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Enhancement of Amplify-and-Forward Cooperative Relay Technique over Nakagami Fading Channel

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Abstract

As demand for wireless communication grows, its system is usually affected by channel impairment that degrade the performance. The traditional Amplify-and-Forward (AF) cooperative relaying technique, used to address the problem, often performs poorly because it amplifies not just the signal but also the noise. Therefore, this study introduces an enhanced AF relaying technique that uses spectral subtraction to reduce noise amplification. A signal is transmitted from the source through a Nakagami-m fading channel. At the relay node, the received signal undergoes spectral subtraction to remove noise, and is then amplified using adaptive gain. The amplified signal is then forwarded to the destination via multiple paths. The signals are combineddestination combines these signals using a hybrid Selection Combiner-Maximal Ratio Combiner (SC-MRC) to improve overall signal quality. The mathematical analysis of Bit Error Rate (BER) and Throughput (TP) shows that this enhanced AF technique significantly outperforms the traditional method. It achieved a 25.65% reduction in BER and an 82.83% increase in TP, demonstrating that it is a viable solution for improving the performance of cooperative communication systems.

Keywords: Amplify-and-forward, cooperative communication, spectral subtraction, Multipath Fading, Throughput (TP) and Bit Error Rate (BER)

1. Introduction

Wireless Communication (WC) system can be described as an information sharing method between multiple points which operates without any physical linkage between two or more points. The system communicates through space rather than electrical conductors which enables connection between its points as compared to traditional wired communication methods. The system does not impose distance limitations because points can freely join the system without electrical conduits to connect them. The current WC demand is growing rapidly because both connected devices have experienced exponential growth while new wireless device discoveries expand access to wireless services [1 – 3]. The operation of WCs faces performance limitations due to Multipath Fading which occurs because of channel impairments during signal transmission. Channel impairment that includes channel attenuation and distortion results in the degradation of signals during their transmission throughout the channel. The channel impairment that in WC include multipath propagation, shadowing and path loss [4 – 6]. The combine effect of channel impairment is Multipath Fading (MF), which is the fluctuation in the received signal at the destination. Channel fluctuations reach levels where the receiver's sensitivity threshold becomes ineffective thus causing poor signal reception that produces negative effects on receiver performance. The adverse effects caused by channel degradation require compensation to restore system performance in WC networks. Various compensation techniques have been designed to reduce fading problems in WC systems. These strategies include space diversity and equalization of various methods as well as empirical prediction models. Space diversity includes Cooperative Diversity (CD) as one of its essential components, allows the source node to transmit information to the destination through many intermediate nodes (relays) [7 - 10].

Cooperative Diversity (CD) is based on the idea that placing relay nodes between the source and destination will improve efficiency and improves reliability of the system. In the CD technique, the destination receives the transmitted signal with multiple copies (the copies of a signal that are generally affected by different and statistically independent fading paths). The two basic cooperative networks are formed by two basic relaying mechanisms, Decode and Forward (DF) and Amplify and Forward (AF). Previous study on CD revealed that the performance of AF relaying has been far worse than that of DF relaying because the signal amplification that amplifies the noise and diminish the efficiency of transmitting signal at the destination. Nevertheless, it will cause a signal outage at the destination if the channel between source and relay is faded and the relay does not completely decode the signal in DF [13] and [16 – 17]. Based on that, an enhanced AF relay protocol was proposed in this paper to suppress the noise amplification and enhance the performance of the system. Adaptive gain based on CSI is used at the relay node to reduce power consumption in the relay node. Furthermore, the performance of an AF relay technique is further improved by conducting multiple relay selections in SNR mode and choosing relays with an SNR greater than the predefined threshold SNR.

There have been several existing works on the AF cooperative relaying technique. The author in [18], analysed a linear processing design of AF relays which maximizes the system throughput. Using fixed gain AF techniques, a design of a multiple relay network is performed. At the destination, the multiple copies of the transmitted signal were combined by MRC. By comparing the current conventional air flow technique that was used with the technique, results showed that the technique was better suited to system throughput. Though, the technique amplify noise due to signal amplification thereby, making received signal worse, thereby reducing the overall performance of the system. The modification of the Multiple Antennas Amplify and Forward (MAAF) relays over the Nakagami fading channel was also carried out in [19]. The conventional MAAF relay protocol was changed by replacing the single RF chains and match filter mMRC. The modified technique gave low OP, BER and processing time. Despite that, the OP and BER become poor due to noise amplification. Hence, the aim of this paper is to raise the reliability of the AF relay protocol by adding spectral subtraction to completely compensate the noise amplification suffered by the system. The adaptive gain is used to control the relay node power consumption according to the CSI in this study. In addition, the best receiver can be selected using SNR for multi-relay selection by choosing relays with SNR higher than a given threshold to enhance the performance of the AF relay technique by improving SP. In this study, the following have been made in the contribution to knowledge

i. establish an AF cooperative relay technique with reduced noise amplification due to spectral subtraction and multiple relay selection.
ii. develop an AF cooperative relay technique with reduced power consumption due to adaptive gain used at the relay node

The remainder of this paper is organized as follows: Section 2 provides a comprehensive description of the research methodology. Section 3 presents simulation results, comparing the proposed technique with existing approaches. Finally, Section 4 concludes the paper.

2. Methods

Multiple relays were used to receive the transmitted signal at the relay node. The SNR at individual relay node is obtained and use to select the relays that participate in the second hop transmission based on the set threshold. The relay will be selected and second hop transmission will be carried out if the SNR at the relay node is greater than the set threshold of 1.5 dB. Otherwise, that relay node will be on sleep for that some time before the SNR of that relay node reaches 1.5 dB and likewise put that relay node into sleep mode as well. A possible noise in the signal is removed through a noise removal operation on the signal to get through the selected relays. The amplified signal is multiplied with the relay gain and is expected this to be a clean signal which is a resultant signal. To reduce power consumption at the relay node, the gain of the relay is made adaptive to the channel gain at a given time. In the second transmission hop as shown in Figure 1, the amplified signal is forwarded to the destination. Hybrid SC-MRC is utilized to combine the multiple copies of the signal at the destination. From the signals of highest strength, one is chosen and weighed with different weights. Figure 1 shows h_{SR} as the source to relay channel and h_{RD} is the relay to destination channel. In this paper, the channel gain at a given time is obtained, where the relay gain is made adaptive. The instantaneous channel gain "H_{sr}" at each relay node is given in [20] as

$$H_{sr} = \frac{\left(N \times 10^{R/B}\right) - 1}{P_t} \tag{1}$$

where: P_t is the transmit power

B is the channel bandwidth

N is the noise spectral density

R is the bit rate

The adaptive relay gain for the enhanced technique is obtained as

$$\beta = \left(\frac{P_r}{P_{ts} \frac{\left(N \times 10^{R/B}\right) - 1}{P_t} + N_r} \right)^{\frac{1}{2}} \tag{2}$$

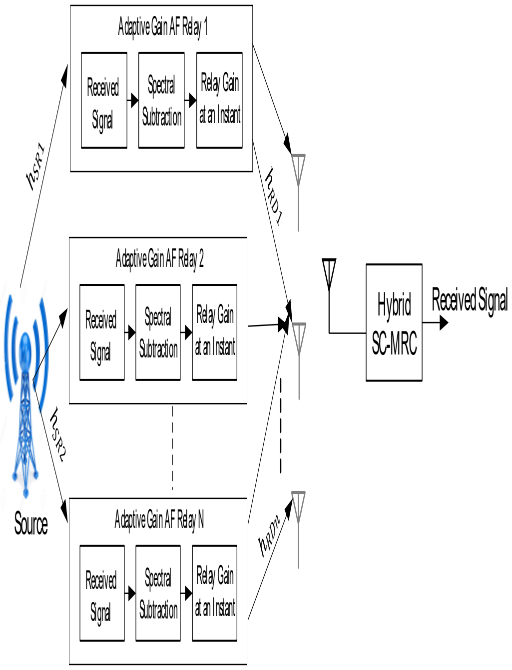

Figure 1: Block Diagram of an Enhanced AF Relay Technique

By solving Equation (2), the adaptive relay gain for the enhanced technique is obtained as

$$\beta = \left(\frac{P_r}{\frac{\left(N \times 10^{R/B}\right) - 1 + P_t N_r}{P_t}} \right)^{\frac{1}{2}} \tag{3}$$

$$\beta = \left(\frac{P_r P_{ts}}{N_r \left(P_{ts} \times 10^{R/B}\right) - 1} \right)^{\frac{1}{2}} \tag{4}$$

Equation (4) is the adaptive relay gain for the enhanced technique and it is a function of channel gain. However, the desired signal at the relay node $x_R(t)$ is given as

$$x_R(t) = y_R(t) - n_R(t) \tag{5}$$

where: $y_R(t)$ is the noisy signal at the relay node

$n_R(t)$ is the noise power at the relay node

But noise power is given as

$$n_R(t) = KTB \tag{6}$$

where: K is Boltzman constant

B is the bandwidth

T is the temperature

Using Equations (5) and (6), the desire signal at the relay node $x_R(t)$ is obtained as

$$x_R(t) = y_R(t) - KTB \tag{7}$$

Therefore, the amplified signal at the relay node $x_{RA}(t)$ which is the product of Equations (4) and (7) is obtained as

$$x_{RA}(t) = \left(y_R(t) - KTB\right) \times \left(\frac{P_r P_{ts}}{N_r \left(P_{ts} \times 10^{R/B}\right) - 1} \right)^{\frac{1}{2}}$$

(8)

Thus, during the second hub transmission, multiple antennas are used for broadcasting the amplified signal and noise free signal at the relay node to the destination. At the destination, the combined signal is then produced from a combination of the multiple copies of the received signal and this is performed using hybrid SC-MRC. The channel gain between the relay and destination $'H_{RD}'$ at a particular time multiplied by constant $^{P_t}/_N$

constitutes the instantaneous SNR of individual branch at destination. Therefore, the instantaneous SNR of the received signal $'\gamma'$ for individual branch at the destination is given as

$$\gamma = \frac{P_t H}{N}$$

(9)

Therefore, the instantaneous SNR of all the branches at the destination is the output SNR of hybrid SC-MRC 'SNR_{SC-MRC}' that is, the output SNR of the received signal at the destination for the proposed enhanced technique is obtained as

$$SNR_{SC-MRC} = \frac{1}{NSC}\left(\sum_{i=1}^{SC}\max\left(x_{RA}(t)\right).a_i\right)^2$$

(10)

where: $\max\left(x_{RA}(t)\right)$ is the output of individual SC

a_i is the weighing factor of individual branch

The PDF of the received signal for the proposed enhanced technique, using the PDF of the received signal "$P_r(r)$" over Nakagami-m fading channel and (10), is obtained as

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m\left(\frac{1}{NSC}\left(\sum_{i=1}^{SC}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right)^{2m-1} \times \exp\left(\frac{-m\left(\frac{1}{NSC}\left(\sum_{i=1}^{SC}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)$$

(11)

In this paper, the number of SC is assumed to be equal to three, therefore, Equation (11) becomes

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^{2m-1} \times \exp\left(\frac{-m\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)$$

(12)

For m equal to 0.5, Equation (12) becomes

$$P_r(r) = \frac{2}{\Gamma(0.5)}\left(\frac{0.5}{2\sigma^2}\right)^{0.5}\exp\left(\frac{-0.5\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)$$

(13)

For m equal to 1, Equation (12) becomes

$$P_r(r) = \frac{2}{\Gamma(1)}\left(\frac{1}{2\sigma^2}\right)\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right) \times \exp\left(\frac{-1\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)$$

(14)

Throughput (TP) and BER are the metrics used to evaluate the performance of the proposed enhanced AF technique and mathematical expression for these two metrics are derived as follow. In this work, Throughput (TP) is the rate at which messages are delivered successfully over a Nakagami-m fading channel and mathematical expression for throughput 'TP' is given as

$$TP = B \times log_2(1 + SNR)$$

(15)

where B is the bandwidth

However, the SNR of the received signal for the enhanced technique is given in Equation (10). Therefore, using Equations (10) and (15), the TP for the proposed enhanced AF technique is obtained as

$$TP = B \times log_2\left(1 + \frac{1}{NSC}\left(\sum_{i=1}^{SC}\max(\gamma).a_i\right)^2\right)$$

(16)

Also, the expression for BER ($P_b(E)$) is given as

$$P_b(E) = \int_o^\infty P_b\left({}^{E}/_{\gamma}\right)P_R(\gamma)d\gamma \qquad (17)$$

where: γ is the received SNR for the enhanced technique

$P_R(\gamma)$ is the PDF of the received signal for the enhanced technique.

Therefore, by using Equations (10) and (11), the BER for the proposed technique is obtained as

$$P_b(E) = \int_o^\infty P_b\left({}^{E}/_{\gamma}\right) \times \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^{2m-1} \times \exp\left(\frac{-m\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)d\gamma$$

(18)

According to Adeyemo et al. (2020), conditional error probability $P_b\left({}^{E}/_{\gamma}\right)$ is given as

$$P_b\left({E}/{\gamma}\right) = {1}/{2}\exp\left(a\gamma\right)$$
(19)

where: $a = 0.5$ for non-coherent modulatio

For non-coherent modulation, Equation (19) becomes

$$P_b\left({E}/{\gamma}\right) = {1}/{2}\exp\left(0.5\gamma\right) \tag{20}$$

Therefore, by using Equations (18) and (20), the BER for the enhanced AF technique is obtained as

$$P_b(E) = 0.5 \times \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \int_o^\infty \left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^{2m-1} \times \exp\left(0.5\gamma + \left(\frac{-m\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)\right)d\gamma$$
(21)

For m equal to 0.5, Equation (21) becomes

$$P_b(E) = 0.5 \times \frac{2}{\Gamma(0.5)}\left(\frac{0.5}{2\sigma^2}\right)^{0.5} \int_o^\infty \exp\left(0.5\gamma + \left(\frac{-0.5\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)\right)d\gamma$$
(22)

Similarly, for m equal to 1, Equation (21) becomes

$$P_b(E) = \frac{1}{\Gamma(1)}\left(\frac{1}{2\sigma^2}\right) \int_o^\infty \left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right) \times \exp\left(0.5\gamma + \left(\frac{-\left(\frac{1}{3N}\left(\sum_{i=1}^{3}\max\left(\gamma x_{RA}(t)\right).a_i\right)^2\right)^2}{2\sigma^2}\right)\right)d\gamma \tag{23}$$

3. Results and Discussion

The metrics used to evaluate the performance of the Enhanced Amplify and Forward (EAF) cooperative relay protocol over the Nakagami-m fading channel is BER and TP. BER values were obtained with different numbers of propagation paths and different modulation schemes in comparison with the work of [18]. The BER for the enhanced and conventional AF at L = 2 for 4QAM and 16QAM modulation schemes in the Nakagami-m fading channel is depicted in Fig. 2. At SNR of 8 dB, BER values of 1.92×10^{-8} and 2.02×10^{-8} were obtained for the enhanced and conventional AF, respectively using 4QAM modulation scheme, while the corresponding BER values obtained using 16QAM modulation scheme were 4.59×10^{-8} and 4.59×10^{-6}. In the results obtained, it was found that the AF technique provided better performance with low BER at the two modulation schemes considered taken into consideration with the conventional technique. This is due to the spectral subtraction used in the proposed enhanced AF technique that reduced amplified noise usually takes place during the amplification of the signal. Figure 3 shows the BER values gained at L = 4 using 4QAM and 16QAM modulation schemes for the enhanced and the conventional AF cooperative relaying protocols over the Nakagami-m channel. The BER values obtained at SNR of 8 dB with 4QAM modulation scheme were 6.39×10^{-10} and 6.59×10^{-8} for the enhanced and conventional AF, respectively, while the corresponding BER values obtained using 16QAM modulation scheme were 1.53×10^{-9} and 1.64×10^{-7}. Results obtained showed that BER reduced as the number of paths increased for both the two techniques. It is because of the reduction in error rate as the signal strength increases. BER versus SNR for the proposed enhanced AF technique with various numbers of propagation paths for 4QAM and 16QAM modulation schemes are shown in Fig. 4. The results revealed that the reduction in BER is proportional to the increase in the number of paths and that the brought about by signal strength increase as the number of path increases. Additionally, while 4QAM performed better with low BER at all the number of paths considered, 16QAM modulation schemes demonstrated a lower transmission rate, albeit with better low bandwidth efficiency (BER) than the 4QAM modulation scheme. Nevertheless, all the cases treated are found to perform with low BER, while conventional AF gives poor performance, whenever compared with the proposed enhanced AF technique due to spectral subtraction and hybrid SC – MRC used in during signal amplification that reduced amplified noise and signal strength is also increased simultaneousely.

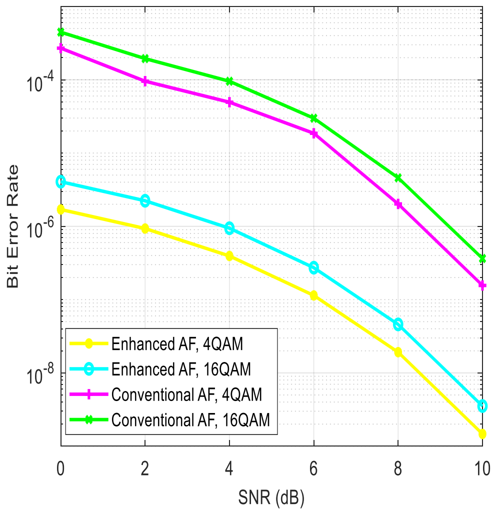

Figure 2: BER against SNR for the enhanced and conventional AF at L = 2 with different modulation schemes over Nakagami-m fading channel

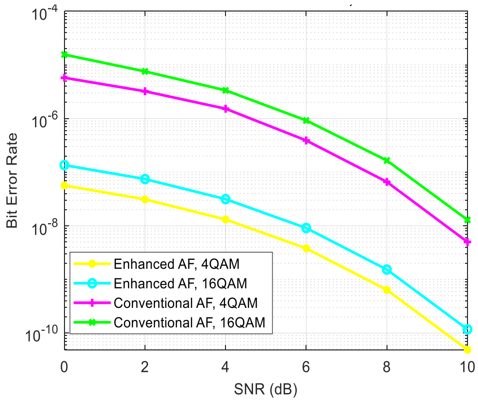

Figure 3: BER versus SNR for the enhanced and conventional AF at L = 4 with different modulation schemes over Nakagami-m fading channel

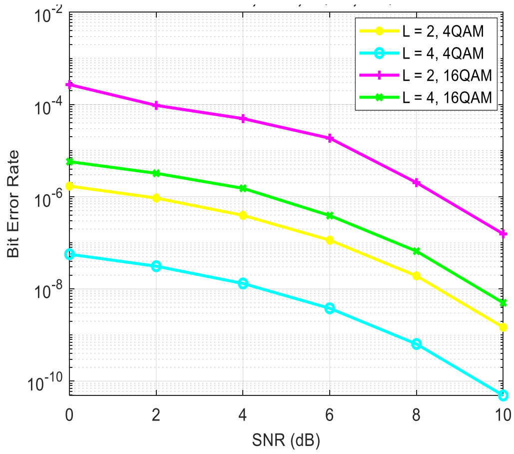

Figure 4: BER versus SNR for the proposed enhanced AF at different number of propagation path and modulation schemes over Nakagami-m fading channel

TP values are also obtained at different propagation paths, SNR and modulation scheme to evaluate the performance of the propose enhanced technique. Figure 5 presents TP against SNR for the enhanced and conventional AF at L = 2 using 4QAM and 16QAM modulation schemes over Nakagami-m fading channel. At SNR of 8 dB, the TP values of 5.2021 and 4.3092 bit/sec are obtained for the EAF and conventional AF, respectively using 16QAM modulation scheme, while the corresponding TP values obtained using 16QAM were 4.5699 and 3.1771 bit/sec. From the results obtained, the proposed EAF gives better performance with high TP values when compared with the conventional AF. This is due to hybrid SC-MRC and spectral subtraction used the enhanced technique that increase signal strength thereby reducing the error rate at the destination. The TP values obtained at L = 4 using 4QAM and 16QAM modulation schemes for the proposed EAF and conventional AF cooperative relaying protocols over Nakagami-m fading channel is presented in Figure 6. The TP values obtained at SNR of 8 dB with 4-QAM modulation scheme were 10.8732 and 6.2755 bit/sec for the enhanced and conventional AF, respectively, while the corresponding TP values obtained using 16QAM modulation scheme were 8.1254 and 4.6268 bit/sec. The effect of number of paths on the TP for the enhanced AF technique using different modulation scheme is presented in Figure 7. The results obtained showed that, at all the modulation schemes considered, TP increases as the number of propagation paths increases and this is due to increase in signal strength as number of propagation paths increases. Results obtained also revealed that at all the number of paths considered, TP values increase as the constellation size of the modulation reduces. This is due to robustness of signal in the channel when transmitting at the lower constellation size, though at the expense of low transmission rate. However, in all the scenario considered, enhanced AF technique gave better performance with high TP values when compared with conventional AF. This is due to spectral subtraction and hybrid SC-MRC that reduce the amplified noise and increase signal strength, respectively

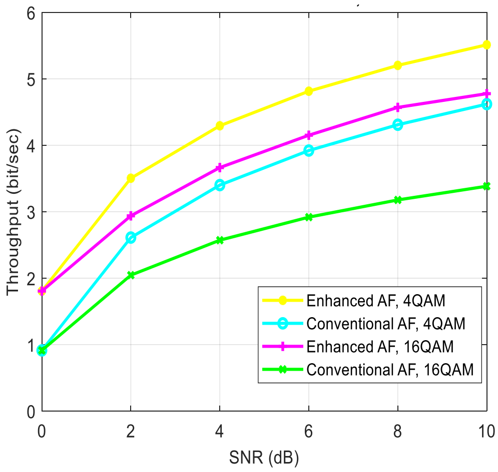

Figure 5: TP versus SNR for the enhanced and conventional AF at L = 2 with different modulation schemes over Nakagami-m fading channel

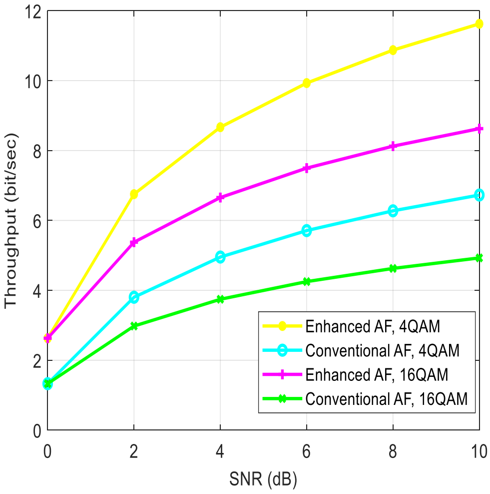

Figure 6: TP against SNR for the enhanced and conventional AF at L = 4 with different modulation schemes over Nakagami-m fading channel

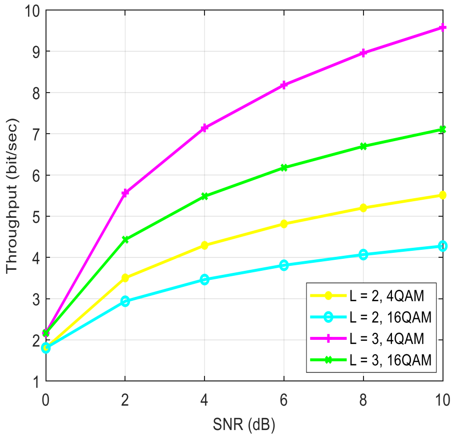

Figure 7: Throughput (TP) versus SNR for the enhanced AF at different number of propagation path and modulation schemes over Nakagami-m fading channel

4. CONCLUSION

An Enhanced Amplify and Forward (EAF) relay protocol operates through Nakagami-m fading channels is proposed in this paper. After transmission at the relay node, additional message duplicates are obtained from the same signal. SNR-based relay selection follows the transmission of second-hop signals by selecting one of the involved relays. The applied spectral subtraction processes combine with signal amplification which operates on chosen relays and then forwards information to the destination. All received signal copies serve the destination for combination through SC-MRC operation. The PDF of the received signal enables the derivation of mathematical BER and TP expressions for evaluating the proposed EAF technique performance. The received signal was modeled over the Nakagami-m fading channel using the system model at both the Relay node and destination point while the simulation noise was represented by AWGN and AWGN elements. M-QAM signaling schemes were tested with different AWGN trials while the fading envelope coefficient operated on each scheme. Multiple signal copies at the destination enable the evaluation of 'L' (2, 3, 4) propagation paths on the proposed EAF technique. The research evaluated BER and TP performance values of enhanced and conventional AF through different SNR conditions using multiple signal paths. An evaluation of the enhanced AF and conventional AF performance takes place through the utilization of BER and TP metrics across different 'L' propagation paths and SNR values. The developing signal processing method yielded stronger performance because spectral subtraction was implemented before amplification so BER remained lower and TP reached higher levels. The simulation findings revealed that BER value lowers according to the path number and SNR strength but TP value grows with rising path count together with SNR strength. The improvement in signal strength occurs because both SNR and the number of paths continue to increase. The 4QAM modulation yielded lower BER and higher TP across all number of paths when compared to the 16QAM modulation for both techniques. The channel provides increased signal resistance during lower constellation transmission yet achieves this by operating at a slow data transmission speed.

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