ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2015

Performance Analysis of Cooperative Relaying over α-µ Fading Channel

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ABSTRACT: In this paper outage and bit error rate (BER) performance of cooperative communication wireless system with multiple parallel relays over alpha mu (α-µ) fading channel is analysed. We have seen that cooperative system operating in maximal ratio combining – decode and forward protocol (MRC-DF) outperforms maximal ratio combining – amplify and forward protocol (MRC-AF) and similarly selection combining – decode and forward (SC-DF) outperforms (SC-AF). Performance of full-duplex (FD) system improves in contrary to half-duplex (HD) system with increase in number of parallel relays. Comparative performance of the systems have been analysed with varying parallel relays and established by simulation over α-µ channel in AF and DF protocols for HD and FD communication systems.

KEYWORDS: α-µ fading; cooperative; amplify-and-forward; decode-and-forward; outage probability; bit error rate.

I. INTRODUCTION

In a wireless network, relaying schemes provide promising technologies to transmit at higher data rate to destinations farther away. The relay based communication is an active and vital area of research in wireless communication today. In [3] a low mobility cellular relaying system downlink have been considered where two mobile users are served by two neighbouring decode-and-forward relays. It is shown that the diversity of each user's received data signal can be improved by receiving data from multiple relays. A study of the role of cooperative relays has been done in [4] to provide and improve secure communication rates through DF strategies in a full-duplex multiple relay network with an eavesdropper. In [5] a maximum-likelihood (ML) decoder have been derived for the DF protocol with a single pair of source and destination with one relay. Investigation of the possible enhancement of cooperated system using decode and forward protocol have been carried out in [6]. The benefits of AF and DF cooperative relay for secure communication are investigated in [7]. The capacity regions are investigated for two relay broadcast channels in [8] where relay links are incorporated into two-user broadcast channels to support user cooperation. In [9] the drawback of cooperative relaying has been addressed regarding its spectral inefficiency, and its channel over reservation compared to direct transmissions. Low-complexity cooperative diversity protocols have been developed and analyzed in [10] that combat fading induced by multipath propagation in wireless networks. A novel and unified analysis is proposed in [11], which is based on the moment-generating function approach, to efficiently and accurately compute the higher order statistics of the channel capacity for AF multi-hop transmission over generalized fading channels. In [13] relay and destinations are using MRC or SC have been analysed in possible four combinations with varying path loss condition

The paper is organized as follows. In Section 2, the α-µ fading model and its Probability density function is briefly discussed. In Section 3, the cooperative communication wireless system with multiple parallel relays in amply-and-forward and decode-and-forward protocols have been analysed. In Section 4, selection combining and maximal ratio combining is discussed. Monte-Carlo simulation results for outage probability and BER performance of the cooperative wireless system over α-µ fading channel by varying the number of parallel relays in AF and DF protocols for HD and FD systems are presented in Section 5. The paper is concluded by Section 6.

DOI: 10.15680/IJIRCCE.2015. 0308115

II. THE α-μ FADING CHANNEL

In the recent past α-μ fading model [1] has been proposed to describe the mobile radio signal considering two important phenomenon of radio propagation non-linearity and clustering. The α-μ represents a generalized fading distribution for small-scale variation of the fading signal in a non line-of-sight fading condition. Alpha-mu distribution is written in terms of two physical parameters, namely α and μ. The power parameter ($\alpha > 0$) is related to the non-linearity of the environment i.e. propagation medium, whereas the parameter ($\mu > 0$) is associated to the number of multipath clusters.

Table-1: Algorithm for generation of α-μ distributed random variable

1.	**Procedure *α-μ*** random variable generation
2.	$\alpha \leftarrow$ Channel Parameter
3.	$\mu \leftarrow$ Channel Parameter
4.	x ← Number of random variables
5.	$\Omega \leftarrow$ Mean
6.	$\sigma^2 \leftarrow$ Variance
7.	H ← zero matrix of order 1×x
8.	**for** $i \leftarrow 1$ to μ **do**
9.	H = H + matrix of order 1×x having complex Gaussian random variable i.e. $X(\Omega, \sigma^2) + j\,X(\Omega, \sigma^2)$
10.	end **for**
11.	Fading envelope ← H^{α}
12.	**end** procedure

In [1, 2] the α-μ fading distribution and its probability density function has been described. In the α-μ distribution, it is considered that a signal is composed of clusters of multipath waves. In any one of the cluster, the phases of the scattered waves are random and have similar delay times. The delay-time spreads of different clusters is relatively large. Therefore the obtained envelope, is a non-linear function of the modulus of the sum of the multipath components. The α-μ probability density function (PDF), $f_R(r)$ of envelope R is given as

$$f_R(r) = \frac{\alpha\ \mu^{\mu}\ r^{\alpha\mu - 1}}{\hat{r}^{\alpha\mu}\ \Gamma(\mu)}\ \exp\left[-\mu\,\frac{r^{\alpha}}{\hat{r}^{\alpha}}\right] \tag{1}$$

where $\alpha > 0$ is the power parameter, and α-root mean value of R^{α} is given as

$$\hat{r} = \sqrt[\alpha]{E(R^{\alpha})} = \sqrt[\alpha]{2\mu\sigma^2}$$

where $\mu \geq 0$, is inverse of variance of α-μ envelope R^{α}, and

$$\Gamma(z) = \int_0^{\infty} t^{z-1} e^{-t} dt$$ is the Gamma function.

Algorithm given in Table.1 is used for generation of α-μ distributed random variable in the simulation work reported in this paper. Analytical and simulated results for PDF of fading envelope of α-μ fading channel defined by (1), are shown for α=2 and μ=2 in fig.1. It is verified that both the analytical and simulated results are matching.

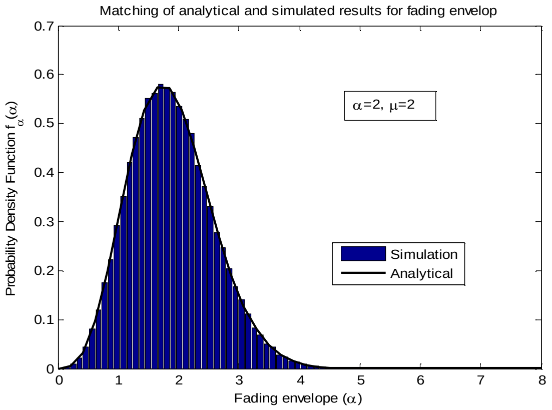

Fig.1. Matching of analytical and simulated results of α-μ fading envelope for α=2, μ=2

III. COOPERATIVE COMMUNICATION SYSTEMS

In a two-hop multi-relay wireless cooperative communication system shown in fig.2., the signal is transmitted as broadcast through the multiple -relay network placed between source and destination. In the communication system shown in fig.2,

The relay network consists of n relays $=\left(\left\{r_k\right\}_{k=1}^{n}\right)$

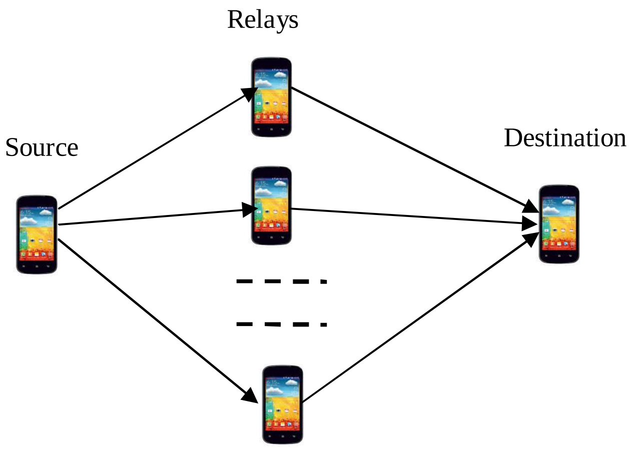

Fig.2. Cooperative Communication system with parallel multiple-relays

Due to half-duplex nature of relays, source (s) transmits to all n relays i.e. (r_1, r_2,……r_k,……r_n) in first time-slot. Then in second time-slot r_1 will transmit to destination (d), in 3rd time-slot r_2 transmits to d and so on. In $(n+1)^{th}$ time slot r_n will transmit to d. Direct link available between source and destination has not been taken into consideration. PDF of the received SNR is defined by (2) since channel is assumed to be α-μ distributed. PDF of SNR (γ) of α-μ fading is given in [12] as

$$f_{\gamma_{ij}}(\gamma)=\frac{\alpha\,\mu^{\mu}\,\gamma^{\frac{\alpha\mu}{2}-1}}{2\,\Gamma(\mu)\,\bar{\gamma}_{ij}^{\,\alpha\mu/2}}\;e^{-\mu\left(\frac{\gamma}{\bar{\gamma}_{ij}}\right)^{\alpha/2}} \qquad (2)$$

here, $i\in\left\{s,r_k\right\},\ j\in\left\{r_k,d\right\},\ i\,\&\,j\neq r_k$ simultaneously.

DOI: 10.15680/IJIRCCE.2015. 0308115

A. *Amplify and Forward (AF):*

If in the communication system shown in fig.2, the relays receives the signal in first hop, amplifies it and then transmits in next hop, it is called amplify and forward mode of relaying. Assuming that source transmitting signal *x*, which is received by k^{th} relay as

$$y_{s,r_k} = h_{s,r_k} x + n_{s,r_k} \tag{3}$$

The relays equalize the influence of the fading channel between the source and the relay. This will be accomplished by scaling the received signal by a factor *G*. Thus, the signal received by k^{th} relay is forwarded to destination as

$$y_{r_k,d} = G\, h_{r_k,d}\, y_{s,r_k} + n_{r_k,d} \tag{4}$$

where

$h_{s,r_k}, h_{r_k,d}$ = fading amplitude defined by eq.(1) for the source-to-k^{th} relay, k^{th}relay-to-destination respectively for $\alpha-\mu$ wireless channel.

$n_{s,r_k}, n_{r_k,d}$ = Additive White Gaussian Noise (AWGN) of the source-to- k^{th}relay, k^{th}relay-to-destination respectively

Tl with variance σ^2 for $\alpha-\mu$ wireless channel.

$$y_{r_k,d} = h_{r_k,d} G\, y_{s,r_k} + n_{r_k,d} = h_{s,r_k} h_{r_k,d} Gx + h_{r_k,d} G n_{s,r_k} + n_{r_k,d} \tag{5}$$

Thus, SNR at destination for relay link from (5) will be

$$\text{SNR}=\frac{\text{Signal power}}{\text{Noise power}} = \frac{(h_{s,r_k} h_{r_k,d} G)^2}{(h_{r_k,d} G)^2 \sigma^2 + \sigma^2} \tag{6}$$

$$\text{SNR} = \frac{h_{s,r_k}^2 h_{r_k,d}^2}{h_{r_k,d}^2 \sigma^2 + \sigma^2 / G^2} = \frac{\frac{h_{s,r_k}^2}{\sigma^2} \frac{h_{r_k,d}^2}{\sigma^2}}{\frac{h_{r_k,d}^2}{{}^2} + \frac{1}{\sigma^2 \; {}^2}} \tag{7}$$

$$\text{Let, SNR}= \gamma_i = \frac{h_i^2}{\sigma^2}, \text{ and } G^2 = \frac{1}{h^2 \quad \sigma^2} \tag{8}$$

Therefore SNR for AF, k^{th} relay link from (7) & (8) will be,

$$\gamma_{AF}^{k} = \frac{\gamma_{s,r_k} \gamma_{r_k,d}}{\gamma_{s,r_k} + \gamma_{r_k,d} + 1} \tag{9}$$

Thus, in AF protocol two-hop system, multi-copies of signal *x* is received by the destination through multiple relays. These signals may be combined with any of the different combining techniques. The optimum combining technique that maximizes the overall signal to noise ratio is called the maximal ratio combiner (MRC). SNR for MRC will be

$$\gamma_{AF}^{MRC} = \gamma_{AF}^{1} + \gamma_{AF}^{2} + \ldots\ldots + \gamma_{AF}^{k} + \ldots\ldots + \gamma_{AF}^{n} \tag{10}$$

From the SNR for MRC-AF obtained in (10), the PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for MRC - AF may be given as

$$P_{out}\Big|_{AF}^{MRC} = \int_0^{\gamma_{th}} f_{\gamma_{AF}^{MRC}}(\gamma)\, d\gamma \tag{11}$$

$$BER\left(P_e\Big|_{AF}^{MRC}\right) = \int_0^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{AF}^{MRC}}(\gamma)\; d\gamma \tag{12}$$

where γ_{th} is threshold SNR, a is a constant [14, Eq. (5.1)] and depends on modulation & detection combination.

In place of MRC if selection combining (SC) is used which is based on principle of selecting the best signal among all the signals received from different branches at the destination, then the SNR for SC will be

$$\gamma_{AF}^{SC} = \max\left(\gamma_{AF}^{1}, \gamma_{AF}^{2}, \ldots\ldots, \gamma_{AF}^{k}, \ldots\ldots, \gamma_{AF}^{n}\right) \qquad (13)$$

Now from the SNR for SC obtained in (13), similarly as above PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for SC - AF may be given as

$$P_{out}\Big|_{AF}^{SC} = \int_{0}^{\gamma_{th}} f_{\gamma_{AF}^{SC}}\left(\gamma\right) d\gamma \qquad (14)$$

$$BER\left(P_e\Big|_{AF}^{SC}\right) = \int_{0}^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{AF}^{SC}}\left(\gamma\right)\, d\gamma \qquad (15)$$

B. *Decode and Forward (DF):*

The decode and forward (DF) is a digital & regenerative scheme, where relay receives the signal, decodes it and after encoding retransmit it to the destination. Noise does not propagate, because noise is not amplified as it is excluded by the decoding process. In DF processing time is higher causing delay, hence DF is not suitable for delay sensitive signals. The signal received at k^{th} relay from source is given by (3), the signal is decoded at k^{th} relay and encoded.

Let the encoded signal be $\hat{x}_k$.

This will be obtained by maximum likelihood detector, when signal x_k is estimated by relay.

$$\hat{x}_k = \arg\min_{x} \left| y_{s,r_k} - h_{s,r_k} x \right|^2 \qquad (16)$$

Hence, the signal received in DF, at destination will be

$$y_{r_k,d} = h_{r_k,d}\,\hat{x}_k + n_{r_k,d} \qquad (17)$$

The SNR for both hops for k^{th} relay is defined as below

$$\gamma_{s,r_k} = \frac{h_{s,r_k}^2 P_s}{\sigma^2} = \delta_{s,r_k} P_s \qquad (18)$$

$$\gamma_{r_k,d} = \frac{h_{r_k,d}^2 P_{r_k}}{\sigma^2} = \delta_{r_k,d} P_{r_k} \qquad (19)$$

where $\delta_{s,r_k} = \frac{h_{s,r_k}^2}{\sigma^2}$, and $\delta_{r_k,d} = \frac{h_{r_k,d}^2}{\sigma^2}$, P_s and P_{r_k} are the transmit power at source and k^{th} relay respectively.

The, SNR at destination for k^{th} relay link in DF will be

$$\gamma_{DF}^{k} = \min\left(\gamma_{s,r_k},\ \gamma_{r_k,d}\right) \qquad (20)$$

In DF, multi-copies of signal will be received by the destination through multiple relays. When these signals are combined by MRC techniques, which maximizes the overall signal to noise ratio. The SNR for MRC-DF will be

$$\gamma_{DF}^{MRC} = \gamma_{DF}^{1} + \gamma_{DF}^{2} + \ldots\ldots + \gamma_{DF}^{k} + \ldots\ldots + \gamma_{DF}^{n} \qquad (21)$$

From the SNR for MRC-DF obtained in (21), PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for MRC - DF may be given as

$$P_{out}\Big|_{DF}^{MRC} = \int_{0}^{\gamma_{th}} f_{\gamma_{DF}^{MRC}}\left(\gamma\right) d\gamma \qquad (22)$$

$$BER\left(P_e\Big|_{DF}^{MRC}\right) = \int_{0}^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{DF}^{MRC}}\left(\gamma\right)\, d\gamma \qquad (23)$$

Instead of MRC-DF if SC is used which is based on principle of selecting the best signal among all the signals received from different braches at the destination, then the SNR for SC-DF will be

$$\gamma_{DF}^{SC} = \max\left(\gamma_{DF}^{1},\gamma_{DF}^{2},\ldots\ldots,\gamma_{DF}^{k},\ldots\ldots,\gamma_{DF}^{n}\right) \qquad (24)$$

Now from the SNR for SC-DF obtained in (24), similarly as above PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for SC - DF may be given as

$$P_{out}\Big|_{DF}^{SC} = \int_{0}^{\gamma_{th}} f_{\gamma_{DF}^{SC}}\left(\gamma\right) d\gamma \qquad (25)$$

$$BER\left(P_e\Big|_{DF}^{SC}\right) = \int_{0}^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{DF}^{SC}}\left(\gamma\right)\, d\gamma \qquad (26)$$

IV. DIVERSITY COMBINING TECHNIQUES

With diversity technique multiple copies of the same signal is received on different branches, which undergo independent fading. Thus having more than one path to select the SNR at receiver may be improved by selecting appropriate combining technique. Following diversity combining techniques for α-μ fading distribution are discussed.

A. *Selection Combining (SC):*

Selection combining is based on the principle of selecting the best signal among all the signals received from different branches at the receiving end. In this method, the receiver monitors the SNR of the incoming signal, and the branch with highest instantaneous SNR is connected to demodulator. SNR of selection combining is given as

$$\gamma_{SC} = \mathrm{Max}\left(R_1^2, R_2^2, \ldots, R_k^2, \ldots, R_n^2\right) \qquad (27)$$

Where R_k is the fading envelope seen by antenna at receiver and R_k^2 is fading power for k^{th} relay channel at receiver.

B. *Maximal Ratio Combining (MRC):*

In this all branches are optimally combined at the receiver. MRC requires scaling and co-phasing of individual branch. All the signals are weighted according to their individual signal to noise power ratios and then summed. Thus MRC produces an output SNR, which is equal to the sum of the individual SNRs. SNR of MRC for α-μ fading distribution is given as

$$\gamma_{MRC} = R_1^{\,2} + R_2^{\,2} + \ldots. + R_k^{\,2} + \ldots. + R_n^2 \qquad (28)$$

V. SIMULATION RESULTS AND DISCUSSIONS

Outage and BER performance for cooperative communication system with multiple parallel relays, over α-μ fading channel is obtained by Monte-Carlo simulation for half-duplex (*HD*) and full-duplex (*FD*) systems. The *HD* system allows two-way communication by using same channel for both transmission and reception. Thus at any given time, the user can only either transmit or receive information. Whereas *FD* system allows simultaneous two-way communication. Here transmission and reception are on two different channels. Relay operation in *HD* mode, requires additional time slot to separate the incoming and outgoing signals hence consumes extra resource (bandwidth). *FD* mode in single operating frequency does not require extra time-slot, hence there is no bandwidth expansion. Relay operating in this mode have separate set of transmitting and receiving antennas but still suffer from loop interference due to insufficient electrical isolation between transmitting and receiving set antennas.

The communication system shown in fig.2 has been considered in this simulation. Outage probability and BER performance simulated results for different number of parallel relays are shown in fig. 3 to fig.8 for amplitude-and-forward protocol and in fig. 9 to fig. 14 for decode-and-forward protocol. In these simulation 100000 bits have been considered for a particular α, μ, and relay combination. The direct link between source-destination is not considered in this simulation. The threshold value of cooperative relaying is defined as

$$\text{since, } R = \frac{1}{n+1}\log_2(1+SNR) \;\Rightarrow\; (n+1)R = \log_2(1+SNR)$$
$$\Rightarrow\; 2^{(n+1)R} = 1 + SNR \;\Rightarrow\; \text{threshold } SNR = 2^{n+1} - 1 \tag{29}$$

Here R is assumed to be unity for numerical evaluation. Each cooperative relay utilizes one time slot out of $(n+1)$ time slots, hence spectrum efficiency of such systems become $1/(n+1)$ part of available spectrum. So, modulation parameter $M = 2^n$ has been chosen in the simulation for faithful comparison between different numbers of cooperative relay nodes.

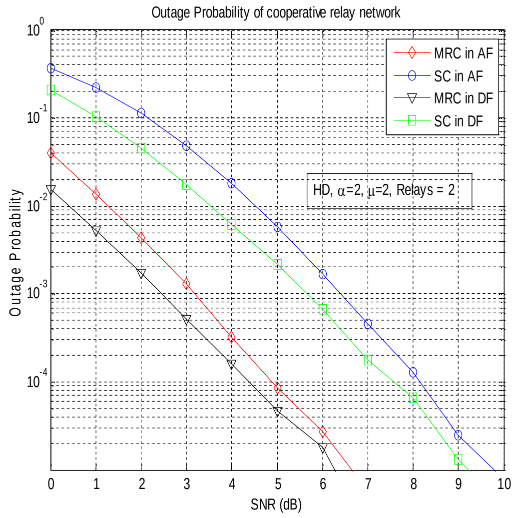

Fig. 3. Outage of half-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=2.

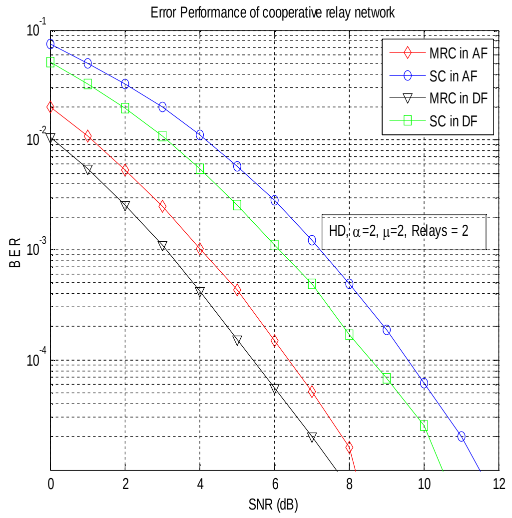

Fig. 4. BER of half-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=2.

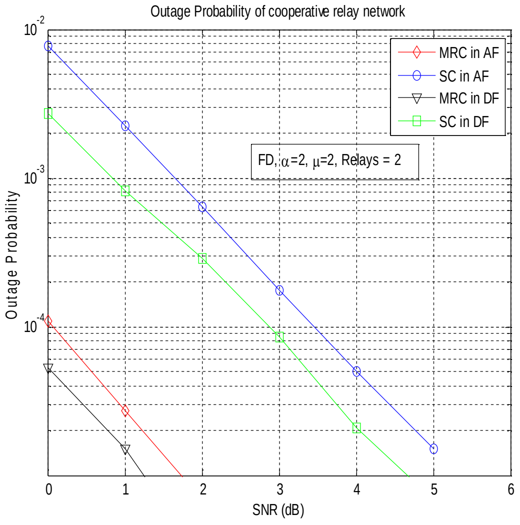

Fig. 5. Outage of full-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=2.

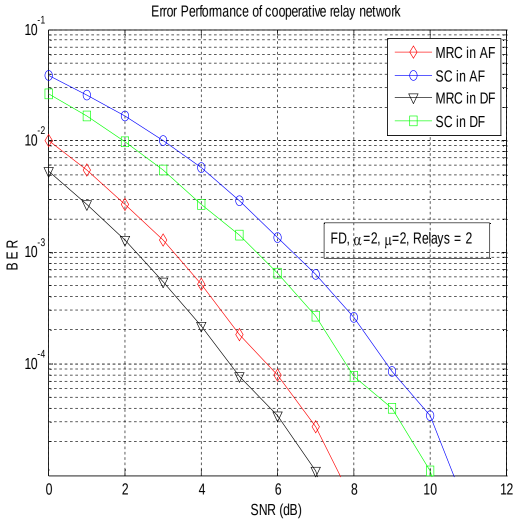

Fig. 6.BER of full-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=2

In fig.3 the outage performance for HD relaying for 2 parallel relays, and α=2, μ=2 is shown. It is seen that at 5 dB SNR, the outage for MRC-AF is 8.0×10^{-5} but for MRC-DF is 4.0×10^{-5}, and for SC-AF is 6×10^{-3} whereas for SC-DF is 2×10^{-3} . In fig.4, we find the BER for same system at 6 dB SNR as 1.5×10^{-4} for MRC-AF, 5.0×10^{-5} for MRC-DF and for SC–AF as 3.0×10^{-3} whereas for SC–DF as 1.2×10^{-3}. In fig.5 the outage for FD relaying for 2 parallel relays, α=2, and μ=2 is shown. It is seen that at 1 dB SNR, the outage for MRC-AF is 2.8×10^{-5} but for MRC-DF is 1.5×10^{-5}, and for SC-AF is 2.3×10^{-3} whereas for SC-DF is 8×10^{-4} . In fig.6, we find the BER for same system at 6 dB SNR as 8×10^{-5} for MRC-AF, 3.5×10^{-5} for MRC-DF and for SC–AF as 1.5×10^{-3} whereas for SC–DF as 6.5×10^{-4} .

In fig.7 the BER performance for half duplex system with 3 parallel relays, α=2 and μ=2 is shown. It is seen that at 6 dB SNR, the BER for MRC-AF is 5.5×10^{-3}, but for MRC-DF is 2.0×10^{-3} and that for SC-AF is 5×10^{-2} whereas for SC-DF is 3×10^{-2}. From fig. 7 we observe MRC-DF outperforms MRC-AF and similarly SC-DF outperforms SC-AF. Further, error performance for full duplex system with 3 parallel relays, α=2 and μ=2 is shown in fig.8, we find the BER at 3 dB SNR for MRC-AF is 3.0×10^{-4}, but for MRC-DF is 9.0×10^{-5} and that for SC-AF is 8×10^{-3} whereas for SC-DF is 3.5×10^{-3}.

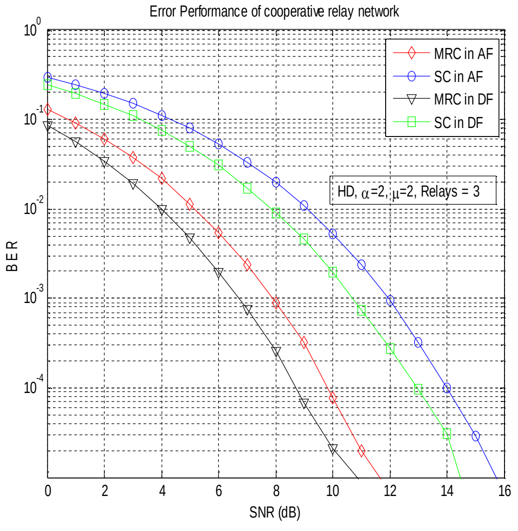

Fig. 7.BER of half-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=3.

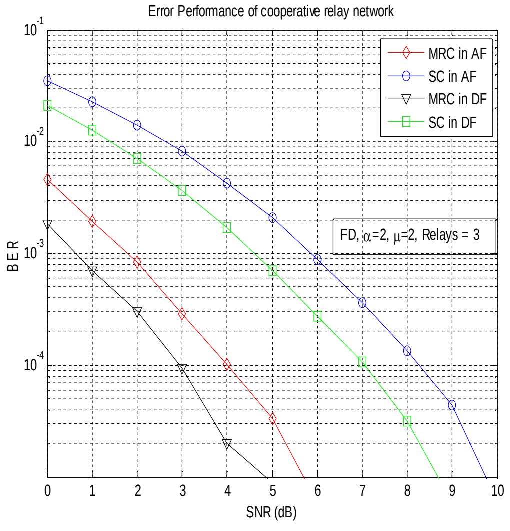

Fig. 8.BER of full-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=3.

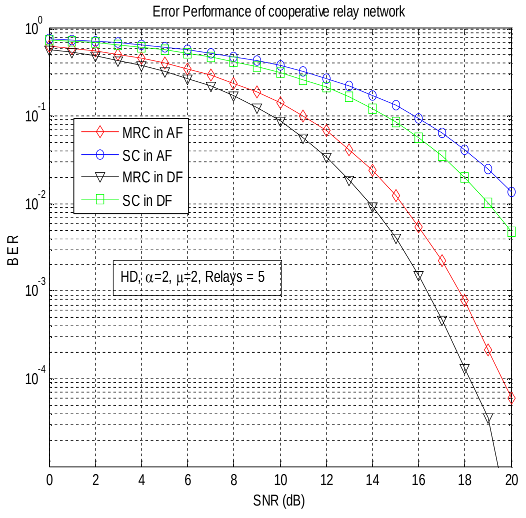

Fig. 9.BER of half-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=5.

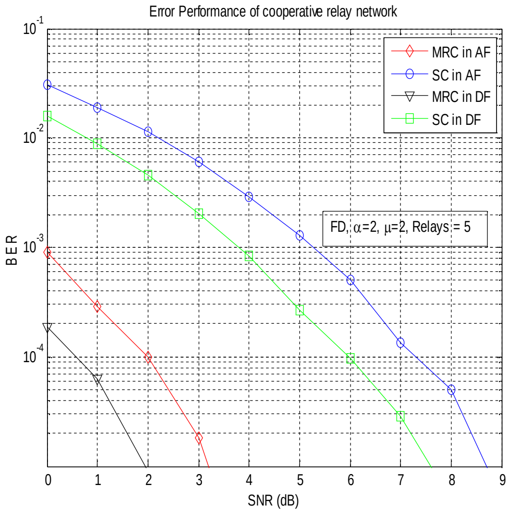

Fig. 10.BER of full-duplex cooperative relaying over α-μ fading channel for α=2, μ=2, Relays=5.

In fig.9 the BER performance for half duplex system with 5 parallel relays, α=2 and μ=2 is shown. It is seen that at 16 dB SNR, the BER for MRC-AF is 5×10^{-3}, but for MRC-DF is 1.5×10^{-3} and that for SC-AF is 9×10^{-2} whereas for SC-DF is 5.5×10^{-2}. Further, error performance for full duplex system with 5 parallel relays, α=2 and μ=2 is shown in fig.10, we find the BER at 1 dB SNR for MRC-AF is 2.8×10^{-4}, but for MRC-DF is 6.0×10^{-5} and that for SC-AF is 2×10^{-2} whereas for SC-DF is 7.5×10^{-3}. The simulation results shows that as expected outage and BER performance for MRC is always better than SC. We also observe that as the number of relays are increased the BER performance deteriorates for half-duplex system and performance improves for full duplex system.

VI. CONCLUSION AND FUTURE WORK

In this paper outage probability and BER performance of cooperative communication with multiple parallel relays have been analysed for amplify-and-forward (AF) protocol, and decode-and-forward (DF) protocol with maximal ratio combining (MRC) and selection combining (SC) over α-μ fading channel for half-duplex (HD) and full-duplex (FD) wireless systems. It is noticed from comparison of simulation results that MRC-DF outperforms in outage and BER with respect to MRC-AF and similarly SC-DF outperforms SC-AF. The effect of number of parallel relays on outage and BER performance is brought out. It has been analysed that with increase in parallel relays, performance deteriorates for half-duplex system due to increase in time slots but improves in full-duplex system due to proper utilisation of spectrum. The MRC-AF and MRC-DF system outperforms the SC-AF and SC-DF communication systems respectively with large margin, and this difference increases with increase in number of parallel relays. However, for full duplex relays or a scenario where spectrum efficiency is not an important issue, performance of such systems improves with increment of relays. This analysis will be helpful for further investigation of cooperative wireless systems with multi-hop relay over α-μ fading channel.

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ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2015

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