

Performance Analysis of Improved Technique for Optimal Frequency Spectrum Utilization Considering Energy and Eigenvalue Detectors

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Abstract
Recently, exponential rise in the demand of wireless communication has led to gross reduction in the availability of wireless frequency spectrum to meet the proliferation of demands. Overlay and underlay cognitive radio used to address this problem is characterized with poor management of the assigned spectrum. The basic and essential mechanism of cognitive Radio (CR) to find unused spectrum is called Spectrum Sensing. This is important in optimizing frequency allocation for the increasing wireless communication system. Hence, this paper developed an energy efficient spectrum sensing technique for detection of white and brown space using energy and eigenvalue detector. Based on a predefined switching algorithm, the developed spectrum sensing system switches between overlay and underlay approach when there is presence of white space and brown space respectively. During the underlay approach, the cognitive user (CU) signal is coded using a Code Division Multiple Access (CDMA) to prevent primary users (PU) receiver from hearing CU signal and thereby improve the security of CU. Also, Hybrid Decode Amplify and Forward (H-DAF) cooperative relay technique is incorporated to enhance the coverage area of the cognitive user. However, during the overlay approach, H-DAF cooperative relay technique will be in sleep mode since CU can transmit with the maximum transmitting power. During the underlay approach, the received signal at the relay node is decoded, amplified, and coded using CDMA before forwarding to the CU receiver. The paper compared the performance of the two detectors by simulating the developed algorithm using MATLAB R2021a. Evaluation was based on Throughput, Spectrum Utilization Efficiency, and Spectral Efficiency by comparing Energy detector and Eigen Value detector.
Keywords: Energy Detector (ED), Eigenvalue Detector (EVD), White Space, Brown Space, Spectrum Sensing (SS), Code Division Multiple Access (CDMA).
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1. Introduction

The performance of cognitive Radio (CR) is dependent on the secondary users' (SU) capacity to limit interference to primary user (PU) while maintaining a consistent quality of service (QoS) for its operations. Consequently, precise detection of PU existence has been deemed the most significant component in determining the integrity of CR networks (Alias, 2016; Anande and Patil, 2020; Liu *et al.*, 2022). Chembe *et al.* (2017) and Ojo *et al.* (2022) asserted that either a single user (SU), known as Non-Cooperative Sensing (NCS), or a collection of SUs known as Cooperative Sensing (CS), is required to achieve SS. Due to multipath propagation, NCS experiences receiver uncertainty when SU is outside the PU's transmission range. Contrarily, CS overcomes the difficulties of NCS and accomplishes a reliable detection that reduces interference from SU to PU (Sandeep, 2017; Ojo *et al.*, 2018). Additionally, CS enables SUs to collaborate on spectrum sensing to increase the veracity of the sensing even at poor PU signal intensity (Kevin, 2012; Bogucka *et al.*, 2015). Either a distributed approach (DA) or a centralized approach (CA) is used to achieve CS; CA is made up of numerous local sensing SUs, and a central entity called the Fusion Centre (FC). According to the CA strategy, each SU conducts local sensing and transmits its results to the FC for optimal decision-making. Meanwhile, in DA, SUs conducts local sensing and distribute observations without FC. Due to less reporting overhead between SUs, CA is associated with better detection performance and spectrum efficiency than DA (Hu *et al.*, 2015; Sandeep, 2017).

The multipath propagation phenomenon, in which the sent signal spreads in many reproductions due to obstruction in the terrestrial environment, also affects a CR's sensing precision. Adeyemo *et al.* (2014) and Adeyemo *et al.* (2019) described how the impacts of multipath propagation, such as signal fading and delay spread, generate fluctuations in the received signal that decrease the sensing accuracy of CR and result in interference. Thus, the two antenna topologies employed in CS to collaboratively detect an occurrence of PU signal are Single Antenna (SA) and Multiple Antenna (MA). While MA uses a single antenna at PU and multiple antennas at SU, a single antenna is used at both PU and SU in a SA topology. Due to the stronger PU signal, MA outperforms SA; nevertheless, a diversity combiner is needed to combine the many copies of the PU signal (Reba *et al.*, 2017). The type of diversity-combining approach utilized in SS has an impact on MA performance as well. Maximal Ratio

Combiner (MRC), Equal Gain Combiner (EGC), and Threshold Combiner (TC) are some of the adopted diversity combiners (Kumar *et al*., 2021). The outcome of earlier research showed that MRC and EGC perform better than TC due to their combiner nature. However, because of its less complicated hardware than MRC, EGC is frequently employed in the literature (Adeyemo *et al.*, 2019; Ojo *et al.*, 2020).

To identify the presence of white space and brown space, several detection methods, which includes Energy Detector (ED), Eigenvalue Detector (EVD), and Cyclostationary Detector (CD), have been proposed in the literature (Dong *et al.*, 2015; Nikhil and Rita, 2017; Sarala *et al.*, 2020; Murugan and Sumithra, 2021). Since prior knowledge of the licensed user is optional for this work, ED and EVD will be implemented (Manikandan *et al.*, 2016; Gevira, 2016). As a result, this paper proposes a cognitive radio system that alternates between an overlay and an underlay approach. When white space is present, the system will employ an overlay technique, and when there is brown space, it switches to an underlay strategy. To expand the coverage area of SU during the underlay approach, the system will use cooperative communication, in which the source transmits the signal to the destination across several nodes *i.e.,* relays (Nasir, 2017). Cooperative communication aims to increase SU's effectiveness and dependability by placing relay nodes halfway between the source and the destination. Two fundamental relaying protocols used in cooperative networks are amplify and forward (AF) and decode and forward (DF). In AF, the relay boosts the signal received from the source and re-transmits it through the channel between the relay and the destination. Contrarily, DF re-encodes and transmits the encoded signal to the destination after decoding the signal from the source (Nasir, 2017; Ojo *et al.*, 2018). The cognitive cycle's block diagram is depicted in Figure 1.

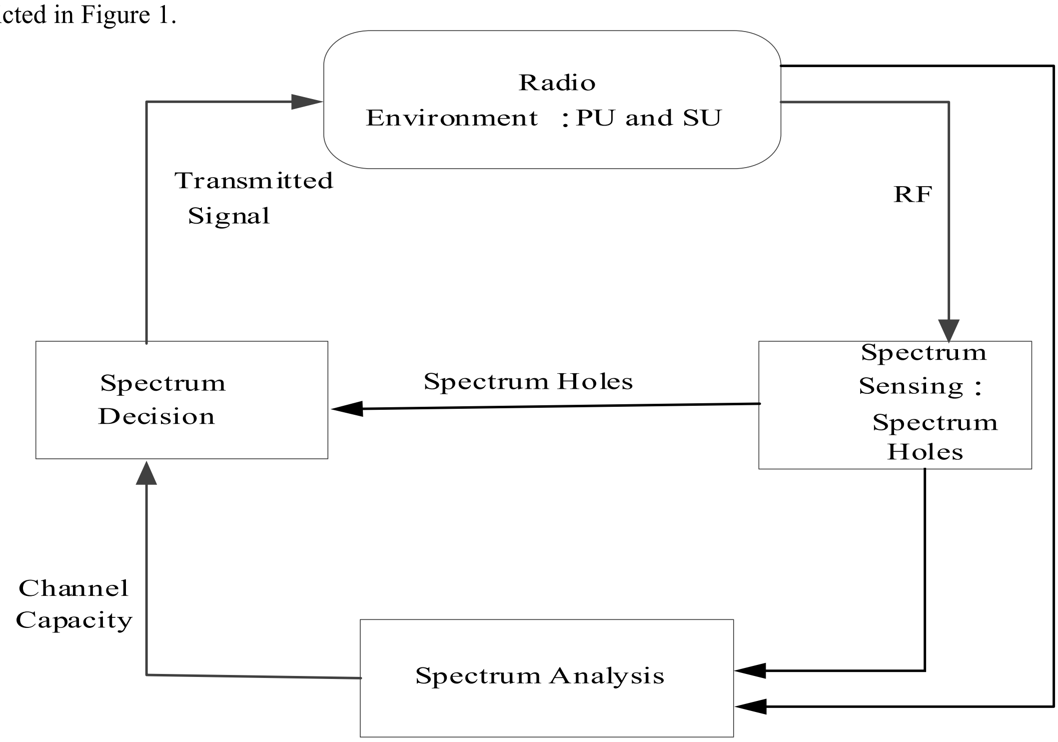

Figure 1: Block Diagram of Cognitive Cycle (Kevin, 2012; Ojo *et al.*, 2022).

Spectrum Sensing (SS) involves an unlicensed user scanning the available spectrum to look for licensed users and pinpoint any gaps in coverage (Gevira, 2016; Ojo *et al.*, 2020). SS involves detecting spectrum holes (white space) by sensing frequency spectrum in the cognitive user's immediate surroundings. SU keeps an eye on the spectrum bands that are open, records the data, and finds the gaps in the spectrum. The accuracy of spectrum shearing networks, which has been regarded as the most crucial aspect in assessing their performance, is determined using appropriate SS technique (Ojo *et al.*, 2021; Ojo *et al.*, 2022). It uses in-band sensing to look for the re-entry of PU on the spectral hole that the SU is now using or out-of-band sensing to find additional potential spectrum spaces. Out-of-band sensing helps SU find a viable spectrum hole and acts as a backup if the PU of the spectrum used at the time is active (Ojo and Fagbola, 2015). SS is a crucial component of spectrum shearing to find the spectrum hole that SU exploits for its operation and to shield PU from interference. The sensing is described as a method of determining the presence of a signal in a noisy environment and is based on a well-known technique called signal detection.

2. Development of Detection Techniques

Centralized-based cooperative spectrum sensing was used in this research to detect white and brown space precisely. To perform local spectrum sensing, multiple cognitive users (CUs), indicated as M_{cu}, were employed.

The sensing judgments from various CUs will be fused together using the OR rule to produce a result for global sensing. Since ED and EVD don't require synchronization between the licensed and cognitive users, they will be employed as a detector for local sensing. Cognitive user selection will be used to choose the users who will participate in the local sensing to lower the power consumption during the spectrum sensing.

2.1 Development of a Fading Channel

As illustrated in Figure 2, where H_1 and H_2 are representations of the Rayleigh and log-normal fading channels, respectively, the composite Rayleigh and log-normal fading channel will be regarded as the combined fading channel. The effectiveness of the suggested energy-efficient optimal frequency spectrum management technique will be assessed across the combined fading channel, with the composite fading channel being employed in the modeling. The adopted Probability Density Function (PDF) for the composite fading channel '$\delta_{RL}(u)$' is follows (Ojo *et al.*, 2020).

$$\delta_{RL}(u) = \int_0^\infty \delta_R(u).\ \delta_L(u)du \tag{1}$$

where: $\delta_R(u)$ is PDF of Rayleigh fading channel denoted by $P_R(u)$, is given as

$$P_R(u) = \frac{u}{\alpha^2} exp - \left(\frac{u^2}{2\alpha^2}\right) \qquad 0 \leq \text{u} \leq \infty \tag{2}$$

where: r is the amplitude of the received signal,
α is the root mean square (rms) value of the received signal,
α^2 is the time-averaged power of the received signal, and
$2\alpha^2$ is the pre-detection mean power of the received signal.

$\delta_L(u)$ is PDF of log-normal fading channel, which is given inthe received signal envelope, $P_L(u)$, of this kind of fading is given as:

$$P_L(u) = \frac{10/_{ln10}}{u\alpha(2\pi)^{\frac{1}{2}}} exp\left(-\frac{(lnu-\mu)^2}{2\alpha^2}\right) \tag{3}$$

where: u is the amplitude of the received signal, and
µ and α are the mean and the standard deviation of lnu, respectively

Therefore, substituting Equations (2) and (3) into Equation (1), the expression for composite fading channel is obtained as

$$\delta_{RL}(u) = \int_0^\infty \frac{u}{\alpha^2} exp - \left(\frac{u^2}{2\alpha^2}\right) \frac{10/_{ln10}}{u\alpha(2\pi)^{\frac{1}{2}}} exp\left(-\frac{(lnu-\mu)^2}{2\alpha^2}\right) du \tag{4}$$

Solving Equation (4), the expression for $P_{RL}(u)$ is obtained as:

$$\delta_{RL}(u) = \frac{1.74}{\alpha^3} \int_0^\infty \left(exp\left(\frac{-u^2}{2\alpha^2}\right) exp - \left(\frac{lnu-\mu}{2\alpha^2}\right)^2\right) du \tag{5}$$

$$\delta_{RL}(u) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \int_0^\infty exp\left(\frac{-u^2}{2\alpha^2}\right)\left(exp\left(\frac{2\mu lnu}{2\alpha^2}\right) - \left(\frac{lnu^2}{2\alpha^2}\right)\right) du \tag{6}$$

$$\delta_{RL}(r) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \int_0^\infty exp\left(\frac{-u^2}{2\alpha^2}\right)\left(exp\left(lnr\,\frac{(\mu-1)}{\alpha^2}\right)\right) du \tag{7}$$

$$\delta_{RL}(r) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \int_0^\infty exp\left(\frac{-u^2}{2\alpha^2}\right) u^{\left(\frac{\mu}{\alpha^2}\right)} du \tag{8}$$

$$\delta_{RL}(r) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \int_0^\infty u^2 . exp\left(\frac{-u^2}{2\alpha^2}\right) du \tag{9}$$

Let $u = \alpha . x$; $du = \sigma dx$, substituting into Equation (9) gives:

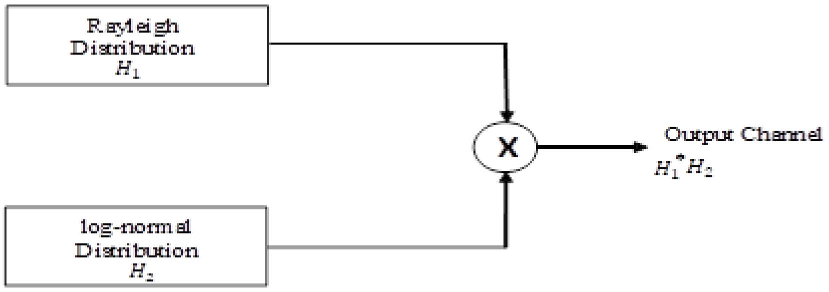

Figure 2: Composite Rayleigh and log-normal fading distribution

$$\delta_{RL}(u) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \int_0^\infty \alpha^2 x^2 . exp\left(\frac{-\alpha^2 x^2}{2\alpha^2}\right) \alpha dx \quad (10)$$

$$\delta_{RL}(u) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \alpha^3 \int_0^\infty x^2 . exp\left(\frac{-x^2}{2}\right) dx \quad (11)$$

Integrate Equation (11) with respect to x gives

$$\delta_{RL}(u) = \frac{1.74}{\alpha^3} exp\left(\frac{-\mu^2}{2\alpha^2}\right) \alpha^3 \left(\left(\frac{\pi}{2}\right)^{1/2}\right) \quad (12)$$

$$\delta_{RL}(u) = \frac{1.74}{2}\left(exp\left(-\frac{\mu^2}{2\alpha^2}\right)(2\pi)^{1/2}\right) \quad (13)$$

$$\delta_{RL}(u) = 0.87(2\pi)^{1/2}\left(exp\left(-\frac{\mu^2}{2\alpha^2}\right)\right) \quad (14)$$

2.2 Local spectrum sensing using Energy Detector (ED).

Cognitive User (CU) antennas will pick up the signal that the Licensed User (LU) broadcast over the composite Rayleigh and log-normal fading channel. Due to its increased diversity gain and lower hardware complexity, Equal Gain Combiner (EGC) will be utilized to combine the LU signals at the RF stage. As shown in Figure 3, the signal output of the EGC will be applied to the ED, and H_{rl} is the i^{th} channel gain of the composite Rayleigh and log-normal fading channel. To determine if there is white space present or brown space, the output of ED will be compared with the decision threshold. If the output of ED exceeds the predetermined threshold, it is decided that brown space is present since CU is still being transmitted; otherwise, white space is present, meaning the spectrum is not being used at that time. The Probability of False Alarm (PFA) of 5% (0.05) will be used to determine the threshold to balance the effectiveness of spectrum management with the protection of LUs.

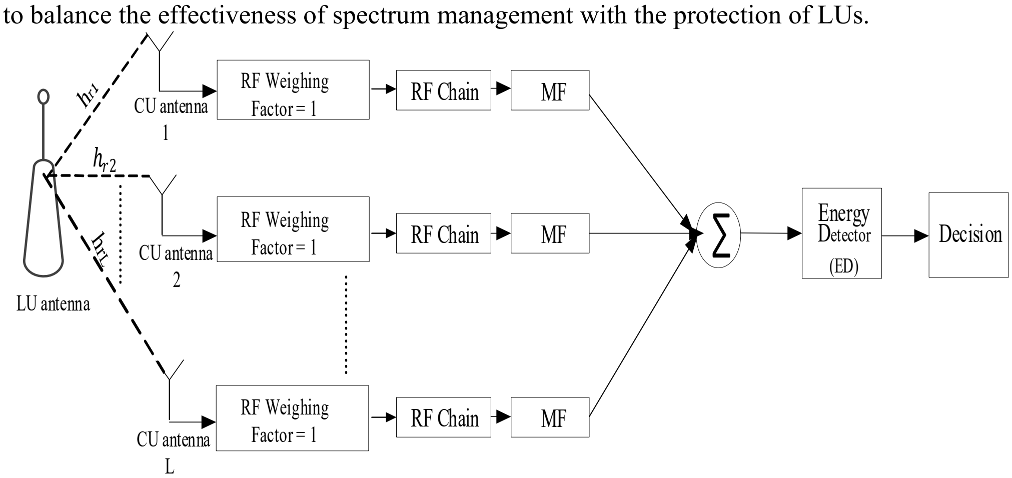

Figure 3: Block diagram of local sensing for the proposed technique using ED.

The received signal $g(i)$ at the i[th] CU antenna is given as:

$$g(i) = V(i) + N(i) \quad (15)$$

where $V(i)$ is the CU signal power on the i^{th} branch.
$N(i)$ is the noise present on the i^{th} branch.

The output of energy detection, "E_{time}" is expressed by Refik (2010) and Adeyemo *et al.* (2019) as:

$$E = \sum_{n=1}^{P} |g(n)|^2 \tag{16}$$

$$E \geq ã \tag{17}$$

where: P is the symbol length to be sensed,
$g(n)$ is the transmitted signal by PU, and
ã is the set threshold.

The SNR of EGC output 'SNR_{EGC}' is given by Goldsmith (2004) as:

$$SNR_{mEGC} = \frac{1}{NL}\left(\sum_{i=1}^{L} S(i)\right)^2 \tag{18}$$

where: $S(i)$ is the signal power on each branch
L is the number of branches and w is the noise present on each branch

Using Equations (16) and (18), the output of ED, E_{EGC}, becomes

$$E_{EGC} = \sum_{n=1}^{P} \left| \frac{1}{NL}\left(\sum_{i=1}^{L} g_n(i)\right)^2 \right|^2 \tag{19}$$

Spectrum sensing then uses test statistics to decide whether it is white or brown space that is present. The test statistic is given as:

$$E_{EGC} > ã \tag{20}$$

where ã is the decision threshold which based on PFA, and this will be derived to set decision threshold.

The following is how the probability of a false alarm (PFA) for local sensing employing ED to detect the presence of white or brown space is derived as follows:

The total noise power 'N_{tot}' at the output of EGC is expressed by Goldsmith (2004) as:

$$N_{tot} = \sum_{i=1}^{L} k_i N_i \tag{21}$$

where k_i is the weight on each branch, and
N_i is the noise power on each branch

Using Equation (19), the output of ED 'E_{EGC}' under null (H_0) hypothesis is expressed as:

$$E_{EGC/H_0} = \sum_{n=1}^{P} \left| \sum_{i=1}^{L} k_i(n) N_i(n) \right|^2 \tag{22}$$

E_{EGC/H_0} is the sum of square; therefore, the distribution of the test statistic becomes a chi-square distribution. Thus, the distribution of the ED, $f_{EGC/H_0}(\varphi)$ output is given by Refik (2010) as:

$$f_{EGC/H_0}(\varphi) = \frac{1}{\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{P}{2}} 2^{P/2}\Gamma(P/2)} \varphi^{(P/2)-1} \exp\left(-\frac{\varphi}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}\right) \tag{23}$$

To obtain PFA, Equation (12) is integrated with respect to the degree of freedom, φ that is

$$PFA_{EGC} = \int_{\frac{ã}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} f_{EGC/H_0}(\varphi)\, d\varphi \tag{24}$$

$$PFA_{EGC} = \int_{\frac{ã}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} \frac{1}{\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{P}{2}} 2^{P/2}\Gamma(P/2)} \varphi^{(P/2)-1} \exp\left(-\frac{\varphi}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}\right) d\varphi \tag{25}$$

$$PFA_{EGC} = \frac{1}{\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{N}{2}} 2^{N/2}\Gamma(N/2)} \int_{\frac{ã}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} \varphi^{(N/2)-1} \exp\left(-\frac{\varphi}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}\right) d\varphi \tag{26}$$

Integrating Equation (26) with respect to φ, using change of variable, the closed form expression of PFA, 'PFA_{EGC}' for the proposed technique is express as

$$PFA_{EGC} = \frac{1}{\left(\sum_{n=1}^{p}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{p}{2}} 2^{p/2}\Gamma(p/2)} \times$$

$$\int_{\frac{\tilde{a}}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} \frac{2^{P/2}\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{(P/2)}}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)} t^{(P/2)-1} exp^{-t} 2\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)dt \quad (27)$$

$$PFA_{EGC} = \frac{2^{P/2}\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{P}{2}}}{\left(\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)\right)^{\frac{P}{2}} 2^{P/2}\Gamma(P/2)} \int_{\frac{\tilde{a}}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} t^{(P/2)-1}\exp(-t)\,dt \quad (28)$$

$$PFA_{EGC} = \frac{1}{\Gamma(P/2)} \int_{\frac{\tilde{a}}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}}^{\infty} t^{(P/2)-1}\exp(-t)\,dt$$

(29)

Using incomplete gamma function $\Gamma(c, f) = \int_c^{\infty} t^{f-1}\exp(-t)dt$; the mathematical expression of PFA 'PFA_{EGC}' for the proposed technique is obtained as

$$PFA_{EGC} = \frac{\Gamma\left(\frac{\tilde{a}}{2\sum_{n=1}^{P}\sum_{i=1}^{L}\alpha_i^2(n)}, P/2\right)}{\Gamma(P/2)} \quad (30)$$

where $\Gamma(.)$ is the gamma function, and
α_w^2 is the variance of the noise.

The energy of the received signal at the CU will be obtained using Equation (19) and compared with the set threshold. If the energy obtained is higher than the set threshold, brown space is present, otherwise white space is present.

2.3 Local spectrum sensing using Eigenvalue detector (EVD).

The maximum and minimum eigenvalues of the covariance matrix of the received signal serve as the foundation for the non-coherent detector known as the Eigenvalue Detector (EVD). In EVD, the received signal is used to create the covariance matrix first. The covariance matrix is then used to find the highest and lowest eigenvalues. To assess if there is a PU signal present or not, the greatest to minimum eigenvalue ratio is contrasted with the predetermined threshold. The maximum and minimum eigenvalues are equal under the H_0 hypothesis, or when the spectrum is at rest; as a result, their ratio is equal to unity and is employed as a threshold. However, when the spectrum is active, or under the H_1 hypothesis, the maximum and minimum eigenvalues do not equal each other, and their ratio is then compared to a predetermined (Yonghong and Ying-Chang, 2009; Nandkishor and Sonawane, 2016).

The PU signal is present if the maximum to minimum eigenvalue ratio under the H_1 hypothesis is bigger than the maximum to minimum eigenvalue ratio under the H_0 hypothesis; otherwise, the PU signal is absent. The threshold in EVD, in contrast to ED, is independent of the noise variance, solving the noise uncertainty issue. Additionally, EVD performs better than ED since it can pick up highly correlated signals, which is difficult to do with ED. However, the construction and decomposition of the received signal's covariance matrix make EVD computationally complicated (Yonghong and Ying-Chang, 2009). According to the H_0 theory proposed by Nandkishor and Sonawane (2016), the received signal $Y_i(n)$ is given as:

$$Y_i(n) = \sum_{n=1}^{p}\sum_{k=0}^{q} h_n(k)x_n(k) + w_n(k) \quad (31)$$

where: p is the number of licensed user's signal,
x_n is the licensed user's signals,
$h_n(k)$ is the channel response from PU signal,
$w_n(k)$ is the noise present.

The sample covariance matrix $'R_C'$ is given by Yonghong and Ying-Chang (2009) as:

$$R_C(N) = \frac{1}{Z}\boldsymbol{X}^{\boldsymbol{q}}\boldsymbol{X}^{+(\boldsymbol{q})} \quad (32)$$

where: Z is the number of collected samples,
$\boldsymbol{X}^{\boldsymbol{q}}$ is the square matrix,
$\boldsymbol{X}^{+(\boldsymbol{q})}$ is the transpose of matrix X^q

Accordingly, the characteristic equation of a square covariance matrix 'A' is given as:

$$det(A - \beta I) = 0 \quad (33)$$

where: β is the eigenvalue, and
I is the identity matrix.

The received signal 'S' from CU antennas for the proposed technique is given as

$$S = \sum_{i=1}^{P_a} \sum_{j=1}^{Q_l} V(j) + N_i(j) \tag{34}$$

where: P_a is the number of antennas,
Q_l is the number of branches received by individual antenna,
$V_i(j)$ is the i[th] LU signal from the j[th] branch
$N_i(j)$ is the AWGN present on the LU link

$$\boldsymbol{V} = \begin{bmatrix} S_{1,1} & S_{1,2} \dots\dots & S_{1,Q} \\ S_{2,1} & S_{2,2} \dots\dots & S_{2,Q} \\ & & \vdots \\ S_{P,1} & S_{P,2} & S_{P,Q} \end{bmatrix} + \begin{bmatrix} N_{1,1} & N_{1,2} \dots\dots & N_{1,Q} \\ N_{2,1} & N_{2,2} \dots\dots & N_{2,Q} \\ & & \vdots \\ N_{P,1} & N_{P,2} & N_{P,Q} \end{bmatrix} \tag{35}$$

According to Syed *et al*. (2016), covariance V_C of the signal received is given as

$$\boldsymbol{V_C} = \frac{1}{P}(\boldsymbol{V})\boldsymbol{V}^T \tag{36}$$

where: $\boldsymbol{V^T}$ is the transpose of the signal received.

Using Equation (33), the maximum eigenvalue, τ_{max} and the minimum eigenvalue, τ_{min}, can be obtained from Equation (36) as

$$det(\boldsymbol{V_C} - \tau I) = 0$$

Solving Equation (36) and substituting into Equation (33) gives

$$det \begin{bmatrix} V_{C1,1} - \tau & V_{C1,2} \dots\dots\dots & V_{C1,Q} \\ V_{C2,1} & V_{C2,2} - \tau \dots\dots & V_{C2,Q} \\ & & \vdots \\ V_{CP,1} & V_{CP,2} & V_{CP,Q} - \tau \end{bmatrix} = 0 \tag{37}$$

τ with the highest value is the maximum eigenvalue, while τ with the lowest value is the minimum eigenvalue. Therefore, the test statistics 'Z' for EVD is given as

$$Z = \frac{\tau_{max}}{\tau_{min}} \tag{38}$$

The probability of detecting the presence of white or brown space at the local sensing using EVD P_{EVD} is given as:

$$P_{EVD} = \Pr(Z > 1) \tag{39}$$

Therefore, if $Z > 1$, white space is present, otherwise, brown space is present.

2.4 Improved sensing techniques for detecting white or brown space.

With the use of centralized cooperative spectrum sensing, the findings of global sensing will be used to identify the presence of white or brown space. At the Fusion Centre (FC), the local sensing results from each CU will be fused to provide the global sensing result. Due to its improvement in LU protection, the OR fusion rule will be employed to merge the local sensing findings from individual CU. To establish if there is white or brown space, the global sensing result 'P_{OR}' is expressed as:

$$P_{OR} = 1 - (1 - P_{EVD})^{L_{cu}} \tag{40}$$

where: P_{EVD} is the probability of detecting the presence of white or brown space.
L_{cu} is the number of CU participate in the local sensing

3. Result for Comparative Analysis of Performance of ED and EVD in EEOFSM

Figures 4 to 6 present throughput comparison analysis of ED and EVD signal detections for the developed EEOFSM at different SNRs with different numbers of CU. At CU of 4 and CU antenna of 3, ED has throughput values of 5.9077 Mbps and 39.52 Mbps at SNRs 4dB and 10dB respectively while EVD has 4.8 Mbps and 30.4 Mbps at same SNR values. Correspondingly, at higher number of CU of 6 and CU antenna of 4, ED gave throughput values of 9.6 Mbps and 60.8 Mbps at SNRs 4dB and 10dB respectively while EVD has 7.3846 Mbps and 46.7692 Mbps at same SNR values.

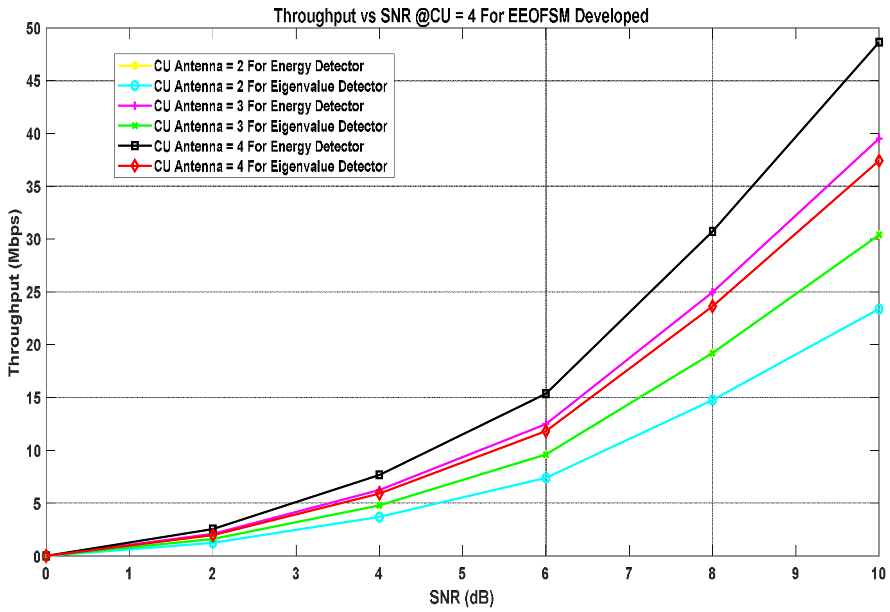

Figure 4: Throughput comparison of ED and EVD sensing techniques at CU of 4 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

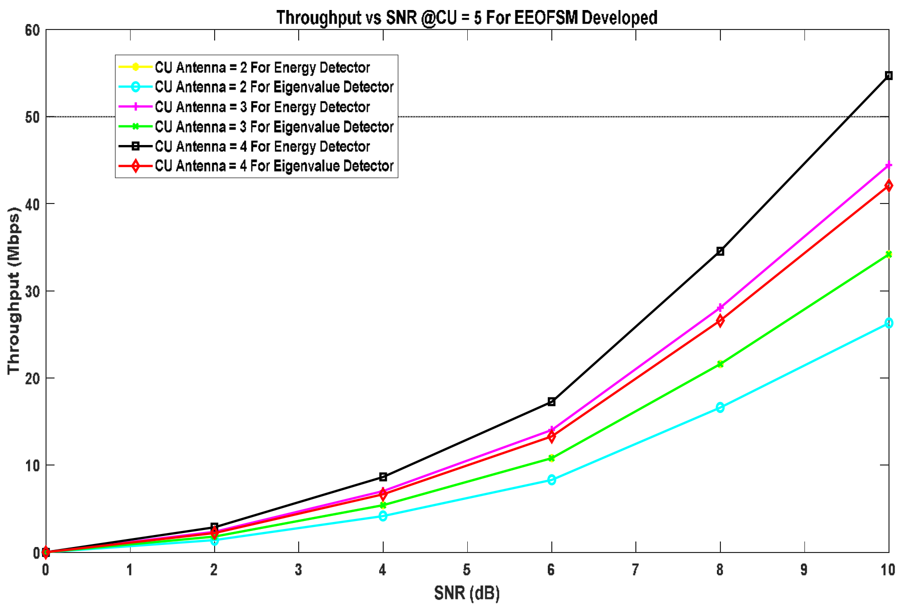

Figure 5: Throughput comparison of ED and EVD sensing techniques at CU of 5 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

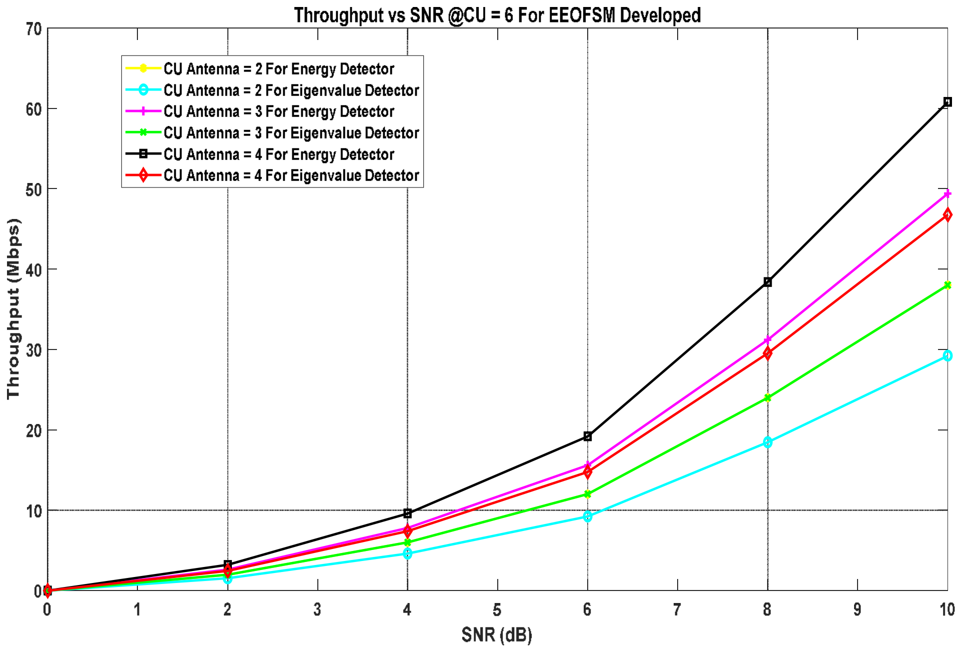

Figure 6: Throughput comparison of ED and EVD sensing techniques at CU of 6 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

Figures 7 to 9 give a graphical representation of Spectral efficiency comparison of the developed EEOFSM between ED and EVD signal detections. At given CU of 5 and CU antenna of 4, ED gave a spectral efficiency value of 10.5984 bits/Hz and 14.6088 bits/Hz with EVD having values of 8.1526 bits/Hz and 11.2375 bits/Hz at SNRs 4dB and 10dB respectively.

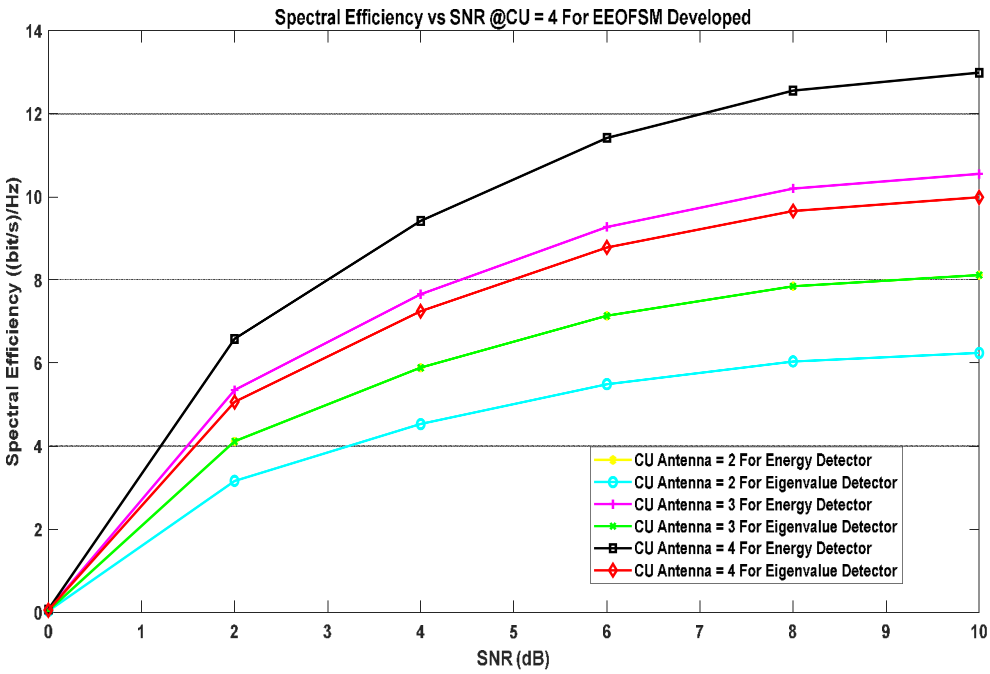

Figure 7: Spectral Efficiency comparison of ED and EVD sensing techniques at CU of 4 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

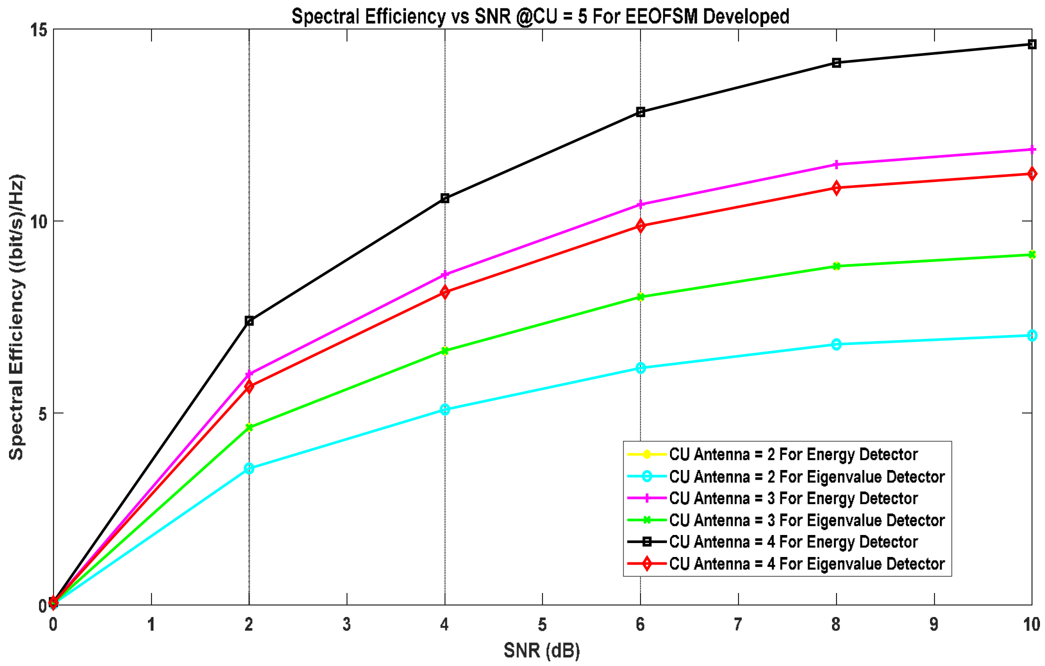

Figure 8: Spectral Efficiency comparison of ED and EVD sensing techniques at CU of 5 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

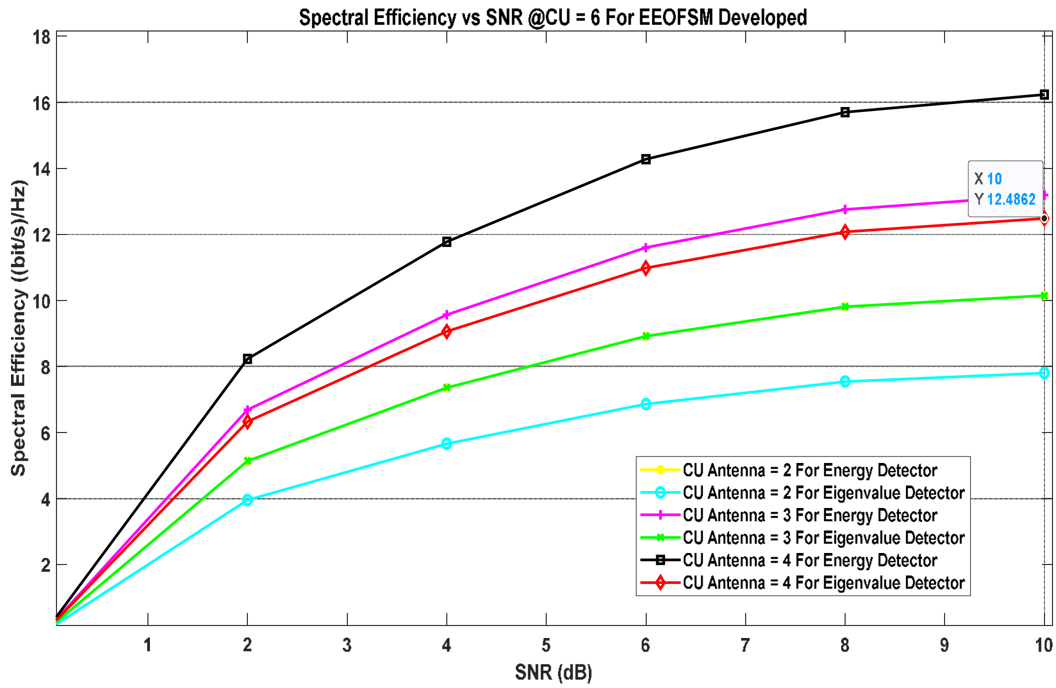

Figure 9: Spectral Efficiency comparison of ED and EVD sensing techniques at CU of 6 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

Figures 10 to 12 reveal that at CU of 6 and CU antenna of 3, ED Spectrum Utilization Efficiency metrics performed better with 7.3846 and 49.400 at 4dB and 10dB SNRs as compared with EVD with 6 and 38 Spectrum Utilization Efficiency at same SNR.

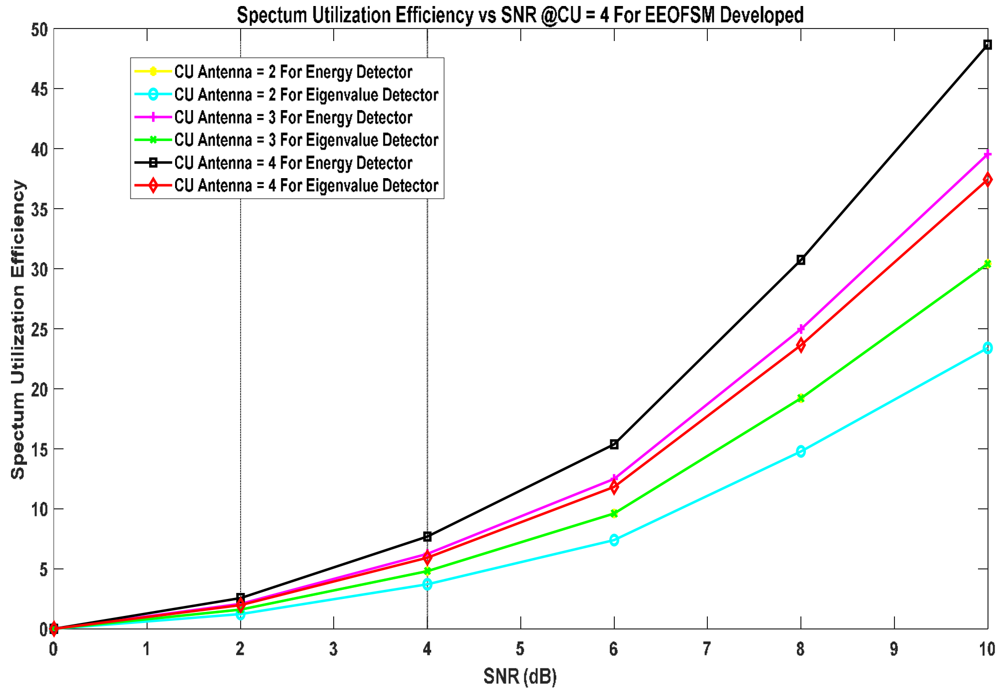

Figure 10: Spectral Utilization Efficiency comparison of ED and EVD sensing techniques at CU of 4 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

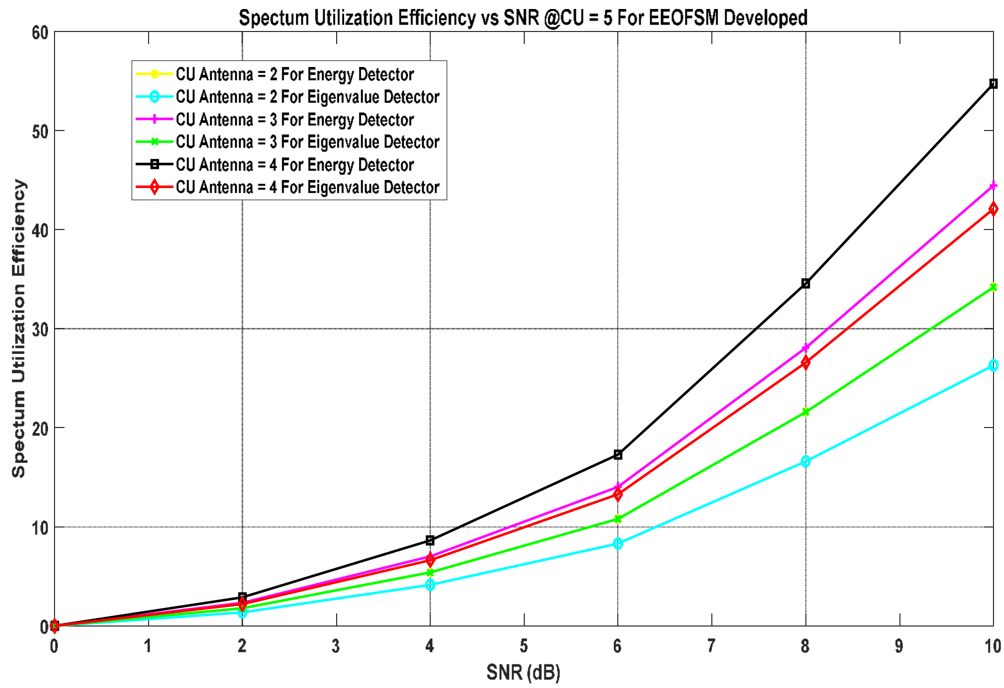

Figure 11: Spectral Utilization Efficiency comparison of ED and EVD sensing techniques at CU of 5 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

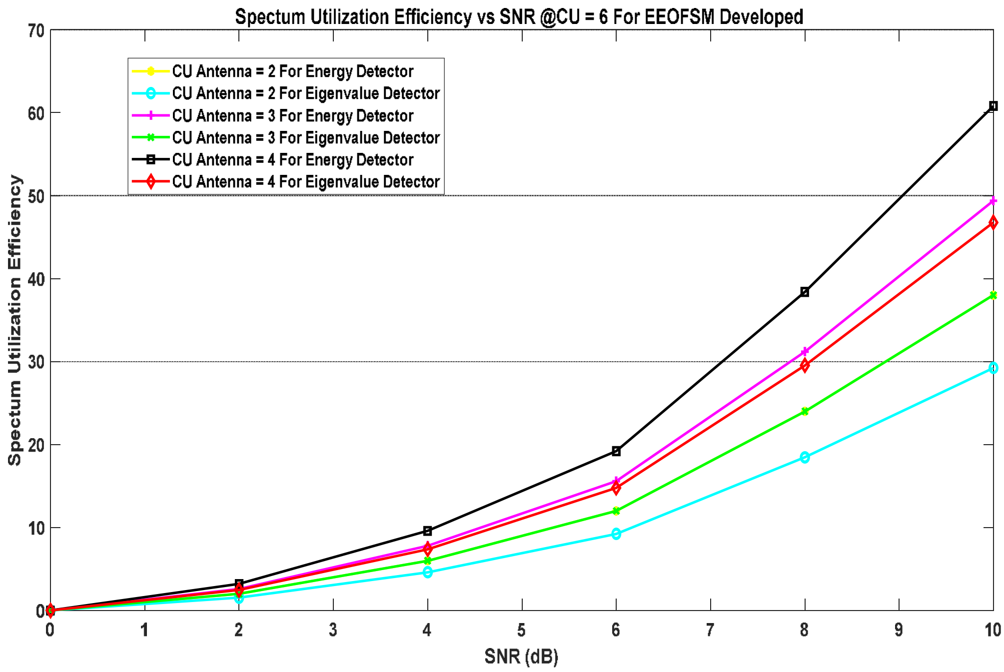

Figure 12: Spectral Utilization Efficiency comparison of ED and EVD sensing techniques at CU of 6 with varying CU antennae 2, 3 and 4 for the developed EEOFSM.

The results obtained revealed that ED performs better as compared to EVD due to poor detection rate of EVD when compared with ED. In ED, since the set threshold is a function of noise, at low signal strength, it would be difficult to determine the noise from the signal. In this work, to improve the signal strength, the use of Equal Gain Combiner to combine the multiple copies of PU signal was introduced. This reduced the probability of false alarm towards increasing the detection rate.

4. Conclusion

Energy Detector (ED) and Eigen Value Detector (EVD) were used to conduct Local Spectrum Sensing (LSS) across the combined fading channel. Equal Gain Combiner (EGC) was used to combine numerous copies of Primary User (PU) signals that were received via different Secondary User (SU) antenna at different gain levels. The chance of detecting white or brown space via ED was determined using a closed form expression for chance of False Alarm (PFA). The covariance matrix of the received PU signals was then used to calculate the ratio of maximum to minimum eigenvalues, which was then utilized as a test statistic to determine whether white or brow space could be detected using EVD. The 'M' (4, 5, 6) CUs were added to the system model for LSS to perform local sensing and assess the impact of the system performance on the number of CU antenna. To reduce power consumption during local sensing, CU selection and Radio Frequency (RF) energy harvesting were also done there. To establish if there is white or brown space, the sensing data from each individual CU were merged using the OR rule.

In the suggested method, the system alternates between the overlay and underlay techniques while cooperating communication is based on the detection of white and brown space. Additionally, it can be inferred from the data that ED has the highest values for all the performance indicators employed, which supports its superior performance over EVD in the constructed system. By integrating the characteristics of PU signals in the established technique, a stronger signal is produced, improving the accuracy of the identification of white and brown areas. As a result, ED is a superior detector to EVD in a system with a stronger PU signal. From the results, it was also concluded that ED performs better with more CUs and CU antennas. The developed EEOFSM technique as well as the two already existing techniques, namely the overlay and underlay techniques, were also tested to determine how the number of CU and CU antenna affected the system performance. The results obtained showed that for all three techniques, the system performance increases with an increase in CU and CU antenna. As a result, the developed EEOFSM approach demonstrated effective spectrum management over a combined Rayleigh and log-normal fading channel with minimized PU and CU interference.

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Conflict of Interest
The authors declare that they have no conflicts of interest.

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