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Performance Analysis of Multi-Hop Relay- Network over α-μ Fading Channel

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Abstract
In this paper outage and bit error rate (BER) performance of multi-hop, serial relay-network wireless communication system over alpha mu (α-μ) fading channel is analysed for half-duplex (HD) and full-duplex (FD) systems. We have seen that multi-hop serial relay network operating in decode and forward (DF) protocol outperforms amplitude and forward protocol system, and full-duplex outperforms half-duplex system. Comparative performance of the AF and DF systems has been analyzed and established by simulation over α-μ channel with varying serial relays and different α and μ values for half-duplex and full-duplex systems.

Keywords
α-μ fading; amplify-and-forward; decode-and-forward; outage; bit error rate.

I. Introduction

The relay based communication is an active and vital area of research in wireless communication today. In a mobile network, relaying schemes provide promising technologies to transmit at higher data rate to destinations farther away. In [3] end-to-end error probability has been derived for multi-hop networks employing CDMA transmission in a multiuser environment. It has been shown that as the number of user increases improvement from relaying decreases. Symbol error rate and PDF have been derived for multi-hop amplify-and-forward relay system in [4]. An extended form of multi-hop communication systems is introduced in [5] which allows the application of multiple-input-multiple-output capacity enhancement techniques over spatially separated relaying mobile terminals to drastically increase end-to-end capacity. The capacity regions are investigated for two relay broadcast channels in [6] where relay links are incorporated into two-user broadcast channels to support user cooperation. In [7] 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 [8] that combat fading induced by multipath propagation in wireless networks. A novel and unified analysis is proposed in [9], which is based on the moment-generating function approach for AF multi-hop transmission over generalized fading channels. In [11] 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 multi-hop, serial relay-network wireless communication system over *α-μ* fading channel with amply-and-forward and decode-and-forward protocols have been analysed. In Section 4, Monte-Carlo simulation results for outage probability and BER performance of the multi-hop, serial relay-network wireless system over *α-μ* fading channel with varying number of serial relays and α and μ parameters are presented. The paper is concluded by Section 5.

II. The μ Fading Model

The multipath fading in wireless communication is modeled by several distribution such as Rayleigh, Rician, Weibull, Nakagami. 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. As given in its name, 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. Further, the delay-time spreads of different clusters is generally relatively large. As a result, 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

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

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=3 and μ=3 in fig.1. It is verified that both the analytical and simulated results are matching.

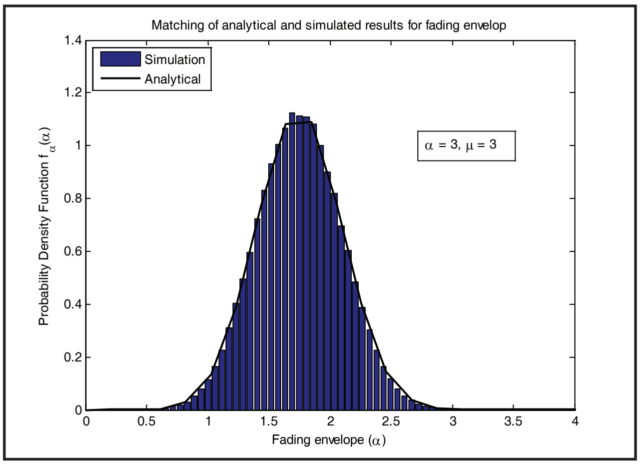

Fig.1 : Matching of analytical and simulated results for α-μ fading envelope for α=3 and μ=3

III. Multi- Hop Relay-Network Systems

In a multi-hop serial relay-network wireless communication system shown in fig.2., the signal is transmitted as broadcast through the serial relay network placed between source (s) and destination (d).

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

In the communication system shown in fig.2, s transmits to relay 1 ($s \rightarrow r_1$) in first time-slot, in second time slot relay 1 transmits to relay 2 ($r_1 \rightarrow r_2$) and so on, and finally in $(n+1)^{th}$ time slot relay n transmits to d ($r_n \rightarrow d$). PDF of the SNR for α-μ distributed channel is defined by (2).

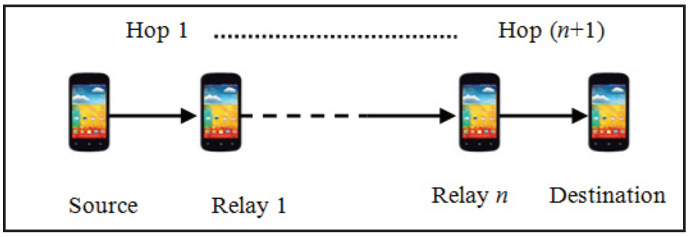

Fig.2 : Multi-hop relay network communication system

PDF of SNR (γ) of α-μ fading [10] is

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

here, $i \in \{s, r_k\}$, $j \in \{r_k, d\}$.

A. Amplify and Forward (AF)

During AF protocol in the communication system shown in fig.2, the relays receives the signal, amplifies it and then transmits to next stage. Assuming that source transmitting signal x, which is received by 1^{st} relay as

$$y_{s,r_1} = h_{s,r_1} x + n_{s,r_1} \qquad (3)$$

The received signal is scaled by a factor G_1, gain of relay 1. Thus, the signal received by 1^{st} relay is forwarded to 2^{nd} relay, and is received at 2^{nd} relay as

$$y_{r_1,r_2} = G_1 h_{r_1,r_2} y_{s,r_1} + n_{r_1,r_2} \qquad (4)$$

where

h_{r_i,r_j}, n_{r_i,r_j} = fading amplitude defined by eq.(1) and Additive White Gaussian Noise (AWGN) with variance σ^2 respectively for the (node $r_i \rightarrow$ node r_j) link of $\alpha - \mu$ wireless channel.

The received signal at relay 2 simplified from (4) as

$$y_{r_1,r_2} = h_{s,r_1} h_{r_1,r_2} G_1 x + h_{r_1,r_2} G_1 n_{s,r_1} + n_{r_1,r_2} \qquad (5)$$

Thus, SNR at receiver of relay 2, from (5) will be

$$\text{SNR} = \frac{(h_{s,r_1} h_{r_1,r_2} G_1)^2}{(h_{r_1,r_2} G_1)^2 \sigma^2 + \sigma^2} \qquad (6)$$

$$\text{SNR} = \frac{h_{s,r_1}^2 h_{r_1,r_2}^2}{h_{r_1,r_2}^2 \sigma^2 + \sigma^2 / G_1^2} = \frac{\frac{h_{s,r_1}^2}{\sigma^2} \frac{h_{r_1,r_2}^2}{\sigma^2}}{\frac{h_{r_1,r_2}^2}{\sigma^2} + \frac{1}{G_1^2 \sigma^2}} \qquad (7)$$

$$\text{Let, } \text{SNR} = \gamma_i = \frac{h_i^2}{\sigma^2}, \text{ and } G_1^2 = \frac{1}{h_{s,r_1}^2 + \sigma^2} \qquad (8)$$

Hence SNR for AF at receiver of relay 2 from (7) & (8) will be,

$$\gamma_{AF} = \frac{\gamma_{s,r_1}\gamma_{r_1,r_2}}{\gamma_{s,r_1} + \gamma_{r_1,r_2} + 1} \approx \frac{\gamma_{s,r_1}\gamma_{r_1,r_2}}{\gamma_{s,r_1} + \gamma_{r_1,r_2}} = \frac{1}{\frac{1}{\gamma_{s,r_1}} + \frac{1}{\gamma_{r_1,r_2}}} \qquad (9)$$

Since $(\gamma_{s,r_1} + \gamma_{r_1,r_2}) \gg 1$

Similar to (5), the received signal at relay 3 will be

$$y_{r_2,r_3} = h_{s,r_1} h_{r_1,r_2} h_{r_2,r_3} G_1 G_2 x + h_{r_1,r_2} h_{r_2,r_3} G_1 G_2 n_{s,r_1} + h_{r_2,r_3} G_2 n_{r_1,r_2} + n_{r_2,r_3} \qquad (10)$$

Similarly as in (10), the received signal at relay k will be

$$\begin{aligned} y_{r_{k-1},r_k} &= h_{s,r_1} h_{r_1,r_2} h_{r_2,r_3} \ldots\ldots h_{r_{k-1},r_k} G_1 G_2 \ldots\ldots G_{k-1} x \\ &+ h_{r_1,r_2} h_{r_2,r_3} \ldots\ldots\ldots h_{r_{k-1},r_k} G_1 G_2 \ldots\ldots G_{k-1} n_{s,r_1} \\ &+ h_{r_2,r_3} \ldots\ldots\ldots h_{r_{k-1},r_k} G_2 \ldots\ldots G_{k-1} n_{r_1,r_2} \\ &+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &+ n_{r_{k-1},r_k} \end{aligned} \qquad (11)$$

Finally the received signal for multi-path serial-relays at destination d will be

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$$y_{r_n,d} = h_{s,r_1}h_{r_1,r_2}h_{r_2,r_3}\,.....\,h_{r_n,r_d}G_1G_2......G_n x$$
$$+h_{r_1,r_2}h_{r_2,r_3}.........h_{r_n,r_d}G_1G_2......G_n n_{s,r_1}$$
$$+h_{r_2,r_3}h_{r_3,r_4}.........h_{r_n,r_d}G_2G_3......G_n n_{r_1,r_2}$$
$$+ ....$$
$$+h_{r_{k-1},r_k}h_{r_k,r_{k+1}}....h_{r_n,r_d}G_{k-1}G_k....G_n n_{r_{k-2},r_{k-1}}$$
$$+ ....$$
$$+ n_{r_n,r_d} \qquad (12)$$

Following steps of (6) to (9) SNR at receiver of d for AF protocol multi-path serial-relays can be generalised for n relays, and will be [9, Eq.(1)] and [12, Eq.(4)] as

$$\gamma_{AF} = \frac{1}{\frac{1}{\gamma_{s,r_1}} + \frac{1}{\gamma_{r_1,r_2}} + ... + \frac{1}{\gamma_{r_{n-1},r_n}} + \frac{1}{\gamma_{r_n,d}}} \qquad (13)$$

From the SNR for AF protocol obtained in (13), the PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for multi-hop serial relay-network system with AF protocol may be given as

$$P_{out}\big|_{AF} = \int_0^{\gamma_{th}} f_{\gamma_{AF}}(\gamma)\,d\gamma \qquad (14)$$

$$BER\left(P_e\big|_{AF}\right) = \int_0^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{AF}}(\gamma)\,d\gamma \qquad (15)$$

where γ_{th} is threshold SNR, a is a constant [13, Eq. (5.1)] and depends on modulation & detection combination.
The threshold value of relaying for (n+1) hops is defined from

$$\text{since, } R = \frac{1}{n+1}\log_2(1+SNR)$$
$$\text{or } (n+1)R = \log_2(1+SNR)$$
$$\text{or } 2^{(n+1)R} = 1 + SNR$$
$$\text{or threshold } SNR = \gamma_{th} = 2^{n+1} - 1 \qquad (16)$$

Here R is assumed to be unity for numerical evaluation. Each serial 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 $M = 2^{n+1}$ and $\gamma_{th} = (2^{n+1} - 1)$ has been chosen in half duplex (HD) for faithful comparison between different numbers of cooperative relay nodes, whereas in full duplex (FD) M is taken as 2 and γ_{th} =1.
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.

B. Decode and Forward (DF)

The decode and forward (DF) is a digital and regenerative scheme, where relay receives the signal, decodes it and after encoding retransmit it to the destination. Noise does not propagate, because the noise will not be amplified and is excluded by the decoding process. The signal received at 1st relay is given by (3), thereafter signal is decoded at 1st relay and encoded.

Let the encoded signal be $\hat{x}_1$.

This will be obtained by maximum likelihood detector, when signal x_1 is estimated by relay 1.

$$\hat{x}_1 = \arg\min_x \left|y_{s,r_1} - h_{s,r_1}x\right|^2 \qquad (17)$$

Hence, the signal received in DF, at relay 2 will be

$$y_{r_1,r_2} = h_{r_1,r_2}\hat{x}_1 + n_{r_1,r_2} \qquad (18)$$

The SNR for 1st hop and 2nd hop i.e. input and output hops of 1st relay is defined as

$$\text{For } 1^{st} \text{ hop,} \quad \gamma_{s,r_1} = \frac{h^2_{s,r_1}P_s}{\sigma^2} \qquad (19)$$

$$\text{For } 2^{nd} \text{ hop,} \quad \gamma_{r_1,r_2} = \frac{h^2_{r_1,r_2}P_{r_1}}{\sigma^2} \qquad (20)$$

P_s and P_{r1} are the transmit power at source and 1st relay respectively and have been normalized to unity.
Similar to (19), (20), SNR for all other hops may be given as

$$\text{For } k^{th} \text{ hop,} \quad \gamma_{r_{k-1},r_k} = \frac{h^2_{r_{k-1},r_k}P_{r_{k-1}}}{\sigma^2} \qquad (21)$$

$$\text{For last i.e. } (n+1)^{th} \text{ hop,} \quad \gamma_{r_n,d} = \frac{h^2_{r_n,d}P_{r_n}}{\sigma^2} \qquad (22)$$

The, SNR in DF protocol with multi-hop serial-relay system, at receiver of d will be

$$\gamma_{DF} = \min\left(\gamma_{s,r_1},\ \gamma_{r_1,r_2},....,\gamma_{r_{k-1},r_k},....,\gamma_{r_{n-1},r_n},\gamma_{r_n,d}\right) \qquad (23)$$

From the SNR for DF obtained in (23), PDF of SNR may be obtained with help of (2). Thereafter the outage and BER for DF may be given as

$$P_{out}\big|_{DF} = \int_0^{\gamma_{th}} f_{\gamma_{DF}}(\gamma)\,d\gamma \qquad (24)$$

$$BER\left(P_e\big|_{DF}\right) = \int_0^{\infty} Q\left(a\sqrt{\gamma}\right) f_{\gamma_{DF}}(\gamma)\,d\gamma \qquad (25)$$

IV. Simulation Results and Discussions

Outage and BER performance for multi-hop relay-network communication system over α-μ fading channel is obtained by Monte-Carlo simulation for half-duplex (*HD*) and full-duplex (*FD*) systems. The communication system shown in fig.2 has been considered in this simulation. Outage probability and BER performance for amplitude-and-forward protocol and decode-and-forward protocol simulated results considering various number of serial relays for half-duplex are shown in fig. 3 to fig.8 and for full-duplex are shown in fig. 9 to fig.14. In these simulation 100000 bits have been considered for a particular α, μ, and relay combination.
Half-duplex simulation results are shown in fig.3 to fig.8. In fig.3 the outage performance for serial relays=2, and α=2, μ=2 is shown. It is seen that at 10 dB SNR, the outage for AF protocol is 1.5×10^{-1}, and that for DF is 1.8×10^{-2}. In fig.4, we find the BER for same

system as 3.4×10^{-2} for AF, and 5.5×10^{-3} for DF. In fig.5 and fig.6 all the parameters i.e. serial relays, α and μ are increased to 3, we notice that at 10 dB SNR, for AF and DF outage as 6.5×10^{-1} and 1.2×10^{-2}, and BER as 2.5×10^{-1} and 2.8×10^{-2} respectively. In fig.7 and fig. 8 serial relays are again increased to 5 and α and μ parameters are maintained as 3, we notice that at 10 dB SNR for AF and DF outage is same approximately 9.5×10^{-1}, and BER as 8.5×10^{-1} and 5.7×10^{-1} for AF and DF respectively.

Full-duplex simulation results are shown in fig.9 to fig.14. In fig.9 the outage performance for serial relays=2, and α=2, μ=2 is shown. It is seen that at 10 dB SNR, the outage for AF protocol is 2×10^{-2}, and that for DF is 7×10^{-4}. In fig.10, we find the BER for same system as 2×10^{-2} for AF, and 3×10^{-3} for DF. In fig.11 and fig.12 all the parameters i.e. serial relays, α and μ are increased to 3, we notice that at 10 dB SNR, outage for AF as 6×10^{-1} and at 6 dB SNR outage for DF as 9×10^{-5}, and BER as 4×10^{-2} and 2.8×10^{-4} respectively at 10 dB SNR. In fig.13 and fig. 14 serial relays are again increased to 5 and α and μ parameters are maintained as 3, we notice that at 10 dB SNR for AF outage is 8×10^{-1} and at 6 dB SNR for DF outage is 2×10^{-4}, and BER as 2.8×10^{-1} and 3.5×10^{-4} for AF and DF respectively.

The simulation results shows that as expected outage and BER performance for DF protocol is always better than AF protocol. We also observe that as the number of serial relays are increased, outage and BER for AF and DF deteriorates. Further deterioration in AF is more comparative to DF, because in AF with increase in number of relays, noise also gets amplified accordingly. We also observe that performance of full-duplex is better than half-duplex for similar configuration, due to proper utilization of spectrum. Thus we observe that with increase in relays communication of longer range is achieved but at the cost of deterioration in outage and BER performance.

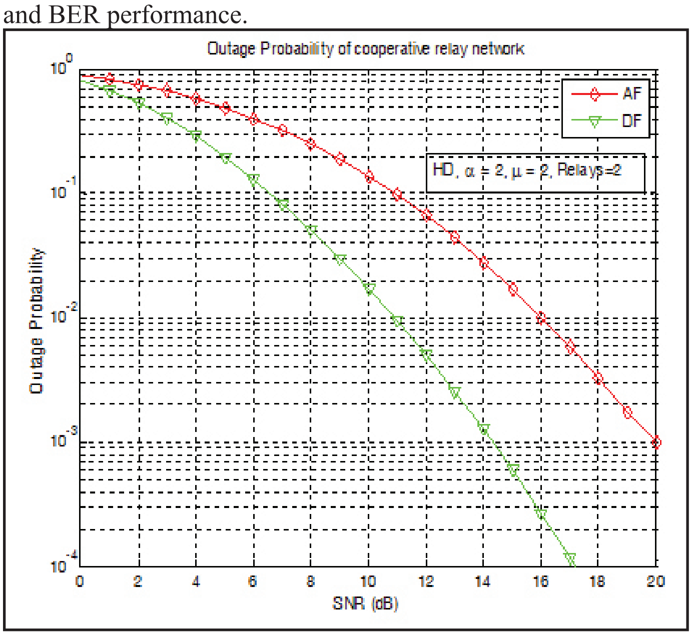

Fig. 3 : Outage of Multi-Hop Half-Duplex Relay-Network over α-μ fading channel for α=2, μ=2, Relays=2.

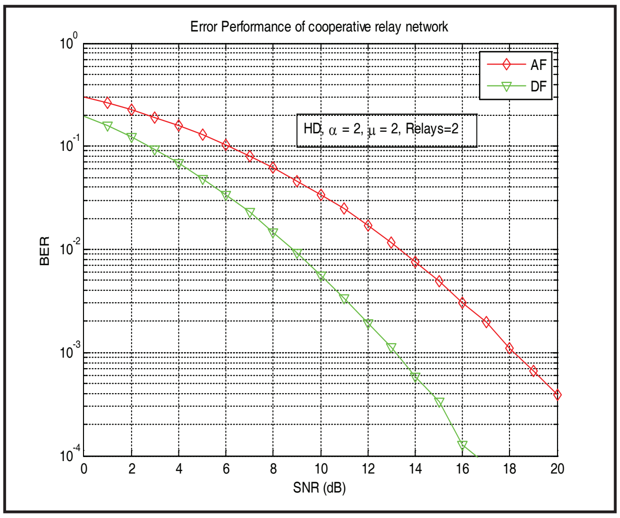

Fig. 4 : BER of Multi-Hop Half-Duplex Relay-Network over α-μ fading channel for α=2, μ=2, Relays=2.

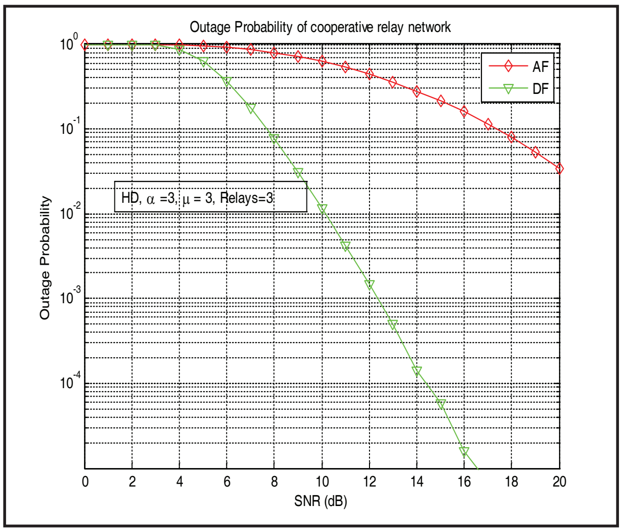

Fig. 5 : Outage of Multi-Hop Half-Duplex Relay-Network over α-μ fading channel for α=3, μ=3, Relays=3.

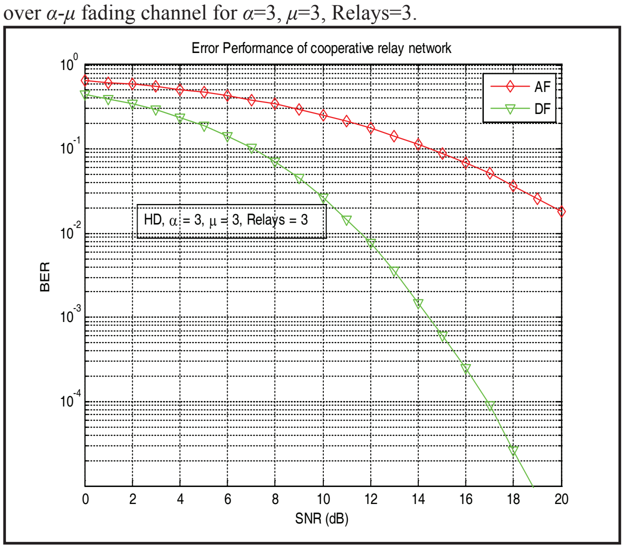

Fig. 6 : BER of Multi-Hop Half-Duplex Relay-Network over α-μ fading channel for α=3, μ=3, Relays=3.

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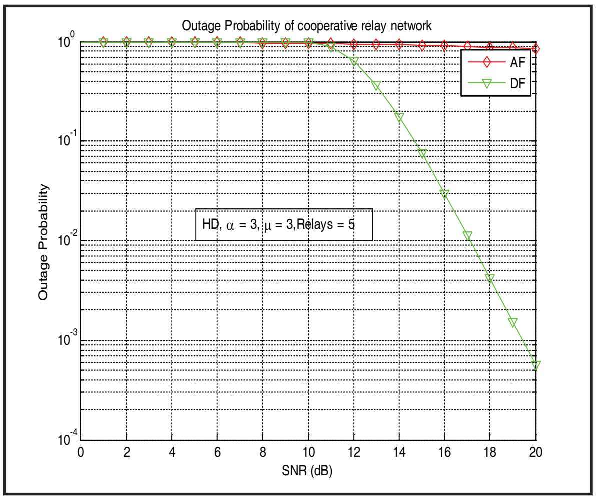

Fig. 7 :. Outage of Multi-Hop Half-Duplex Relay-Network over *α-μ* fading channel for *α*=3, *μ*=3, Relays=5.

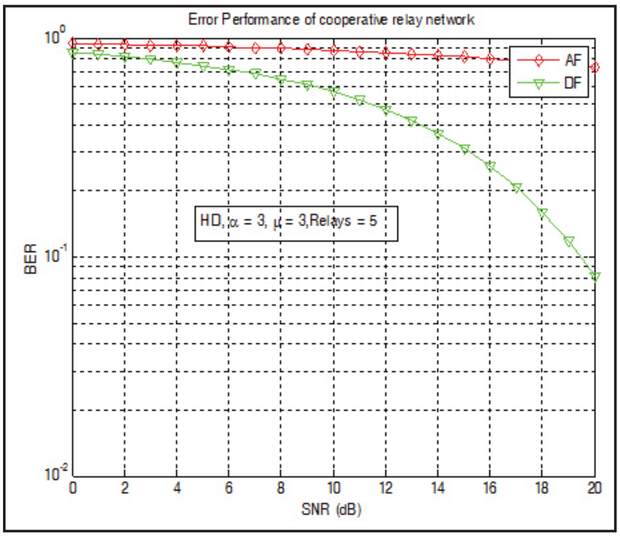

Fig. 8. BER of Multi-Hop Half-Duplex Relay-Network over α-μ fading channel for α=3, μ=3, Relays=5.

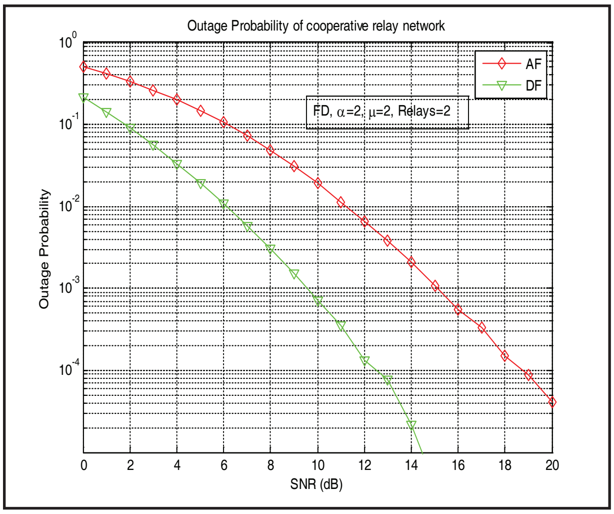

Fig. 9 : Outage of Multi-Hop Full-Duplex Relay-Network over *α-μ* fading channel for *α*=2, *μ*=2, Relays=2.

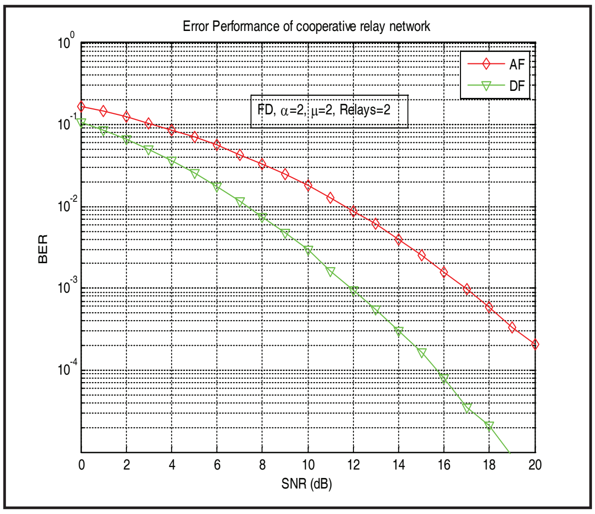

Fig. 10 : BER of Multi-Hop Full-Duplex Relay-Network over *α-μ* fading channel for *α*=2, *μ*=2, Relays=2.

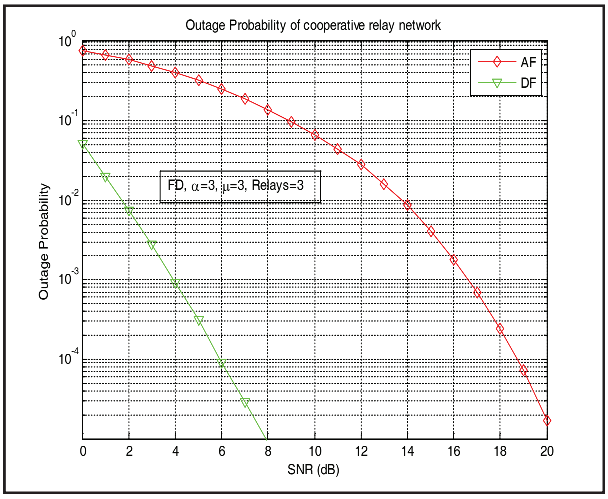

Fig. 11 : Outage of Multi-Hop Full-Duplex Relay-Network over *α-μ* fading channel for *α*=3, *μ*=3, Relays=3,

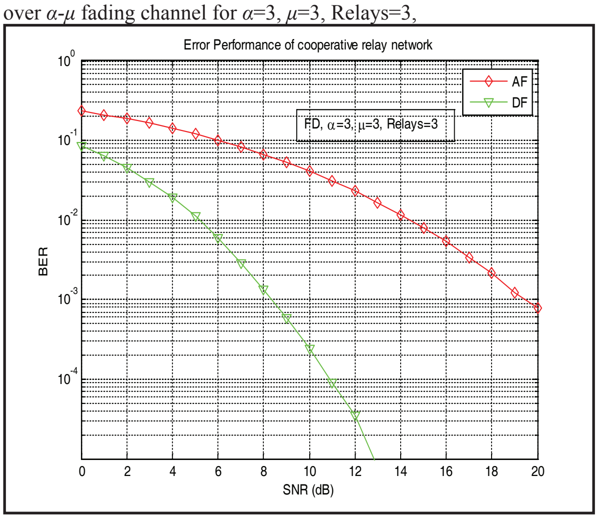

Fig. 12. BER of Multi-Hop Full-Duplex Relay-Network over *α-μ* fading channel for *α*=3, *μ*=3, Relays=3.

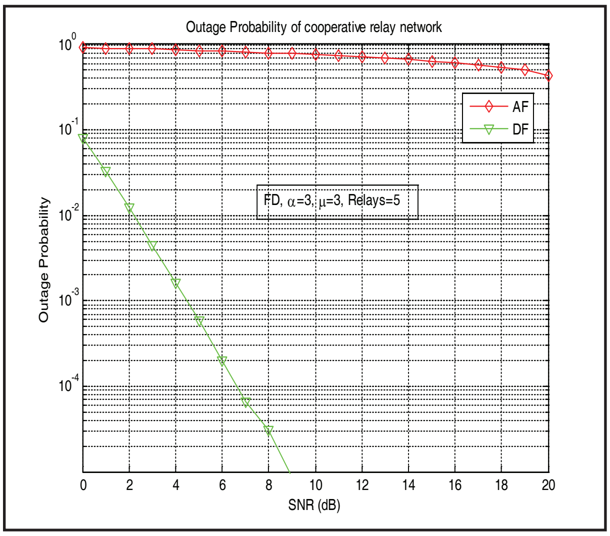

Fig. 13. Outage of Multi-Hop Full-Duplex Relay-Network over α-μ fading channel for α=3, μ=3, Relays=5.

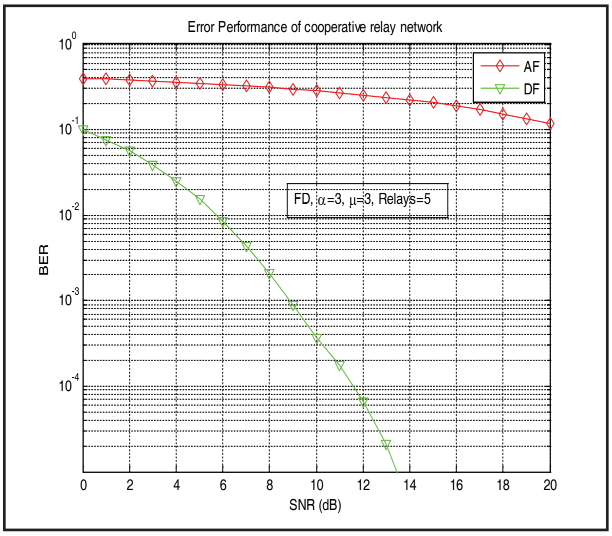

Fig. 14. BER of Multi-Hop Full-Duplex Relay-Network over α-μ fading channel for α=3, μ=3, Relays=5.

V. Conclusion

In this paper outage probability and BER performance of multi-hop relay-network wireless communication system have been analysed for amplify-and-forward (AF) protocol, and decode-and-forward (DF) protocol over α-μ fading channel. The outage and BER performance AF protocol is compared with DF protocol with help of simulation results. The effect of number of serial relays on outage and BER performance is brought out. It has been analyzed that with increase in number of serial relays, longer range communication is achieved on the price of spectrum efficiency for half-duplex. For same spectrum efficiency, full-duplex relays outperforms half-duplex relays. As number of relays increases noise is amplified and forwarded in next hop for the case of AF relay and error is forwarded in next hop for the case of DF relay hence performance deteriorates. Further, DF protocol outperforms AF protocol systems with large margin, and this difference increases with increase in number of serial relays. Full-duplex performance is much better than half-duplex for same system configuration. This analysis will be helpful for further investigation of cooperative wireless systems with multi-hop and parallel relays over α-μ fading channel.

VI. Acknowledgment

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