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EMD-Based Amplify Quantized and Forward Cooperative Relaying Technique for Wireless Communication System

Samson Iyanda OJO[1], James Oluwatomisin Oladapo[2], Robert Oluwayimika ABOLADE[1], Isaac Adewale OJEDOKUN[3], Oluwatobi Omolola OYEDOKUN[1]

[1]*Electronic and Electrical Engineering Department, Ladoke Akintola University of Technology, Ogbomoso*
siojo83@lautech.edu.ng/roabolade@lautech.edu.ng/oooyedokun@lautech.edu.ng

[2]*Electrical Electronic Engineering Department, the Federal Polytechnic, Ede*
tomiseg1234@gmail.com

[3]*Electronic/Electrical Engineering Department, Bowen University, Iwo*
isaac.ojedokun@bowen.edu.ng

Corresponding Author: tomiseg1234@gmail.com, +2348060070735
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Abstract: *Wireless communication system is crucial to telecommunications infrastructure and has played an essential role in national growth. However, the system's performance is hindered by multipath propagation, which has negatively impact in its performance. Amplify Quantized and Forward (AQF) cooperative relaying technique is ineffective because signal quality is degraded by amplification and blockages during transmission from the relay to the destination. Hence, an EMD-based AQF cooperative relaying for wireless communication system is proposed to enhance the existing AQF. The relays responsible for sending data to the second hub were determined by the multiple relay selection process. The selected relays processed the signal by passing it through EMD and amplifying it with the relay gain. Subsequently, the boosted signal was uniformly quantized at the relay nodes before its final send-off to the destination in the second transmission phase. The results showed that the proposed EMD-AQF technique outperformed the existing AQF, achieving a 74.5% reduction in bit error rate and a 65.8% increase in throughput.*

Keywords: *Amplify Quantized and Forward (AQF), Cooperative Communication, Quantized and Forward, Diversity Combiner and Empirical Mode Decomposition*

1. INTRODUCTION

Wireless Communication (WC) has seen enormous growth, becoming a crucial technology for diverse economic sectors (banking, marketing) and an integral part of daily life. WC operates by transmitting Electromagnetic (EM) waves through open space. Unfortunately, the quality of these waves is significantly degraded by phenomena like reflection, diffraction, and scattering as they travel. This physical interaction creates multipath propagation, which manifests as signal strength variations known as multipath fading, ultimately hindering the system's efficiency [1,2,3,4]. Cooperative Communication (CC) is a strategy used in Wireless Communication (WC) to combat the negative effects of multipath fading. The system operates by sending the source signal to the destination using multiple relay nodes along the way. CC is beneficial because it extends the network's coverage and improves the system's efficiency and reliability without needing a power increase. The three main methods for relaying signals in CC networks are Amplify and Forward (AF), Decode and Forward (DF), and Quantized and Forward (QF) [5,6,7].

Under the AF protocol, the relay node simply amplifies the signal it receives and then forwards it toward the destination. The DF protocol requires the relay node to fully process (decode and re-encode) the signal before sending it to the destination. Also, in QF, the received signal is converted into a discrete representation before being sent to destination. Amplify and Forward (AF) and Quantized and Forward (QF) techniques are commonly preferred in wireless communication because they are simpler and less complex to implement than Decode and Forward (DF). The major drawback of the DF method is its conditional transmission: a DF relay will only forward the signal if the received quality (like the SNR) exceeds a specific threshold; otherwise, the relay remains silent, resulting in a signal outage at the final destination [8, 9, 10, 11]. The Amplify and Forward (AF) technique is vulnerable to noise because it is an analog process. Conversely, the Quantized and Forward (QF) technique, while digital, cannot boost the signal strength, leading to poor coverage. To combine the strengths of both methods, the AQF cooperative relaying technique was introduced. AQF works by first amplifying the signal received at the relay and then quantizing the amplified signal before sending it to the destination. This process makes the signal less susceptible to noise on the link between the relay and the destination [12, 13, 14]. The existing AQF exhibits suboptimal performance owing to the inherent noise amplification associated with signal amplification. Channel blockages between the relay and the final receiver led to variations in the signal quality received at the destination, and this variability ultimately degrades the effectiveness of the AQF system [3, 4, 9]. Therefore, in this paper an EMD based AQF cooperative protocol is proposed to enhance the performance of the existing AQF.

There have been several existing works on AQF relaying technique to address the problem of multipath propagation in WC. In Xianglan [15], AQF relay, incorporating quadrature amplitude modulation was carried out. According to the author, the relay performed uniform quantization on the amplified version of the received signal before it is forwarded to the destination. The results of the simulation revealed the superiority of the proposed technique over only AF and QF techniques. The technique is hindered by noise amplification because the signal's noise is boosted along with the desired signal during the amplification stage that precedes quantization. Also, low complexity detection of linear signal on the two-way QF relay technique was proposed in Jihyun & Xianglan [16]. In the paper, the phases of the signals received were quantized in the relay node using Linear Combining (LC) and the reconstructed signal was broadcasted to the users. The results of the paper revealed that, a reasonable symbol error rate was achieved using LC compared to ML. However, QF can only quantize the signal but cannot increase the strength of the signal, thereby suffers from low coverage area. Furthermore, in Xianglan [17], MIMO Detection on AQF relay scheme was proposed to address the problem of multipath propagation in WC. In the paper, the received signal was uniformly quantized and amplified before it is forwarded to the destination at the relay node using detection method. The proposed technique significantly reduced the complexity of the detection technique. Prior research on AQF relaying indicates that its performance is hampered by noise that is amplified along with the signal during the pre-quantization stage. Additionally, physical blockages between the relay and the destination create a challenging environment where the signal travels via diverse paths. Because these paths differ in strength, angle, and delay, the received signal at the destination suffers from significant fluctuations. Therefore, this paper, proposed EMD based QAF cooperative relaying technique for wireless communication system to improve the existing QAF. The contributions of this paper are outlined as follows:

i. Establishing novel AQF cooperative relay approach that decreases noise amplification by incorporating EMD into the process before the signal is amplified
ii. deriving mathematical expressions of BER and Throughput (TP) for the enhanced AQF technique under Nakagami-m fading conditions

2. LITERATURE SURVEY

Empirical Mode Decomposition (EMD) and Maximal Ratio Combiner (MRC) are the two major techniques used in this paper to enhance the performance of the existing AQF technique.

2.1 Empirical Mode Decomposition

EMD is a denoising technique that operates based on iterative process by generating various components of the original signal and the various components generated is known as Intrinsic Mode Function (IMF). The technique decomposes time series signal, into a complete and finite set of frequency and amplitude modulation components known as IMF, via shifting process. Shifting process is one of the main concepts of the EMD in which the iteration continues over the signal until a stoppage criterion is satisfied. However, the number of iterations in each shifted IMF depends on the signal length as well as smoothness [18, 19]. The IMF has to meet two key requirements. Firstly, number of zero that crossings and extrema in the data should be nearly equal or identical. Secondly, mean value signal defined by the local minima and local maxima must be zero at any given point [19, 20]. The original signal can be reconstructed as indicated in (1) by [19]

$$\breve{x}(n) = \varphi(n) + \sum_{j=1}^{M} IMF_i(n) \tag{1}$$

where $\breve{x}(n)$ is the reconstructed signal
$\varphi(n)$ is the residue of $x(n)$
M is the number of shifted IMF

EMD technique is applied to the signal received at the relay node before signal amplification to remove the noise that might be present.

2.2 Maximal Ratio Combiner

MRC is a technique in which the different copies of the signals are co-phased and multiplied with respective weight factor before summing. It is a useful technique that combat problem of fading by improving performance of the system. In this technique, signals from various branches are aligned in phase and assigned different weights before being summed. The weights are proportional to the levels of the respective signals to maximize the overall SNR. The technique is the optimal combining scheme, irrespective of independent fading statistics [21, 22]. MRC involves receiving antennas that capture the signal, which has been degraded as it travels through space. The signal is processed through individual channel estimators to obtain the channel gain for each branch. The signal then passes through a matched filter to remove the unwanted signal that might be present in the signal and summed up [23, 24]. The SNR output of MRC 'SNR_{MRC}' is given in [23] as

$$SNR_{MRC} = \frac{\left(\sum_{i=1}^{L} a_i r_i\right)^2}{\sum_{i=1}^{L} a_i^2 w} \quad (2)$$

where: r_i represent the power of the signal on each branch
a_i represent the weighing factor
L is the count of branches, and w is the measure of noise power present on every branch.

2.3 Quantization in Wireless Communication

Quantization is the mapping of analog (continuous amplitude) signal into digital (discrete amplitude) signal. The mapping is done into discrete and countable levels popularly known as quantization level with each of the level representing fixed amplitude. The analog sampled signal, though it is discrete in time but the amplitude remains continuous, therefore, there is a need for signal quantization to convert the amplitude from continuous to discrete. The quantization levels do not actually necessarily have to be equally spaced to give a linear sampling of continuous amplitude signal. However, in most systems, the samples are equally spaced and this results into two fundamental forms of signal quantization namely uniform and non-uniform quantization. Uniform quantization is a technique in which the levels of quantization are uniformly spaced and each step size is representing constant amount of amplitude of analog which remains constant throughout the waveform of the signal. On the other hand, non-uniform quantization describes the quantization in which space between the step size known as quantized level is non-uniform [25]. The quantization level "Q_l" is given by [25] as

$$Q_l = 2^{B_r} \quad (3)$$

where B_r is the number of bit
The SNR 'γ' of the quantized signal is given by [26] as

$$\gamma = V + 20log2^{B_r}(\gamma_a(t)) \quad (4)$$

where: $\gamma_a(t)$ is the signal power of analog signal

3. PROPOSED EMD BASED AQF COOPERATIVE RELAYING TECHNIQUE

This paper utilizes multiple relays to receive multiple versions of the source signal. A relay selection strategy based on SNR is implemented. Relays with SNR exceeding a threshold of 1.5 dB are selected for participation in the second transmission phase, while others remain inactive. Selected relays employ EMD to reduce noise in their received signals. Subsequently, the denoised signals are amplified and quantized before being broadcast to the destination. MRC is employed to combine signals received at destination. This involves assigning weights to each received path and co-phasing the signals to prevent signal cancellation before summing them together. The instantaneous SNR of individual branch at the relay node is influenced by the channel gain experienced between the source and the relay node at a particular time and a fixed value of $^{P_t}/_{N}$. The SNR of the signal received for each branch at the relay node is presented in Equation (5) as

$$\gamma = \frac{P_t h_{SR}}{N} \quad (5)$$

The SNR of all the branches were obtained using Equation (3) and the value was compared with the set threshold. The selection criteria dictate whether an eligible relay will proceed to assist with the second transmission phase or switch off into sleep mode.

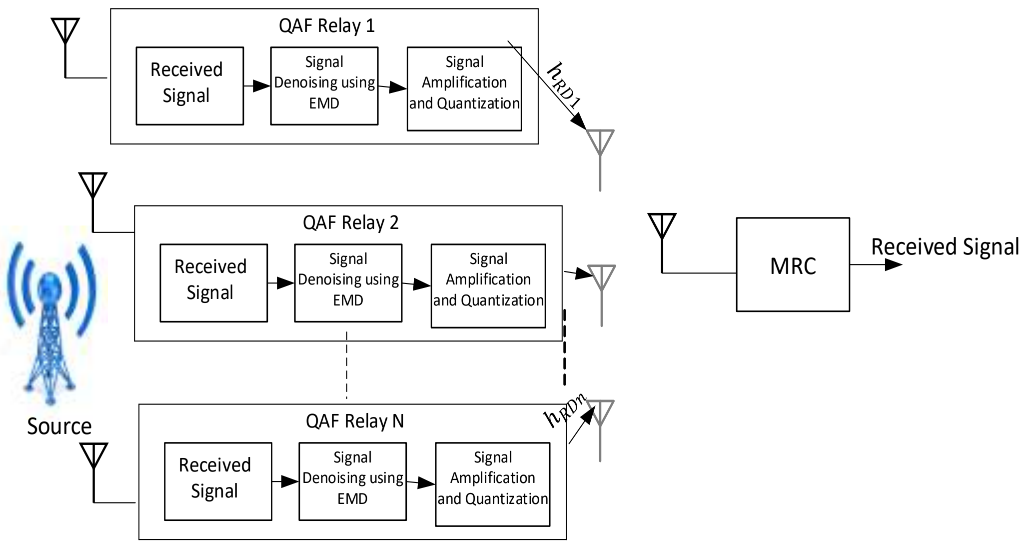

Figure 1: Architecture of the proposed EMD based AQF cooperative relaying protocol

The signal at the selected relay 'x_i' is made to pass through EMD for signal denoising. The signal output of EMD '$\breve{x}(n)$' is given in Equation (1). The signal output of the EMD was boosted (amplified) by multiplied by the relay amplification factor. Therefore, the signal output '$\delta(i)$' for the proposed technique is the product of EMD output signal and the relay gain and this is obtained as

$$\delta(i) = \breve{x}_i(n)\left(\frac{P_r}{P_r x h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}} \quad (6)$$

The boosted signal was quantized through uniform quantization. The SNR '∝' of the output signal is given in (3) and the constant V for uniform quantization is expresses as given in Equation (4). Therefore, substituting Equation (4) into Equation (3), the SNR '∝'of the signal quantized is given as

$$\propto = 10log12 + 10log\left({}^{f_s}/_{2B}\right) + 20log2^{B_r}(\gamma_a(t)) \quad (7)$$

$$\propto = 10.79 + 10log\left({}^{f_s}/_{2B}\right) + 20log2^{B_r}(\gamma_a(t)) \quad (8)$$

For bit rate of 2, Equation (8) becomes

$$\propto = 10.79 + 10log\left({}^{f_s}/_{2B}\right) + 12.04(\gamma_a(t)) \quad (9)$$

$$\propto = 23.19 + 10log\left({}^{f_s}/_{2B}\right)(\gamma_a(t)) \quad (10)$$

Using (6) and Equation (10), the output signal of the proposed EMD based AQF 'γ_{QF}'at the relay node is obtained as

$$\gamma_{QF} = 23.19 + 10log\left({}^{f_s}/_{2B}\right)\left(\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right) \quad (11)$$

The output signal was then radiated to the destination through Nakagami-m fading. The different versions of the signal reaching the destination are combined through MRC. The SNR output of MRC 'SNR_{MRC}' is given in Equation (2). Therefore, substituting Equation (11) into Equation (2) gives

$$SNR_{MRC} = \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_s}/_{2B}\right)\left(\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)\right)^2}{\sum_{i=1}^{L} a_i^2 w} \quad (12)$$

Using Equation (12), The Probability Density Function (PDF) of the signal for the enhanced system operating over a Nakagami-m fading is derived as follow

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_s}/_{2B}\right)\left(\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(\frac{-m\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_s}/_{2B}\right)\left(\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)\right)^{2^2}}{\sum_{i=1}^{L} a_i^2 w}}{2\sigma^2}\right) \quad (13)$$

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_s}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-m2\sigma^2\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_s}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (14)$$

For m equal to 0.5, Equation (14) becomes

$$P_r(r) = \frac{2}{1.772}\left(\frac{0.5}{2\sigma^2}\right)^{0.5}\left(\frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({f_s}/{2B}\right)\check{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({f_s}/{2B}\right)\check{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (15)$$

For m equal to 1, Equation (14) becomes

$$P_r(r) = \frac{1}{\sigma^2}\left(\frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({f_s}/{2B}\right)\check{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-2\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({f_s}/{2B}\right)\check{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (16)$$

3.1 Throughput (TP)

The expression for throughput ‘TP’ and bit rate ‘R’ is given in Equations (17) and (18), respectively in [27] as

$$TP = R(1 - OP) \quad (17)$$

where R is transmission rate and it is given as

$$R = B \times log_2(1 + SNR) \quad (18)$$

where: B is the channel bandwidth

Therefore, using Equations (18) and (17), the expression for throughput is obtained as

$$TP = B \times log_2(1 + SNR)(1 - OP) \quad (19)$$

The SNR for the improved technique is mathematically presented in Equation (12). Therefore, using Equations (12) and (19), the expression of TP is obtained as

$$TP = B \times log_2\left(1 + \frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({f_s}/{2B}\right)\check{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)(1 - OP) \quad (20)$$

Equation (20) represents the throughput for the proposed technique. The system's outage probability is determined by comparing the received signal's SNR against a threshold of 2 dB. An outage occurs if the received SNR falls below this 2 dB threshold; otherwise, the signal is successfully received.

3.2 Bit Error Rate

The expression for Bit Error Rate ($P_b(E)$) in [28] as

$$P_b(E) = \int_o^\infty P_b\left({E}/{\gamma}\right) P_R(\gamma)d\gamma \quad (21)$$

where: $P_R(\gamma)$ is the PDF of signal received as given in Equation (16). Using Equations (16) and (21), the expression for BER is obtained as

$$P_b(E) = \int_o^{\infty} P_b\left({}^{E}/_{\gamma}\right) \times \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-m2\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) d\gamma \quad (22)$$

But conditional error probability $P_b\left({}^{E}/_{\gamma}\right)$ is given as

$$P_b\left({}^{E}/_{\gamma}\right) = {}^{1}/_{2}\exp(0.5\gamma) \quad (23)$$

Therefore, Substituting Equation (23) into (22) gives

$$P_b(E) = \int_o^{\infty} \exp(0.5\gamma) \times \frac{1}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-m2\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) d\gamma \quad (24)$$

$$P_b(E) = \frac{1}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-m2\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \int_o^{\infty} \exp(0.5\gamma)\, d\gamma \quad (25)$$

Integrating Equation (25) with respect to γ and substituting upper and lower limit gives

$$P_b(E) = \frac{1}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times \exp\left(-m2\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (26)$$

For m equal to 0.5, the BER for the proposed technique is obtained as given in (27)

$$P_b(E) = \frac{1}{\Gamma(\mathrm{m})}\left(\frac{0.5}{2\sigma^2}\right)^{0.5} \exp\left(-\sigma^2 \frac{\left(\sum_{i=1}^{L} 23.19a_i + 10log\left({}^{f_S}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (27)$$

For m equal to 1, the BER for the proposed technique is obtained as

$$P_b(E) = \frac{1}{2\sigma^2\Gamma(\mathrm{m})}\left(\frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({}^{f_s}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)\times$$

$$\exp\left(-2\sigma^2\frac{\left(\sum_{i=1}^{L} 23.19a_i+10log\left({}^{f_s}/_{2B}\right)\breve{x}_i(n)\left(\frac{P_r}{P_r h_{sri}^2+N_{ri}}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \quad (28)$$

Equations (27) and (28) are the BER for the proposed technique at m equal to 0.5 and 1, respectively.

4. SIMULATION RESULTS AND DISCUSSION

The EMD-AQF cooperative relaying technique is evaluated using the BER metric, which measures its performance in Nakagami-m fading channel conditions. The BER performance of the enhanced technique was compared with the results of a previous study in [29] under various conditions of propagation paths and modulation schemes. In this paper, existing AQF cooperative relaying technique represent the work in [29]. The performance of the new EMD-AQF technique was assessed against the existing AQF technique in a Nakagami-m fading channel with two branches (L=2), using both 4QAM and 16QAM modulation as shown in Figure 2. The proposed EMD-AQF clearly outperformed the existing AQF by achieving lower BER. This improvement is attributed to the use of EMD before signal amplification, which effectively removes noise. Furthermore, both techniques performed better with 4QAM than with 16QAM, demonstrating the general principle that using a smaller constellation size (4-QAM) reduces the error rate, though this comes at the cost of a lower data transmission rate.

The values of BER obtained at L of 4 using 4QAM and 16QAM for the proposed and existing AQF over Nakagami-m fading channel is presented in Figure 3. At SNR of 6 dB with 4QAM, the BER values obtained were 8.24×10^{-11} and 2.61×10^{-8} for the proposed EMD-AQF and existing AQF technique, respectively, while 4.12×10^{-9} and 1.3×10^{-7} were the corresponding BER values obtained using 16QAM. Figure 4 depicts BER versus SNR for the proposed EMD-AQF technique at different number of propagation path with 4QAM and 16QAM modulation schemes. Simulation results demonstrate that BER decreases with an increasing number of signal paths for both 4QAM and 16QAM modulations. This improvement is attributed to the increased signal strength resulting from multiple paths. 4QAM consistently outperforms 16QAM across all path numbers, exhibiting lower BER. This is expected, as higher-order modulations inherently have a higher probability of error. However, the proposed EMD-AQF technique consistently surpasses the existing AQF technique in terms of BER performance. This performance gain is attributed to the effective noise reduction achieved by applying EMD prior to signal amplification.

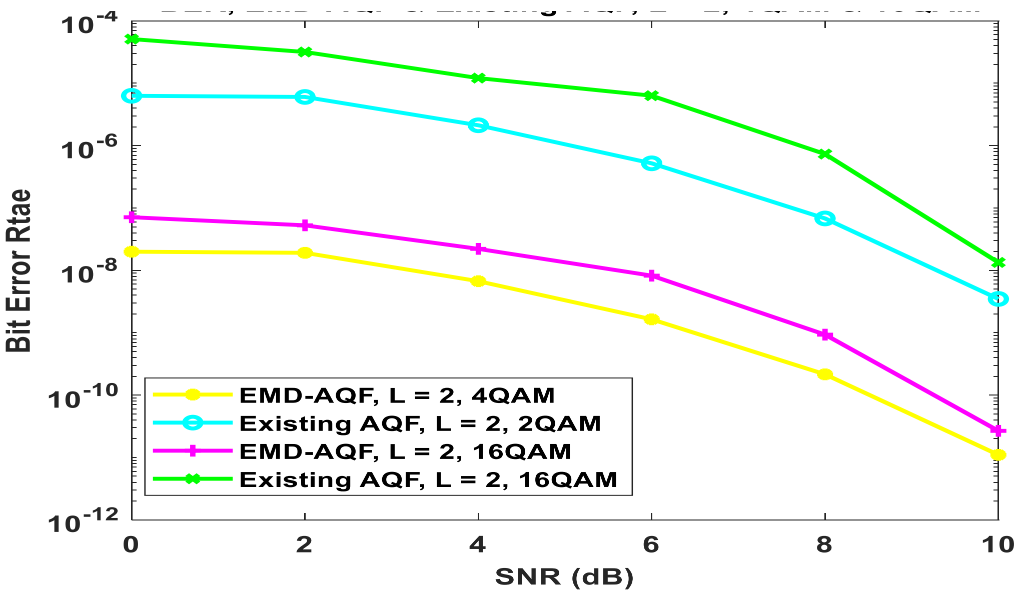

Figure 2: BER against SNR for the proposed EMD-AQF and existing AQF at L of 2 with different modulation schemes in a Nakagami-m fading environment

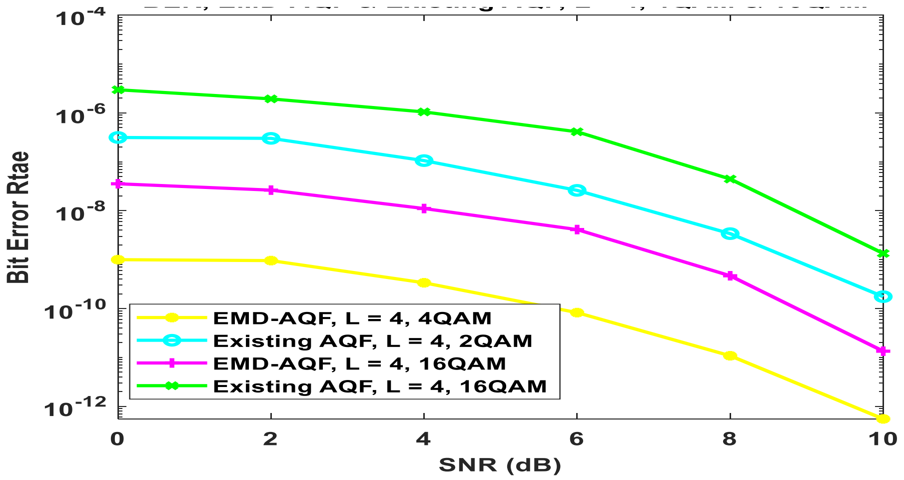

Figure 3: BER versus SNR for the proposed EMD-AQF and existing AQF at L of 4 with different modulation schemes in a Nakagami-m fading environment

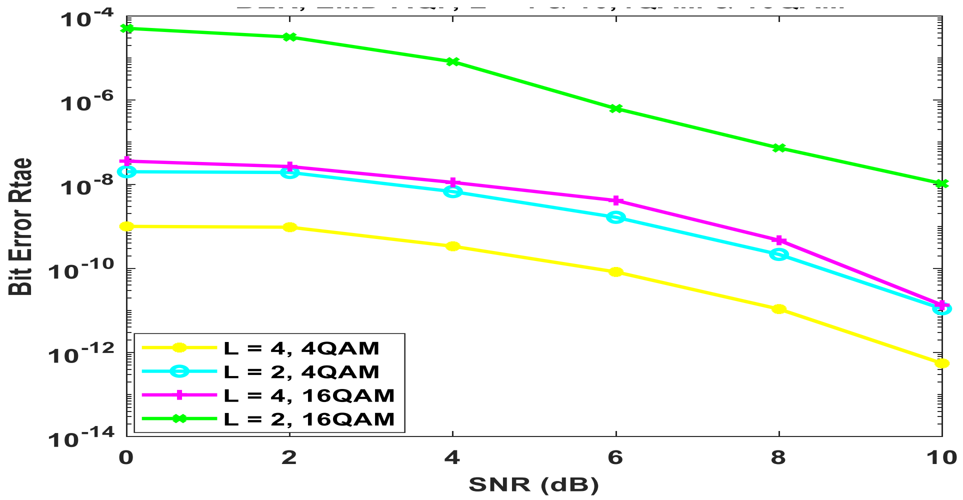

Figure 4: BER versus SNR for the proposed EMD-AQF at different number of paths and constellation size of the modulation schemes in a Nakagami-m fading environment

This study evaluated TP performance of the proposed EMD-AQF technique under various conditions, including different propagation paths, SNRs, and modulation schemes. TP values for the proposed technique are compared to those of the existing AQF technique for 4QAM and 16QAM modulations with two propagation paths (L=2) in a Nakagami-m fading environment. As shown in Figure 5, at an SNR of 6 dB, the proposed EMD-AQF achieved higher TP values (5.8136 bit/sec for 4QAM and 5.1511 bit/sec for 16QAM) compared to the existing AQF (3.9207 bit/sec for 4QAM and 2.9181 bit/sec for 16QAM). This superior performance of the proposed technique can be attributed to two key factors: Firstly, the application of EMD at the relay node, which effectively reduces noise before signal amplification, leading to lower error rates at the destination. Secondly, the utilization of MRC at the destination, which enhances the received signal strength by combining multiple signal copies.

The TP values obtained at L of 4 using 4QAM and 16QAM modulation schemes for the proposed EMD-AQF and existing AQF cooperative relaying protocols over Nakagami-m fading channel is presented in Fig. 6. The proposed EMD-AQF technique achieved a higher throughput than the existing AQF technique under both 4QAM and 16QAM modulation schemes. At an SNR of 6 dB, the throughput of the EMD-AQF technique was 10.9304 bit/sec with 4QAM and 8.4968 bit/sec with 16QAM, while the corresponding throughputs of the existing AQF technique were 5.7098 bit/sec and 4.2497 bit/sec, respectively. The impact of the number of propagation paths on the TP performance of the proposed EMD-AQF technique is analyzed for different modulation constellations in Fig. 7. The results demonstrate a clear trend of increasing TP as the number of paths grows. This improvement can be attributed to the constructive interference and enhanced signal strength resulting from the reception of multiple signal copies over different propagation paths. The TP increased as modulation constellation size decreased for all the propagation paths considered. This is due to the fact that while transmitting at a lower constellation size, the signal is more reliable, but this comes at the cost of slower data transfer. However, in all the cases considered, the proposed EMD-AQF technique gave better performance with higher TP values when compared with the existing AQF. This is due to EMD and MRC that reduces the amplified noise and increase signal strength, respectively.

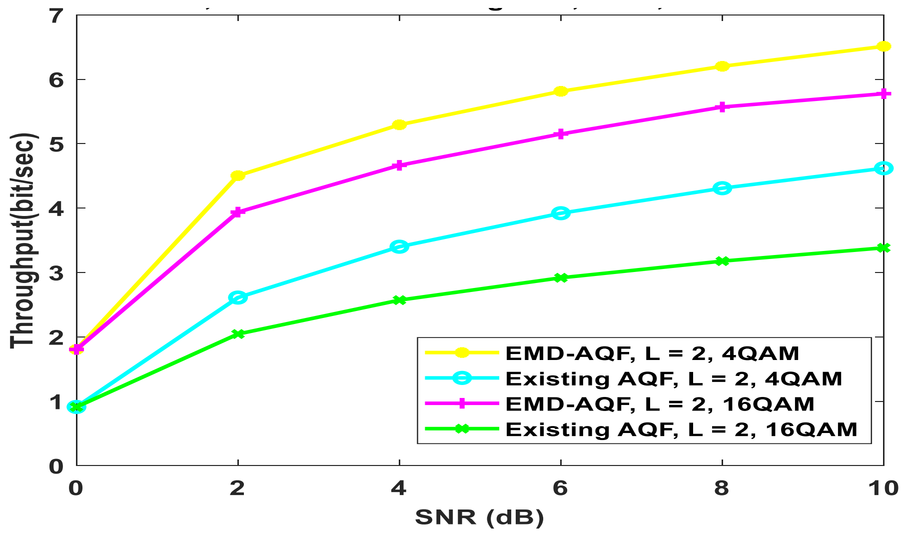

Figure 5: TP against SNR for the proposed EMD-AQF and existing AQF at L of 2 with different modulation schemes in a Nakagami-m fading environment.

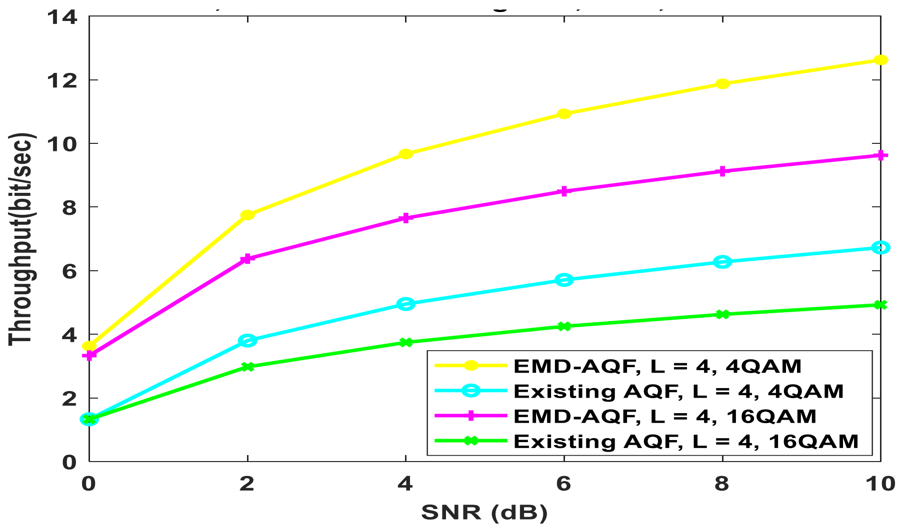

Figure 6: TP versus SNR for the EMD-AQF and existing AQF at L of 4 with different modulation schemes in a Nakagami-m fading environment

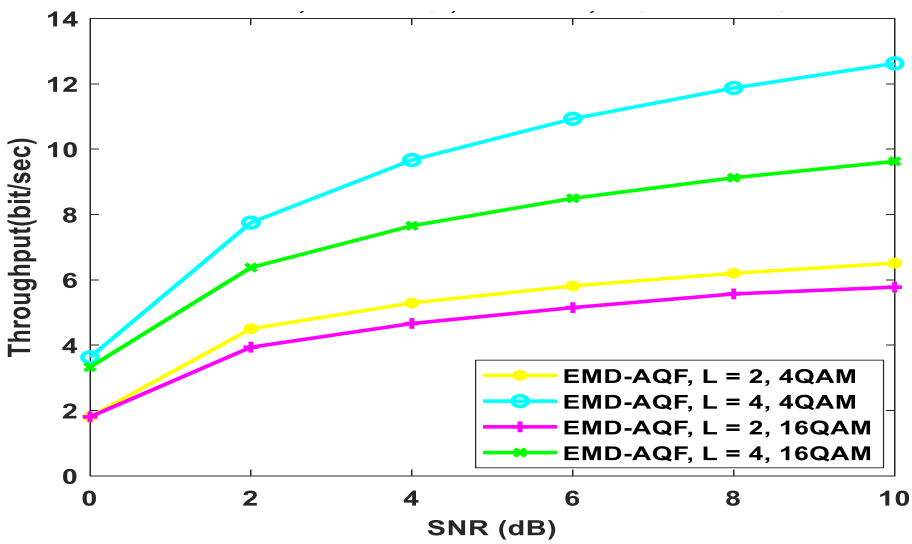

Figure 7: TP versus SNR for EMD-AQF at different number of paths and constellation size of the modulation schemes over Nakagami-m fading.

5. CONCLUSION

The study has established a novel AQF cooperative relay approach that decreases noise amplification by incorporating EMD into the process before the signal is amplified. The mathematical expressions of BER and Throughput (TP) for the enhanced AQF technique under Nakagami-m fading conditions. Also, the study analyzed the effect of varying the number of propagation paths (L) and the SNR on the system. The Bit Error Rate (BER) and Throughput (TP) of the proposed EMD-AQF were directly compared against the existing AQF technique. The results clearly demonstrated that the proposed EMD-AQF technique outperformed the existing AQF, yielding lower BER (fewer errors) and higher TP (faster data transfer). This superior performance is specifically attributed to the EMD step at the relay, which effectively removes noise before amplification, thereby preventing noise from being boosted. The use of MRC at the destination also contributed to the improved signal quality.

REFERENCES

[1] Binh, V. N. & Kiseon, K. (2016). Performance Analysis of Amplify-and-Forward Systems with Single Relay Selection in Correlated Environments, *Sensors MDPI*, 1-25, doi.org/10.3390/s16091472
[2] Amogh, R. & Carl, P. D. (2019). Adaptive Transmission in Cellular Networks: Fixed-Rate Codes with Power Control with Physical Layer Rate less Codes, *IEEE Transactions on Wireless*, **8**(6): 3005 – 3018, doi:10.1109/TWC.2019.2908169
[3] Admoon, A., Rosdiadee, N. & Mahamod, I. (2019). Wireless energy harvesting with cooperative relaying under the best relay selection scheme, *international journal of energies* **6(**2): 1-12, doi.org/10.3390/en12050892
[4] Hui, H. (2021). Intelligent Resource Allocation Method for Wireless Communication Networks Based on Deep Learning Techniques, *Hindawi Journal of Sensors*, 1-12, **doi.org/10.1155/2021/3965087**
[5] Tafzeel, R. A. (2012). Cooperative communications, Ph.D thesis submitted to Department of Communication Engineering, *Stockholm University*, *Sweden*, 1-328,doi: uk.bl.ethos.800588
[6] Nasir, H. (2017). Cooperative communication in relay assisted wireless access networks, Ph.D thesis submitted to Faculty of Science and Engineering, Queensland University of Technology, 1-179.
[7] Ojo, F.K., Akande, D.O & Salleh, M. F. M. (2018). An overview of RF energy harvesting and information transmission in cooperative communication networks, *International Journal of Telecommunication Systems, Springer* **7**(2):1-4, doi:10.1007/s11235-018-0483-8
[8] Rajkumar G. (2016), Performance Evaluation of Maximum Ratio Combining Scheme in WCDMA System for different Modulation, *International Journal of Emerging Technologies in Engineering Research* **4**(5):240-242, doi.org/10.3390/electronics13153087
[9] Yingting, L., Yinghui, Y., Guanghui, Y. & Yongli, Z. (2020). Outage Performance Analysis for an Opportunistic Source Selection Based Two-way Cooperative Ambient Backscatter Communication System, *IEEE Communications Letter*, 1-15, doi: 10.1109/LCOMM.2020.3029246
[10] Nasir, H. (2017). Cooperative communication in relay assisted wireless access networks, Ph.D thesis submitted to Faculty of Science and Engineering, Queensland University of Technology, 1-179.
[11] Wang, H., Dong, J., Tang, K. & Shi, H. (2021). Outage Performance Analysis of NOMA in Wireless Powered Cognitive Radio Networks with AF and DF Relaying Techniques, Entropy, 1-26, doi.org/10.3390/e23111463
[12] Shao, I. C. (2011). Performance of amplify-and-forward cooperative communications with the *n*th best-relay selection scheme over Nakagami-*m* fading channels, *172 IEEE Communications Letters*, **15**(2): 173-175, doi:10.1109/LCOMM.2010.121310.101381
[13] Iancu, A., Nico, A., Herwig, B. & Marc, M. (2012). Quantize and Forward Cooperative Communication: Channel Parameter Estimation, IEEE Transactions on Wireless Communications, **11** (3): 1-13, doi:10.1109/TWC.2012.010312.110595
[14] Nasaruddin N., Yusnidar, O. & Elizar, P (2017). Performance Evaluation of Amplify-Quantize and Forward Protocol for Multi-relay Cooperative Networks, *ECTI Transactions on Electrical Engineering, Electronics, and Communications* 15 (1): 1-11, doi.org/10.37936/ecti-eec.2017151.171272
[15] Xianglan, J. (2022). Amplify–Quantize–Forward Relay Channel with Quadrature Amplitude Modulation, IEEE Access, 1-10, doi:10.1109/ACCESS.2022.3199432
[16] Jihyun, P. & Xianglan, J. (2023). Low-Complexity Linear Signal Detection on Two-Way Quantize-Forward Relay Channel, IEEE Wireless Communications Letters, 1-5, doi:10.1109/LWC.2023.3314808
[17] Xianglan J. (2024). MIMO Detection on Amplify-Quantize-Forward Relay Channel, *IEEE Transactions on Vehicular Technology*, 1-13, 10.1109/TVT.2024.3360511.
[18] Al-Badrawi, M. H. (2017). Statistical Properties and Applications of Empirical Mode Decomposition, Ph.D thesis, University of New Hampshire Scholars' Repository, 1-100.
[19] Boudraa, A. O., Cexus, J. C. & Saidi, Z. (2014). EMD-Based Signal Noise Reduction, *International Journal of Signal Processing*, 1(1): 1-6, doi.org/10.3390/s21165271
[20] Wahiba, M. & Rais, E. (2017). New Denoising Method Based on Empirical Mode Decomposition and Improved Thresholding function, *Journal of Physics*: Conf. Series **87** (2): 1-7, doi: 10.1088/1742-6596/787/1/012014

[21] Admoon, A., Rosdiadee, N. & Mahamod, I. (2017). Wireless energy harvesting with cooperative relaying under the best relay selection scheme, *international journal of energies* **6(**2): 1-12, doi:10.3390/EN12050892
[22] Adeyemo, Z.K., Badrudeen & Abolade, R.O., (2013), Inter-symbol Interference Distortion Cancellation Using a Modified Maximal Ratio Combiner in Mobile Wireless Communication, *Journal of Information Engineering and Application,* **3**(8): 16-17.
[23] Goldsmith, A.J. (2004). Wireless Communication” first Edition. Cambridge University press. Cambridge, England, 10-44.
[24] Islam, M. J. (2009). Performance analysis of diversity techniques for wireless communication system, MSc thesis submitted to School of Engineering, Blekinge Institute of Technology, 1-34.
[25] Nasaruddin N., Ernita, D. M. & Ramzi, A. (2021). Outage Probability and Power Efficiency of Quantize-and-Forward Relay in Multi-hop D2D Networks, *IEEE Xplore*, 184-191, doi:10.1109/BCWSP50066.2020.9249476
[26] Rathod, R. N. & Holia, M.S. (2017). Quantization and Speech Coding for Wireless Communication, International Conference on Research and Innovations in Science, *Engineering &Technology: selected Papers in Engineering*, 1-9.
[27] Haitao, Z., Emiliano, G. P., Song, A. & Jibo, W. (2011). Calculating End-to-End Throughput Capacity in Wireless Networks with Consideration of Hidden Nodes and Multi-rate Terminals, *IEEE Access*, 1-5, doi:10.1109/VETECS.2011.5956285
[28] Adeyemo Z. K., Ojo S. I., Omowaiye R. O. & Bamikefa I. A. (2020). Adaptive Selection Combiner over Log-normal Fading Channel in Wireless Communication System, *Universal Journal of Electrical and Electronic Engineering* **7**(5): 263-272, doi:10.13189/ujeee.2020.070501
[29] Keerthana, M. L. & Sivakannu, G. (2018). Performance Enhancement of Wireless Networks Using Cooperative Diversity Techniques, *Journal of Analog and Digital Communications*, 3 (3): 1-8, doi:10.1109/LCOM.2007.348292