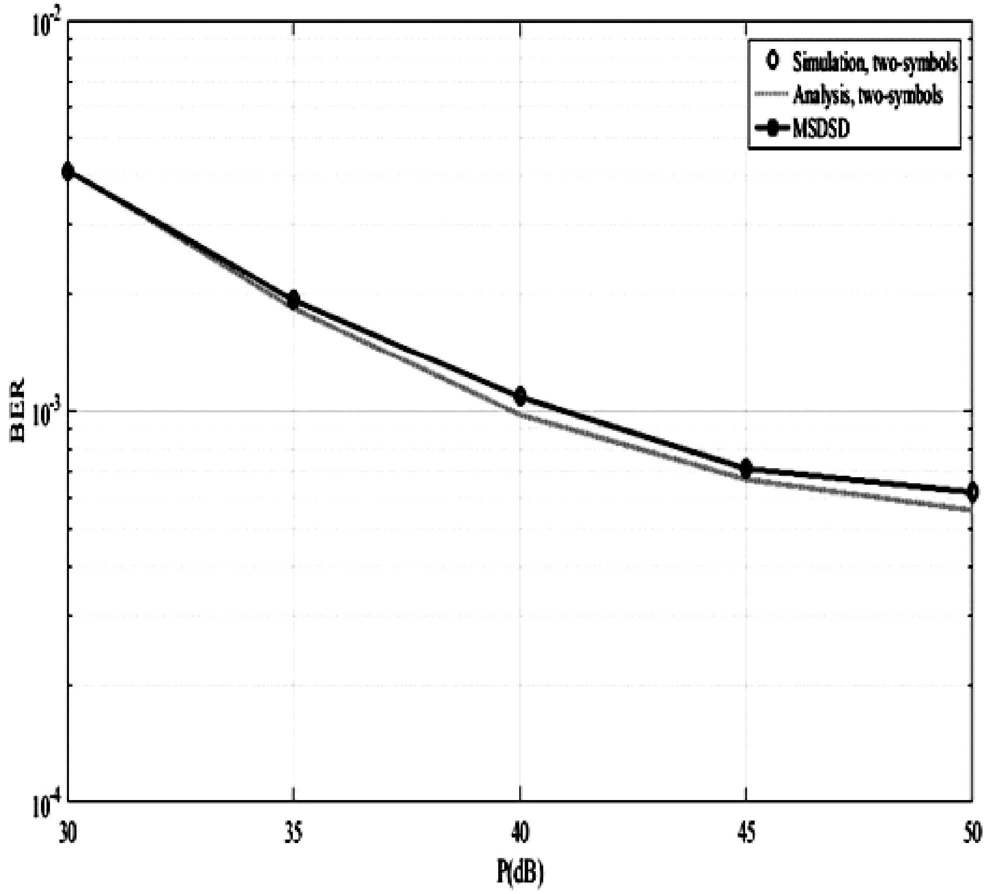

Figure 3: BER of a D-DH network in different fading cases using DQPSK and non-coherent detection with N = 2 and N = 10 symbols.

seen that the MSDSD-DH is able to bring the performance of the system in Case II and Case III very close to that of Case I.

4. CONCLUSIONS

The performance of the best relay selection scheme and MRC reception at the destination for cooperative diversity networks with amplify and forward relaying over independent and non-identically distributed Rayleigh fading channels is analyzed. The Rayleigh fading channel is used because the direct link between source and destination is in deep fade. The closed form expressions for the probability of error and the outage probability are established in this paper. It is concluded that the best relay selection scheme save resources as compared to the regular cooperative diversity networks. By increasing the number of relays in regular cooperative diversity network the channel capacity is reduced by 1/M while in relay selection scheme the channel capacity is reduced by just 50%. So by increasing the number of relays in best-relay selection scheme the diversity order will increase without any decrease in channel capacity. In best relay selection scheme minimum signal overhead is involved at cost of minor complexity. Finally it is concluded that the overall performance of the system is dependent on the improvement in any link but of course the better performance can be achieved if the quality of both links is improved

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