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Comparative Analysis of Performance of a Developed Energy-efficient Optimal Frequency System Versus Existing Overlay and Underlay Approaches

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ABSTRACT
This paper proposed an effective switching technique between Overlay Cognitive Radio (OCR) and Underlay Cognitive Radio (UCR) in a wireless communication system. The availability of white or brown space is achieved using energy detector and the system switches to overlay approach when there is presence of white space, and instantly switches to underlay approach when there is presence of brown space based on the switching algorithm. Also, Hybrid Decode Amplify and Forward (H-DAF) cooperative relay technique is incorporated to enhance the coverage area of the cognitive user. 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 proposed spectrum management system is simulated using MATLAB R2021a and evaluated using Throughput (TP) and Spectral Efficiency (SE) by comparing with the existing overlay and underlay CR approach. The simulated outcomes showed the designed system demonstrated improved switching system and performances than the existing techniques with highest TP and SE values and can be adopted in wireless communication designs for effective frequency spectrum usage.

General Terms
Wireless communication, Spectrum Sensing, Code-Division Multiple Access

Keywords
Cognitive radio; Dynamic Spectrum Access; white space; brown space; signal to interference ratio; Spectrum Utilization Efficiency.

1. INTRODUCTION
Wireless communication systems (WCS) are experiencing expansion because of their usefulness across all spheres of life and this expansion has led to an increase in daily bandwidth usage. However, the assigned bandwidth can only be used by the user whether it is active or not, and this has led to a shortage of available spectrum. Access to a wider spectrum is inevitable as the existing ones are insufficient because of increased users. Proffering solution to this, Cognitive Radio (CR) technology was suggested as it allows unlicensed users to make use of the unused licensed spectrum without interfering with the rightful licensed users. CR promotes dynamic spectrum access (DSA). The two basic forms of cognitive radio in wireless communication are Overlay CR (OCR) and Underlay CR (UCR). Overlay Cognitive Radio (OCR) is a technique in which unauthorized users make use of the assigned spectrum when white space is present while Underlay Cognitive Radio (UCR) makes use of the spectrum when brown space is present.

This necessitates upgrades of wireless mobile systems to accommodate this exponential increase. The merits of the radio frequency (RF) spectrum in wireless communication system are inexhaustible. A very large number of wireless applications and services use the RF spectrum for data transmission. Due to importance of RF spectrum, it's limited allocation to various licensed users have led to its scarcity and unavailability for the new users [1]. The available free Industrial, Scientific, and Medical (ISM) spectrum bands are also congested for various wireless services [2]. This insufficiency of RF spectrum has a way of slowing down the future growth of WCS [3,4]. Considering the rise in demand for RF spectrum and its scarcity, efforts are being put in place by scholars for an alternative means of utilizing the available RF spectrum. Recently, research has proven that the existing bands can be shared by another user. Research carried out by concerned users around the globe (government, institutions, research *etc.*) has proven that an apportioned part of the spectrum are being underutilized aside from the ISM and cellular technologies bands [5]. The process whereby a user stays on the assigned spectrum is known as Fixed Spectrum Access. This approach has been shown to be inefficient based on the results of the research conducted [6].

Attempts to overcome the challenges of insufficient spectrum has given rise to a new concept of allowing the new wireless system access. This solution is found in Cognitive radio (CR) as a promising technique is proposed to overcome the insufficiency of available communication spectrums. CR senses the spectral environment and uses the information gathered to opportunistically provide wireless links needed optimally for communication. It comprises of two major users; the Primary User (PU) who is the licensed user with full privileges to the assigned spectrum and the Secondary User

(SU) or the Cognitive User is the unlicensed user that makes use of radio spectrum when not in use [7,8,9]. The given passage describes the concept of Cognitive Radios (CR) and their role in dynamic spectrum access. It states that Primary Users (PUs) have higher priority or 'legacy rights' to use a specific part of the spectrum, while Secondary Users (CUs) have a lower priority and must exploit the spectrum without causing interference to PUs. CUs are required to have CR capabilities, which include sensing the spectrum to identify areas not occupied by PUs. They then search the unused spectrum to enhance their own spectrum utilization. This approach contrasts with the traditional fixed spectrum allocation model. Cognitive Radios achieve dynamic spectrum access by implementing a cognitive cycle, which ensures the integrity of the CR network and protects PU activities. As illustrated in Figure 1, the cognitive cycle consists of four operations: Spectrum Sensing (SS), where the CR system detects spectrum availability; Spectrum Analysis (SA), where the system analyzes the sensed spectrum to gather information; Spectrum Decision (SD), where the system determines the best available spectrum for CU usage; and Data Transmission (DT), where the system transmits data using the selected spectrum.

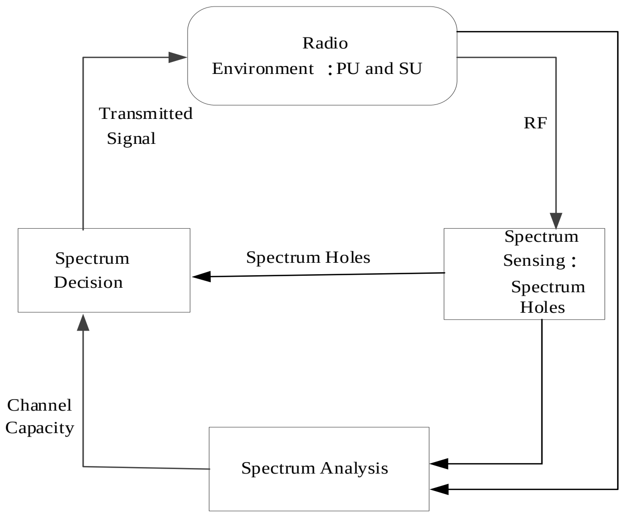

Fig. 1: Block Diagram of Cognitive Cycle [10,11]

The accessibility of SU is that licensed spectrum is a function of presence of white space or brown space. White space or hole is the idle spectrum that is due to absence of PU, while brown spaces are the unused spectrum by the licensed user during its available period. Therefore, 'overlay' and 'underlay' are the two major approaches in a cognitive radio system. Overlay CR (OCR) is a technique in which unlicensed user make use of the assigned spectrum when white space is present, while Underlay CR (UCR) is a technique in which SU make use of allocated spectrum when there is presence of brown space [12,13,14]. In overlay approach, unlicensed users are only allowed to make use of assigned spectrum when it is not use by the licensed user. SU must wait until PU is not active before it can transmit through the licensed spectrum. The moment a licensed user wishes to access the spectrum, all the SUs using it must leave immediately and look for other idle spectrum. On the other hand, in the underlay approach, both the SU and PU can use the assigned spectrum at the same time provided the interference at the licensed user is kept at an acceptable level. The unlicensed users do not have to wait until the licensed users are not active, rather both the users can transmit at the same time by maintaining interference below a prescribed level [15,16].

High SU interference which is majorly due to inaccurate detection of white and brown space is a major challenge of existing work on CR. Inaccurate detection of white and brown space will result in ineffective switching between overlay and underlay CR which led to high interference, thereby increasing the error rate of cognitive user. Bandwidth inefficiency is another problem associated with the previous work on CR. Due to large reporting overhead between the SUs during white or brown spaces detection using cooperative sensing, Bandwidth inefficiency results in low spectral efficiency of cognitive user. The problem of 'hidden terminal' occurs when the CU is shadowed, in severe multipath fading or inside buildings with high penetration loss [17]. Furthermore, the existing work suffered extra energy consumption due to spectrum sensing cooperative communication required to identify backup spectrum and power allocation enhancement, respectively. Therefore, this research proposes a cognitive radio system that switches between overlay and underlay for effective switching technique in a wireless communication network.

Several authors have carried out research on OCR and UCR for efficient management of the assigned spectrum. The authors in [18] carried out power minimization in a dual hop underlay cooperative CR with relay network for maximal resource allocation to investigate multiple users with one-way dual-hop multiple relay CR underlay approach. Results obtained revealed that the proposed scheme has reduced power consumption compared to the existing scheme. However, the proposed system suffered from SU's inability to transmit signal at higher transmitting power even when the licensed user is not active. Cooperative spectrum sensing optimization for cognitive radio in sixth generation networks to aid the optimal management of the assigned spectrum using Manta Ray Foraging (MRFO) algorithm was proposed by the authors in [19]. The result showed the enhanced technique had more efficient spectrum sharing than the existing overlay cognitive radio. However, unlicensed users can only make use of the assigned spectrum when there is a presence of white space, even when the licensed user is transmitting at a safe interference power constraint resulting in poor management of the available spectrum.

The authors in [20] developed a learning approach for achieving power control in a full duplex underlay CR network to improve the performance of the existing underlay CR system using full duplex cooperative communication. The outcome results established that the proposed technique achieve lowest number of average transactions and was able to reduce at least 98.1% and 53.3% of the storage resources and computing time respectively, which verified the effectiveness of the proposed scheme. However, in the proposed technique, cognitive user transmits at a reduced power even when the licensed user is not active, thereby reducing the throughput and increasing the error rate of cognitive user. Also, the authors in [21] proposed a DDPG-based throughput optimization with AoI constraint in ambient backscatter assisted overlay CR network to improve the performance of the existing overlay CR network. The results of the paper showed that throughput of the proposed CR network was close to the optimal throughput of the baseline scheme and the age of information of the proposed CR network was close to the optimal age of information baseline scheme. However, in all the scenarios considered, SU can only make use of the spectrum when the licensed user is not active, resulting in poor management of the assigned spectrum. Therefore, the major contributions of this paper are:

1) Development of switching algorithm that switches between overlay and underlay in Cognitive Radio for Optimal frequency spectrum management system in wireless communication.

2) Comparatively Analyze the performance of the developed system that switches between OCR and UCR technique for the efficiency of the assigned spectrum.

2. SPECTRUM SENSING APPROACH

All material on each page should fit within a rectangle of 18 x Spectrum Sensing is important for SU to determine the availability of spectrum hole and protects PU from interference. Signal detection is known as the sensing technique called signal detection, being defined as a method of identifying the availability of a signal in a noisy environment. Analytically, signal detection is reduced to a simple identification, formalized as a hypothesis as expressed below:

$$H1: y(n) = p(n)\, h + w(n) \quad (1)$$

$$H0: y(n) = w(n) \quad (2)$$

where: *y (n)* is the received signal by SU; *p (n)* is the transmitted signal from PU; *h* = channel coefficient; *w (n)* = Additive White Gaussian Noise; *H0* = sensing states for absence; *H1* = sensing state for the presence of signal. In other words, *H0* = null hypothesis indicating the absence of the primary user and *H1* is alternative hypothesis that indicates availability of primary user.

Sensing time should be chosen meticulously to avoid harmful interference to the primary system. At long sensing time, a PU is likely to enter the band at which a CU operates causing interference. Also, lengthening the sensing time may result in missing chances for using the spectrum when a PU has left a band while the CU is still waiting for the end of the sensing time. According to [17], the three aspects of PU detection that need to be verified and quantified to define metrics for CR systems are:

1. The time preceding the detection

2. The time to make the spectrum free once a PU has been detected

3. The efficacy of PU detection: this is the probability of missed detection PMD and the probability of false alarm PFA.

Bayesian and Neyman-Pearson sense proposed a ratio test for binary hypothesis for optimal decision [22]. Confirming the present hypothesis, the owner constructs the likelihood ratio, ʌ(y), of the hypothesis with a detection threshold η [21].

$$\frac{p(y/H1)}{p(y/H0)} \frac{^{H_0}{<}\eta}{_{H_1}{>}\eta}\, \eta \quad (3)$$

Where p(y/H1), i ∈ {0, 1} stands for joint probability distribution function of the measured samples, y, on each hypothesis. Replacing the probability distribution function p(y/H1), i ∈ {0, 1} in equation 3, the likelihood ratio can be written as a function measuring produce F(y):

$$F(y) = \frac{^{H_0}{<}\eta}{_{H_1}{>}\eta}\, \eta, \quad (4)$$

Where the function, F(y), is test statistic. The detector evaluates the statistic, F(y), and compares it with a detection threshold, η. Using decision rule in equation (4), hypothesis H1 is considered if F(y) > η and hypothesis H0 if otherwise.

Two out of Four possible outcome are erroneous with the evaluation of the decision rules [18]:

• Firstly, declaring *H1* under *H1* hypothesis, there is a primary signal in the measured signal sample,

• Secondly, declaring *H0* under *H0* hypothesis, there is no primary signal in the measured signal sample,

• Thirdly, declaring *H1* under *H0* hypothesis leads to Probability of False Alarm (PFA). The detector does not correctly detect the presence of primary signal in the measured signal sample resulting in false alarm as the detector mistakes *H0* for *H1*, here, a spectrum opportunity is overlooked by the detector and

• Fourthly, declaring *H0* under *H1* hypothesis leads to Probability of Miss Detection (PMD). This is incorrect detection as there is no primary signal in the measured signal as the detector mistakes *H1* for *H0*, this is misdetection leading to a collision with PUs.

The probability of declaring "the absence of primary signal in the presence of primary signal is PMD. PFA on the other hand shows that primary signal exists in the absence of primary signal [23]. Error resulting from False alarm causes inefficient spectrum usage which contradicts the major reason for spectrum sensing, correct detection. Due to the statistical nature of the environment making this practically impossible, the signal detectors used for sensing operation are designed to operate within prescribed minimum error levels. The biggest issue for Spectrum Sensing is Missed detection because of its interference with the licensed user. PFA should be kept as low as possible, to enable the system to exploit all possible transmission properties [7,23]. The Spectrum sensing-based reliability model for signal level is usually defined in terms of two erroneous metrics. These are evaluated when the probability distribution function of the measured samples is conditioned on each hypothesis and known. The detection threshold of the detector is set; ideally, the detector design caters for minimizing these errors that can be varied by adjusting the detection threshold. However, the minimization contains two contradictory requirements; as one error reduces, the other error increases [18].

2.1 Proposed Technique

This work uses blind energy detection wherein the prior knowledge of PU signal is unknown; *E* gives the output of energy detection, as expressed [9,18]:

$$E = \sum_{n=1}^{P} |g(n)|^2 \quad (5)$$

$$E \geq \tilde{a} \quad (6)$$

where: P as the symbol length to be sensed; $g(n)$ is the transmitted signal by PU, and $\tilde{a}$ is the set threshold. Equation (6) represents the threshold which indicates whether PU signal exists or not.

Equal Gain Combiner (EGC) is a diversity combining technique used in combining all the signal branches by multiplying with equal weights irrespective of the signal amplitude. The signals are co-phased of all signals to avoid signal cancellation. Therefore, the implementation of EGC required simple phase lock summing circuit. Block diagram of EGC is shown in Figure 2. It consists of channel impulse responses h_1, h_2 …. h_L which have equal gains. These are being received by the antennas, processed by Radio Frequency (RF) chain, Matched Filter (MF) and each path has different delays before summing. EGC was used in this research due to its better performance and reduced hardware complexity. The SNR of EGC output ‘SNR_{EGC}’ is given as [24]:

$$SNR_{mEGC} = \frac{1}{NL}\left(\sum_{i=1}^{L} S(i)\right)^2 \qquad (7)$$

where: $S(i)$ is the signal power on each branch, L is the number of branches and N is the noise present on each branch. The EGC output signal is fed to ED, $H_{L(t)}$ is the L^{th} channel gain of composite Rayleigh and log-normal fading channel. Output of ED will be compared with the decision threshold to determine whether it is white space that is present or brown space. With the output of ED greater than the set threshold, brown space is present as CU's transmission is ongoing; else, white space connoting that the spectrum is idle. The received signal $g(L)$ at the L^{th} CU antenna is given as:

$$g(L) = V(L) + N(L) \qquad (8)$$

where $V(L)$ is CU signal power on the L^{th} branch and $N(L)$ is noise present on the L^{th} branch.
Using Equations (5) and (7), the output of ED, E_{EGC}, becomes

$$E_{EGC} = \sum_{n=1}^{P} \left| \frac{1}{NL}\left(\sum_{i=1}^{L} g_n(L)\right)^2 \right|^2 \qquad (9)$$

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

$$E_{EGC} > \tilde{a} \qquad (10)$$

where ã is the decision threshold based on PFA. To set the threshold, Probability of False Alarm (PFA) of 5% (0.05) will be used to decide the balance between the LU protection and spectrum management efficiency.

2.2 Operation of the proposed technique

The availability of white or brown space is determined using Equation (10). The system switches to an overlay approach when there is presence of white space, and instantly switches to underlay approach when there is presence of brown space based on the switching algorithm presented in Algorithm 1. 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 signal at the relay node is amplified by multiplying with the relay gain. The gain of relay ‘β’is given in [25] as:

$$\beta = \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}} \qquad (11)$$

where: P_r is the relay power; h_{sr}^2 is the CU transmitter to relay channel coefficient; N_r is the noise present at the relay node. Hence, the signal received ‘γ_{RD}’ at the destination in the second phase is obtained as

$$\gamma_{RD} = \beta h_{RD}\gamma_r + N_D \qquad (12)$$

where: h_{RD} is the relay to CU receiver channel coefficient; γ_r is the signal received at the relay node; N_D is the noise at the CU receiver.

Therefore, by using Equations (11) and (12), the strength of the received signal at the CU receiver ‘γ_{RCU}’ during underlay approach is obtained as

$$\gamma_{RCU} = \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}} h_{RD}\gamma_r + N_D \qquad (13)$$

where γ_r is the decoded signal at the relay node.

Algorithm 1: Switching Algorithm for ED

```
Begin
Initialize g_n(i), L, N, P, ã
Receiving antenna= multiple antenna
Combine the received signals using EGC
Compute energy of the received signal using equation (3.15)
is E_EGC > ã
if (E_EGC > ã) then
        brown space is present
        apply underlay approach
        code the CU transmitting signal with CDMA
        form pseudorandom code
        XOR CU signal with the pseudorandom code
        send active mode to H-DAF
        H-DAF process the SU signal using equation (3.34)
else if (E_EGC ≤ ã) then
        white space is present
        apply overlay approach
        increase the SU transmission power
        send silent mode to H-DAF
        continue until E_EGC > ã then
        apply underlay approach
        code the CU transmitting signal with CDMA
        form pseudorandom code
        XOR CU signal with the pseudorandom code
else
        apply overlay approach
End
```

2.3 Evaluation of the proposed technique

This section presents the metrics for analyzing the performance of the proposed technique include Throughput (TP) and Spectral Efficiency (SE).

2.3.1 Throughput

Given the expression for outage probability “P_{out}“ is given according in equation:

$$P_{out} = \int_{o}^{\gamma th} P_\gamma(\gamma)d\gamma \qquad (14)$$

where γ is the SNR of the received signal; $P_\gamma(\gamma)$ is the probability distribution function of γ and γ^{th} is the specified threshold.
The expression for throughput ‘TP’ is given as:

$$TP = R(1 - P_{out}) \qquad (15)$$

Putting equation (14) into (15), the expression for throughput for the proposed work is obtained as:

$$TP = R\left(1 - \int_{o}^{\gamma th} P_\gamma(\gamma)d\gamma\right) \qquad (16)$$

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where γ is the SNR at the CU receiver and P_γ is the PDF of the received CU signal.

2.3.2 Spectral Efficiency (SE)

Capacity of channel (C_p) is given as

$$C_p = B \times log_2(1 + SNR) \quad (17)$$

Where: C_p is the capacity of the channel; B is the channel bandwidth; *SNR* is the signal to noise ratio of the received signal.

The expression for spectral efficiency 'SE' is given as

$$SE = \frac{C_p}{B} \quad (18)$$

Substituting equation (17) into (18), the expression for spectral efficiency for the proposed technique is obtained as

$$SE = \frac{B \times log_2(1+SNR)}{B} \quad (19)$$

The proposed technique underlay and overlay approaches are simulated using MATLAB R2021a and the simulation parameters are presented in Table 1.

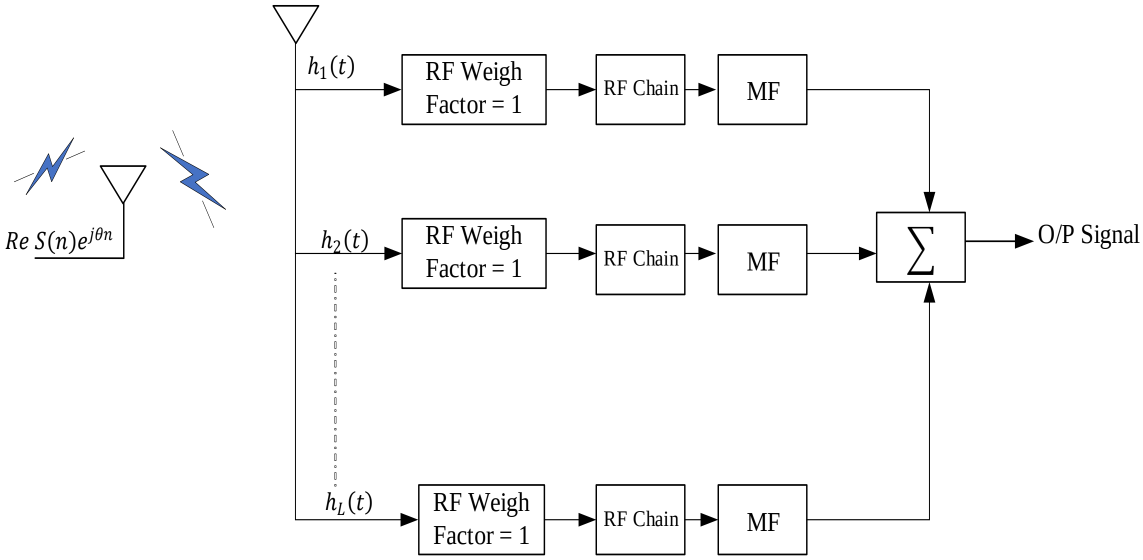

Fig. 2: Block diagram of Equal Gain Combining technique [9].

Table1: Simulation parameters for the proposed technique

Parameters	Type
Modulation scheme at licensed user	GMSK
Fading Channel	Combined Rayleigh and log-normal
Noise	AWGN
Signal to Noise Ratio	(0:2:10)
Probability of False Alarm	0.05
Detector	ED
Number of licensed user antenna	1
Number of cognitive user antenna	2, 3, 4
Carrier frequency	1800 MHz
Transmit filter	Square Root Raised Cosine
Receiver matched filter	Square Root Raised Cosine
Symbol length	8 symbols
Noise variance	1

3. SIMULATION RESULTS

The metrics deployed in evaluating the performance of the developed technique are TP and SE. Evaluation is done by comparing the performance of the developed Energy-Efficient Optimal Frequency Spectrum Management (EEOFSM) technique with the work of Lu *et al.* [20] and Liu *et al.* [26]. Throughout this report, the underlay technique represents the work of Lu *et al.* [20], overlay technique represents the work of Lui *et al.* [26] and the proposed technique is named EEOFSM developed. Figures 3 to 5 present the TP versus SNR for the proposed technique, underlay, and overlay techniques at different number CU antenna. For simplicity in the discussion of results, the proposed technique is named EEOFSM. Therefore, wherever EEOFSM has been mentioned, it refers to the proposed technique.

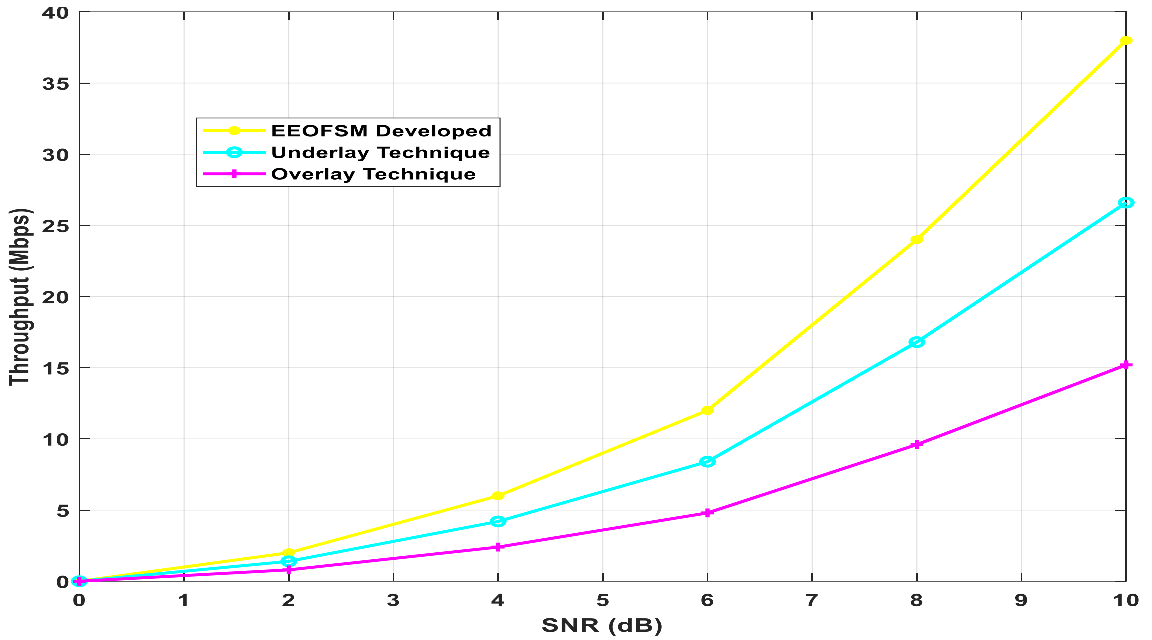

Fig. 3: Throughput versus SNR for EEOFSM, underlay and overlay techniques at CU of 6 with CU antenna of 2.

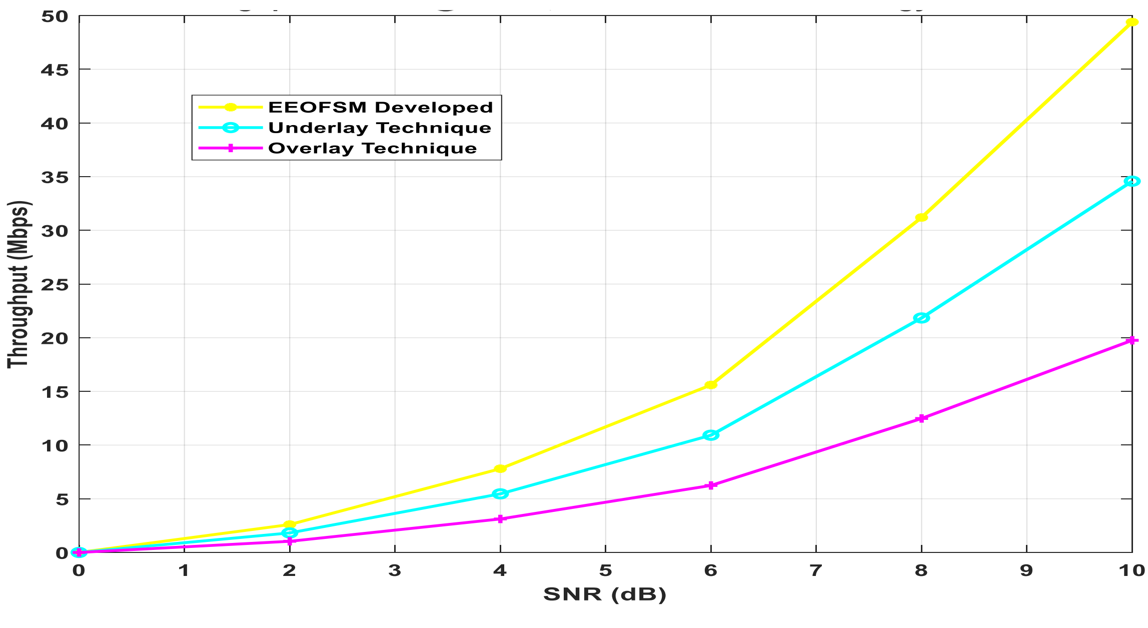

Fig. 4: Throughput versus SNR for EEOFSM, underlay and overlay techniques at CU of 6 with CU antenna of 3.

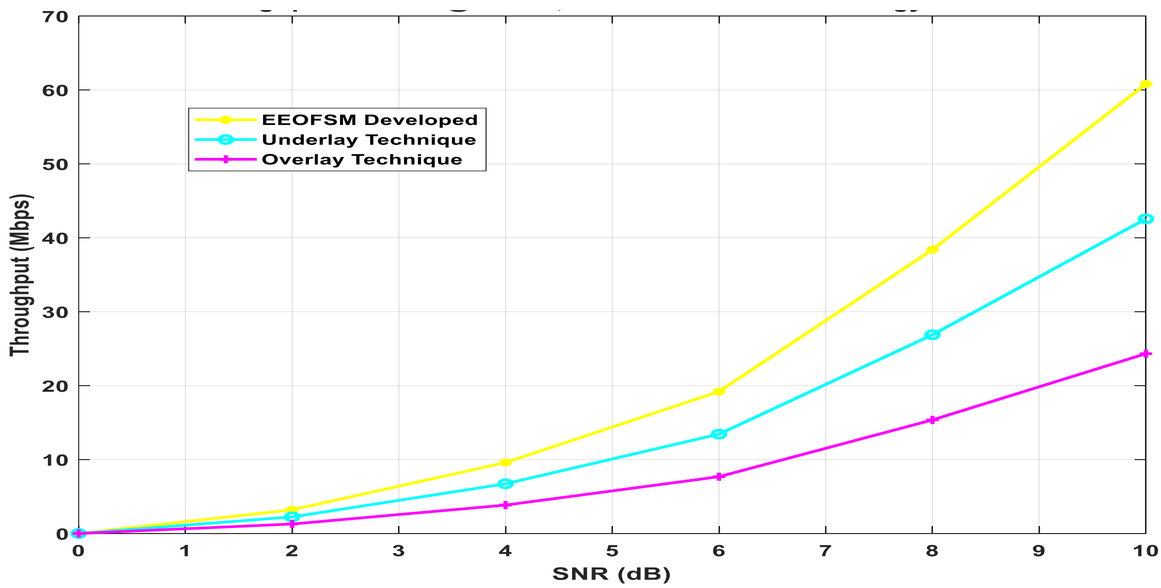

Fig. 5: Throughput versus SNR for EEOFSM, underlay and overlay techniques at CU of 6 with CU antenna of 4.

Figure 3, presents TP values versus SNR for EEOFSM, underlay and overlay at CU of 6 and CU antenna of 2. The TP values obtained at SNR of 4 dB were 6.0, 4.2 and 2.4 Mbps for EEOFSM, underlay, and overlay techniques, respectively, while at SNR of 10 dB, 38, 26.6 and 15.2 Mbps were the corresponding TP values obtained for EEOFSM, underlay, and overlay techniques, respectively. Similarly, the TP values obtained versus SNR for CU of 6 and CU antenna of 3 is presented in Figure 4. The TP values obtained at SNR of 4 dB were 7.8, 5.5 and 3.1 Mbps for EEOFSM, underlay, and overlay techniques, respectively, while the corresponding TP values obtained at SNR of 10 dB were 49.4, 34.6 and 19.8 Mbps, respectively. Similarly, Figure 5 shows the TP versus SNR with CU of 6 and number of CU antenna of 4 for EEOFSM, underlay, and overlay techniques. The TP values obtained at SNR of 4 dB were 9.6, 6.7 and 3.8 Mbps for EEOFSM, underlay, and overlay technique, respectively, while the corresponding values obtained at SNR of 10 dB were 60.8, 42.6 and 24.3 Mbps, respectively. From all the results obtained also revealed that, at all the SNRs considered, the proposed EEOFSM technique gave the highest TP values while overlay technique gave the lowest values indicating the highest number of information that is successfully arrives at the receiving end of CU. The highest values of TP obtained for the developed EEOFSM techniques is due to spectrum band that is fully exploited by the CU with little or no interference between PU and CU. The best performance of the EEOFSM is also due to relay technique used which improves the coverage area of the CU signal during the underlay approach. Furthermore, the best performance of the proposed EEOFSM technique is because of the reduced interference between PU and cognitive user resulting from accurate detection of PU signal.

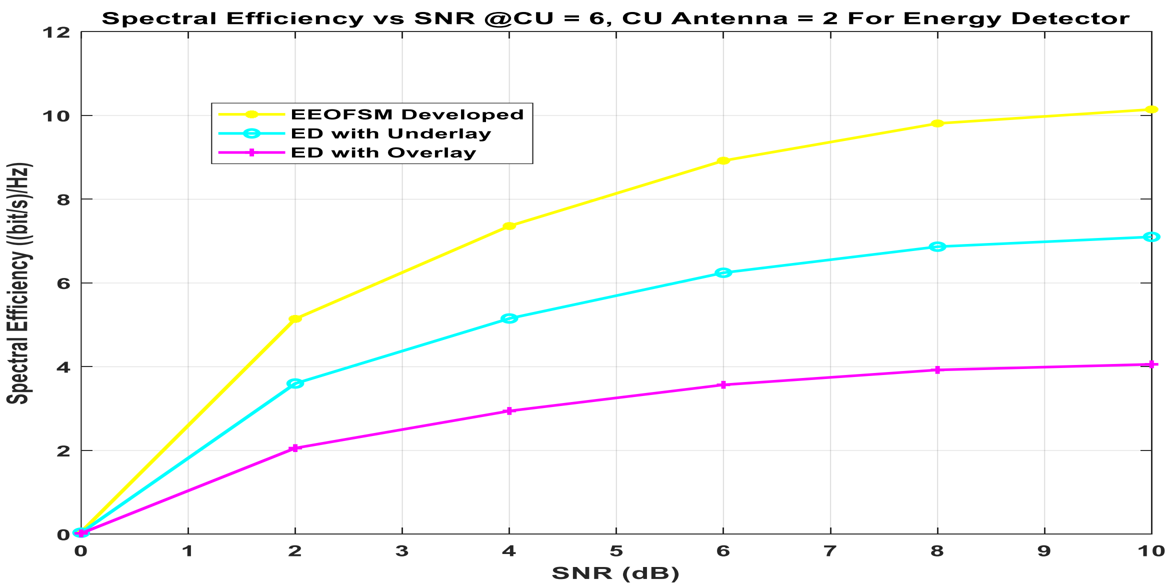

Fig. 6: Spectral Efficiency versus SNR for EEOFSM underlay and overlay techniques at CU of 6 and CU antenna of 2.

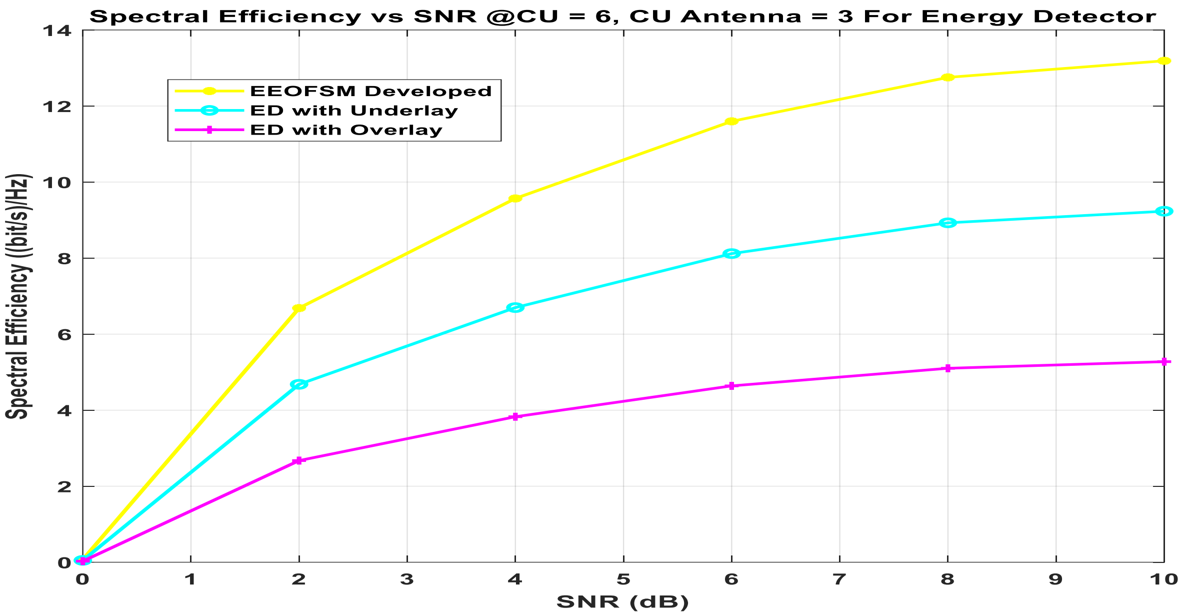

Fig. 7: Spectral Efficiency versus SNR for EEOFSM, underlay and overlay techniques at CU of 6 and CU antenna of 3.

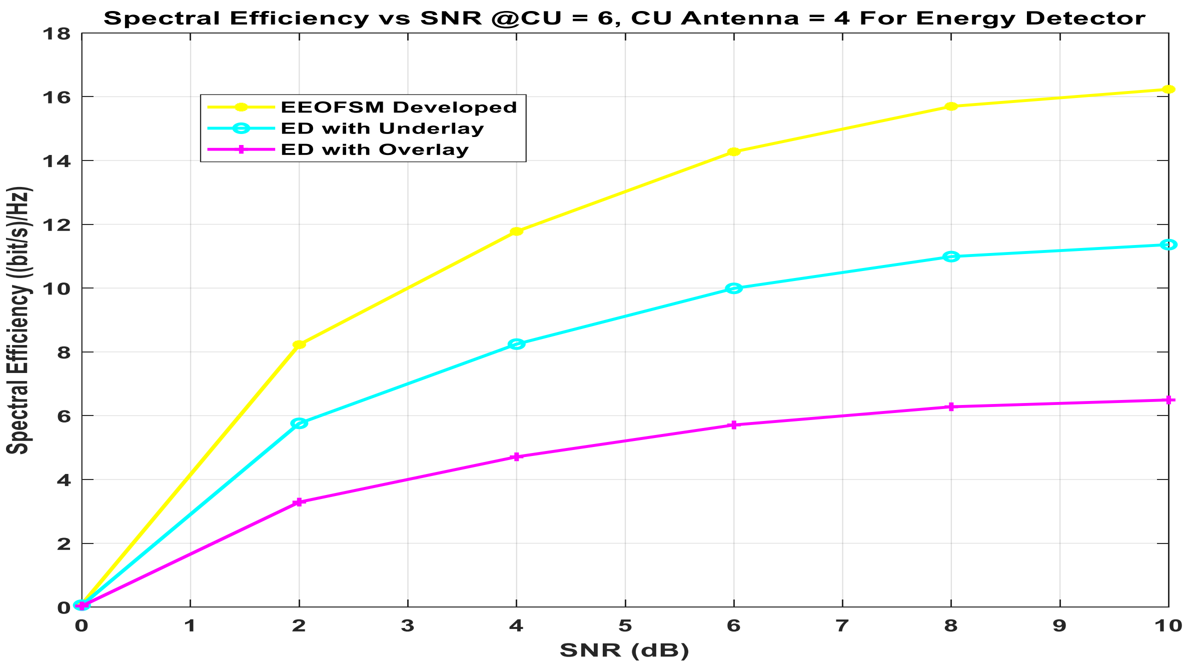

Fig. 8: Spectral Efficiency versus SNR for EEOFSM, underlay and overlay techniques at CU of 6 and CU antenna of 4.

Figures 6 to 8 present the SE versus SNR for the proposed technique, underlay, and overlay techniques at different number CU antenna. Figure 6 depicts the SE values versus SNR for the three techniques at CU of 6 and CU antenna of 2. At SNRs of 4 dB SE values of 7.3600, 5.1520 and 2.9440 bps/Hz were obtained for EEOFSM, underlay, and overlay, respectively, while the corresponding values of SE at SNR of 10 dB were 10.1450, 7.1015 and 4.0580 bps/Hz. From Figure 7, SE values of 9.568, 6.6976 and 3.8272 bps/Hz were obtained at SNR of 4 dB for EEOFSM, underlay, and overlay, respectively, while 13.1885, 9.2320 and 5.2754 bps/Hz were the corresponding SE values obtained for EEOFSM, underlay, and overlay, respectively, at SNR of 10 dB. Figure 8 depicts the SE values obtained at different SNR using CU of 6 and CU antenna of 4. The SE values obtained at SNR of 4 dB were 11.7760, 8.2432 and 4.7104 bps/Hz for EEOFSM, underlay, and overlay, respectively, while at SNR of 10 dB, the corresponding values of SE were 16.2320, 11.3624 and 6.4928 bps/Hz for EEOFSM, underlay, and overlay, respectively.

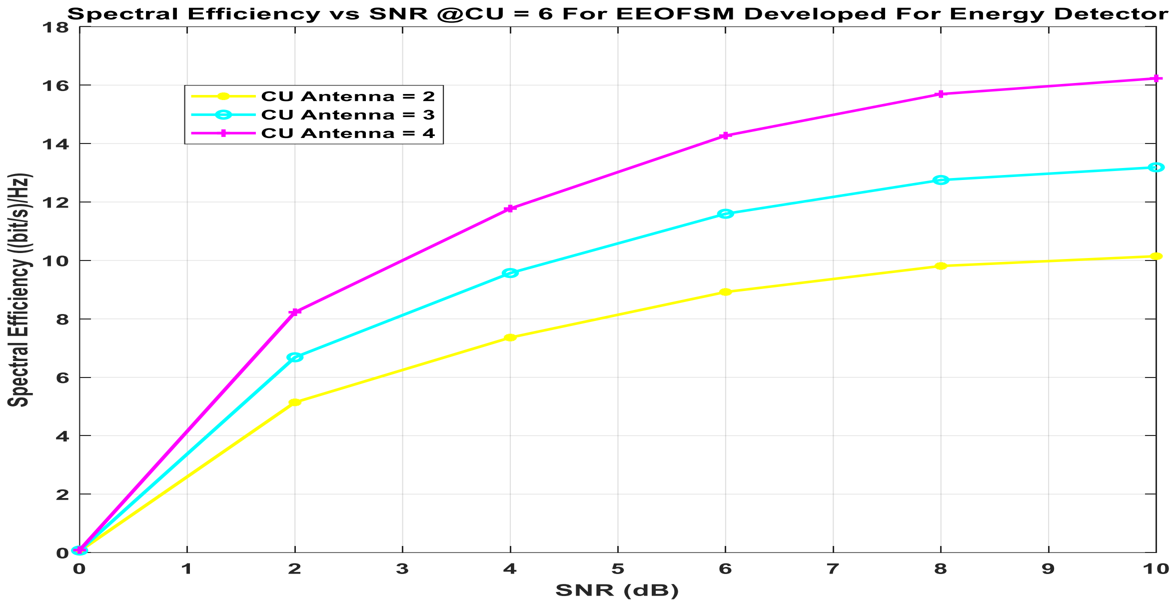

Fig. 9: Spectral Efficiency versus SNR for EEOFSM techniques at a fixed CU of 6 with different number of CU antenna.

In all the scenarios considered, the developed EEOFSM gave a better result with the highest value of SE than the two existing techniques, that is, overlay and underlay techniques. This justifies the bandwidth efficiency of the developed technique when compared with the existing techniques.

It can also be deduced from Figure 9 that the highest value of SE was obtained at the configuration of CU of 6 with CU antenna of 4 and this justifies the importance of higher detection rate and higher signal strength in a cognitive radio system. The higher detection rate reduces CU interference which in turn increases the number of bits that will be successful at the CU receiver, thereby increasing the throughput of the system. Also, higher signal strength increases throughput thereby increasing the bandwidth efficiency of the system.

4. CONCLUSION

This study proposes switching algorithms between overlay and underlay of cognitive radio in a wireless communication system. The transmitted PU's signal are combined using Equal Gain Combiner (EGC) and the combined signal is made to pass through energy detector for detection of white or brown space. The detected spaces are used to develop a frequency spectrum management system that switches between overlay and underlay CR based on switching algorithm. The proposed spectrum management system is simulated using MATLAB R2021a and evaluated using TP and SE by comparing with the existing overlay and underlay technique. The simulated results obtained revealed that the proposed technique demonstrates better spectrum management than the existing overlay and underlay techniques with highest TP and SE values. The effective spectrum usage of the proposed technique is because of simultaneously usage of the assigned spectrum by LU and CU with maximum CU transmitting power when PU is not active. However, overlay technique gives the lowest values of TP indicating the low amount of output information because CU can only make use of the assigned spectrum if and only if, PU is not active, resulting in wastage of unused brown space by PU. The results obtained also revealed that, for all the three techniques, TP, and SE increase as SNR increases and this is due to accurate detection of PU signal by CU at higher signal strength which in turn reduce the rate of false alarm during idle spectrum detection.

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