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Empirical Mode Decomposition Based Amplify and Forward Technique for Cooperative Cognitive Radio System

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***Abstract**: The rapid growth in the mobile industry due to increase in number of users accessing diverse* services causes a *high demand for radio spectrum. Nonetheless, the radio spectrum allocated for different wireless communication services is restricted. Cooperative Cognitive Radio (CCR) technique with Amplify and Forward (AF) relaying protocol used to address the problem suffers from noise amplification resulting in poor reception at the destination. Hence, in this paper, Empirical Mode Decomposition (EMD) based AF technique for CCR system was carried out to improve the performance of the existing CCR with AF relaying protocol. The transmitted signal from Primary User (PU) was received at the Secondary User (SU) where SU superimposed its own signal using Exclusive OR (XOR) rule. The combined signal from XOR was made to pass through EMD and amplified using AF by multiplying with the relay gain. The amplified signal was radiated to PU and SU receivers during the second hop transmission. The multiple copies of the receive signal at the SU receiver at different number of path (L = 2, 4) were combined at destination using Maximal Ratio Combiner (MRC). Mathematical expression for Bit Error Rate (BER) and Throughput (TP) were derived using the Probability Density Function (PDF) of the Nakagami-m fading distribution. Extensive simulations using MATLAB R2021a were employed to assess the effectiveness of the proposed technique and evaluated using BER and TP by comparing with the existing AF CCR. The EMD based AF technique proposed gave better performance with 75.2% reduction in BER and 21.86% increase in TP over the existing AF technique for CCR. The proposed technique can be deployed to improve the performance of cooperative cognitive radio system.*

***Keywords:** Cognitive Radio (CR), Amplify and Forward (AF) Cooperative Communication, Empirical Mode Decomposition (EMD), Exclusive OR, Primary User and Secondary User*

1. INTRODUCTION

The developments in wireless communication are increasing to accommodate new users and new technologies such as Internet of Things (IoT), video streaming and high-speed download. Widespread growth in wireless technologies has encouraged developers and investors to offer new wireless applications and services with worldwide connectivity resulting in exponential increase in the bandwidth requirement. The high increase in bandwidth requirement resulting in shortage of frequency spectrum. The existing spectrum is finite and becoming increasingly congested as more users access wireless communication services [1, 2, 3]. The shortage of spectrum known as spectrum scarcity becomes more and more serious as greater bandwidth is required to support a wide range of applications across various economic sectors in every nation. Although the radio spectrum is theoretically vast, the ranges of frequency available are limited for commercial application and must support the ever-growing demand for wireless communication services. Different studies from the literature have confirmed that, the scarcity of spectrum is majorly due to underutilization of assigned spectrum band and averagely, spectrum utilization is less than 15% [4, 5, 6]. To address future needs for achieving improved spectrum efficiency and system performance, the concept of Cognitive Radio (CR) is widely regarded as a promising technology for enhancing radio spectrum utilization [2, 7, 8]. The CR has been introduced to improve spectrum utilization by enabling the sharing of available radio spectrum between Primary Users (PUs), who are licensed, and Secondary Users (SUs), who are unlicensed. The basic idea of CR is to allow unauthorized user to have access to the radio spectrum originally licensed to the authorized user, provided the transmission of SU does not have any adverse effect on the performance of PU. The technique enhances spectrum utilization efficiency by allowing unauthorized users to access licensed spectrum without disrupting the licensed user. The technique utilizing dynamic spectrum access was proposed as a promising technology for enhancing the efficiency of the limited and valuable radio spectrum [3]. In order to allow both the SU and PU to access the assigned spectrum simultaneously, Cooperative Communication (CC) in which a source transmits signal to the destination through multiple nodes (relays) is incorporated with CR, known as Cooperative CR (CCR).

The basic idea of CCR is to improve the efficiency and reliability of SU by making it to transmit all the time and not only when PU is not active [9, 10, 11]. In CCR, SU acts as a relay node by receiving the PU signals, superimposes its own information on the signals received from PU, and forward the superimposed signal to both the PU and SU receiver. The CCR improves the efficiency and reliability of SU by making it to transmit all the time and not only when PU is not active. In this approach, SU access the spectrum by relaying the PU signal from PU transmitter to the PU receiver so that certain Quality of Service (QoS) requirement is satisfied [12, 13, 14, 15]. The basic relaying protocol that has been used in CCR are Decode and Forward (DF) and Amplify and Forward (AF). In AF protocol, SU amplifies the PU signal received and retransmits the amplified signal to the destination. On the other hand, in DF protocol, SU decodes and re-encodes the PU signal before forwarding to the destination [16, 17]. However, AF protocol has a simple operation than the DF protocol but suffers from noise amplification due to its analog nature, thereby making it to be susceptible to noise, and affects the communication system [18, 19, 20, 21]. There has been several existing works on CCR using AF relaying technique to address the problem of underutilization. In [22], spectrum sharing with discrete time energy harvesting for PU was proposed to address the problem of underutilization. In the paper, the authors proposed a spectrum-sharing protocol for CR networks that accommodated a primary transmitter with energy constraints, which harvests energy from received radio frequency signals. The results demonstrated that the proposed spectrum-sharing protocol significantly outperformed non-cooperative scenario using spectrum efficiency. However, the technique suffers from noise amplification that occurs during the signal amplification resulting in poor reception at the destination. Also, in [23], an optimal relay selection strategy within a cooperative spectrum sharing framework for mobile-based end users was proposed to address the problem of underutilization of spectrum. In the paper, author used half-duplex transmission between a single PU and a single SU. The results obtained in the paper showed that, the technique outperformed non- cooperative using spectrum usage efficiency. Furthermore, in [24] a novel spatial modulation assisted CCR with energy harvesting was introduced to enhance the spectral and energy efficiency of wireless communication networks. The proposed technique offered improvements in spectral and energy efficiency compared to non-cooperative CR. However, the system suffered from high outage probability at the destination due to inability of SU to decode the PU signal.

In summary, previous works on CCR with AF relay technique are characterized with noise amplification at the SU receiver resulting in poor reception of signal at the both PU and SU receivers. Therefore, this paper, proposes an Empirical Mode Decomposition (EMD) based AF technique for CCR system to improve the performance of existing CCR with AF. Since the existing fixed spectrum allocation policy is no longer a feasible approach and happened to be the major cause of spectrum scarcity in wireless communication system. Therefore, the proposed EMD based AF technique for CCR in wireless communication network is important for efficient and effective utilization of radio spectrum.

The contributions of this paper are outlined as follows:

i. establishing a new CCR AF technique with reduced noise amplification due to EMD used before signal amplification.
ii. deriving mathematical expressions of Bit Error Rate (BER) and Throughput (TP) for the proposed technique over Nakagami-m fading channel.

The rest of this paper is organized as follows: Section 2 provides a review of the literature relevant to the proposed technique, Section 3 details the methodology used, Section 4 presents the simulation results comparing the proposed technique with existing ones for CR, and Section 5 provides the conclusions of the paper.

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 AF based CCR.

2.1 Empirical Mode Decomposition

Empirical Mode Decomposition (EMD) is one of the denoising technique that operates based on iterative process by generating various components of the original signal 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 [25, 26]. The IMF must satisfy two major conditions. Firstly, the number of zero-crossings and extrema in the dataset must be equal or differ by at most one. Secondly, the mean value signal defined by the local minima and local maxima must be zero at any given point [26, 27]. The original signal can be reconstructed as indicated in Equation (1) by [25]

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

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 SU node before signal amplification to remove the noise that might present.

2.2 Maximal Ratio Combiner

Maximal Ratio Combiner (MRC) is one of the technique in which the different copies of the signals are co-phased and multiplied with respective weight factors before summing. It is a useful technique that combats 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 signal-to-noise ratio. The technique is the optimal combining scheme, independent fading statistics [19, 28]. MRC involves receiving the uncorrected signals which been degraded as they travels through space. The signal is processed through individual channel estimators to estimate 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 [29, 30]. The SNR output of MRC 'SNR_{MRC}' is given by [29] 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 represents the power of the signal on each branch
a_i represents the weighing factor
L represents the number of branches, while w denotes the noise power on each branch.

3. PROPOSED EMD BASED AMPLIFY AND FORWARD COOPERATIVE COGNITIVE RADIO TECHNIQUE

In this paper, SU acts as a relay node by receiving the PU signals, superimposes its own information on the received PU signals and forward the superimposed signal to both the PU and SU receivers. In CCR, the unlicensed user accesses the licensed spectrum by relaying the licensed user's signal from the PU transmitter to the SU and PU receivers. Therefore, PU signal is propagated from the PU transmitter as shown in Figure 1. The SU transceiver acts as a relay by receiving the PU signal and superimposed its own signal on the received PU signal using XOR '$G_{XOR}(t)$'given in Equation (3) as

$$G_{XOR}(t) = x_{SU}(t) \oplus x_{PU}(t) \quad (3)$$

where: $x_{SU}(t)$ is the SU signal
$x_{PU}(t)$ is the PU signal

The combined signal $G_{XOR}(t)$ was made to pass through EMD to remove the noise that might present. The resultant clean signal was amplified using AF cooperative relaying technique by multiplying with relay gain before radiating during second hub transmission. The combined signal at the SU node was made to pass through EMD for signal denoising. The signal output of EMD '$\breve{G}_{XOR}(t)$' is given in Equation (4). The clean signal output of the EMD was amplified by multiplying with the relay gain. Therefore, the combined transmitting signal at the SU node designated as $\breve{G}_{XOR}^{AF}(t)$ is the product of EMD output signal and the relay gain given in Equation (4) as

$$\breve{G}_{XOR}^{AF}(t) = \breve{G}_{XOR}(t)\left(\frac{P_r}{P_r h_{sri}^2 + N_{ri}}\right)^{\frac{1}{2}} \quad (4)$$

Therefore, the transmitting signal at the SU node using AF cooperative communication technique and EMD is obtained in Equation (5) as

$$\breve{G}_{XOR}^{AF}(t) = \left(\breve{x}_{SU}(t) \oplus x_{PU}(t)\right) \times \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}} \quad (5)$$

The signal was radiated to both PU and SU receivers during the second hub transmission using SU transmitting antenna. The combined, clean and amplified signal from SU node was received at the SU and PU receivers. In order to retrieve the received signal at the receiving end of the SU, the received signal was XOR with the original SU signal '$G_{XOR}(t) \oplus x_{SU}(t)$' as given in Equations (6)

$$\breve{G}_{XOR}^{AF}(t) \oplus x_{SU}(t) = \left(\left(\breve{x}_{SU}(t) \oplus \breve{x}_{PU}(t)\right) \times \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right) \oplus x_{SU}(t) \quad (6)$$

According to Wang *et al*. [31], assigning the values 1 and 0 to $\breve{x}_{SU}(t)$ and $x_{PU}(t)$, respectively, Equation (7) becomes

$$G_{XOR}^{AF}(t) = \breve{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}} \quad (7)$$

The multiple copies of the signal at the SU receiver were combined using MRC by weighing the received paths with different weights. The weighted signals were co-phased to avoid signal cancellation before summing. The SNR output of MRC 'SNR_{MRC}' is given in Equation (2). Therefore, substituting Equation (7) into (2) gives

$$SNR_{MRC} = \frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w} \quad (8)$$

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

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} exp\left(\frac{-m\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^{2^2}}{\sum_{i=1}^{L} a_i^2 w}}{2\sigma^2}\right) \quad (9)$$

$$P_r(r) = \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} exp\left(-m\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2 \sum_{i=1}^{L} a_i^2 w}\right) \quad (10)$$

For m equal to 0.5, Equation (10) becomes

$$P_r(r) = 1.11\left(\frac{0.5}{2\sigma^2}\right)^{0.5} \exp\left(-0.5\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2 \sum_{i=1}^{L} a_i^2 w}\right) \quad (11)$$

Similarly, for m equal to 1, Equation (10) becomes

$$P_r(r) = \left(\frac{1}{2\sigma^2}\right)\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w} \exp\left(-\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2 \sum_{i=1}^{L} a_i^2 w}\right) \quad (12)$$

Equations (11) and (12) are the PDF of the received signal for the proposed EMD based AF technique for cooperative cognitive radio system over Nakagami-m fading channel at m equal to 0.5 and 1, respectively.

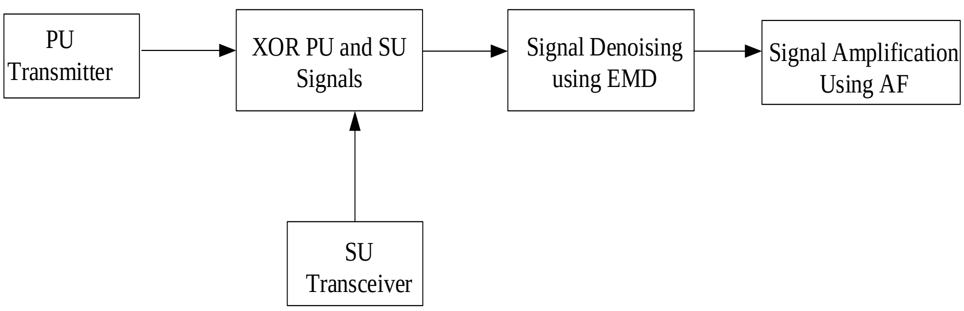

Figure 1: Block diagram of the proposed EMD based AF CCR

3.1 Throughput (TP)

In this paper, Throughput (TP) is used as the rate at which messages are delivered successfully over Nakagami-m fading channel. The expression for throughput 'TP' and bit rate 'R' is given in Equations (13) and (14), respectively as

$$TP = R(1 - OP) \tag{13}$$

where R is the rate of transmission and it is given as

$$R = B \times log_2(1 + SNR) \tag{14}$$

where: B is the channel bandwidth
SNR is the signal to noise ratio of the received signal

Therefore, by substituting Equations (8) and (14) into (13), the expression of the throughput for the proposed technique is obtained as;

$$TP = Blog_2\left(1 + \frac{\left(\sum_{i=1}^{L} a_i \breve{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)(1 - OP) \tag{15}$$

However, according to Panel *et al.* and Tu *et al*. [32, 33] OP is given as

$$OP = 1 - Pr(\gamma_{SU} > \gamma_{th}) \tag{16}$$

where: $\gamma_{th} = 2^{\xi} - 1$ and denotes the target SNR

ξ is the target rate

Therefore, by substituting Equation (16) into (15), the TP of the proposed technique is obtained as

$$TP = Blog_2\left(1 + \frac{\left(\sum_{i=1}^{L} a_i \breve{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)\left(Pr(SNR > \gamma_{th})\right) \tag{17}$$

Using Equation (8), the TP for the proposed technique is obtained as

$$TP = Blog_2\left(1 + \frac{\left(\sum_{i=1}^{L} a_i \breve{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)\left(Pr\left(\frac{\left(\sum_{i=1}^{L} a_i \breve{x}_{SU}(t)\left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w} > \gamma_{th}\right)\right) \tag{18}$$

3.2 Bit Error Rate (BER)

The expression for Bit Error Rate BER is given in Equation (19) by [34] as

$$BER = \int_{\circ}^{\infty} \frac{1}{2} \exp(-0.5r) \;\; P_r(r) \mathrm{d}r \tag{19}$$

Using Equation (12), the BER for the proposed technique is obtained as

$$BER = 0.5\int_o^{\infty} \exp(0.5r) \times \frac{2}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times$$

$$\exp\left(-m\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2\sum_{i=1}^{L} a_i^2 w}\right) dr \quad (20)$$

$$BER = \frac{1}{\Gamma(\mathrm{m})}\left(\frac{m}{2\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \times$$

$$\exp\left(-m\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2\sum_{i=1}^{L} a_i^2 w}\right) \int_o^{\infty} \exp(0.5r)\, dr \quad (21)$$

Integrating Equation (3.18) with respect to r and substituting upper and lower limit gives

$$BER = \frac{-1}{\Gamma(\mathrm{m})}\left(\frac{m}{\sigma^2}\right)^m \left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)^{2m-1} \exp\left(-m\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2\sum_{i=1}^{L} a_i^2 w}\right) \quad (22)$$

For m equal to 0.5, the BER for the proposed technique is obtained as

$$BER = \frac{-1}{1.8}\left(\frac{0.5}{\sigma^2}\right)^{0.5} \exp\left(-\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{4\sigma^2\sum_{i=1}^{L} a_i^2 w}\right) \quad (23)$$

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

$$BER = \left(\frac{-1}{\sigma^2}\right)\left(\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right) \exp\left(-\frac{\left(\sum_{i=1}^{L} a_i \check{x}_{SU}(t)\left(\frac{P_r}{P_r h_{Sr}^2+N_r}\right)^{\frac{1}{2}}\right)^2}{2\sigma^2\sum_{i=1}^{L} a_i^2 w}\right) \quad (24)$$

Equations (23) and (24) are the BER for the proposed technique at m equal to 0.5 and 1, respectively.

4. SIMULATION RESULTS AND DISCUSSION

The performance of the proposed EMD-AF technique for CRN was evaluated using BER and TP as performance metrics. BER is used to measure the number of erroneous bit at the SU, while, TP is used to measure the amount of data successfully received at the SU destination. The flowchart of the simulation process is presented in Figure 2, while the simulation parameters for the proposed technique are presented in Table 1. The BER values at different propagation paths with different constellation sizes were obtained and compared with the work in [23]. In this paper, existing AF represents the work in [23]. Also, during the simulation process, the constellation size of the modulation were varies to check the effect of constellation size on the proposed technique.

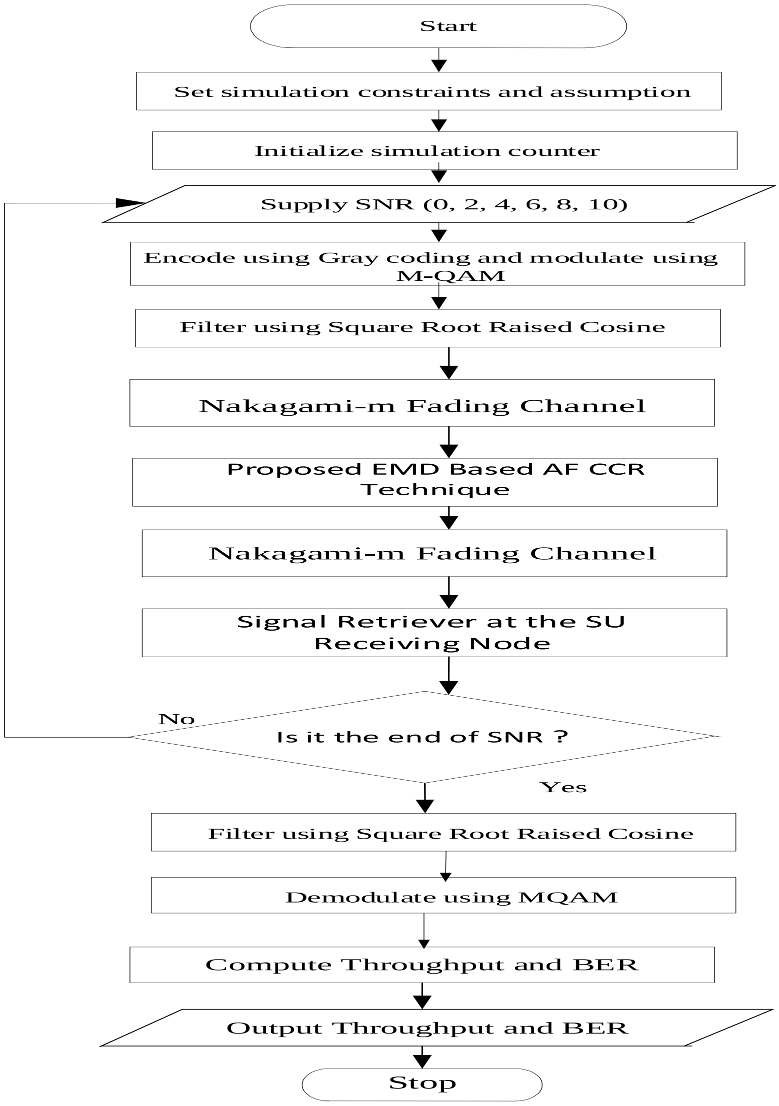

Figure 2: Flowchart of the simulation process.

Table 1: System simulation parameters for the proposed technique

Parameters	Specifications
Modulation schemes	M-QAM
Fading	Nakagami-m Fading channel
Number of Path	2 and 4
Carrier Frequency	2300MHz
Noise	AWGN
Signal Bandwidth	2 MHz
SNR	0,2,4.........,10

Figure 3 presents the BER versus SNR for the proposed EMD-AF and existing AF at L of 2 over Nakagami-m fading channel. At SNR of 6 dB with 4QAM modulation scheme, BER values of 1.64×10^{-5} and 5.2×10^{-4} were obtained for the proposed EMD-AF and existing AF, respectively, while the corresponding BER values obtained at 16QAM modulation scheme were $3.0 \times 10^{-5}$and 9.5×10^{-4} for the proposed EMD-AF and existing AF, respectively. The results obtained revealed that, the proposed EMD-AF technique gave better performance with lower BER values when compared with the existing AF technique for CCR. This is due to EMD applied before signal amplification that denoised the noise that present in the transmitted signal. The BER values obtained for the proposed EMD-AF and existing AF with L of 3 at different constellation sizes were presented in Figure 4. The BER values obtained at SNR of 6 dB with 4QAM were 8.24×10^{-7} and 2.61×10^{-5} for the proposed EMD-AF and existing AF, respectively, while with the 16QAM modulation scheme, 1.51×10^{-6} and 4.76×10^{-5} were the corresponding BER values obtained for the proposed EMD-AF and existing AF, respectively.

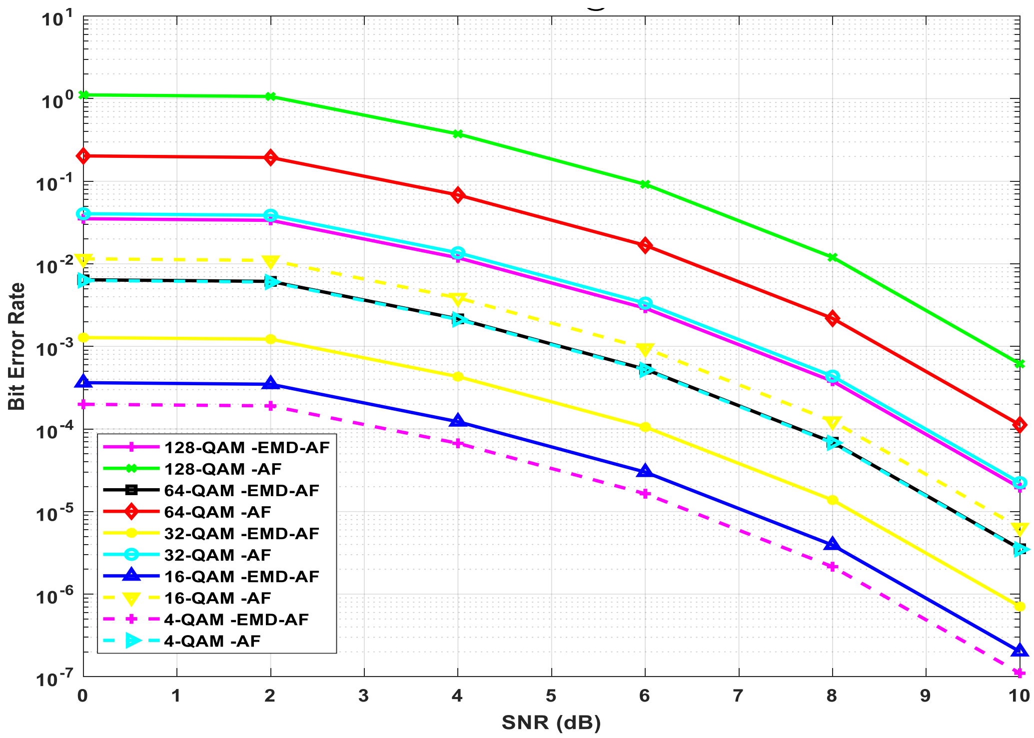

Figure 3: BER versus SNR for the proposed EMD-AF and existing AF technique for CCR with two paths (L=2) and different modulation schemes

The results obtained revealed that, both the proposed EMD-AF and existing AF techniques gave better performance with lower BER using 4QAM modulation scheme than 16QAM modulation scheme. This is due to number of signal received in error that reduces as the constellation size of the modulation scheme decreases, though at the expense of low transmission rate. Therefore, the rate of transmission and allowable error rate must be taken into consideration before selecting appropriate constellation size for any type of modulation used at the source. Figure 5 depicts BER versus SNR for the proposed EMD-AF and existing AF technique at varying number of path and fixed constellation size. The results obtained for the two constellation sizes of the modulation considered that is, 4QAM and 16QAM showed that, BER values decrease as the number of paths increases. Furthermore, at all the number paths considered, 4QAM gave better performance with lower BER than 16QAM modulation schemes. This is due to the number of signal received in error that reduces at the destination as the constellation size of the modulation scheme decreases though at the expense of low transmission rate. However, in all the cases considered, proposed EMD-AF technique gave better performance with lower BER values than existing AF technique and this is due to EMD applied before signal amplification that denoised the noise that present at the SU node in the proposed technique.

Figure 6 revealed TP versus SNR for the proposed EMD-AF and existing AF technique at L of 2 using 4QAM and 16QAM modulation schemes. At SNR of 6 dB, the TP values of 2.948805 and 2.419808 bit/sec were obtained for the proposed EMD-AF and existing AF technique using 4QAM modulation scheme, while the corresponding TP values obtained using 16QAM were 3.39009 and 2.781505 bit/sec. From the results obtained, the proposed EMD-AF gave better performance with high TP values compared with the existing AF technique. This is due to EMD incorporated at the SU node that denoise the noise present before signal amplification, thereby reducing the poor reception at destination. The better performance of the proposed technique is also due to MRC used at the destination that increase the strength of the received signal by combined the multiple copies of the received signal at SU receiver. The TP values obtained at L of 4 using 4QAM and 16QAM modulation schemes for the developed EMD-AF and existing AF technique CCR over Nakagami-m fading channel is presented in Figure 7. The TP values obtained at SNR of 6 dB with 4QAM modulation scheme were 5.89831 and 4.837704 bit/sec for the proposed EMD-AF and existing AF technique, respectively, while the corresponding TP values obtained using 16QAM modulation scheme were 6.78127 and 5.560005 bit/sec. The effect of number of paths on the TP for the proposed EMD-AF technique using different modulation scheme is presented in Figure 8. The results indicated that, across all the modulation schemes examined, throughput (TP) increases with the number of propagation paths, attributed to the rise in signal strength as the number of paths increases. Results obtained also revealed that at all the number of paths considered, TP values increases as the constellation size of the modulation reduces. This is due to robustness of signal in the channel when transmitting at a lower constellation size, though at the expense of low transmission rate. However, in all the cases considered, the proposed EMD-AF technique gave better performance with higher TP values than existing AF technique. This is due to EMD incorporated at the SU node in the proposed technique to denoise the noise that might present before signal amplification, thereby reducing the poor reception at destination. The performance of the proposed technique is also due to MRC used at the destination that increases the strength of the received signal by combining the multiple copies of the received signal at SU receiver.

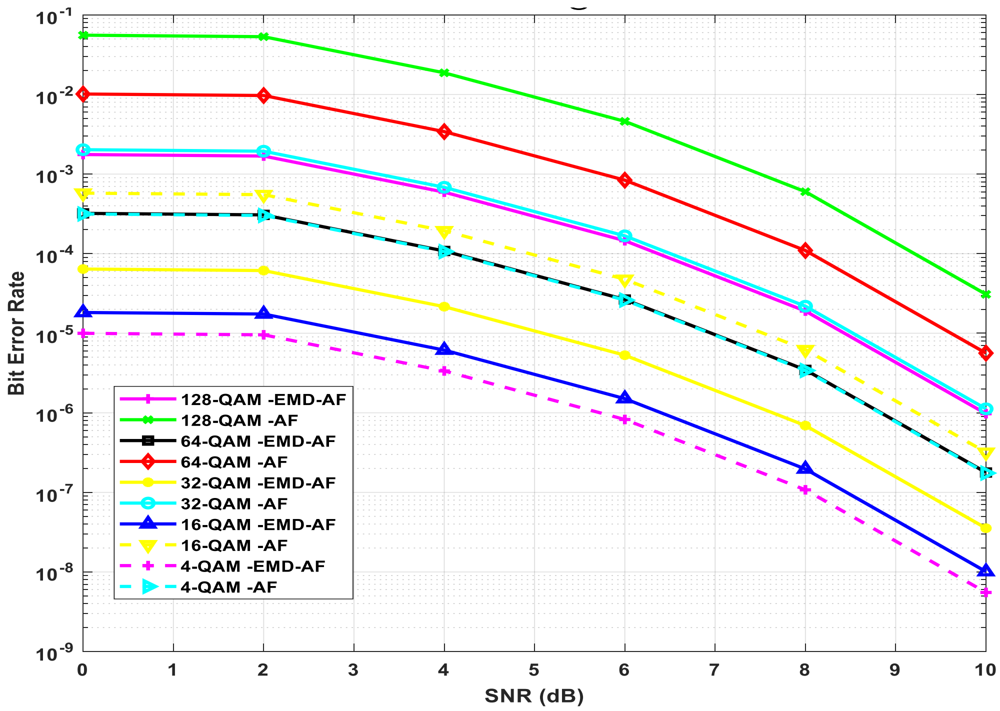

Figure 4: BER versus SNR for the proposed EMD-AF and existing AF technique for CCR with three paths (L=3) and different modulation

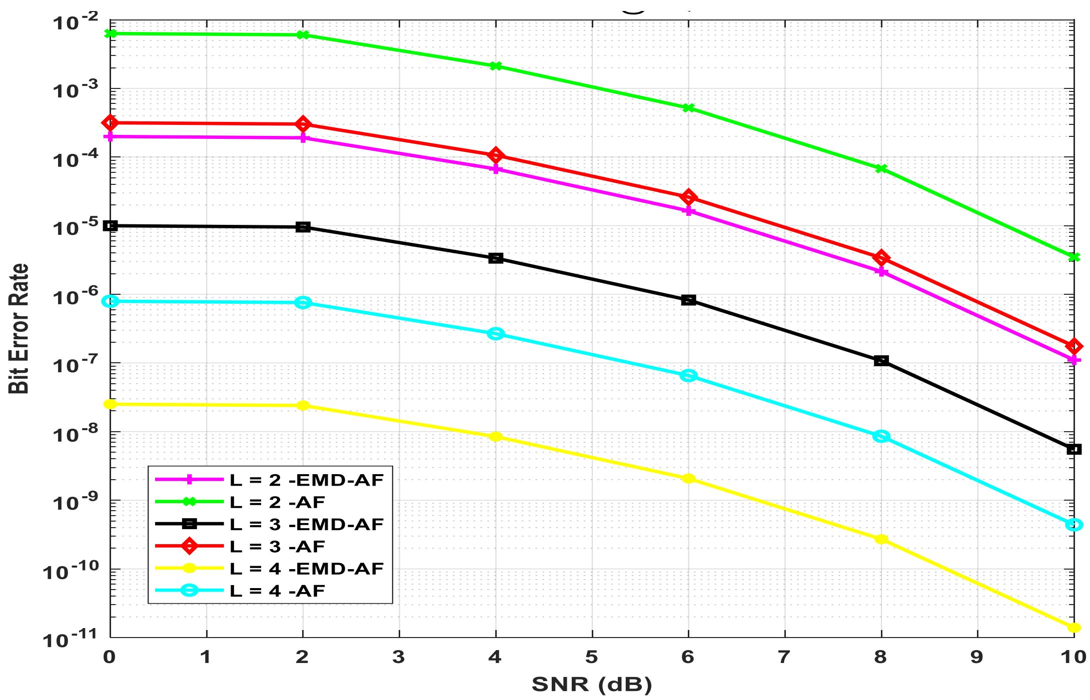

Figure 5: BER versus SNR for the proposed EMD-AF and existing AF technique for CCR with different number of paths and fixed constellation size

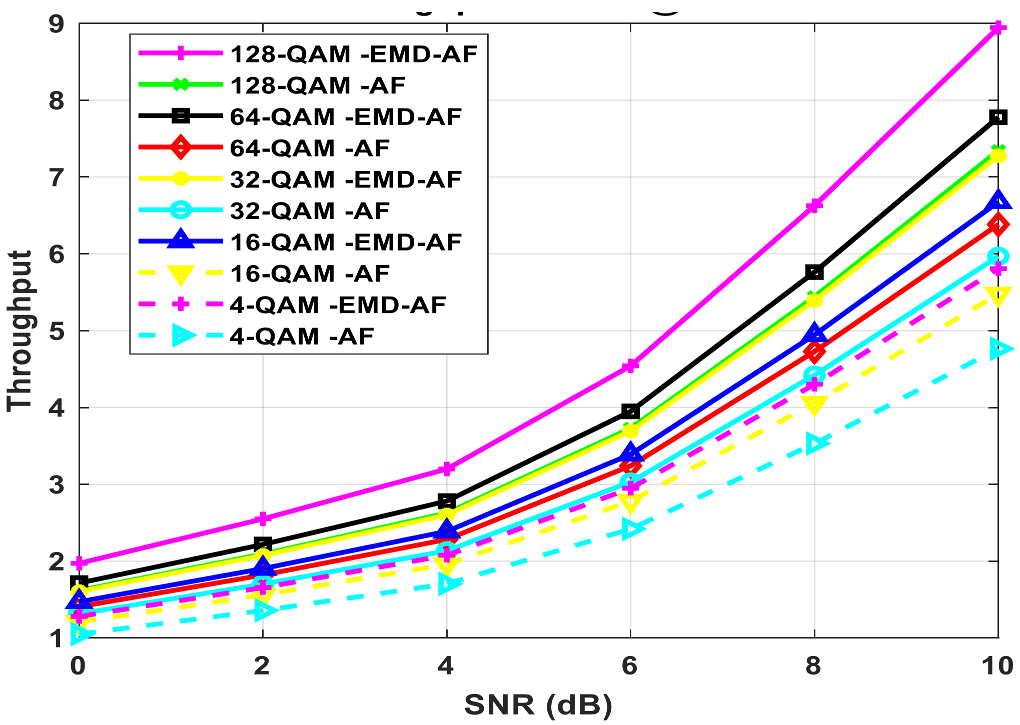

Figure 6: TP versus SNR for the proposed EMD-AF and existing AF technique for CCR with two paths (L=2) and different modulation schemes

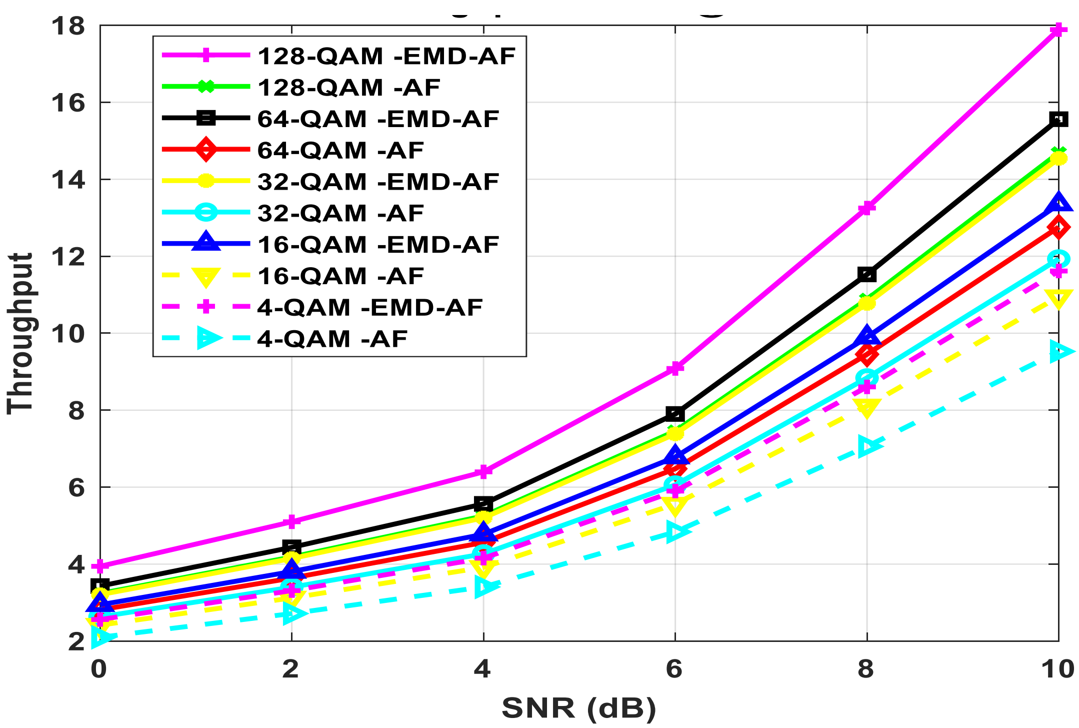

Figure 7: TP versus SNR for the developed EMD-AF and existing AF technique for CCR with four paths (L=4) and different modulation schemes

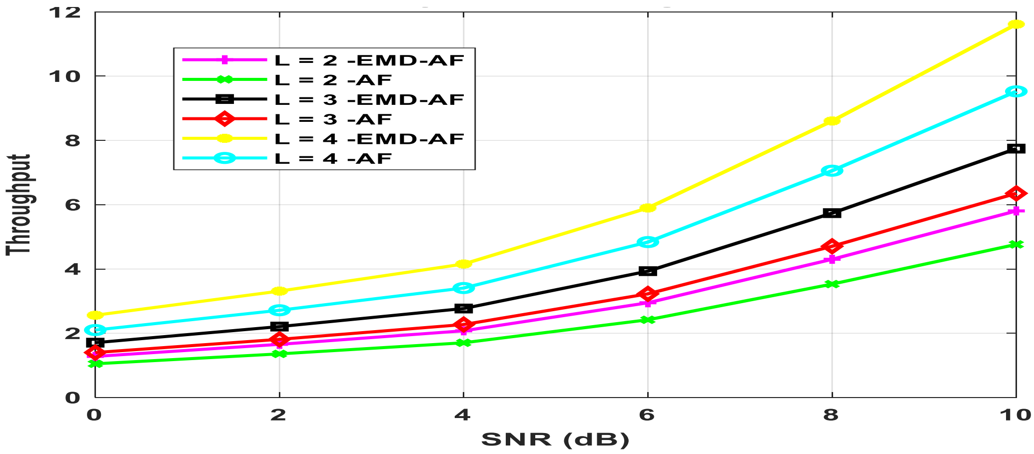

Figure 8: TP versus SNR for the developed EMD-AF and existing AF technique for CCR with different number of paths and fixed constellation size

5. CONCLUSION

In this paper, EMD-AF technique for CCR system has been carried out. BER and TP served as the performance metrics to assess the effectiveness of the proposed EMD-AF technique for CCR. The system model for the proposed technique was transmitting by propagating signal from the PU over Nakagami-m fading channel. The PU signal was then received at the SU and superimposed its own signal using exclusive OR (XOR) rule. The combined signal was made to pass through EMD and amplify using AF cooperative relaying technique by multiplying with the relay gain. The amplified signal was then transmitted to PU and SU receiver during second hop transmission. The multiple copies of the received signal at the SU receiver were combined using MRC. In the simulation process, the system model for the proposed technique were modeled using Nakagami-m fading channel, while the noise was modeled as AWGN for the received signal at both the SU transmitter and destination. The coefficient of the fading envelop was multiplied with M-QAM signaling schemes with addition of AWGN at different trial. The multiple copies of the signals at the destination were received at varying propagation paths 'L' (2, 3, 4) to investigate the effect of number of paths on the proposed EMD-AF technique for CCR. The BER and TP values for the proposed EMD-AF and existing AF technique were obtained at different SNRs with different number of paths. Performance of the proposed EMD-AF and existing AF technique was evaluated at different propagation paths 'L' with different SNRs using BER and TP as performance metrics. The results obtained revealed that the proposed EMD-AF technique showed better performance with lower BER and higher TP than the existing AF technique. This is due to EMD applied at the SU node to denoise the noise that might present before carrying out signal amplification leading to reduction in the rate of poor reception at SU receiver. The better performance of the proposed technique is also due to MRC used at the SU receiver that increased the strength of the received signal by combining the multiple copies of the received signal. Also the results obtained showed that for the two techniques, BER reduces as number of paths and SNR increases, while TP increases as the number of paths increases. Furthermore, for the proposed EMD-AF and existing AF technique, 4QAM modulation scheme gave better performance with lower BER and higher TP at all the number of paths considered than the higher values of QAM modulation scheme. This is because of the signal's robustness in the channel when transmitting at a lower constellation size, albeit at the cost of a reduced transmission rate. Therefore, the proposed EMD-AF technique has been shown better performance than existing AF technique for CCR system and can be deployed to improve the performance of wireless communication system.

REFERENCES

[1] Kevin, C. (2012). Spectrum Sensing, Detection and Optimization in Cognitive Radio for Non-Stationary Primary User Signals. Unpublished Ph.D Thesis submitted to Queensland University of Technology, Network and Communication, Faculty of Science and Engineering, 35-146.
[2] Adeyemo, Z. K., Abolade, R.O., Oladimeji, O.B. & Ojo, S.I. (2019). Modification of multiple antenna amplify and forward relay over Nakagami fading channel, *Ubiquitous Computing and Communication Journal*, 1630-1638.
[3] Ojo, S.I., Adeyemo, Z.K., Ojo, F.K., Adedeji, A.A. & Semire, F.A. (2020). Enhancement of Equal Gain Combiner for Detection of Spectrum Hole in a Cognitive Radio System, *Universal Journal of Electrical and Electronic Engineering*, 7(5): 289-298.
[4] Henry, M.A. & Closkey, D. (2005). Spectrum occupancy measurements. Chicago, Illinois, Shared Spectrum Company, Tech. Reg, 23-28
[5] Erpek, T., Steadman, K. & Jones, D. (2007). Spectrum Occupancy Measurements. Dubling Ireland, Shared Spectrum Company, Tech. Rep, 45-58.
[6] Noor, S. (2017). Combine soft hard cooperative spectrum sensing in cognitive radio network, Ph.D Dissertations, submitted to University of Windsor, 1-79.

[7] Wang, B. & Liu, K.J.R. (2011). Advances in Cognitive Radio Networks: A Survey, *IEEE Journal on Signal Processing*, 5(1):5-23.
[8] Abolade, R.O; Ojo, S.I; Ojerinde, I.A; Adetunji, J.S. & Lawal, A.T. (2020). Modification of Maximal Ratio Combining Technique for Detection of Spectrum Hole in a Cognitive Radio Network. *International Journal of Wireless and Microwave Technologies*, 7(2): 9-21.
[9] Bhoopendra, K., Sanjay, K. D. & Isaac, W. (2017). A survey of overlay and underlay paradigms in cognitive radio networks, *International Journal of Communication System*, **10**(3): 1-12.
[10] Khaled, B.I. & Wei, Z. (2009). Cooperative Communication for Cognitive Radio Networks. Proceedings, *IEEE*, 97(5): 878-893.
[11] Dinh-Thuan, D., Anh-Tu, L. & Byung, M.L. (2020). NOMA in Cooperative Underlay Cognitive Radio Networks under imperfect SIC. *IEEE Access*, 1-15.
[12]Duan, L. (2014). Cooperative Spectrum Sharing: A Con T-Based Approach. *IEEE Transactions on Mobile Computing*, 13(1):174-187.
[13] Naeem, M., Anpalagan, A., Jaseemuddin, M. & Lee, D.C.(2014). Resources Allocation Techniques in Cooperative Cognitive Radio Networks. *IEEE Communication Surveys and Tutorials*, 16(2):729-744.
[14] Liang, Y.C., Chen, K.W., Li, G.Y. & Mahonen, P. (2011). Cognitive radio network and Communications: An Overview, *IEEE Transaction on Vehicular Technol*. 60(7):3386-3407.
[15] Kader, M.F. (2017). Cooperative Spectrum Sharing in Cognitive Radio Networks: An interference free approach, Physical Communication, 25(1):66-74.
[16] 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.
[17] Zijian, M., Weifeng, S. & John, D. M. (2016). Amplify and forward relaying protocol design with optimum power and time allocation, *IEEE Waveform and signal processing*, **10**(3):1-4.
[18] 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.
[19] 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.
[20] 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.
[21] 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, 1-6.
[22] Kun T., Shaowei, L. & Quan, X. (2021). Cooperative Spectrum Sharing in Spectrum Domain with Discrete Time Energy Harvesting for Primary User. *ELSEIER Science Direct*, Ad Hoc Networks, 102-474.
[23] Lama, N. Ibrahem, Mamoun, F. Al-Mistarihi, Mahmoud, A. Khodeir, Moawiah Alhulayii, & Khalid, A. Darabkh (2023). Best Relay Selection Strategy in Cooperative Spectrum Sharing Framework with Mobile Based End User. *MDPI, Applied Sciences*, 1-12
[24] Ravindran, R.J., Chelian, V.T., Velmurugan PGS. & Thiruvengadam, S.J. (2023). Novel Spatial Modulation Assisted Cooperative Cognitive Radio Network with Energy Harvesting, Research Square, 1-18.
[25] Al-Badrawi, M. H. (2017). Statistical Properties and Applications of Empirical Mode Decomposition, Ph.D thesis, University of New Hampshire Scholars' Repository, 1-100
[26] Boudraa, A. O., Cexus, J. C. & Saidi, Z. (2014). EMD-Based Signal Noise Reduction, International Journal of Signal Processing, 1(1): 1-6.
[27] Wahiba, M. & Rais, E. (2017). New Denoising Method Based on Empirical Mode Decomposition and Improved Thresholding function, *Journal of Physics*: Conf. Series **78** (2): 1-7.
[28] 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.
[29] Goldsmith, A.J. (2004). Wireless Communication" first Edition. Cambridge University press. Cambridge, England, 10-44.
[30] 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.
[31] Wang, Y., Shiyong, C., Yucheng, W. & Chengxin, Z. (2022). Maximizing Average Throughput of Cooperative Cognitive Radio Networks Based on Energy Harvesting, sensor, 1-17.
[32] Panel, Z.Z., Zheng, C. & Xingwang, L. (2022). Intelligent Sensing and Communications for internet of Everything, OPI Backscatter technology and intelligent reflecting technology surface technology in the Internet of Things, 77-135.
[33] Tu, L., Munyaradzi, M. & Samarendra, N.S. (2022). Physical layer architecture of 5G enable IoT/ IoMT system, OP2 5G IoT and Edge Computing for Smart Healthcare: Intelligent Data-Centric System, 29-43.
[34] Rappaport, T.S. (2002). Wireless communications: principle and practice, prentice hall communication, Chicago 65-205.