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# Performance Enhancement of Amplify Quantize and Forward Cooperative Relaying Technique in a Wireless Communication System

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## ABSTRACT

***Wireless communication systems are of paramount importance in the telecommunication infrastructure and have been playing a leading role in the development of nations. However, the system is characterized by multipath propagation effects that degrade the performance of the system. Amplify Quantize and Forward (AQF) cooperative relaying technique used to address the problem is characterized by poor performance due to signal amplification and obstruction along the propagating channel between the relay and destination. Hence, in this paper, the Enhancement of AQF (E-AQF) cooperative relaying protocol is carried out to improve the performance of the Conventional AQF (C-AQF) technique in a wireless communication system. The transmitted signal from the source is received at the relay node and the received signal is made to pass through spectral subtraction. The resultant signal is amplified using relay gain. The amplified signal at the relay node is quantized using uniform quantization before being forwarded to the destination during second hop transmission using angular beamforming. The multiple copies of the received signal at a varying path (L = 2, 4) are combined at the destination using Equal Gain Combiner (EGC). Mathematical expressions of Bit Error Rate (BER) and Throughput (TP) are derived using PDF. The performance of the proposed technique is evaluated using BER and TP by comparing it with the C-AQF cooperative relay technique. The proposed E-AQF gave better performance with reduced BER and increased TP than the C-AQF. The proposed E-AQF can be deployed to improve the performance of wireless communication systems.***

## INTRODUCTION

Communication through an unbounded environment known as a Wireless Communication (WC) system has experienced tremendous growth due to the emergence of new applications in various sectors of every nation, such as Banking, Marketing, and Security. The system has been receiving much attention in the field of technology and happens to be one of the most active areas of technology that covers all aspects of everyday life. WC is achieved using Electromagnetic (EM) waves that propagate through the space. However, in WC, EM waves are mainly affected by some propagation mechanisms such as reflection, diffraction, refraction, and scattering of signals leading to multipath propagation. The effect of multipath propagation is fluctuation in the received signal known as multipath fading that significantly degrades the performance of the system (Binh and Kiseon, 2016; Amogh and Carl, 2019; Admoon et al., 2019; Hui, 2021). Several methods have been proposed to mitigate the detrimental effect of multipath fading in wireless communication systems, these methods include Cooperative Communication (CC), equalization methods, and empirical prediction models. CC in which the transmitter (source) transmits a signal to the receiver (destination) through multiple nodes (relays) is usually adopted in WC to overcome the detrimental effect of multipath fading. This is due to the ability of the CC to improve coverage of the transmitting system without increasing the transmitting power. Also, cooperative communication has a lower complexity than equalization methods. The basic idea of CC is to improve the efficiency and reliability of the system by positioning relay nodes between the source and destination. Cooperative network comprises three basic relaying protocols, namely; Amplify and Forward (AF), Decode and Forward (DF), and Quantize and Forward (QF) (Nasir, 2017; Ojo et al., 2018; Xianglan, 2022; Abolade *et al*, 2022).

In AF, the relay amplifies the received signal and retransmits the amplified signal to the destination over the channel between the relay and the destination. On the other hand, DF decodes the received signal at the relay node, re-encodes, and forwards the encoded signal to the destination via the channel between relay and destination. Also, in QF, the received signal at the relay node is quantized before forwarding to the destination. AF and DF techniques are usually used in wireless communication due to their simplicity and lower complexity than the DF technique. Furthermore, in the DF technique, the relay can only transmit when the received signal satisfies a certain threshold such as SNR, otherwise, the relay remains silent leading to a signal outage at the destination (Admoon et al., 2019; Nasaruddin et al., 2020; Wang et al., 2021; Jihyun and Xianglan, 2023). However, the AF technique is analog, thereby making it susceptible to noise, that affects the communication system. Also, QF which is digital can only quantize the signal but cannot increase the strength of the signal, thereby suffering from low coverage. To ameliorate the challenges of the two techniques, the Amplify Quantize and Forward (AQF) cooperative relaying technique is proposed. In AQF, the signal received at the relay node is amplified and the amplified signal is quantized before forwarding to the destination, thereby making the signal less susceptible to noise over the channel between the relay and destination (Nasaruddin et al., 2017; Jihyun and Xianglan, 2023; Xianglan, 2024). The existing AQF cooperative relaying technique suffers from noise amplification that occurs during signal amplification before quantization. Also, the obstruction along the propagating channel between the relay and destination results in fluctuation in the received signal at the destination due to different paths having different amplitudes, angles of arrival, and time. The final received signal therefore, consists of a superposition of multiple variations of the quantized signal at the destination radiated from the relay node (Admoon et al., 2019; Dengyong et al., 2020; Jihyun and Xianglan, 2023).

Several works have been proposed to solve the problem of fading in wireless communication using CC. In Xianglan (2024), the MIMO Amplify-Quantize-Forward (AQF) Relay channel to investigate the MIMO AQF relay scheme over the fading channel was proposed. According to the author, the MIMO AQF relay technique consists of a source, relay, and destination. The results obtained revealed that the technique has a better performance than the existing AQF. However, the proposed AQF suffered from noise amplification that degraded the system performance. Also, the obstruction along the propagating channel between the relay and destination that results in fluctuation in the received signal at the destination affects the performance of the AQF technique. Also, complexity linear detection on a way Quantize-Forward Relay channel was carried out in Jihyun and Xianglan (2023). The author considered a half-duplex two-way QF relay protocol. The result of the work revealed that the QF with linear combining detection has a reduced hardware complexity when compared with maximum likelihood detection. However, the QF protocol is characterized by a low coverage area because it can only quantify the signal but cannot increase the strength of the signal. Furthermore, Nasaruddin et al. (2021), outage probability and power efficiency of quantize-and-forward relay in a multi-hop D2D network to mitigate the effect of fading in wireless communication system and to reduce the power consumption of the system. However, in all the scenarios considered, the system has a very high outage probability when transmitting over a long distance and this is due to the QF protocol that suffered from a low coverage area. Therefore, in this paper, performance enhancement of AQF cooperative relaying protocol in a wireless communication system is carried out using spectral subtraction to reduce the noise amplification that degrades the system performance. Also, angular beamforming in which the transmitting signal is directed to a particular receiver at a particular angle is adopted at the relay node to overcome the effect of fading between the relay node and destination thereby improving the performance of the proposed technique (Manar and Mohamed, 2018). The scattering of transmitted signals follows different fading distributions such as Weibull, log-normal, and Rayleigh distributions. Log-normal distribution was adopted in this paper due to its application in modeling both outdoor and indoor environments (Adeyemo et al., 2020). The following outlines the significant contributions of the paper:

i. Establishment of a new AQF cooperative relay technique with reduced noise amplification and enhanced Throughput due to spectral subtraction and angular beamforming used at the relay node.
ii. Derivation of mathematical expressions of Bit Error Rate (BER) and Throughput (TP) for the developed technique over a log-normal fading channel.

## Proposed Enhancement of Amplify Quantize and Forward Cooperative Relaying Technique

The transmitted signal from the source is received at the relay node. The received signal at the relay node is then made to pass through spectral subtraction to limit the noise that might be present. The resultant signal which is expected to be clean is amplified by multiplying with the relay gain. The amplified signal is quantized using uniform quantization and forwarded to the destination during second hop transmission using the angular beamforming technique as shown in Figure 3. The multiple copies of the signal at the destination are combined using EGC by weighing the received paths with equal weight. The weighted signals are co-phased to avoid signal cancellation before being summed up.

Figure 1 $h_{SR}$ represents the source to the relay channel and $h_{RD}$represents the relay to the destination channel. In this paper, the relay gain is made to be adaptive by obtaining the channel gain at a particular time. The instantaneous channel gain "$H_{sr}$ at individual relay nodes is given by Adeyemo *et al*. (2020) as

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

Where: $P_t$ is the transmit power, $B$ is the channel bandwidth, $N$ is the noise spectral density and R is the bit rate. Using Equation (1) and relay gain, the adaptive gain for the proposed technique is obtained as

$$\beta = \left(\frac{P_r}{P_{ts}\frac{\left(N\times10^{R/B}\right)-1}{P_t}+N_r}\right)^{\frac{1}{2}} \qquad (2)$$

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

$$\beta = \left(\frac{P_r}{\frac{\left(N\times10^{R/B}\right)-1+P_tN_r}{P_t}}\right)^{\frac{1}{2}} \qquad (3)$$

$$\beta = \left(\frac{P_rP_{ts}}{N_r\left(P_{ts}\times10^{R/B}\right)-1}\right)^{\frac{1}{2}} \qquad (4)$$

Equation (4) is the adaptive relay gain for the proposed technique. However, from Equation (4), the desired signal at the relay node $x_R(t)$ is given as

$$x_R(t) = y_R(t) - n_R(t) \qquad (5)$$

where: $y_R(t)$ is the noisy signal at the relay node, $n_R(t)$ is the noise power at the relay node According to Rouphael (2014), noise power is given as

$$n_R(t) = KTB \qquad (6)$$

where: $K$ is Boltzmann constant

$B$ is the bandwidth

$T$ is the temperature

Substituting Equation (6) into (5), gives

$$x_R(t) = y_R(t) - KTB \qquad (7)$$

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

$$x_{RA}(t) = (y_R(t) - KTB) \times \left(\frac{P_rP_{ts}}{N_r\left(P_{ts}\times10^{R/B}\right)-1}\right)^{\frac{1}{2}} \qquad (8)$$

The amplified signal is then quantized using uniform quantization, Using the SNR ‘ϒ’ of the quantized signal and the constant V for the uniform quantization the SNR ‘ϒ’of the quantized signal is obtained as

$$\Upsilon = 10log12 + 10log\left({}^{f_s}/_{2B}\right) + 20log2^{B_r}\left(x_{RA}(t)\right) \qquad (9)$$

$$\Upsilon = 10.79 + 10log\left({}^{f_s}/_{2B}\right) + 20log2^{B_r}\left(x_{RA}(t)\right) \qquad (10)$$

For a bit rate of 2, Equation (10) becomes

$$\Upsilon = 10.79 + 10log\left({}^{f_s}/_{2B}\right) + 12.04\left(x_{RA}(t)\right) \qquad (11)$$

$$\Upsilon = 1 + log\left({}^{f_s}/_{2B}\right) + 1.2\left(x_{RA}(t)\right) \qquad (12)$$

Equation (12) is the quantized signal at the relay node which is forwarded to the destination using angular beamforming and ‘$\propto$’ is the transmitting signal. Therefore, using Equations (12), The SNR ‘$\rho$’ of the received signal at the destination ‘$\rho$’ for the proposed technique is obtained as

$$\rho = \frac{\left(q_rHq_t\emptyset(1+log\left({}^{f_s}/_{2B}\right)+1.2\left(x_{RA}(t)\right)\right)^2}{\sigma_n^2} \qquad (13)$$

For the simulation purposes using MATLAB R2024a, the transmitting signals were generated randomly at the source and propagated through a log-normal fading channel. Multiple copies of the transmitted signal are received at the relay node. The received signal is processed using the E-AQF cooperative relaying technique. The resultant signal is forwarded to the destination as second hop transmission using angular beamforming. The multiple copies of the received signal at the destination are combined using EGC. Therefore, by using Equation (13), the SNR, ‘$\rho_{EGC}$’ of the received signal after combiner is obtained as:

$$\rho_{EGC} = \frac{1}{wL}\left(\sum_{i=1}^{L}\frac{\left(q_rHq_t\emptyset(1+log\left({}^{f_s}/_{2B}\right)+1.2\left(x_{RA}(t)\right)\right)^2}{\sigma_n^2}\right)^2 \qquad (14)$$

The PDF of the received signal “$P_r(r)$ for the proposed technique over the log-normal fading channel is obtained as

$$P_r(r) = \frac{4.34}{\rho_{EGC}\sigma(2\pi)^{\frac{1}{2}}} exp\left(-\frac{\left(ln\frac{1}{wL}\left(\sum_{i=1}^{L}\rho_{EGC}\right)^2 - \mu\right)^2}{2\sigma^2}\right) \tag{15}$$

Where: $r$ is the amplitude of the signal received, L is the number of paths, µ and $\sigma$are the mean and the standard deviation of$lnr$, respectively.

The performance of the proposed technique is evaluated using Throughput and BER.

In this paper, Throughput (TP) is the rate at which messages are delivered successfully over a log-normal fading channel. The expression for the 'TP' for the proposed technique is obtained as

$$TP = Blog_2(1 + SNR)(1 - OP) \tag{16}$$

Where: B is the channel bandwidth

But, the expression of SNR for the proposed technique is given in Equation (14), substituting Equation (14) into (16), the expression for Throughput for the proposed technique is obtained as:

$$TP = B \times log_2(1 + \rho_{EGC})(1 - OP) \tag{17}$$

**Throughput (TP)**

$$TP = B \times log_2\left(1 + \frac{1}{wL}\left(\sum_{i=1}^{L}\frac{\left(q_r H q_t \emptyset\left(1 + log\left({}^{f_s}/_{2B}\right) + 1.2\left(x_{RA}(t)\right)\right)\right)^2}{\sigma_n^2}\right)^2\right)(1 - OP) \tag{18}$$

Equation (18) is the TP for the proposed technique and outage probability is obtained by comparing the SNR of the received signal with the set threshold of 2 dB. If the SNR of the received signal falls below the set threshold, there is a signal outage at the destination, otherwise, there is no outage at the destination.

**Bit Error Rate (BER)**

The Bit Error Rate (BER) is the ratio of incorrect bits to the total bits transmitted. The expression of BER ($P_b(E)$) for the proposed technique is given as equation 19. Equation (19) is the BER for the proposed technique

$$P_b(E) \sum_{0}^{\infty} {}^{1}/_{2}\, exp(-0.5\gamma) \frac{4.34}{\rho_{EGC}\sigma(2\pi)^{\frac{1}{2}}} exp\left(-\frac{\left(ln\frac{1}{wL}\left(\sum_{i=1}^{L}\rho_{EGC}\right)^2 - \mu\right)^2}{2\sigma^2}\right) \tag{19}$$

**Simulation Results**

In this paper, BER is one of the metrics used to evaluate the performance of the proposed Enhanced Amplify Quantize and Forward (E-AQF) cooperative relaying technique in a wireless communication system over log-normal fading distribution. The BER values at different numbers of propagation paths with different constellation sizes of the modulation scheme were obtained and compared with the work of Xianglan (2024). Figure 2 presents the BER against SNR for the proposed E-AQF and C-AQF at L of 2 using 4-QAM and 16-QAM modulation schemes over log-normal fading distribution. At SNR of 8 dB, BER values of $2.15 \times 10^{-12}$and $6.79 \times 10^{-8}$ were obtained for the proposed E-AQF and C-AQF, respectively using a 4-QAM modulation scheme, while the corresponding BER values obtained using 16-QAM were $9.41 \times 10^{-11} 5.52 \times 10^{-7}$and for the E-AQF and C- AQF, respectively. The results obtained revealed that the proposed E-AQF technique gives better performance with lower BER values than the C-AQF technique. This is due to spectral subtraction applied before signal amplification that reduced the noise that might be present. Also, the better performance of the proposed technique is due to angular beamforming used at the relay node during second hop transmission. This makes the transmitting signal to be more focused in a certain direction (the targeted destination) thereby forming a focused beam of electromagnetic energy that enhances signal strength at the destination. The results obtained also revealed that both the E-AQF and C-AQF techniques gave a better performance with lower BER using the 4-QAM modulation scheme when compared with the 16-QAM modulation scheme. This is due to the error rate that reduces as the constellation size of the modulation scheme decreases though at the expense of a low transmission rate.

The BER values obtained at L of 4 using 4-QAM and 16-QAM modulation schemes for the proposed E-AQF and C-AQF cooperative relaying protocols over log-normal fading distribution are presented in Fig. 3. The BER values obtained at SNR of 8 dB with 4-QAM modulation scheme are $1.08 \times 10^{-13} 3.40 \times 10^{-9}$and for the proposed E-AQF and C-AQF technique, respectively, while the corresponding BER values obtained using 16-QAM were $4.67 \times 10^{-11} 1.48 \times 10^{-8}$and for the proposed E-AQF and C-AQF technique, respectively. Fig. 4 depicts BER versus SNR for the proposed E-AQF technique at different numbers of propagation paths with 4-QAM and 16-QAM modulation schemes. The results obtained showed that for the two constellation sizes of the modulation considered, BER values decrease as the number of propagation paths increases and this is due to signal strength that increases as the number of propagation paths increases. Also, at all the number of propagation paths considered, the 4-QAM modulation scheme gave better performance with lower BER when compared with the 16-QAM modulation scheme. This is due to a reduction in error rate at the destination as the constellation size of the modulation scheme decreases though at the expense of a low transmission rate. However, in all the cases considered, the proposed E-AQF technique gives better performance with lower BER when compared with the C- AQF. This is due to spectral subtraction applied before signal amplification that limited the noise that might be present. The better performance of the proposed E-AQF technique is also attributed to the angular beamforming used at the relay node to radiate signal during second hop transmission. This makes the transmitting signals to be more focused in a particular direction thereby forming a focused beam of electromagnetic energy that enhances signal strength at the destination.

TP values are obtained at different numbers of propagation paths, SNR, and modulation schemes to evaluate the performance of the proposed E-AQF technique. Figure 5 presents the TP versus SNR for the proposed E-AQF and C-AQF at L of 2 using 4-QAM and 16-QAM modulation schemes over log-normal fading distribution. At SNR of 8 dB, the TP values of 11.2341 and 9.3034 bit/sec were obtained for the proposed E-AQF and C-AQF, respectively using a 4-QAM modulation scheme, while the corresponding TP values obtained using 16-QAM were 10.6086 and 8.1880 bit/sec. From the results obtained, the proposed E-AQF gives better performance with higher TP values when compared with the C-AQF technique. This is due to spectral subtraction applied at the relay node that limits the noise that might be present before carrying out signal amplification thereby reducing the error rate at the destination. The better performance of the proposed technique is also due to angular beamforming and EGC used at the relay node and destination, respectively. These increase the strength of the received signal by forming a focused beam of electromagnetic energy and combining the multiple copies of the received signal at the destination.

The TP values obtained at L of 4 using 4-QAM and 16-QAM modulation schemes for the E-AQF and C-AQF cooperative relaying protocols over log-normal fading distribution are presented in Fig.6. The TP values obtained at SNR of 8 dB with 4-QAM modulation scheme are 16.8976 and 11.2745 bit/sec for the proposed E-AQF and C-AQF, respectively, while the corresponding TP values obtained using 16-QAM modulation scheme are 14.1254 and 9.6268 bit/sec. The effect of several paths on the TP for the proposed E-AQF technique using different constellation sizes of the modulation scheme is presented in Figure 7. The results obtained showed that, at all the constellation sizes considered, TP increases as the number of propagation paths increases and this is due to an increase in signal strength as the 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 the robustness of the signal in the channel when transmitting at the lower constellation size, though at the expense of a low transmission rate. However, in all the cases considered, the E-AQF technique gives better performance with higher TP values when compared with C-AQF. This is due to spectral subtraction and angular beamforming used at the relay node that reduces the noise before signal amplification and forms a focused beam of electromagnetic energy that enhances signal strength at the destination. The better performance of the proposed technique is also attributed to EGC used at the destination that combined the multiple copies of the received signal thereby improving the strength of the signal. The increase in the strength of the received signal reduces the error rate and increases the rate of the number of signals successful at the destination.

## CONCLUSION

This paper has proposed an Enhanced Amplify Quantize and Forward (E-AQF) cooperative relaying technique for wireless communication over a log-normal fading channel. Multiple copies of the transmitted signal from the source are received at the relay node. The received signals are made to pass through spectral subtraction and amplified using relay gain. The amplified signals at the relay nodes are quantized using uniform quantization before being forwarded to the destination during second-hop transmission using angular beamforming. The multiple copies of the received signal at the destination are combined using EGC. In the simulation process, the system model for the received signal at both the relay node and destination is modeled over log-normal fading distribution, while the noise is modeled as AWGN. The coefficient of the fading envelope is multiplied with M-ary Quadrature Amplitude Modulation (M-QAM) signaling schemes with the addition of AWGN at different trials. The multiple copies of the signals at the destination are received at varying propagation paths 'L' (2, 4) to investigate the effect of several paths on the proposed E-AQF cooperative relaying technique. The BER and TP values for the proposed E-AQF and C-AQF techniques are obtained at different SNRs with different numbers of propagation paths. Performance of the proposed E-AQF and C-AQF have been evaluated at different numbers of propagation paths 'L' with different SNRs using BER and TP as performance metrics.

The results obtained revealed that the proposed E-AQF technique showed a better performance with lower BER and higher TP than the C-AQF due to spectrum applied before signal amplification that limits the noise that might be present. Also, the better performance of the proposed technique is due to angular beamforming used at the relay node during second hop transmission. This makes transmitting signals more focused in a certain direction (the targeted destination) thereby forming a focused beam of electromagnetic energy that enhances signal strength at the destination. Furthermore, the better performance of the proposed technique is also due to EGC used at the destination which increases the strength of the received signal by combining the multiple copies of the received signal. The results obtained also revealed that for the two techniques, the BER reduces as the number of paths and SNR increases, while the TP increases as the number of paths and SNR increases. This is due to an increase in signal strength as SNR and the number of paths increase. Furthermore, for the proposed E-AQF and C-AQF, the 4-QAM modulation scheme gives better performance with lower BER and higher TP at all the number of paths considered than the 16-QAM modulation scheme. This is due to the robustness of the signal in the channel when transmitting at the lower constellation size, though at the expense of a low transmission rate. However, in all the cases considered, the proposed E-AQF technique gives better performance with higher TP and lower BER values when compared with the C-AQF.

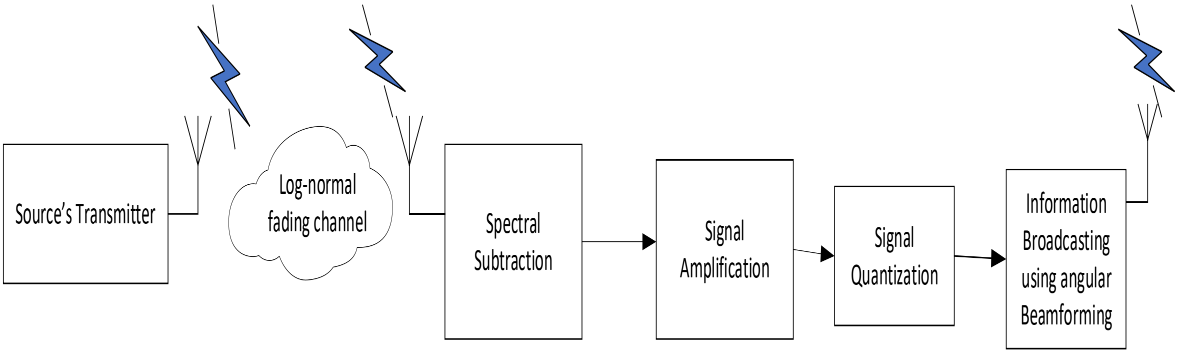

Figure 1: The Proposed Enhanced AQF Relay Technique

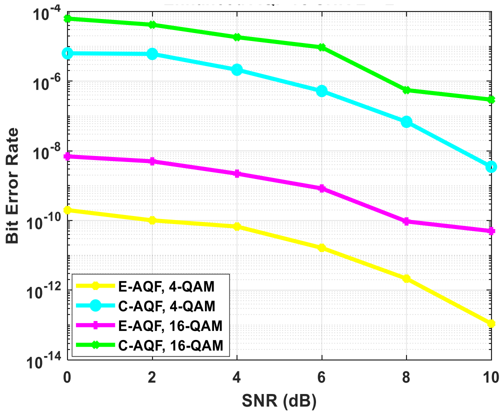

Figure 2: BER against SNR at L of 2

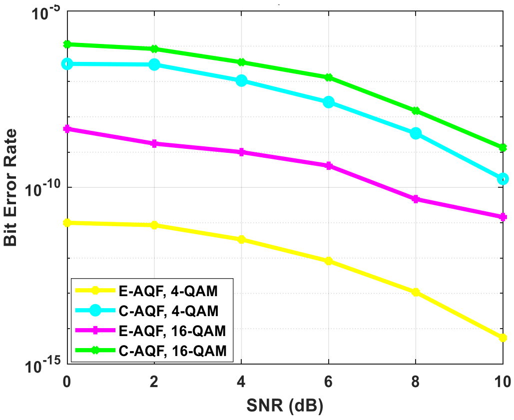

Figure 3: BER against SNR at L of 4

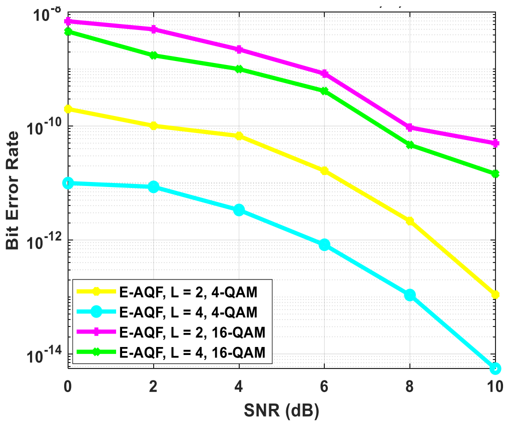

Figure 3: BER against SNR at L of 4

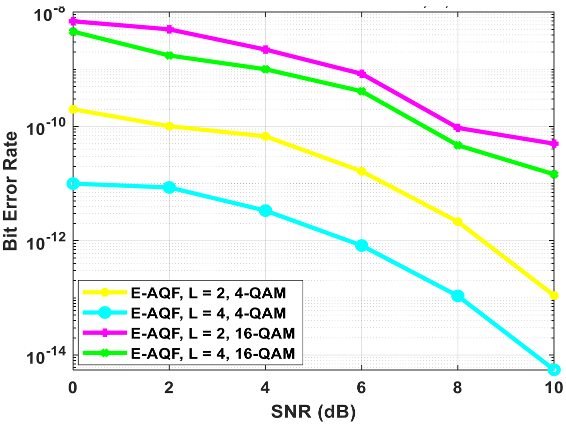

Figure 4: BER against SNR for the proposed E-AQF at different propagation paths and constellation size of the modulation schemes

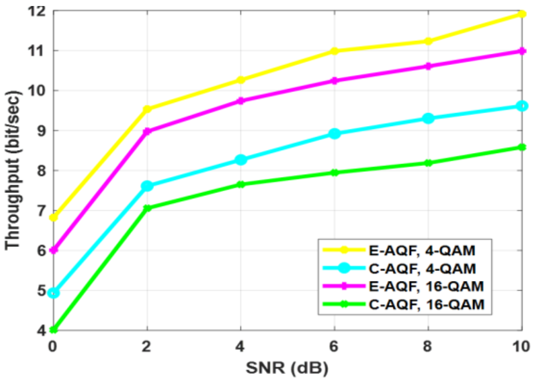

Figure 5: TP against SNR at L of 2

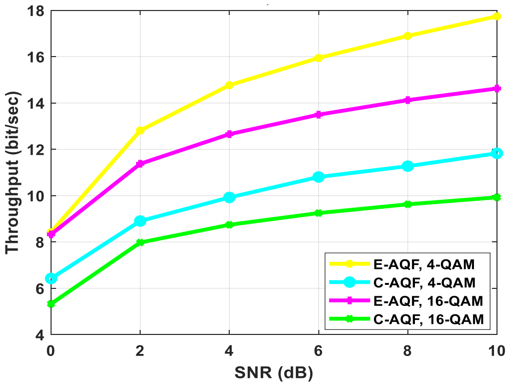

Figure 6: TP against SNR at L of 4

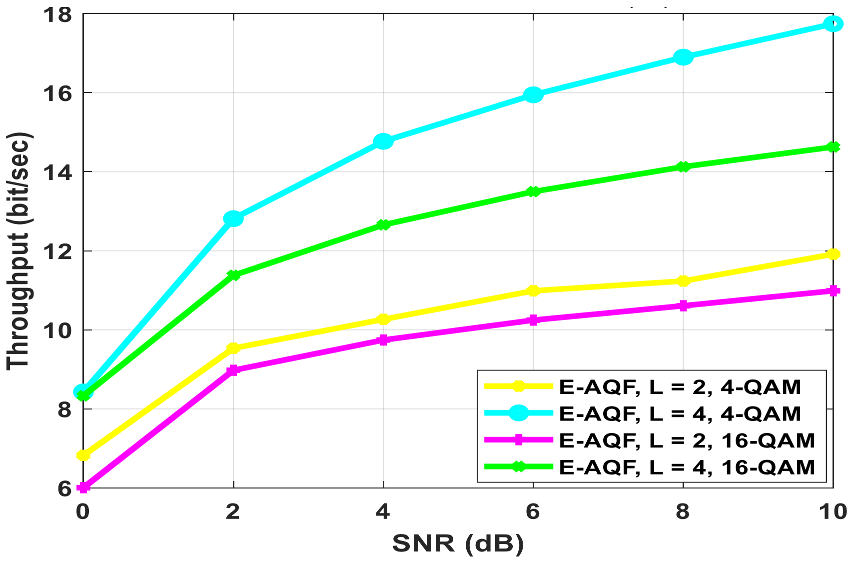

Figure 7: TP against SNR for the proposed E-AQF at different numbers of paths and constellation sizes of the modulation schemes

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