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Performance of MPSK and MQAM Modulation on Cooperative Relaying Systems over Rayleigh Fading Environment

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Abstract— This paper presents the comparison of the performance of relaying strategies in a cooperative wireless system over Rayleigh fading channel. Since the quality of the channel cannot be predicted over an instant of time, there is need for the introduction of a relay node in order to improve the reliability of the received signal at the destination and extend the coverage area of the network. In cooperative wireless systems, the relay node employ amplify and forward (AF); and decode and forward (DF) protocols to retransmits the processed received signal using M-ary Phase Shift Keying (MPSK) and M-ary Quadrature Amplitude Modulation (MQAM) modulation schemes. The destination node combines the received signals from both the relay node as well as the source node using maximum ratio combiner (MRC) due to its optimal performance. The combined signal is evaluated in terms of bit error rate and the result obtained showed that BPSK and 4-QAM has the lowest bit error rate at higher signal to noise ratio (SNR) in AF relaying and in DF relaying protocols because of their low symbol period.

Index Terms—Amplify and Forward, Cooperative relay, Decode and Forward, Rayleigh fading

1 Introduction

Cooperative diversity or communication has not too long ago been proposed as paradigm shift for the next generation wireless system with an effective approach to combat channel fading and enhance the system performance in wireless communication networks [1],[2]. The introduction of additional nodes between a point to point communication links, assists in forwarding the signal received from the source node to the destination node is known as a relay node [3].

Cooperative communication systems also suffer from independent and identical channel variations such as shadowing, interference (inter-symbol interference), attenuation, pathloss e.t.c which significantly affects the proper transmission of data between the source and destination nodes [4]. In order to combat these effects, there is need to exploit the inherent advantages of a mitigating technique that allow mobile terminals to cooperate with high demand for high data rate services [5] and create a means that provides spatial diversity gain via virtual antennas to improve the system performance and also guarantee a good quality of service (QoS) desired by various media classes [1] and at the same time extend the coverage area of the network without requiring significant infrastructure deployment cost [6],[7],[8].

Several strategies employed by cooperating radio have been reported in [5],[3],[6],[9] for fixed relaying schemes such as AF and DF, [6],[1],[10] worked on Selection relaying schemes with the primary goal of channel measurement between cooperating terminals while [11],[6] worked on Incremental relaying schemes based limited feedbacks from destination terminals. Other strategies include Estimate and Forward [12] and Coded Cooperation which integrate channel coding into it [13],[14],[15]. Also, the performance analysis of relaying protocol for cooperative communication system over Nakagami-m fading channels was reported in [16], [17] and a lot of have been done over Rayleigh fading channels [18]. Therefore, this paper presents the BER performance of MPSK and MQAM modulation schemes in a cooperative relaying system over Rayleigh fading environment.

2 System Model

Figure 1 depicts the block diagram of the system model for the AF relaying protocol.

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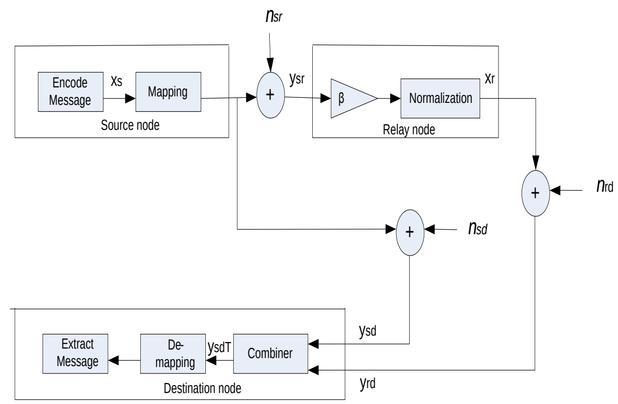

Fig. 1. System model for the AF relaying protocol.

The source node broadcast its signal to both the relay as well as the destination node in the first time slot. The signal is received at both the relay node and the destination node. The received signal at the relay y_{sr} as well as the destination nodes y_{sd} as given by [2],[16]

$$y_{sr} = \sqrt{P_t}h_{sr}x_s + n_{sr} \tag{1}$$

$$y_{sd} = \sqrt{P_t}h_{sd}x_s + n_{sd} \tag{2}$$

In the second time slot, the relay node assist in amplifying the version of the signal received using an amplifying factor and then retransmits the signal to the destination node and is given by [19] as

$$y_{rd} = \beta\sqrt{P_r}h_{rd}x_r + n_{rd} \tag{3}$$

where the amplifying factor which is inversely proportional to the energy of the transmitted bit

$$\beta = \frac{\sqrt{P_t}}{\sqrt{P_t|h_{sr}|^2 + N_0}} \tag{4}$$

where h_{sr}, h_{sd} and h_{rd} are the channel fading coefficient in Rayleigh fading environment and is modeled as zero mean independent complex Gaussian random variables with variances σ_{sd}^2, σ_{sr}^2 and σ_{rd}^2 respectively. P_t is the transmitted power, x_s and x_r are the transmitted signals from the source and processed retransmitted signal at the relay nodes respectively, n_{sr}, n_{sd} and n_{rd} are the additive white Gaussian noise modeled as zero mean with variance N_0.
Therefore, (3) is rewritten as

$$y_{rd} = \frac{\sqrt{P_t}}{\sqrt{P_t|h_{sr}|^2 + N_0}}\sqrt{P_t}h_{rd}(\sqrt{P_r}h_{sr}x_s + n_{sr}) + n_{rd} \tag{5}$$

$$y_{rd} = \frac{\sqrt{P_r P_t}}{\sqrt{P_t|h_{sr}|^2 + N_0}}h_{sr}h_{rd}x_s + \frac{P_t}{\sqrt{P_t|h_{sr}|^2 + N_0}}h_{rd}n_{sr} + n_{rd} \tag{6}$$

The last two expressions in (6) is the composite noise detected at the destination and is modeled as zero mean, complex Gaussian random variable with variance expressed in [20] as.

$$\tilde{N}_0 = \left(\frac{P_t}{P_t|h_{sr}|^2 + N_0}|h_{rd}|^2 + 1\right)N_0 \tag{7}$$

Maximum ratio combiner is employed at the destination node to combine the received signal transmitted from the source and destination nodes. The combined signal is written as [2]

$$y_{sdT} = \alpha_{sd}y_{sd} + \alpha_{rd}y_{rd} \tag{8}$$

Therefore, the $\alpha_{sd} = \sqrt{P_t}h^*_{sd}/N$ while $\alpha_{rd} = \sqrt{P_r}h^*_{rd}/\tilde{N}$

2.2 Decode and Forward (DF) Protocol

The block diagram of the system model for the DF relaying protocol is as depicted in Figure 2. The source node broadcast its signal to both the relay as well as the destination node in the first time slot. The signal is received at both the relay node and the destination node.

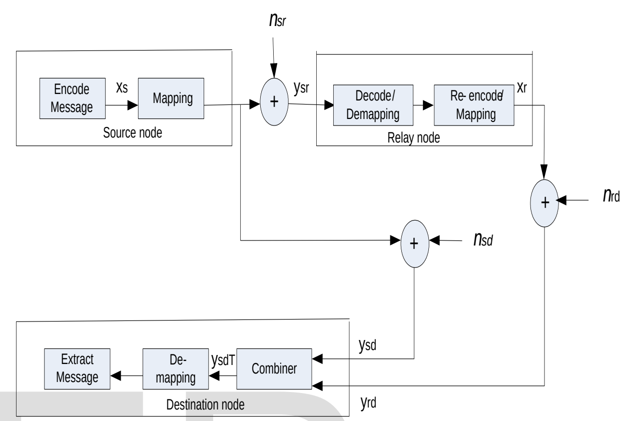

Fig. 2. System model for the DF relaying protocol.

The received signal at the relay y_{sr} as well as the destination nodes y_{sd} is given in (1) and (2). In the second time slot, the relay node processes the signal by decoding and re-encoding the signal received then retransmits the signal to the destination node if the signal is correctly decoded else does not retransmit. The received signal at the destination node, is expressed in [1],[[16] as

$$y_{rd} = \sqrt{P_r}h_{rd}x_r + n_{rd} \tag{9}$$

where P_t is the power used at the relay node in retransmitting the decoded signal.
Maximum ratio combiner is employed at the destination node to combine the received signal transmitted from the source and destination nodes. The combined signal is written as [2]

$$y_{sdT} = \alpha_{sd}y_{sd} + \alpha_{rd}y_{rd} \tag{10}$$

Therefore, the $\alpha_{sd} = \sqrt{P_t}h^*_{sd}/N$ while $\alpha_{rd} = \sqrt{P_t}h^*_{rd}/N$.

2.3 Rayleigh Fading Distribution

To estimate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz the following steps have to be carried out using [11].

This channel fading distribution is considered the worst case scenario of a wireless channel environment. It is statistically modeled for locations with heavy shadowed surrounding consisting of buildings, trees and mountains and characterized with high faded signal when there is no prominent line of sight (LOS). The fading envelope of a Rayleigh distributed signal has a probability density function given as [21],[22],[23]

$$f(r) = \frac{r}{\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \qquad 0 \le r \le \infty \qquad (11)$$

where r is the received signal, $\frac{r^2}{2}$ is the instantaneous power, σ is the root mean square value of the received signal.

Therefore, according to [24], for a Rayleigh independent fading channels with independent exponential random variables, $|h_{sd}|^2 = 1/\sigma^2$, $|h_{sr}|^2 = 1/\sigma^2$ and $|h_{rd}|^2 = 1/\sigma^2$.

2.4 Bit Error Rate (BER) Analysis of MPSK and MQAM

Two modulation schemes used in this work are MPSK and MQAM which are all digital modulation techniques whose baseband signals are represented as time sequence of constellation order denoted as $M = 2^k$. The symbol error probability (P_s) of a coherent modulated signal for MPSK modulation scheme is [25],[26],[27],[21],[28]

$$P_s \approx 2Q\left(\sqrt{2\gamma_s}\sin\left(\frac{\pi}{M}\right)\right) \qquad (12)$$

From (12), the bit error probability is given as

$$P_s = kP_b \qquad (13)$$

therefore,

$$P_b = \frac{P_s}{k} = \frac{2}{\log_2 M} Q\left(\sqrt{2\gamma_b \log_2 M}\sin\left(\frac{\pi}{M}\right)\right) \qquad (14)$$

The P_s of a coherent modulated signal using MQAM modulation scheme is given as

$$P_s \approx \frac{2(\sqrt{M}-1)}{\sqrt{M}} Q\left(\sqrt{\frac{3\gamma_s}{M-1}}\right) \qquad (15)$$

Then using (13), the bit error probability for MQAM modulation scheme is given in [21]

$$P_b \approx \frac{2(\sqrt{M}-1)}{\sqrt{M}\log_2 M} Q\left(\sqrt{\frac{3\gamma_b \log_2 M}{M-1}}\right) \qquad (16)$$

Where $Q = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right)$ is the Marcum function, $erfc$ is the complimentary error function, P_b is the bit error probability.
The signal to noise ratio (SNR) for bit error is

$$\gamma_b = \frac{E_b}{N_0} \qquad (17)$$

Where E_b is the energy per bit.

3 Simulation Parameters

The performance of the two relaying protocols namely: AF and DF relaying protocol and also the effect on MPSK and MQAM modulation schemes are simulated in MATLAB programming environment. The parameters used for the simulation is as shown in Table 1.

Table 1: Simulation parameter

Parameter	Value
Length of message	10^4
Carrier frequency	900 MHz
Propagation environment	Rayleigh fading
P_t and P_r	1W
Speed of light	3e8 m/s
Modulation schemes	MPSK, MQAM
Signal to noise ratio	0dB - 30dB

4 Result and Discussion

The results obtained from the simulation of AF and the DF relaying over Rayleigh fading channel using MPSK and MQAM modulation schemes are presented. Figure 3 shows the result obtained for BER performance of AF and DF relaying protocols using MPSK modulation schemes in the order of 2, 4, 8 and 16. It is observed from the result that as the SNR increases, the BER values for both the AF and DF relaying protocols decreases. For instance at SNR of 10dB, the BER values of 0.03856, 0.10899, 0.225307 and 0.311653 were obtained for AF relaying while 0.0544, 0.1352, 0.2538 and 0.3287 for DF relaying were obtained for modulation orders 2, 4, 8 and 16 respectively. As the SNR increases to 30dB, AF has BER values of 0.00001, 0.00055, 0.000703 and 0.004835 while DF has 0.000052, 0.0013, 0.0042 and 0.0140 for modulation orders 2, 4, 8 and 16 respectively. In Figure 4, the result for AF and DF using MQAM was obtained and follow the same trend as that of MPSK. The result indicates that AF relaying still performs better than DF relaying at the same modulation orders of 4, 16 and 32. This is an indication that the AF relaying protocol is preferred to DF relaying protocol because the relay node for DF does not employ error correction capability.

Figure 5 and Figure 6 compare the results of MPSK and MQAM modulation schemes for AF and DF relaying protocols respectively. In Figure 5, the BER performance comparisons of the lower modulation order for AF relaying are close. For instance at SNR of 10dB, 0.03727 and 0.038535 were obtained for BPSK and 4-QAM while at 30dB the BER values of 0.00001 and 0.000025 were obtained respectively. Also for higher modulation order of 16-PSK and 16-QAM, the result shows that i6-PSK performs better as compared to 16-QAM with BER values of 0.004855 and 0,144058 respectively at 30dB. BER performance comparison for DF relaying protocol is shown in Figure 6. The result obtained shows that DF with BPSK and 4-QAM have the same BER values at all SNRs. For higher modulation schemes of 16-PSK and 16-QAM the BER values of 0.004835 and 0.16271 were obtained at 30dB respectively. This result implies that in other to transmit a signal of length 10^4, BPSK modulation scheme with AF relaying protocol is preferable to 4-QAM with AF relaying, due to little random error experienced by the signal during the transmission process. For that of the DF relaying protocol, either of the BPSK and 4-QAM can be employed as there is no significant difference in their performance. At higher modulation order of 16-PSK and 16-QAM for both AF and DF relaying protocol, the number of erroneous bits received during the transmission process becomes higher.

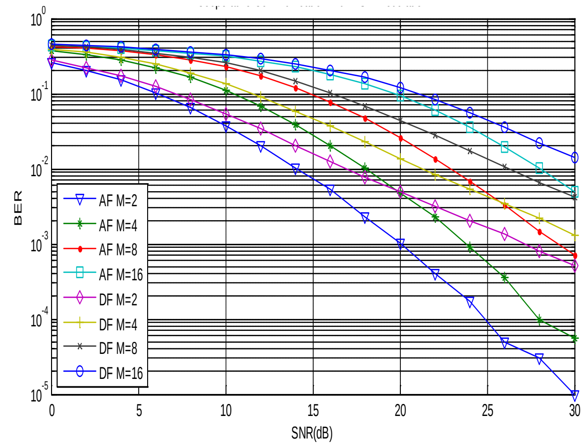

Fig. 3. BER performance of AF and DF relaying using MPSK.

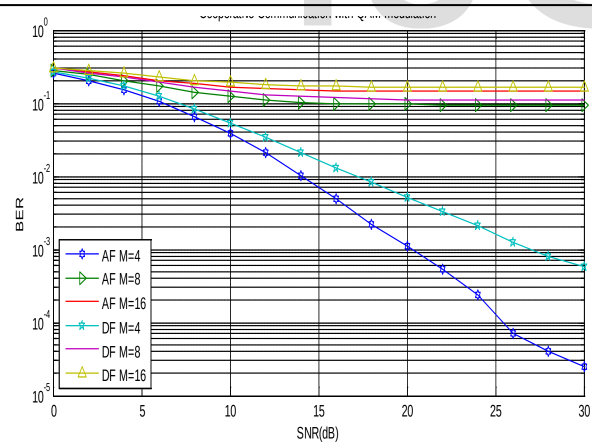

Fig. 4. BER performance of AF and DF relaying using MQAM.

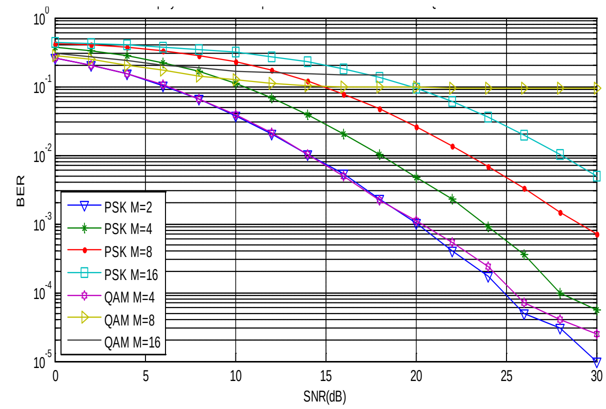

Fig. 5. BER performance of AF relaying using MPSK and MQAM.polarization)

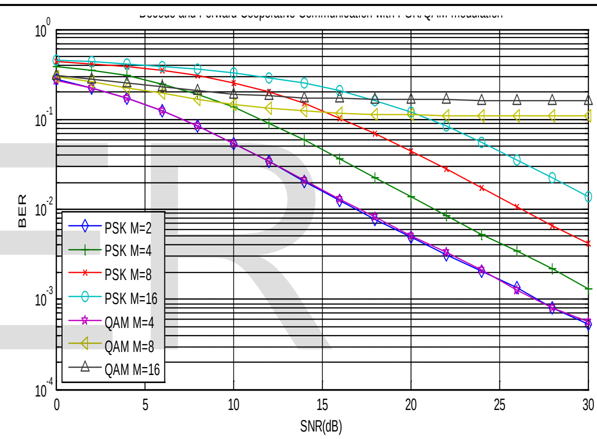

Fig. 6. BER performance of DF relaying using MPSK and MQAM.

5 CONCLUSION

The simulation result obtained in this paper for AF and DF cooperative relaying over Rayleigh fading channel using MPSK and MQAM in MATLAB software environment are presented. The performance comparisons of the simulation were evaluated in terms of BER over a cooperative relaying network using randomly generated data. The results obtained revealed that at higher SNR, the BER values for AF and DF using MPSK and MQAM decreases. Also, as the modulation order increases, the BER values for both MPSK and MQAM increases as SNR increases. BPSK with AF relaying outperforms the results obtained for other modulation schemes for

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AF relaying and as reported in [29] the DF relaying would have performed better if an error correction code is deployed at the relay node for the DF relaying protocol.

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