A Comprehensive Analysis of Energy Efficiency Using Cooperative Spectrum Sensing Network

Naveen Kumar Boddukuri (naveenget426@gmail.com)
National Institute of Technology Mizoram
Debasish Pal
CEERI Pilani: Central Electronics Engineering Research Institute CSIR
Ayan Kumar Bandyopadhyay
CEERI Pilani: Central Electronics Engineering Research Institute CSIR
Chaitali Koley
National Institute of Technology Mizoram

Research Article

Keywords: Radio spectrum, multiple antennas, IED, Rayleigh fading, throughput, energy efficiency

Posted Date: August 3rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1059414/v1

A Comprehensive Analysis of Energy Efficiency Using Cooperative Spectrum Sensing Network

Naveen Kumar Boddukuri[1], Debasish Pal[2], Ayan Kumar Bandyopadhyay[3], and Chaitali Koley[4]

1,4 Department of ECE, National Institute of Technology Mizoram, Chatlang, Mizoram – 796 012, India
naveenget426@gmail.com, chaitali.ece@nitmz.ac.in
2,3 Central Electronics Engineering Research Institute, Pilani, Rajasthan 333031, India
ayan.bandyopadhyay@gmail.com, debasish.pal1975@gmail.com

Corresponding author: Naveen Kumar Boddukuri (e-mail:naveenget426@gmail.com).

Abstract: The proposed cooperative spectrum sensing (CSS) network has promising characteristics that might increase detection performance. This study focuses on identifying unknown signals in a Rayleigh fading environment using an improved energy detector (IED). The suggested network is made up of numerous cognitive radio (CR) nodes, with a number of antennas installed at each CR node and selection combining (SC) used to identify the maximum detection probability. Furthermore, the activity of the primary user (PU) is completed at the fusion centre utilizing fusion rules (FC). The closed-form of missing detection and false alarm probability was initially given elegantly. A quantitative evaluation is presented to estimate average throughput and energy efficiency and overall error rate performance is examined for single and multiple antenna situations. Simulation test-bed is developed in MATLAB, and simulations are used to evaluate throughput and energy efficiency performance with the strong backing of mathematical analysis. Finally, when compared to traditional schemes, the performance of the suggested scheme is enhanced, with OR-Rule outperforming AND-Rule.

Keywords: Radio spectrum, multiple antennas, IED, Rayleigh fading, throughput, energy efficiency.

1. Introduction:

Recent developments in wireless applications have resulted in the continued advancement of wireless technology, and demand has grown at a geometric rate, resulting in a substantial increase in spectrum usage [1]. According to fixed spectrum access (FSA), the added-on utilization causes a shortage of the radio spectrum because the spectrum usage depends on the permitted end users [2-4]. The spectrum active and idle status depends on the licensed user that reflects the inefficiency of the FSA policy. An alternative spectrum policy needs to be developed to meet the rising demand for spectrum usage more efficiently, thus giving rise to dynamic spectrum access (DSA) [5]. The spectrum can be accessed by licensed as well as unlicensed users called secondary users (SU). To reinforce DSA, SUs must have insight capabilities referred as cognitive radios (CR) [6-7]. The increasing demand to access the unused spectrum in wireless communication services is met with CR. The CR's unique technology, which enables a cognitive wireless terminal to dynamically access unoccupied spectrum [8]. The real-time decision making regarding the primary user (PU) through spectrum sensing (SS) which is the critical function of CR [9]. In practice, SS is frequently impeded by two fundamental phenomena, namely multipath fading and interference, the consequences of which cannot be overstated. These disadvantages may drastically impair detection performance, render spectrum sensing unreliable and cause hidden node issues SS is blocked by multipath fading and interference in a realistic environment which makes the system inaccurate. The CSS is a technique for combating multipath fading and improving overall detection performance that makes use of a large number of CR users while doing their own local sensing and exchanging their sensing findings with other users and the FC [10-13]. Various fusion rules are employed at FC to determine whether PU exists or not. As the number of SU grows, so does the amount of energy needed for spectrum detection and reporting to FC increases, this has an effect on the energy efficiency (EE), as energy efficiency value rises as throughput value increases [14-16]. The CSS scheme is addressed in [17-18] which describes about reduction of energy consumption by reducing the amount of SUs. An EE schemes were proposed in [19] to reduce the energy consumption. It was suggested in [20] that the distributed SS algorithm reduces the average energy usage for SS by taking the optimal sensing rate and censoring threshold into account. CSS is addressed in [21] as a way to enhance EE while also saving time. In [22-23], it is suggested that detection threshold value optimized to improve EE when CSS is used with various fading channels. EE in a CR network utilising the CSS scheme is assessed in an AWGN environment using the OR-Rule and the AND-Rule at the FC. For the development of EE, all of the publications listed above employed an energy detection (ED) technique. The ED-based CSS network is more suited to low-noise situations, but its performance is restricted. As a result, utilising an improved energy detector improves detection probability even further (IED). In [24], it is shown that how an IED-based CSS network with several antennas at each SU in the network improves performance.

The paper is organized as follows: Section II briefly discusses the suggested CSS network paradigm. Section III, addresses a study of the energy efficiency and throughput of the proposed network. Section IV represents the simulated results, Lastly Section V deals with the conclusion of the article.

2. Proposed CSS Network Model:

An efficient IED based CSS model is proposed in this paper. In the CSS network, one PU, one FC, multiple SUs is used and each SU consists of multiple antennas. The FC unit controls the three-step process in CSS as follows. As the first step each CR senses the spectrum and store the information with them. In the second step, sensed data is reported to FC via reporting channel. Finally, FC takes a decision about PU with the help of fusion rules.

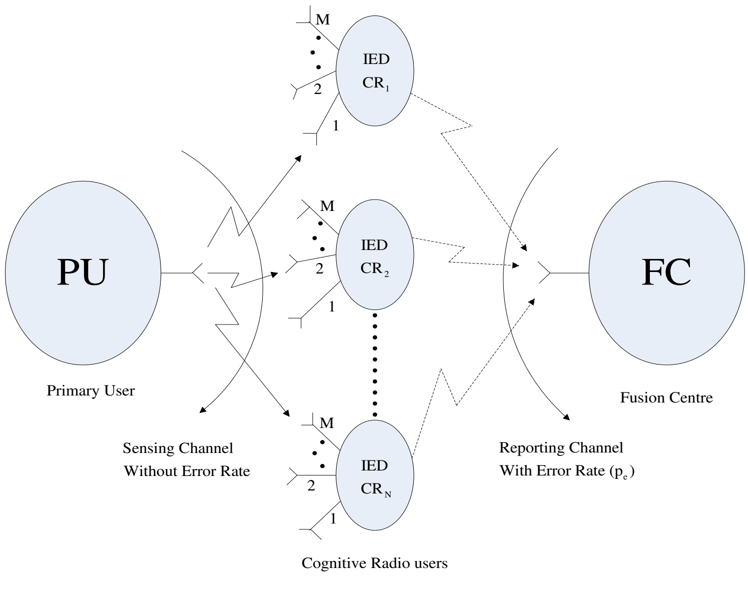

Fig.1. Proposed CSS model.

Based on the signal received at *j*-th CR, activity of PU (H_0: absence and H_1: presence) [25] can be decided using [25];

$$y(\mathrm{t}) = \begin{cases} n_j(t) & : H_0 \\ h_j * s(t) + n_j(t) & : H_1 \end{cases} \tag{1}$$

In eq. (1), *j*-th CR noise value is $n_j(t)$, fading coefficient is represented by h_j, and IED input signal is $s_j(t)$. The spectrum hole is identified using the proposed model CSS network with multiple antennas (*M*) at every CR. The local decision about PU at *i*-th antenna can be expressed as in [26];

$$W_i = |y_i|^p \qquad p > 0 \tag{2}$$

When compare to CED the proposed IED *p*-value must be more than 2 for the better probability of detection. From eq. (2), the largest value of w_i (represented as Z) is selected using selection combining (SC) technique. Finally, decision about PU can be made providing the comparison between detection threshold (λ) value and Z, it follows as [27],

$$Z > \lambda : H_1 \,\&\, Z < \lambda : H_0 \tag{3}$$

The Rayleigh fading channel PDF is given in [28] as;

$$f_{w_i|\mathrm{H}_1}(\mathrm{y}) = \frac{2y^{(2/p)-1}}{p(E_s\sigma_h^2 + \sigma_n^2)} \exp\left(-\frac{\mathrm{y}^{2/p}}{(E_s\sigma_h^2 + \sigma_n^2)}\right) \tag{4}$$

The expression for probability of missed detection (P_m) is possible to quantified as [28];

$$P_m = \left[1 - \exp\left(-\frac{\lambda^{2/p}}{\sigma_n^2(1+\gamma)}\right)\right] \tag{5}$$

where $\gamma = E_s\sigma_h^2/\sigma_n^2$ is S-channel SNR.

At each CR node, P_m expression with number of antennas (*M*) is quantified as [28];

$$P_m = \left[1 - \exp\left(-\frac{\lambda^{2/p}}{\sigma_n^2(1+\gamma)}\right)\right]^M \tag{6}$$

The expression for Probability of false alarm (P_f) is possible to quantified using the following PDF as [29];

$$f_{w_i|\mathrm{H}_0}(\mathrm{y}) = \frac{2y^{(2/p)-1}}{p\sigma_n^2} \exp\left(-\frac{\mathrm{y}^{2/p}}{\sigma_n^2}\right) \tag{7}$$

The expression for P_m is possible to quantified as [28];

$$P_f = \left[\exp\left(-\frac{\lambda^{2/p}}{\sigma_n^2} \right) \right] \tag{8}$$

The expression for P_f is possible to quantified as [28];

$$P_f = 1 - \left[1 - \exp\left(-\left\{ \frac{\lambda^{2/p}}{\sigma_n^2} \right\}^C \right) \right]^M \tag{9}$$

The overall false alarm and missed detection probability expressions are quantified using OR-Rule are given in [30] as;

$$Q_{f,OR} = 1 - \left(1 - P_f\right)^L \tag{10}$$

$$Q_{m,OR} = \left(P_m\right)^L \tag{11}$$

Similarly, for AND-Rule given in [30] as;

$$Q_{f,AND} = \left(P_f\right)^L \tag{12}$$

$$Q_{m,AND} = 1 - \left(1 - P_m\right)^L \tag{13}$$

The flow chart below provides a detailed overview of how we achieved the simulation findings. Initially, we created the necessary signal, an AWGN signal as noise and fading coefficients. Later, we decided on PU by comparing the received signal value to a pre-defined threshold value. Furthermore, in the suggested system architecture, several CRs are employed, and each CR is connected with numerous antennas. The PU decision has been received by all CRs antennas. Following that, we utilised SC technique to determine where the highest value falls at each CR. Now, all CR decisions will be transmitted to the FC, and the existence of PU will be determined at the FC.

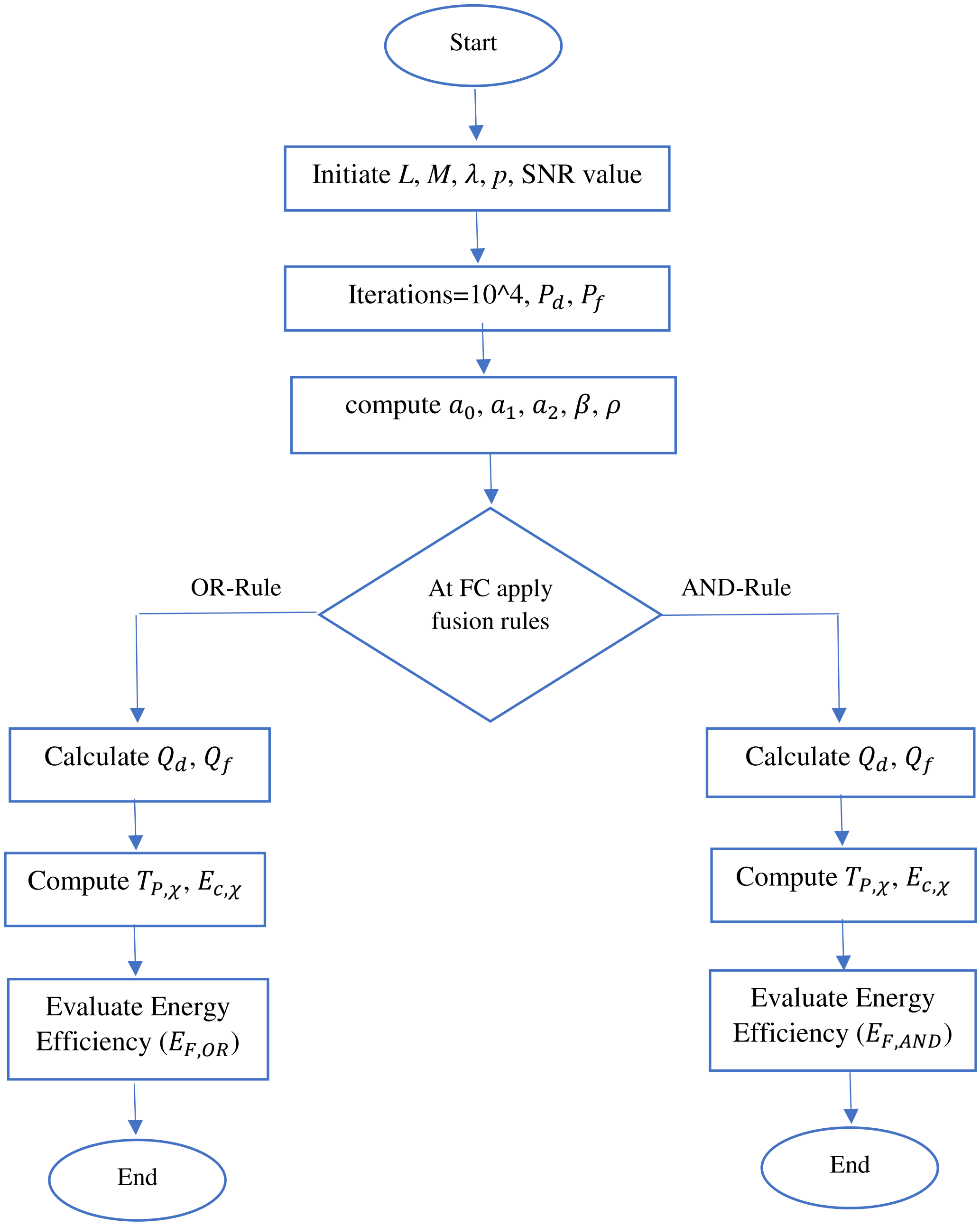

Fig.2. Flow chart for Simulation.

3.Calculation of network parameters

A. Energy Efficiency and Throughput Framework

This section deals with the network parameters called EE and throughput using an expression given in [30]. The average channel throughput (C_{avg}) is expressed for *k*-out-of-*N* fusion rule is shown as;

$$T_{P,\chi}(L) = P(H_1)(1-Q_{m,\chi})t_p + P(H_0)(1-Q_{f,\chi})t_s + P(H_1)Q_{m,\chi}(\overline{t_p}+\overline{t_s}) \quad (14)$$

In the above expression, t_p, t_s, $\overline{t_p}$ and $\overline{t_s}$ are the throughput values of PU and SU networks.

In this paper, CR network is assumed as the limited energy network in fading environment. In the process of maximization of EE, the number of CRs and decision threshold values determined as the key factors. In this context, each node of CR uses energy to perform sensing (e_1), to transmit information to FC, CR required energy (e_2). Similarly, e_p and e_s are energies utilized by PU and SUs. Finally, total energy (E) consumed is calculated as given in [25];

$$
\begin{aligned}
E_{C,\chi}(L) = P(H_1)(1-Q_{m,\chi})\left[L(e_1+e_2)+e_p\right]+P(H_1) \\
Q_{m,\chi}\left[L(e_1+e_2)+e_p+e_s\right]+(1-Q_{f,\chi})P(H_0) \\
\left[L(e_1+e_2)+e_2\right]+p(H_0)Q_{fe}(N)L(e_1+e_2)
\end{aligned} \tag{15}
$$

Energy efficiency can be computed as [30];

$$E_{F,\chi} = \frac{T_{P,\chi}}{E_{\mathrm{C},\chi}} \tag{16}$$

where χ can be OR-Rule or AND-Rule.

B. Computation of Optimal Number of SUs Using OR-Rule

The expression for EE using OR-Rule is given in [30] as;

$$E_{F,\mathrm{OR}} = \frac{T_{P,\mathrm{OR}}}{E_{\mathrm{C,OR}}} \tag{17}$$

$$= \frac{\alpha_0 + \alpha_1(1-Q_{m,OR}) - \alpha_2 Q_{\mathrm{f},OR}}{L[e_1+e_2]+P(H_1)e_p+\beta_{OR}e_s} \tag{18}$$

where

$$\alpha_0 = P(H_1)(\bar{t}_p+\bar{t}_s)+P(H_0)t_s \tag{19}$$

$$\alpha_1 = P(H_1)(t_p-\bar{t}_p-\bar{t}_s) \tag{20}$$

$$\alpha_2 = P(H_0)t_s \tag{21}$$

$$\beta_{OR} = 1-P(H_0)Q_{\mathrm{f,OR}}-P(H_1)(1-Q_{\mathrm{m,OR}}) \tag{22}$$

The maximized value of EE with an optimal SUs using OR-Rule is computed as [30];

$$L_{OR}^{*} = \left\lceil \frac{\ln\left(\dfrac{P_f(\alpha_2-P(H_0)\rho_{OR}e_s)}{(1-P_m)(\alpha_1+P(H_1)\rho_{OR}e_s)}\right)}{\ln\left(\dfrac{P_m}{1-P_f}\right)} \right\rceil \tag{23}$$

where ρ_{OR} is a positive value, it ranges from $0 \leq \rho \leq 1$ and it can be computed as;

$$\rho_{OR} = \left| \frac{P_m \alpha_1 - \left(1 - P_f\right)\alpha_2}{2\left(P\left(H_1\right)P_m e_s - P\left(H_0\right)e_s\left(1 - P_f\right)\right)} \right| \tag{24}$$

C. Computation of Optimal Number of SUs Using AND-Rule

The expression for EE using OR-Rule is given in [30] as;

$$E_{F,\text{AND}} = \frac{T_{P,\text{AND}}}{E_{\text{C,AND}}} \tag{25}$$

$$= \frac{\alpha_0 + \alpha_1\left(1 - Q_{m,\text{AND}}\right) - \alpha_2 Q_{\text{f, AND}}}{L\left[e_1 + e_2\right] + P\left(H_1\right)e_p + \beta_{\text{AND}} e_s} \tag{26}$$

where
$$\beta_{\text{AND}} = 1 - P\left(H_0\right)Q_{\text{f, AND}} - P\left(H_1\right)\left(1 - Q_{\text{m, AND}}\right) \tag{27}$$

The maximized value of EE with an optimal SUs using OR-Rule is computed as [30];

$$L_{AND}^{*} = \left\lceil \frac{\ln\left(\frac{P_m\left(\alpha_1 + P\left(H_1\right)\rho_{\text{AND}} e_s\right)}{\left(1 - P_f\right)\left(\alpha_2 + P\left(H_0\right)\rho_{AND} e_s\right)}\right)}{\ln\left(\frac{P_f}{1 - P_m}\right)} \right\rceil \tag{28}$$

where ρ_{AND} is a positive value, it ranges from $0 \leq \rho \leq 1$ and it can be computed as;

$$\rho_{\text{AND}} = \left| \frac{P_m \alpha_1 - \left(1 - P_f\right)\alpha_2}{2\left(P\left(H_1\right)P_m e_s - P\left(H_0\right)e_s\left(1 - P_f\right)\right)} \right| \tag{29}$$

4.<u>Results and Discussions</u>

We have computed the EE value using an IED-based CSS network and multiple antennas at each SU over Rayleigh fading using various fusion rules at FC. An optimal number of SUs are calculated to maximize the EE value. Finally, total error rate value also calculated. These calculations are explained with the help of simulations in this section.

Figures 3 and 4 show EE analysis for different numbers of SUs using OR-Rule at FC for single and multiple antennas, respectively. The simulation shows that as SUs value rises from L=1 to L=5, the EE value increases by 29% at λ=10. According to the calculations when the M value at SU grows from M=1 to M=2, the EE value increases by 11.4% at λ=10. Tables 2 and 3 clearly demonstrate these similarities. Finally, it is obvious that rise in antennas at each CR enhances the EE value. The simulations are created using the simulation settings provided in Table 1.

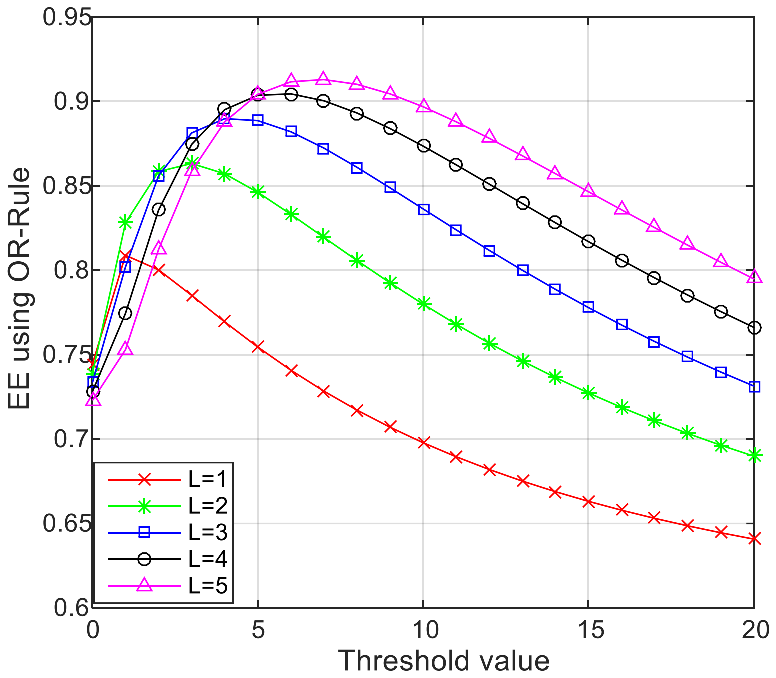

Fig.3. EE analysis for various threshold value using OR-Rule for M=1.

Table 1: Network parameters values.

Parameter	Value	Parameter	Value
t_p	30 bits	e_1	0.1 J
t_s	20 bits	e_2	0.05 J
$\tilde{t}_s$	10 bits	e_p	40 J
$\tilde{t}_p$	5 bits	e_s	10 J
$P(H_0)$	0.5	$P(H_0)$	0.5

Table 2: EE values using OR-Rule for single antenna case (M=1) @ $\lambda = 10$.

Number of SUs	EE value
L=1	0.6979
L=2	0.78
L=3	0.8364
L=4	0.8736
L=5	0.8969

Table 3: EE values using OR-Rule for multiple antennas case (M=2) @ $\lambda = 10$.

Number of SUs	EE value
L=1	0.7842
L=2	0.8836
L=3	0.9265
L=4	0.9413
L=5	0.9432

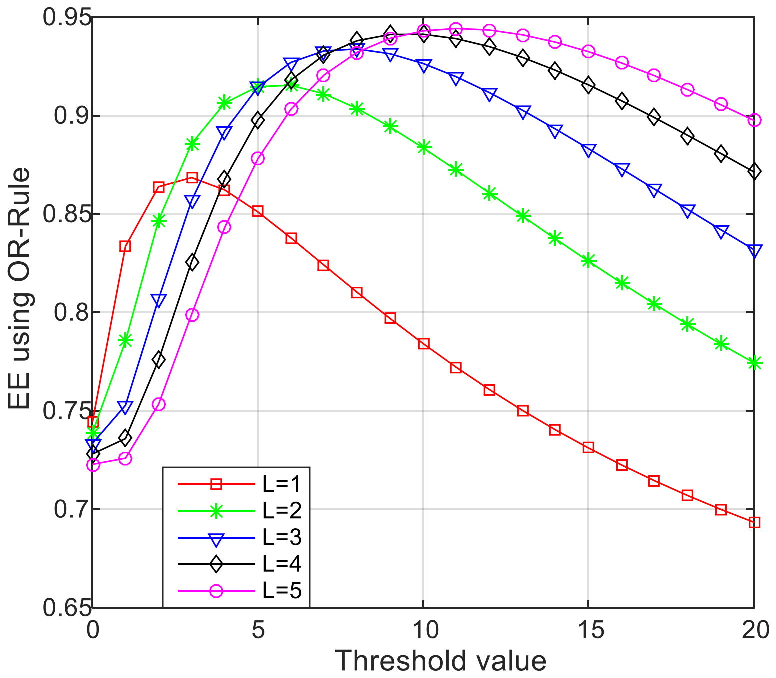

Fig.4. EE analysis for various threshold value using OR-Rule for M=2.

Figure 5 depicts the EE execution for various SNRs with OR-Rule at FC using multiple antennas at SUs. The simulation shows that when the SNR value grows, EE value rises. With M=2, EE value enhances by 18.5%, as SNR value rises from SNR=5dB to SNR=10dB. Table 4 clearly shows these similarities. Finally, it is obvious that SNR raises the EE value.

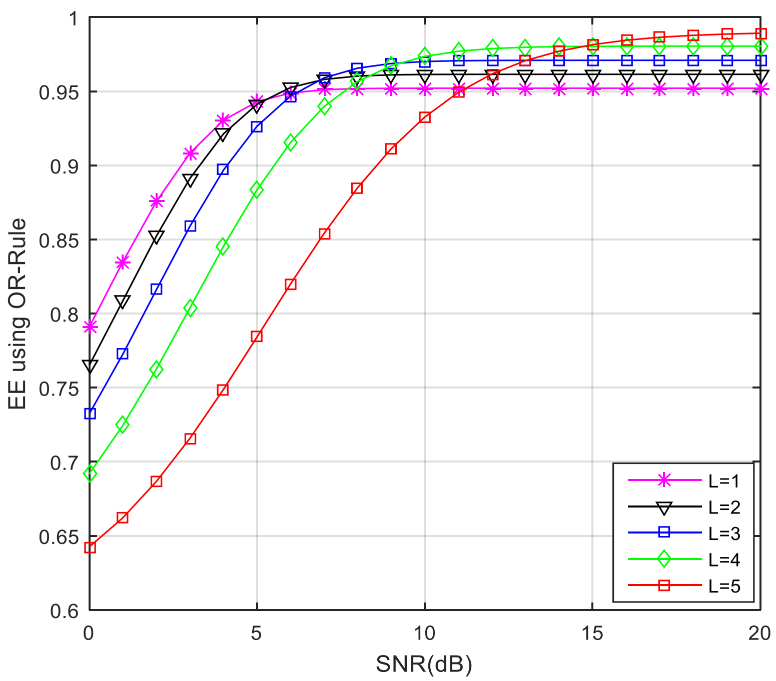

Fig.5. EE analysis for various SNRs using OR-Rule for M=2.

Table 4: EE values using OR-Rule for multiple antennas case (M=2) @ SNR=7dB.

Number of SUs	EE value
L=1	0.9511
L=2	0.9580
L=3	0.9591
L=4	0.9398
L=5	0.8542

Fig. 6 and 7 are depicted to assess EE performance for various number of SUs using AND-Rule at FC for M=1 and M=2, respectively. The simulation shows that when the number of SUs grows from L=1 to L=5, the EE value drops by 21.4% at λ=10 and M=1. The simulations also show that when the number of antennas at each SU grows from M=1 to M=2, the EE value at λ =10 increases by 11.4%. Tables 5 and 6 clearly demonstrate these similarities. Finally, it is obvious that rise in SUs and antennas at each SUs, decreases the EE value utilising the AND-Rule at FC.

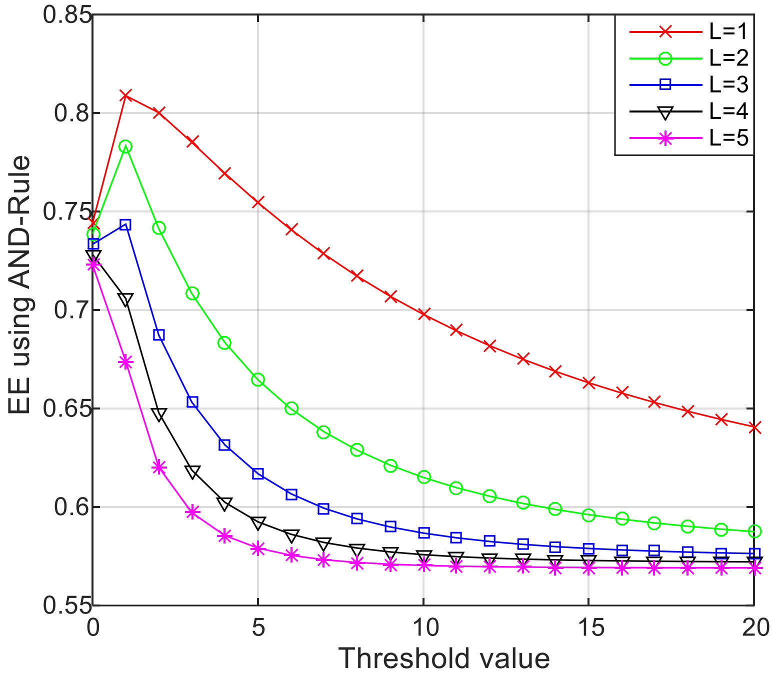

Fig.6. EE analysis for various threshold value using AND-Rule for M=1.

Table 5: EE values using AND-Rule with M=1 @ $\lambda = 10$.

Number of SUs	EE value
L=1	0.6979
L=2	0.6151
L=3	0.5868
L=4	0.5758
L=5	0.5604

Fig.8 depicts the EE performance for numerous SNRs utilising the AND-Rule at FC with M=2. The simulation shows that when the SNR value grows, so does the EE value. As the SNR value rises from SNR=5dB to

SNR=10dB, the EE value improves by 29.1% with M=2. Table 7 clearly shows these similarities. Finally, it is obvious that SNR raises the EE value.

Table 6: EE values using AND-Rule for multiple antennas case (M=2) @ $\lambda = 10$.

Number of SUs	EE value
L=1	0.7842
L=2	0.6859
L=3	0.6324
L=4	0.6209
L=5	0.5859

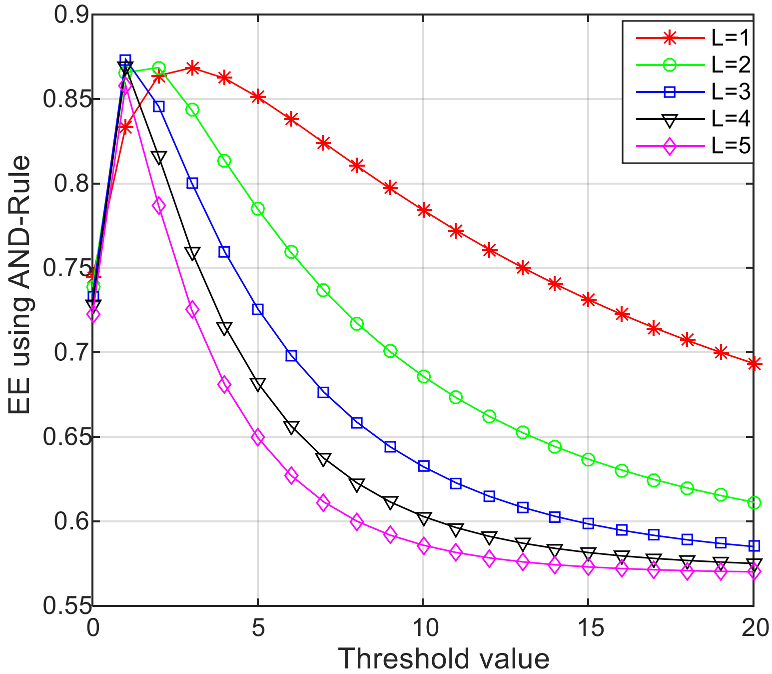

Fig.7. EE analysis for various threshold value using AND-Rule for M=2.

Using the AND-Rule, EE performance falls as the number of CRs rises. As the number of CRs grows according to the AND-Rule, if any one of the CRs reports that PU is missing, the overall decision regarding PU will become zero at FC. According to the AND-Rule, if all of the CRs reported that PU exists, then the ultimate judgement concerning PU is one, else it is zero. As a result, utilising the AND-Rule, the EE value falls as the number of CRs grows.

Table 7: EE values using AND-Rule for multiple antennas case (M=2) @ SNR=7dB.

Number of SUs	EE value
L=1	0.8542
L=2	0.7663
L=3	0.7046
L=4	0.6620
L=5	0.6319

In Fig.9, EE performance comparison of AND, OR fusion rules are evaluated for various SNRs and numerous antennas. It has been discovered that SNR optimises the EE of the AND, OR rule. However, the OR rule outperforms the AND rule. This is due to the fact that when the number of cooperating SUs rises, the likelihood of detection for the OR Rule increases while decreases with AND rule.

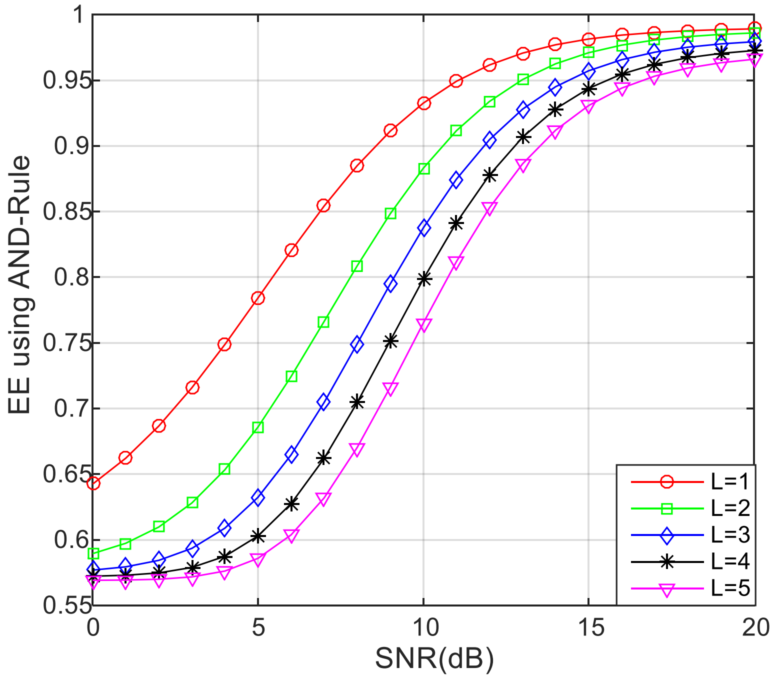

Fig.8. EE analysis for various SNR values using AND-Rule for M=2.

The efficiency of total error probability $(Q_m + Q_f)$ is assessed in Fig.10 for various simulation settings such as λ, (*L*=1, 2,3,4 & 5), (*M*=2), (*p*=3) and utilising OR-Rule at FC. Fig.10 shows that $(Q_m + Q_f)$ value decreases up to minimum point, then it falls with λ, and at larger values of λ, it approaches a constant value. For p=3, M=2, =20 and γ=5dB, $(Q_m + Q_f)$ value falls by 78.3% as rise in L from L=1 to L=5. The optimal threshold (λ_{opt}) value also determined using fig.10. The value at which $(Q_m + Q_f)$ is the smallest that may be treated as λ_{opt}. As L value rises, the λ_{opt} value drops, tilts to the right, and moves away from the origin. Finally, it is clear from the graph that an increase in λ-value, drives the curve to left side, implying that the average error rate moves towards the origin.

In Fig.11 also $(Q_m + Q_f)$ performance is assessed for various parameters λ, (*L*=1, 2,3,4 & 5), (*M*=2), (*p*=3) and using *AND-Rule* at FC. The graph's behaviour is identical to Fig.10, which is clearly illustrated in that simulation. For *p*=3, *M*=2, λ=20 and γ=5dB, $(Q_m + Q_f)$ value falls by 68.1% with the rise in *L* from *L*=1 to *L*=5. Finally, it is clear from the graph that rise in λ -value drives the right side of the curve, indicating that the average error rate changes away from the origin. $(Q_m + Q_f)$ values for various SU values are presented in Tables 8 and 9 for the OR-Rule and the AND-Rule, respectively.

Figs.12 and 13 show the ideal number of SUs for various threshold values when utilising multiple antennas at SUs and the OR-Rule and AND-Rule at FC, respectively. The simulation shows that when the SNR value grows from SNR=5dB to SNR=15dB, the number of SUs decreases from 6 to 4 at λ =10. In the OR-Rule instance, the ideal number of SUs is smaller for lower threshold values and grows as the threshold value increases. Similarly, when the SNR value increases from SNR=5dB to SNR=15dB, the number of SUs decreases from 20 to 5 at λ =5. In the AND-Rule instance, the ideal number of SUs is large for lower threshold values and decreases as the threshold value increases.

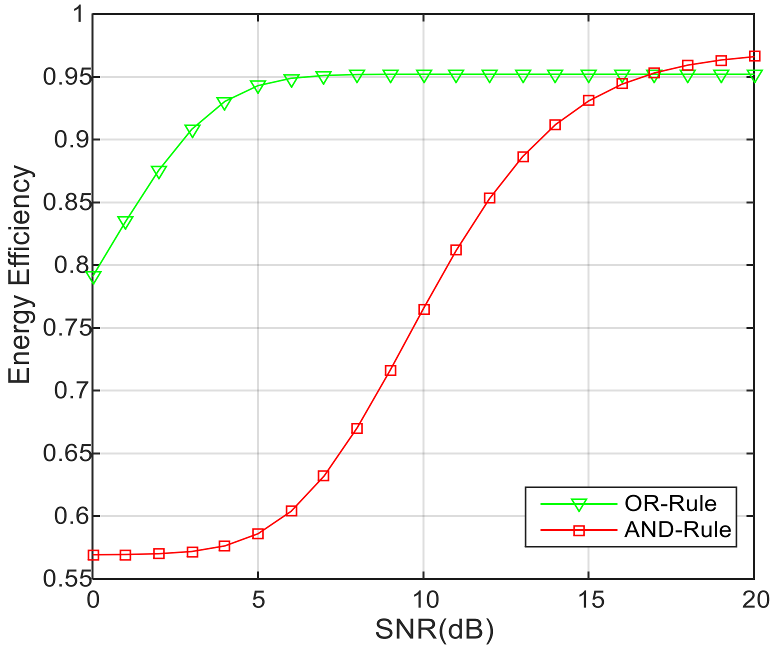

Fig.9. Performance comparison of EE for various fusion rules.

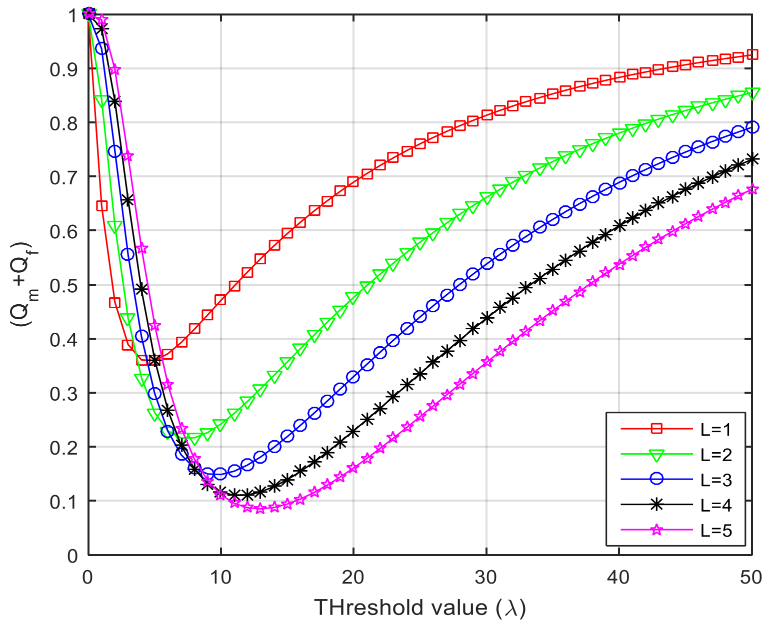

Fig.10 Total error rate performance using OR-Rule at FC.

Table 8: $(Q_m + Q_f)$ values using OR-Rule for multiple antenna case (M=2) @ λ=20.

Number of SUs	$(Q_m + Q_f)$ value
L=1	0.6897
L=2	0.4764
L=3	0.33
L=4	0.2296
L=5	0.1609

Table 9: $(Q_m + Q_f)$ values using AND-Rule for multiple antenna case (M=2) @ λ=20.

Number of SUs	$(Q_m + Q_f)$ value
L=1	0.471
L=2	0.6998
L=3	0.8352
L=4	0.9097
L=5	0.9505

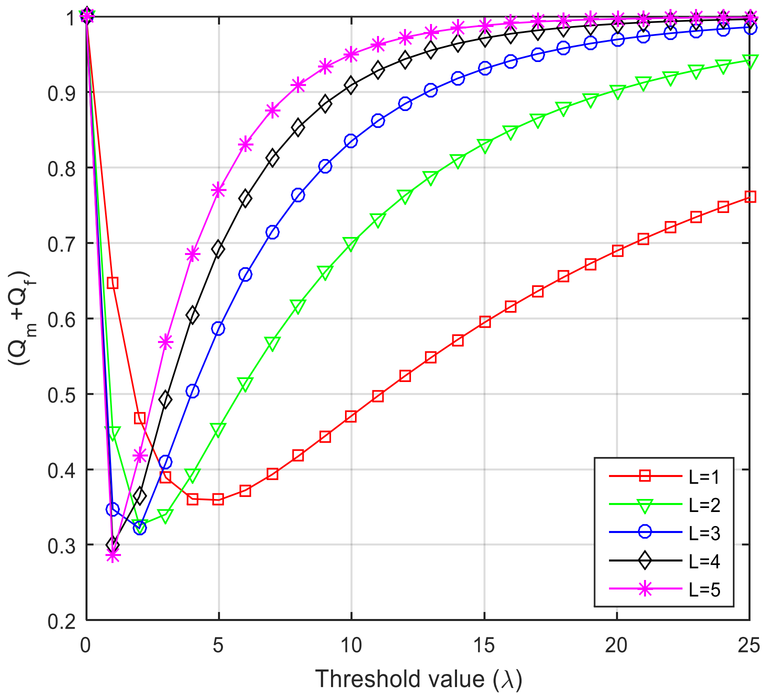

Fig.11 Total error rate performance using AND-Rule at FC.

Energy efficiency value rises with the number of antennas for both fusion rules such as OR-Rule & AND-Rule. We do not have particular value of EE but we need to maximize its value as much as possible. As the EE value is high, it means that we are using spectrum effectively and we are effectively utilizing energy resources.

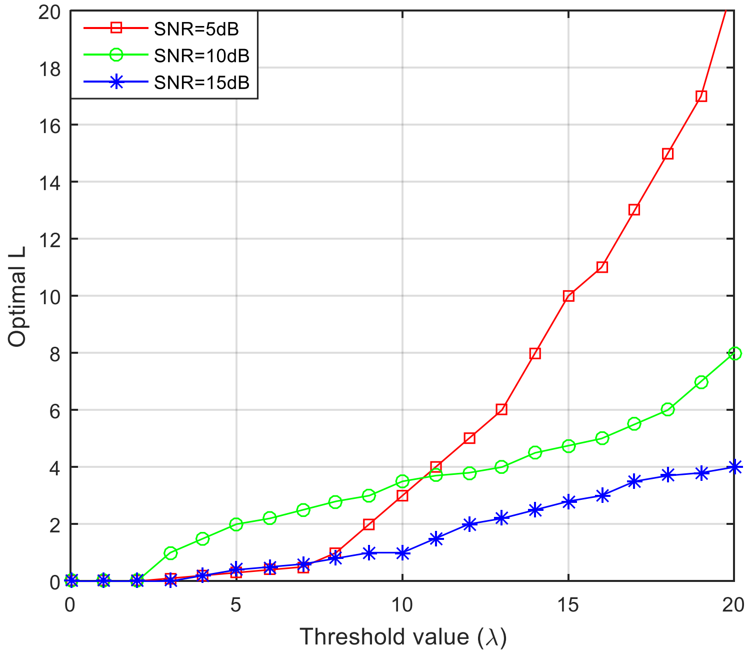

Fig.12 Calculation of Optimal number of secondary users using OR-Rule.

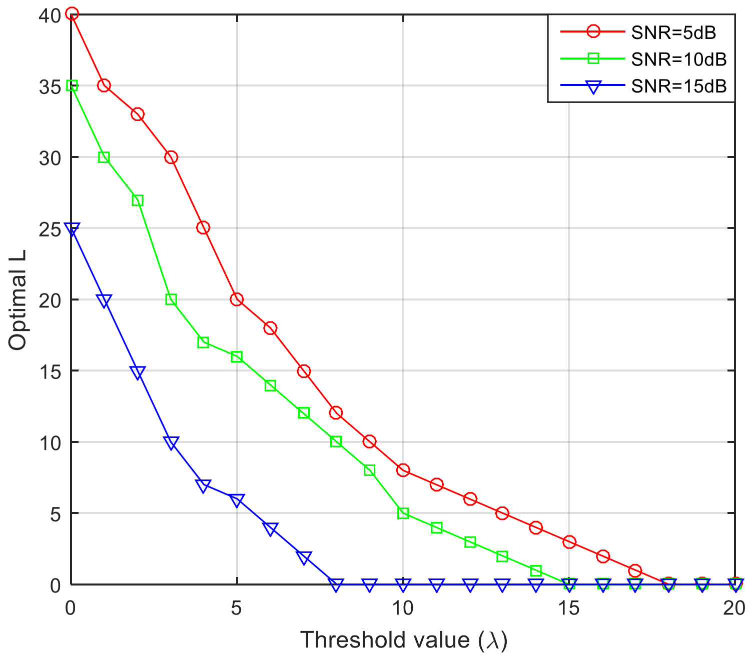

Fig.13 Calculation of Optimal number of secondary users using AND-Rule.

5.Conclusion

This study focuses on identifying unknown signals in a Rayleigh fading environment using the suggested CSS network. The energy efficiency rating has been increased by employing an IED technique and numerous antennas at each CR. Furthermore, the activity of the principal user (PU) is identified at FC utilising fusion rules (OR-Rule and AND-Rule). To measure average throughput and energy efficiency, a mathematical assessment is offered. At

FC, fusion rules (OR-Rule and AND-Rule) are used. Following that, overall error rate performance and a comparison of single and multiple antenna situations are presented. An optimal number of CR users is determined in order to optimise the EE value. Finally, it is concluded that when compared to traditional systems, performance is enhanced with the suggested scheme.

Declarations

Funding

The authors received no financial support for the research work.

Conflict of interest

Please check the following as appropriate:

- All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

- This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

- The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

- The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

Author’s name and Affiliations

(1) Naveen Kumar Boddukuri,

Research Scholar, Department of Electronics and Communication Engineering,

National Institute of Technology Mizoram, Chatlang, Mizoram – 796 012, India.

(2) Debasish Pal,

Central Electronics Engineering Research Institute, Pilani, Rajasthan 333031, India.

(3) Ayan Kumar Bandyopadhyay,

Central Electronics Engineering Research Institute, Pilani, Rajasthan 333031, India.

(4) Chaitali Koley,

Department of Electronics and Communication Engineering,

National Institute of Technology Mizoram, Chatlang, Mizoram – 796 012, India.

Availability of data and material

Data sharing not applicable to this article as no datasets were generated during the current study.

Code Availability

Software Application.

Cover Letter

From
Naveen Kumar Boddukuri,
Research Scholar,
Department of Electronics and Communication Engineering,
National Institute of Technology-Mizoram,
796012, India.

To
Editor-in-Chief
Wireless Personal Communication

Dear **Editor-in-Chief**,

Please find enclosed a manuscript entitled: " A Comprehensive Analysis of Energy Efficiency Using Cooperative Spectrum Sensing Network" which I am submitting for exclusive consideration of publication as an article in Wireless Personal Communications. The paper demonstrates the Energy efficiency analysis using cooperative spectrum sensing network over Rayleigh fading channel. The analysis is carried out using fusion rules such as OR-Rule, AND-Rule at fusion center. An optimal number of secondary users are also calculated to maximize the energy efficiency value. This manuscript has not been published before nor submitted to another journal for the consideration of publication.

Thank you for your consideration of my work. Please address all correspondence concerning this manuscript to me at My College and feel free to correspond with me by e-mail (naveenget426@gmail.com).

Sincerely,

Naveen Kumar Boddukuri

Title : “A Comprehensive Analysis of Energy Efficiency Using Cooperative Spectrum Sensing Network

References

[1] M. C. Chuah and Q. Zhang, (2009). Design and Performance of 3G Wireless Networks and Wireless LANS. Springer.

[2] M. H. Rehmani and Y. Faheem, (2014). Cognitive Radio Sensor Networks: Applications, Architectures, and Challenges. USA: IGI Publishing.

[3] A. Osseiran, J. F. Monserrat, and W. Mohr, (2011). Mobile and Wireless Communications for IMT-advanced and Beyond. Wiley.

[4] A.Medeisis and Oliver Holland, (2014). Cognitive Radio Policy and Regulation, Springer.

[5] E. Hossain, D. Niyato and Z. Han, (2009). Dynamic Spectrum Access and Management in Cognitive Radio Networks. Cambridge Press.

[6] A. Khattab, D. Perkins and M. Bayoumi, (2013). Cognitive Radio Networks From Theory to Practice. Springer.

[7] J. Mitola and G. Q. Maguire, "Cognitive Radio: Making Software Radios More Personal," *IEEE Personal Communications*, Vol. 6, no. 4, pp. 13 – 18, Aug. 1999.

[8] "Cognitive Radio: Brain-Empowered Wireless Communications", *IEEE Journal on Selected Areas in Communications*, Vol. 23, no. 2, pp. 201 – 220, Feb. 2005.

[9] T. Yucek and H. Arslan, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", *IEEE Communications Surveys & Tutorials*, Vol.11, no. 1, pp. 116 –130, March 2009.

[10] W. Wang, L. Zhang, W. Zou and Z. Zhou, "On the Distributed Cooperative Spectrum Sensing for Cognitive Radio", *Intl. Symposium on Commn. And Info. Technologies*, Oct 2007, pp 1496-1501.

[11] F. F. Digham, M-S. Alouini and M.K. Simon, "On the Energy Detection of Unknown Signals Over Fading Channels", *Proc IEEE Trans on Communications*, Jan 2007, Vol 55, pp 21-24.

[12] G. Ganesan and Y. Li, "Cooperative Spectrum Sensing in Cognitive Radio, Part I: Two User Networks", *IEEE trans. on Wireless Communication*, June 2007, pp 2204-2213.

[13] K. B. Letaief and Zhang, "Cooperative Spectrum Sensing" Chapter in *Cognitive Wireless communication Networks*, E. Hossain and V. K. Bhargava, (Eds.), Springer, June 2007.

[14] C. Lee and W. Wolf, "Energy Efficient Techniques for Cooperative Spectrum Sensing in Cognitive Radios", *IEEE CCNC* Jan 2008, pp 968-972.

[15] Peh, E. C. Y., Liang, Y. C., Guan, Y. L., & Pei, Y. (2011). Energy efficient cooperative spectrum sensing in cognitive radio networks. In *Global telecommunications conference* (pp. 1–5). IEEE.

[16] Varshney, P. K. (1997). *Distributed detection and data fusion*. New York: Springer.

[17] Althunibat, S., Narayanan, S., Di Renzo, M., & Granelli, F. (2005). Energy efficient partial-cooperative spectrum sensing in cognitive radio over fading channels. In *IEEE VTC spring* (pp. 1–5).

[18] Althunibat, Saud, & Granelli, Fabrizio. (2014). An objection based collaborative spectrum sensing in cognitive radio networks. *IEEE Comminacation Letters*, *18*(8), 1291–1294.

[19] Althunibat, S., Vuong, T. M., & Granelli, F. (2014). Multi-channel collaborative spectrum sensing in cognitive radio networks. In *IEEE 19th international workshop on CAMAD* (pp. 234–238).

[20] Maleki, S., Pandharipande, A., & Leus, G. (2011). Energy efficient distributed spectrum sensing for cognitive sensor networks. *IEEE Sensors Journal*, *11*, 565–573.

[21] Zhao, N., Yo, F. R., Sun, H., & Nallanathan, A. (2012). An energy efficient cooperative spectrum sensing scheme for cognitive radio networks. In *Global communications conference* (pp. 3600–3604).

[22] Shi, Z., Tec, K. C., & Li, K. H. (2013). Energy efficient joint design of sensing and transmission durations for protection of primary user in cognitive radio systems. *IEEE Communications Letters*, *17*, 565–568.

[23] Hang, Hu, Zhang, Hang, & Yu, Hong. (2015). Energy-efficient design of channel sensing in cognitive radio networks. *Computers and Electrical Engineering*, *42*, 207–220.

[24] A. Singh, M. R. Bhatnagar and R. K. Mallik, "Performance of an Improved Energy Detector in Multihop Cognitive Radio Networks," in *IEEE Transactions on Vehicular Technology*, vol. 65, no. 2, pp. 732-743, Feb. 2016, doi: 10.1109/TVT.2015.2401332.

[25] Digham, F.F., Alouini, S. and Simon, M.K. (2003) 'On the energy detection of unknown signals over fading channels', Proceedings of IEEE International Conference on Communications (ICC'03), Alaska, USA, pp. 3575-3579.

[26] Chen, Y. 2005 'Improved energy detector for random signals in Gaussian noise', IEEE Trans. Wireless. Comm., vol. 9, no. 2, pp. 558-563.

[27] Singh, A., Bhatnagar, M. R. and Mallik, R. K. 2012 'Cooperative spectrum sensing in multiple antenna based cognitive radio network using an improved energy detector', in IEEE Communications Letters, vol. 16, no.1, pp. 64-67.

[28] Ranjeeth, M, Behera. S, Nallagonda. S and Anuradha.S, "Optimization of cooperative spectrum sensing based on improved energy detector with selection diversity in AWGN and Rayleigh Fading," in Proceedings of ICEEOT, Chennai, India, pp. 1-5, 2016.

[29] A. Singh, M. R. Bhatnagar and R. k. Mallik, "Optimization of cooperative spectrum sensing with an improved energy detector over imperfect reporting channel," in Proceedings of IEEE Vehicular Technology Conference (VTC Fall), 2011.

[30] Sudhamani,C., M., S.S.R. Energy Efficiency in Cognitive Radio Network Using Cooperative Spectrum Sensing. *Wireless Pers Commun,* vol.104,907-919 (2019).