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Performance Evaluation of DCSS using Two Level 1-Bit Hard Decision Strategies over TWDP Fading Channel

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ABSTRACT- The spectrum sensing method's dependability is greatly influenced by two of the most crucial factors, including various fading channels and nearby wireless users. Multipath fading, buried terminals, and shadowing are just a few of the challenges encountered by users of non-cooperative spectrum sensing systems. Cooperative spectrum sensing approach gives a remedy for this issue. With the use of the common receiver, CSS permits the user to detect the spectrum. Additionally, it has been separated into distributed CSS (D-CSS) and centralized CSS (C-CSS). By using particular rules to identify the presence of the licensed user, both concepts are compared to one another in this article. The effectiveness of cluster-based distributed cooperative spectrum sensing over two-wave diffuse power fading channels (TWDP Channel) is also examined in the article. Wei-bull and Hoyt fading channels are two examples of fading channels that have previously exploited this idea. In this paper, simulation findings for the less well-known two-wave with diffuse power channels are reviewed. This work mainly focused on CSS over TWDP fading channels along with several proposed approach for two stage hard decision strategies using AND fusion and OR fusion. The simulation performance findings for TWDP fading situation enhance the OR_AND fusion strategy detection performance at various SNR levels. The presented D-CSS approach helps users to get beyond the difficulty they have when using non-cooperative spectrum sensing and lists the relationship among detection efficiency and power consumption for Cognitive radio technology used in constrained wireless environments.

General Terms: Spectrum underutilization, licensed user.
Keywords: Cognitive Radio, Cooperative spectrum sensing, hard fusion strategies, Detection probability, Two-wave with diffuse power fading (TWDP), Missed-detection probability.

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1. INTRODUCTION

As is common knowledge, for humans to address more specific needs like relationships and mental and physical health, certain physiological demands like food, water, air, clothes, shelter, and sleep must be met.

Furthermore, it is difficult to imagine humans existing in a world without wireless technology like mobile smart phones, which enable human communication. Due to the same, the market for electromagnetic radio frequency spectrum has expanded over the past 20 years, making it a precious resource. Wireless communication services have increased significantly as a result. Because of these fixed frequency allocations over a region, a sizable percentage of the spectrum are left unutilized for a sizable period of time or area. The advancement of CR technology is essential for overcoming spectrum shortage. The governments fixed allocation procedures, which allot licensed spectrum to main users (PU), result in an underutilized spectrum since the bulk of it is idle at odd hours and places. The development of new paradigms opens new opportunities for the development of cognitive radio (CR). Joseph Mitola first presented the idea of Cognitive Radio (CR) Technology in 1998 as a revolutionary way to wireless communication in order to overcome the congestion problems [1]. To utilize an unused spectrum over a licensed radio frequency spectrum by the unlicensed user or Secondary user (SU), the CR technology acts a very helpful role which allows the well-organized usage of spectrum by use of spectrum sensing based on opportunistic sharing.

When the licensed frequency channel is not being used by the principal user in CR technology, the unlicensed user or secondary users may use an unused channel for communication. But, as soon as the primary user wants to use the same then secondary users can quit the communication immediately.

While such type of switching occurs, there is a possibility of overlapping. To keep away from this type of overlapping or hindrance the effectual detection of the primary user is a must which is the foremost problem of CR. Spectrum sensing is the prime requirement of CR technology. Understanding a spectral contact or measuring the energy level of radio frequency defines spectrum sensing. For finding spectrum usage across different dimensions which include the parameters like time, frequency, code, and space. Also, the type of modulation, waveform, carrier frequency, and bandwidth are required to define a type of signal [2]. Cognitive radio technology turns out to be intelligent wireless communication technology due to its characteristics. There are many techniques available for the detection of the unused part of a spectrum of primary user transmissions such as Energy detection (ED), Cyclo-stationary feature detection (CFD), and Matched filter detection (MFD) which is having its signals-to-noise ratio and threshold. Below the threshold values, these techniques require more energy, high detection time, and high computational time [2]. "Cognitive radio is an intelligent technology for wireless," according to S. Hykin, "that alerts the outside world and employs the methodology to understand from the environment and adapts the characteristics of received RF stimuli by changing the required parameters in real-time by highly trustworthy communication wherever and whenever requires and competent utilization of spectrum [3].In the non-cooperative (Single user) spectrum sensing methods, each secondary user can sense the unused spectrum. The simplicity and low complexity of the energy detection spectrum sensing approach make it the best choice in any situation. Collaborative spectrum (Multi-user) sensing techniques are suggested [4] to enhance detection performance and address the difficulties of multipath fading, buried terminal issues, and shadowing effects. Using the collaboration of all nearby users to exchange the detected data and come to a consensus on whether the primary user is there or not. The remainder of the paper is provided below; *Section 2* of the article discusses the relevant literature review of prior researchers addressing the cooperative spectrum sensing approach. In *section 3*, we discuss a potential cooperative sensing paradigm and the clustering of secondary users. *Section 4* discusses our unique distributed cluster-based cooperative spectrum sensing method. *Section 5* explains the graphical representation and analyzes the proposed work's detection performance with past benchmark findings. Finally, *section 6* provides our article's conclusion.

2. BACKGROUND

The concepts of non-cooperative and cooperative spectrum sensing technologies are presented in this part [1-2]. Rather than summarizing the relevant previous research work, we gave an overview of suggested articles in depth.

Faten Mashata et al. discuss [2] separating the single user sensing algorithms into coherent and non-coherent sensing categories encourages for the classification of spectrum sensing approaches. Also discuss the basic principle, its comparison, advantages and disadvantages of each method are elaborated with its challenges. The recent cognitive radio standards are addressed for recent industrial efforts in accounts of standard specification.

Megha Motta uses basic hypothesis tests to highlight the decision-making and data fusion strategies for cooperative spectrum sensing approaches. The Likelihood Ratio Test (LRT), the Naymon Pearson Benchmarks, and other fusion techniques served as the foundation for this test. She increased the combination of bits to 4 bits and used all fusion strategies in centralized networks of secondary users [3]. The suggested method compromises between detection performance and channel overhead in order to maximize the advantages of both hard and soft decision fusion procedures. In the case of quantization combination techniques, a better balance amongst detection performance and complexity may therefore be archived.

Fatime Salahdine et al. said that the existing cooperative spectrum sensing methods are lacking in performance in terms of overhead communication, processing time, and sampling complexity. They proposed fast signal acquisition approaches to achieving high detection performance by reducing the processing time [4]. Spectrum sensing accelerates its processing time for higher performance with a low compression fraction and low mistake rates. In order toward sustain the work-load of a single cluster-head; the suggested model may also be expanded by taking into account cluster headship in the cluster as opposed to single headship.

D. Teguig at el. looked at how fusion systems will affect the cooperative spectrum sensing technique. With a trade-off among performance detection and channel overhead, the postulated 3-bit quantized combination approach [5] prevails over the hard and soft decision fusion schemes.

Shrinivas Nallagonda at el. analyzed the performance of the soft fusion scheme and hard fusion scheme for cooperative spectrum sensing in noisy-Rayleigh fading pathways [6]. Using the OR Rule, AND Rule, and majority rule for the hard fusion scheme and SLC, MRC, SC, and SLS for the soft fusion scheme, the performance of CROC, ROC, and the overall error rate has been studied using an energy detection method with the developed analytical framework in Rayleigh faded and noisy environment. The performance of the detector was evaluated with several parameters like the number of secondary users, threshold, and signal to noise ratio, and time-bandwidth products. Finally concluded that the MRC fusion scheme gives outperforms in poorer S-channel fading conditions by using fewer cognitive radio users.

Gaoyu Chen at el. summarizes numerous usual data fusion decision schemes in spectrum sensing using CSS for CR Networks over AWGN channel. To achieve perception results and a reliable system the strategies of data fusion play an important role with the need to consider the trade-off between the overhead of the system and its performance [7].

Suresh kumar Balam, at el. investigated the performance through Complementary ROC, total error rate under the influence of generalized k-μ fading, and noise. They derived the novel-analytic equations for the probability of detection with consideration of k-μ fading and noise [8]. The studied work is useful for futuristic hybrid terrestrial satellite communication networks. Also, concluded that to reduce the missed probability of miss-detection and increase the false alarm probability the values of μ should be high.

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A cluster-based decentralized CSS approach over a Nakagami channel was examined by Giriraj Sharma at el. employing four suggested decision strategies, including OR_OR, OR_AND, AND_AND, and AND_OR [9]. Comparatively speaking to the centralized CSS for other decision strategies, the developed framework employing the OR-OR fusion rule performs better. Additionally, it was discovered that capturing more secondary users increases the chance of detection.

R.John Selwyn at el. considered cluster-based cooperative spectrum sensing to analyze the probability of detection over different fading scenarios [10]. Using QPSK transmission with consideration of 10 secondary users per cluster results were simulated for ROC curves over the Rayleigh channel, Rician Channel, Nakagami-m channel, and Weibull fading channel. By use of cluster-head decreases the workload of the fusion center which increases the life cycle of the cognitive radio network. Also, concluded that the detection performance increases by increasing the number of secondary users in cluster.

Taranginni Shukla at el. proposed centralized cooperative spectrum sensing techniques using optimum voting rule means half voting rule also recognized as a majority rule 'n out of k rule by using parameters such as optimal detection threshold [11]. This condition had been verified through simulated results over an additive white Gaussian noise channel. From that, they found that for achieving better utility function with minimal probability error a suitable selection of the cognitive user is required.

Giriraj Sharma at el. elaborated and said that non-cooperative spectrum sensing has a problem such as consequence of shadowing and unseen user issues owing to the failure of CR users while monitoring unused spectrum. They proposed distributed CSS methods by creating a cluster of secondary users with main four hard fusion decision schemes over different fading channels in Nakagami-m and Rician communication environments [12]. They investigated that the cooperation among secondary user's increases as well as the chances of detecting vacant spectrum also increases by 25% If the quantity of clusters and secondary users both rise. They concluded based on the simulated results that distributed OR_OR decision strategies performed well in the proposed method.

Yashaswini Sharma at el. investigated and compared the centrally controlled CSS and distributed CSS using various hard decision strategies over inadequately faded channels like the Weibull fading channel and Hoyt fading channel, with a focus on the deployment of 4 proposed approach like OR_OR, OR_AND, AND_OR, and OR_OR decision strategies [13]. They deduced from the simulated results that the Weibull channel provided higher detection probability than the Hoyt channel for SNR levels of less than 5 dB. Weibull Channel was able to obtain 0.9 Pd for the AND_OR and OR_AND decision strategies at SNR > 5dB. The OR_AND decision strategy outperformed the other four decision strategies for both channels.

Harjas Kaur at el. investigated multiple-input single-output (MISO) for the TWDP fading channel's actual rate of fading. They came up with a fresh analytical formula for the TWDP fading channel and precisely calculated the effective rate [14]. They discussed classical faded models such as the Rician and Rayleigh fading models are the case of the extraordinary case of TWDP fading channels.

Eleftherios Chatziaantoniou at el examined how well the Energy detection spectrum sensing approach performed in comparison to the TWDP fading model. Also, characterized TWDP fading model with a well-known canonical faded model such as Rician, Rayleigh, and the worse condition of Rayleigh fading model by two Ray fading model [15]. Their results indicate that the performance of detection performance degrades in TWDP fading conditions; however, its shown that when cooperation among use and diversity are employed the performance detection can be improved.

Ruliu Nie at el. Cognitive remotely operated vehicle networks can increase their spectrum efficiency using distributed CSS approaches based on clustering [16]. Max-Min distance clustering techniques are used in the proposed network's initial stage. While in the second stage to achieve hierarchical sensing information fusion two-stage fusion schemes are adopted. From the comparisons of the simulated results, they concluded that the proposed model enhances the detection performance when the nodes are taken in relatively large number.

3. PROPOSED DCSS SYSTEM MODEL

The energy of the signal received in the communication environment informs the Supplementary User (SU) of the presence of PUs. Energy detection receives the input signal y(ŧ), and its binary decision output determines whether primary users are present or not [16–17].

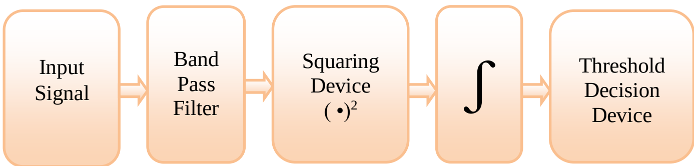

Figure 1: Conventional ED block diagram

It obeys the below two conditions of the hypothesis:

$$x(ŧ) = n(ŧ) \qquad \hat{H}0 \qquad (1)$$

$$x(ŧ) = s(ŧ) + n(ŧ) \qquad \hat{H}1 \qquad (2)$$

From the above hypothesis, $\hat{H}$ 0 indicates the non-existence of PU and $\hat{H}$1 indicates the existence of PU. s(ŧ) is the received signal from the original signal of PU. x(ŧ) is the received signal at the secondary cognitive users. n (ŧ) denotes the additive-white Gaussian noise. PU can be identified by examining the received energy concerning the calculated threshold value [18-19].

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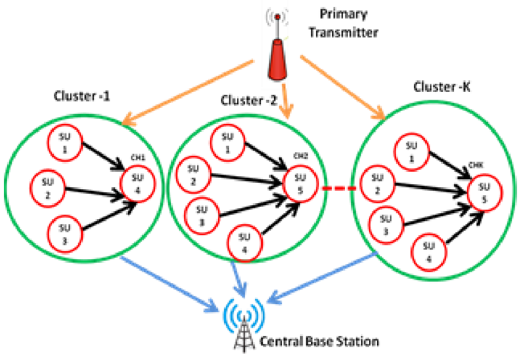

Figure 2: Proposed Cluster based DCSS

The secondary users in our proposed clustering-based D-CSS are separated into clusters. Within the cluster, conventional spectrum sensing is carried out by each Secondary user. The beneficiary SUs of the same cluster that applies hard fusion techniques to determine the existence or absence of PU from the licensed spectrum receives the information as a consequence. The Cluster Head (CH) from each individual cluster makes a final determination about the existence or absence of PUs for the intended spectrum because the proposed system is made up of numerous clusters.

4. PROPOSED D-CSS DESIGN GOAL

In this research, a distributed cluster-based cooperation method for spectrum sensing is developed, to improve the detection performance of the system for the identification of the existence or non-existence of the PUs. As seen in the following *figure 3*, our suggested strategy calls for each secondary user to make judgments on their own utilizing the traditional energy detection method to compare the received signal's energy level to a preset threshold. By averaging the total signal energy received with the total number of secondary users participating in the set-up system, the threshold value can be estimated.

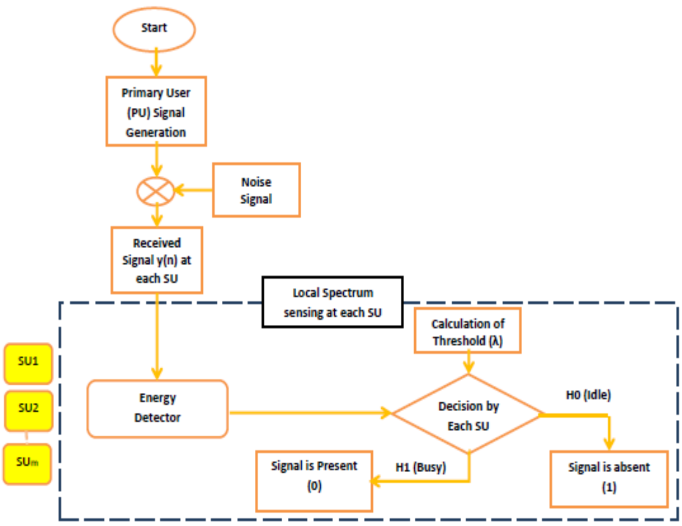

Figure 3: Process flow for combined decision

As shown in *figure 4*, every cluster has one cluster head (CH) among all secondary users within the cluster. The individual CHs of each cluster make a combine decision from the received resulting information of every secondary user by applying the four hard fusion strategies.

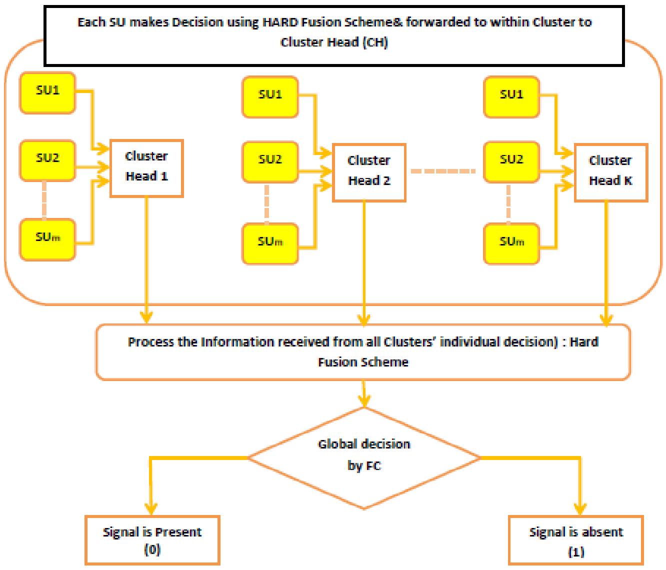

Figure 4: Process flow for Final/Global decision

Finally, all the individual decisions of CHs will combine at the common fusion center to make a final or global decision for deciding the presence of PUs.

Cluster size can be determined by the SU's having maximum received energy participated in the network from the particular PU. To check the performance of cluster-based D-CSS over two-waves with a diffuse-power faded environment, the distance between the PU and SU's is also calculated which also depends on the size of the network. Also, all participating SU's in the network can be divided into clusters with the assistance of a clustering algorithm from the statistics and machine learning toolbox in MATLAB. Within the cluster, every secondary user takes a judgment regarding the existence of PU by performing the local spectrum with threshold comparisons. Subsequently explained the four 1-bit decision rule means the hard fusion schemes for the cluster base distributed Cooperative spectrum sensing techniques.

4.1 The AND_AND Fusion Rule

The participating secondary users within the cluster fused their information among other secondary users of the same cluster using AND rule. Then, every cluster head of participated clusters are mutually combined the individual information and makes a global decision using AND rule.

4.2 The AND_OR Fusion Rule

Similarly, in this scenario, the cluster's SUs fused their knowledge using the AND rule, and the clusters then shared individual results to get a global conclusion using the OR rule.

4.3 The OR_AND Fusion Rule

Similarly, in this scenario, the cluster's SUs fused their knowledge using the OR rule, and the clusters then shared individual results to get a global conclusion using the AND rule.

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4.4 The OR-OR Fusion Rule

Similarly, in this scenario, the cluster's SUs fused their knowledge using the OR rule, and the clusters then shared individual results to get a global conclusion using the OR rule.

Table 1: Summary of implemented decision approach

Combine Decision by Each Cluster head within the Cluster	Global Decision	Implemented hard decision strategies for Cluster based DCSS
AND	AND	AND_AND strategy
AND	OR	AND_OR strategy
OR	AND	OR_AND strategy
OR	OR	OR _OR strategy

The above-furnished *table 1* will helps to understand the whole process of making a final or global decision with our proposed architecture of cluster-based distributed cooperative spectrum sensing model. An individual decision will be taken based on the threshold comparison. Combine decision and the global decision will be taken by a set of implemented hard fusion rules as given in the above tabular last column.

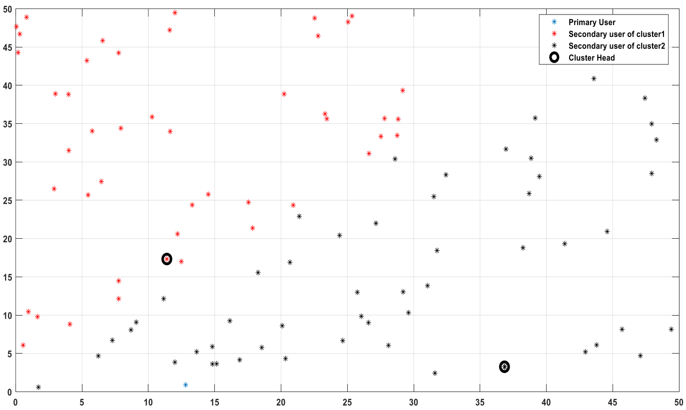

Figure 5: Cluster formulation for DCSS

Figure 5 shows that a cluster is constructed through participating secondary users in the communication environment. According to our proposed cluster-based DCSS, we considered 2 clusters for the simulation results. The number of secondary users is divided into these 2 clusters based on received energy levels and the distance between each SU and PU. The primary user is indicated by a blue Asterisk in the above result. Secondary users of cluster 1 are indicated by Red Asterisk while in cluster 2 SU's are indicated by a black Asterisk. To implement a two-stage fusion scheme, each cluster has its cluster head (CH) and that is encircled by a black ring. The cluster head is nothing but any secondary user within the cluster but the declaration of CH is made by those SU that has more energy level among all SU within the same cluster. In the above case, we have considered the total number of 100 SU's and 1 primary user which are scattered in the dimension of the area that is 50x50.

5. EXPERIMENTAL RESULTS

To investigate the performance of cluster-based DCSS with different hard fusion schemes over a TWDP fading environment the simulation result discussion is given in this section. The simulation results are obtained using MATLAB R2021a software. In this section, results, and graphs are obtained for different fusion rules for proposed architecture over a TWDP fading environment and those results are compared with the CSS model over the same environment.

Experimental result simulations are obtained with time-bandwidth product u =5. The 100 SUs are split into 2 clusters, each of which has a cluster-head (CH) and secondary users made up of the remaining users. For two waves with diffuse power (TWDP) channels using cluster base DCSS and CSS with various fusion rules, the simulation results are displayed between the missed-detection probability (Pmd) and SNR (dB), false alarm probability (Pfa) versus probability of detection (Pd), and SNR (dB) versus detection probability (Pd). In this paper, for plotting the graphs of cluster-based DCSS, four fusion rules (AND_AND, AND_OR, OR_AND, OR_OR) are used for TWDP faded channel.

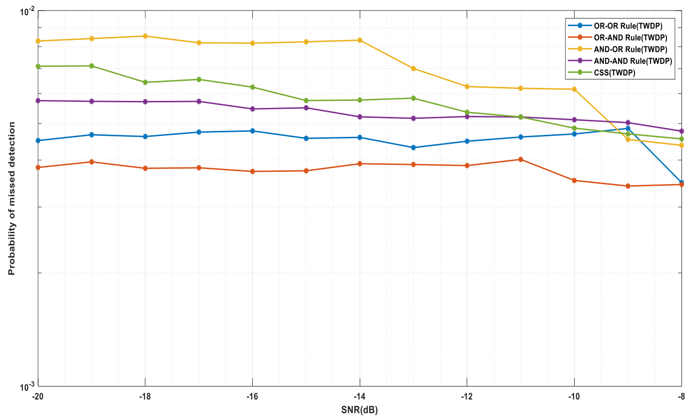

Figure 6: SNR Vs Pmd over TWDP fading channel using 4 decison strategies

The OR_OR decision, OR_AND decision, AND_OR decision, and AND_AND decision for Cluster-based DCSS and CSS technique along two-wave using diffused power channel are emphasized in *figure 6's* ROC of SNR (dB) vs. the missed-detection probability. The simulated result shown above has an SNR value that ranges from -20 dB to -8 dB. Four fusion rules are used to depict the performance of cluster-based DCSS in the TWDP fading environment.

Table 2: P_{md} values at different values of SNR

SNR (dB)	Probability of missed-detection (P_{md})				
	OR_OR Decision	OR_AND Decision	AND_OR Decision	AND_AND Decision	(CSS)
-20	0.00451	0.00382	0.00830	0.00575	0.00710
-18	0.00462	0.00380	0.00855	0.00572	0.00644
-16	0.00478	0.00373	0.00818	0.00547	0.00625
-14	0.00459	0.00391	0.00834	0.00521	0.00578
-12	0.00449	0.00386	0.00627	0.00522	0.00536
-10	0.00469	0.00353	0.00617	0.00512	0.00486
-9	0.00485	0.00341	0.00454	0.00503	0.00469
-8	0.00348	0.00344	0.00438	0.00477	0.00455

The likelihood of missed-detection probability is consistently the lowest values for the OR_OR decision strategy, AND_AND decision strategy, and OR_AND decision strategy when compared to the CSS approach over the TWDP fading environment, as it can be seen from the aforementioned simulation result data. As shown in *figure 6* and the tabular statistics above, the OR_AND decision strategy consistently has a lower probability of missed detection when the SNR ranges from -20 dB to -8 dB, providing superior performance than the other decision strategies and CSS method. On the other hand the AND_OR decision strategy, indicates an inappropriate performance under realistic conditions. For example, when ranges of SNR values are between -20 dB to -8 dB the missed-detection probability values are nominal in the case of the OR_AND decision strategy.

The likelihood of detection utilizing the cluster-based DCSS technique for the OR_OR strategy, OR_AND strategy, AND_OR strategy, and CSS method over the TWDP fading scenario is compared in *figure 7* with account of SNR fluctuation from -20 dB to -8 dB The simulation's output depicts how cluster-based DCSS performs at various SNR levels.

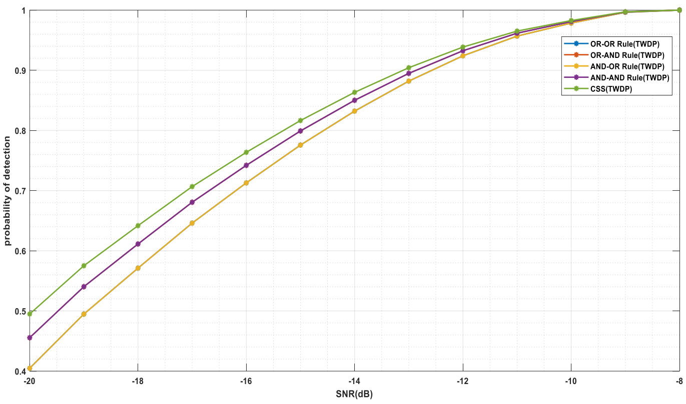

Figure 7: Probability of detection comparisons between OR_OR strategy, OR_AND strategy, AND_OR strategy, AND_AND strategy using cluster based DCSS and CSS method over TWDP fading environment at SNR variation values

Table 3: P_d values at different values of SNR

SNR (dB)	Probability of Detection (P_d)				
	OR_OR Decision	OR_AND Decision	AND_OR Decision	AND_AND Decision	(CSS)
-20	0.4047	0.4555	0.4047	0.4555	0.4949
-18	0.5712	0.6113	0.5712	0.6113	0.6417
-16	0.7129	0.7420	0.7129	0.7420	0.7636
-14	0.8321	0.8501	0.8321	0.8501	0.8633
-12	0.9240	0.9325	0.9240	0.9325	0.9386
-11	0.9568	0.9616	0.9568	0.9616	0.9652
-10	0.9785	0.9809	0.9785	0.9809	0.9827
-9	0.9964	0.9968	0.9964	0.9968	0.9971
-8	1.0000	1.0000	1.0000	1.0000	1.0000

It can be observed from the above simulation result statistics that detection probability always higher for OR-AND decision strategy, AND-AND decision strategy with compare to OR-OR decision strategy and AND-OR decision strategy at SNR variation from -20 dB to -8 dB. While CSS approach is achieved superior performance than these four fusion decision strategies. For instance, all fusion rules and CSS techniques have about comparable values for the likelihood of detection when the SNR fluctuation is between -12 dB and -8 dB. In general, it can be shown that SNR values should be in the range of -13 dB to -8 dB in order to attain probabilities of detection of 0.9 or higher.

6. CONCLUSION

To address the problems of hidden node difficulties and shadowed effects across AWGN, Rayleigh, Rician, Nakagami-m fading, Wei-bull, and Hoyts fading environments, many researchers in this study examine and describe cooperative spectrum sensing solutions. In this article, we use a lesser studied fading channel i.e. Two waves with a diffuse power channel to optimize the detection performance. Finally, we enhanced the cooperative spectrum sensing method through clustering of SU's and implemented two-stage hard fusion schemes for two waves with diffuse power (TWDP) faded environment. Performance of distributed CSS for TDWP fading channels utilizing OR_OR, OR_AND, AND_OR, AND_AND decision strategies are compared. The TWDP channel reports improved performance for DCSS OR-AND, AND-AND rules. To achieve more than 0.85 probability of detection (Pd), the SNR values vary between -13 dB to -8 dB. The detection probability is approximately equal when the SNR value is more than -12dB for all fusion rules and CSS methods. The minimum values of probability of missed detection are achieved for the OR_AND decision strategies over the TWDP fading environment. However, the main drawback of conventional spectrum sensing can be minimized when the SU's can work or cooperatively take a decision. By making a cluster of secondary users and its cooperation with the two-stage decision by hard fusion schemes the status of PU can be identified accurately.

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