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Efficacy of Decentralized CSS Clustering Model Over TWDP Fading Scenario

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Abstract— Cognitive Radio technology, which lowers spectrum scarcity, is a rapidly growing wireless communication technology. CR technology detects spectrum holes or unlicensed spectrums which primary users are not using and assigns it to secondary users. The dependability of the spectrum-sensing approach is significantly impacted from two of the most critical aspects, namely fading channels and neighboring wireless users. Users of non-cooperative spectrum sensing devices face numerous difficulties, including multipath fading, masked terminals, and shadowing. This problem can be solved using a cooperative- spectrum-sensing technique. For the user, CSS enables them to detect the spectrum by using a common receiver. It has also been divided into distributed CSS and centralized CSS. This article compares both ideas by using a set of rules to find out whether a licensed user exists or not. This thought was previously used to the conventional fading channels, such as the Rician, Rayleigh and the nakagami-m models. This work focused on D-CSS using clustering approach over TWDP fading channel using two-phase hard decision algorithms with the help of OR rule as well as AND rule. The evaluation of the proposed approaches clearly depicted that the sack of achieve a detection-probability of greater than 0.8; the values SNR varies between -14 dB to -8 dB. For all two-phase hard decision algorithms using proposed approach and CSS techniques, the detection probability is essentially identical while the value of signal to noise ratio is between -12 dB to -8dB. Throughout this work, we assess performance of cluster-based cooperative spectrum-sensing over TWDP channel with the previous findings of AWGN, Rayleigh, and wei-bull fading channels. The obtained simulation results show that OR-AND decision scheme enhanced the performance of the detector for the considered range of signal to noise ratios.

Keywords- Cognitive Radio, Secondary user, Decentralized Co-operative Spectrum Sensing, Cluster head, detection probability, false-alarm probability.

I. INTRODUCTION

Various international and national administrative agencies have implemented a series of laws over the last few decades, leading to radio spectrum crowding. As a possible consequence of devoting vast spectrum allocations to services that are inconsistent but quite demanding, there is now an artificial scarcity in spectral range to support the ever-growing wireless applications. As reason of a contradiction in national interests, the possibility of spectrum reallocation is economically unfeasible, and any future allocations would require global discussions. Cognitive radio (CR) platform provides an intriguing alternative by enabling secondary users (commonly referred as CR terminal) to access the spectrum beside the licensed users (referred as PU's) which have subscribed for the sole use of the radio spectrum.

In contrast, FCC spectral occupancy measurements indicat e that the majority of licenced bands are not used for large part s of time [1-3]. The idea behind cognitive radio is that it will help the radio system make better use of the available spectrum by employing intelligent and learning processes. Cognition's goal is to provide a means of coexistence for both licensed and unlicensed users of CR technologies by minimizing the amount of interference between them. Non-licensed users can send and receive data during the times when licensed users are not using such frequencies. When looking for licensed users, spectrum sensing plays a crucial role in determining their existence or non-existence [3-7]. Spectrum sensing relies heavily on CR's ability to perform following functions as depicted in figure 1 [8-10]. Spectrum sensing is the process of identifying empty channels within a frequency band by identifying the existence or non-existence of a PU inside a permitted spectrum. By capturing the optimal spectrum for a given application, as part of its spectrum management process, CR meets the needs of its users in terms of their ability to communicate. When a prime user has to transmit again, a secondary user with spectrum mobility

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quickly reallocates the channel or spectrum band to the primary user. Spectrum sharing involves coordinating with other parties to find the most optimal frequency band.

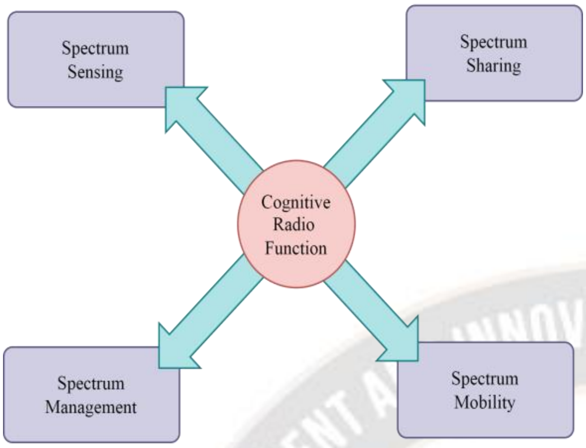

Figure 1. Cognitive radio functions

Spectrum sensing techniques fall into two categories: Local spectrum sensing and co-operative spectrum sensing. Every CR conducts itself a spectrum sensing locally. It is accompanied by numerous obstacles that make it difficult to recognize vulnerability. Among these are sensitivity requirements, receiver uncertainty, and the hidden node issue. Cooperative Sensing offers a superior solution to all of the aforementioned obstacles [14-15].

When the size of the communication network grows, its performance may deteriorate. This is due to the reason that growing the network capacity and the communication overhead inside the network both leads to substantial increases. To reduce the size of the massive communication network and improve the effectiveness of its operations, clustering is one of the most studied approaches. The network is partitioned into logical groups using clustering, with the groups' membership determined by the network's attribute and the needs of the application. Some of the benefits of cluster-based networks over flat ones are such as growing the capacity of the network, more network resilience, and lower power consumption etc.

This paper includes reviews and a discussion of the difficulties connected with cooperative spectrum sensing. The distributed cooperative spectrum sensing employing a clustering strategy over two waves with diffuse power channels has been addressed, as well as two stages of hard-fusion decision schemes to improve detection performance.

The rest of the study is presented below. In the second section, we look at what other investigators have said about the cooperative spectrum sensing approach. The different structure of the cooperative sensing paradigm is explained in section-3. The novel cooperative distributed cluster-based spectrum sensing approach is covered in section-4. We describe the simulation statistics for the suggested protocol and compare the proposed study's detector performance to several established standards. Section 6 of our article provides a brief description of all its contents

II. Literature review

Nandine et al. [13] reviewed and discussed recent studies of spectrum-sensing techniques in CR networks. A brief explanation of the three main techniques; non-cooperative spectrum-sensing, cooperative spectrum-sensing and interference-based sensing has been provided. This review found that compared to non-cooperative sensing methods, cooperative spectrum sensing methods are superior for signal detection.

Salah et al. [14] presented a complete analysis of the mechanisms of cognitive radio network clustering and how nodes can work together to achieve common goals. They focused on the discussions of co-operative spectrum-sensing, clustering prospects and limitations, and categories of cluster relayed spectrum sensing with cooperation among un-licensed users. To begin, a high-level overview of the grouping relayed on cooperative spectrum sensing architecture will be presented. After that, the fundamental ideas behind sensing overhead and efficiency as well as cooperative sensing are broken down and discussed. In addition to this, comparisons are made between different clustering sensing models, and the various schemes are placed into distinct categories. Also investigated in the cognitive radio system was indeed the concept of clustering objectives.

Simpson et al. [15] suggested ways for using evidence-based decision-fusion-CSS to boost SU flexibility, increase reliability, and address the hidden terminal challenge. When combined with SU's sensing data evidence, conflicting evidence and also the standard Dempster-Shafer paradigm might give contradictory conclusions and poor CSS performance. A well-organized evidence-based decision fusion strategy CSS is suggested to resolve conflicting data and improve CSS performance. The simulation findings demonstrated that in realistic settings, comparing the proposed scheme to the conventional proposed decision approach, the recommended scheme improves the CSS system's functionality. It does not account for the variation in local sensing integrity between SUs.

Rangel et al. [16] discussed the theoretical foundations for cognitive radio and a variety of sensing mechanisms in CR networks. They presented ordinary detection of the co-operative spectrum, hard fusion (AND, OR, Majority rule) and soft decision (SC, SLS, SLC, MRC) decision schemes, and an examination of said rules of cooperative sensing in real environments. Lastly, the outcomes of the evaluation of the performance of fusion rules in cooperative remote sensing were presented.

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Errong et al. [17] proposed a mixed terminal based low-energy-adaptive clustering-hierarchy (LEACH) algorithm that uses data from a variety of nodes. The method begins with a sink node (SN) updating and broadcasting aggregated data, preceded by every cognitive-node calculating its own competition radius depending on the deployed densities of cognitive-nodes and finally a compete for cluster-head's (CHs) using the specified trade rules. During the censoring phase of CHs, some unneeded CHs are eliminated in an effort to find the optimal number of clusters, allowing for a more uniform distribution of CHs over the HCRSN. To efficiently monitor the allocation of Cognitive nodes across numerous groups of SNs and the power usage across cluster heads, non-CH SNs and CNs select the closest cluster heads through the smallest value to engage depending on computation formulas of weights accumulation of some criteria such as area and link type. In considerations of channel probability detection, network longevity, and an equality in CN allocation among groups and CHs in terms of energy consumption, experimental results performed better for the proposed approach. Last but not least, boosting the effectiveness of energy utilization, a mathematical derivation of the ideal utilization ratios of numbers with commencing energy of Cognitive nodes and Sensor networks is described.

Mukhrjee et al. [18] addressed real-time power allotment for cluster heads (CH) in cognitive radio sensor networks (CRSN). Secondary user (SU) spectrum sensing outputs for a non-ergodic system are employed in the research. Multiple nodes in a cooperative sensing network coordinate its spectral sensing results through mutual communication. As a result, the SU nodes in every cluster continuously sense the spectrum by drawing power from the CRSN. All CHs are now being used in a particular region for spectrum sensing, which results in significant energy savings. Distributed-artificial-intelligence allocates resources, vector quantization recognizes adjacent active SU nodes, and auto-correlation-error (AE) predicts the instantaneous activities of PUs. Both theoretical calculation and computer simulations confirmed the proposed approach.

Yang et al. [19] explored the distributed co-operative spectrum-sensing in diverse CR networks using distinct spectrum-sensing algorithms and channel environments for each secondary user (SU). They developed a dynamic grouping-based fusion rule for primary user and SU mobility to tackle spectrum sensing. The approach can dynamically group SUs with a clustering parameter. Group-1 SUs cannot cooperate, while groups-2 and 3 have individual weighting factors. The suggested fusion rule solely processes each SU's individual decision result, significantly reducing data communication overload and processing delay. Outcomes of simulation demonstrate that the suggested fusion mechanism improves dynamic clustering of SUs and fusing detected information. Proposed approaches outperformed the OR fusion, AND fusion, equal gain combining, and highest SNR under the similar circumstances.

Hossain et al. [20] discussed cluster-based CCRNs could benefit from the proposed notion of multiple-reporting-channels (MRC) by allowing secondary-users to prolong their sensing time throughout the reporting timestamp. This method involves giving every cluster its own reporting channel. Every SU inside a cluster reports its sensed information to its CH through its allocated single reporting-channel, allowing for longer total SU sensing-times. The FC renders its final judgment depending on the existence of the PU signal, which is reported by every CH via the specialized reporting channels. The time for sensing throughout all secondary users is much improved compared to a non-sequential method, and the reporting-time duration for all CHs is reduced compared to a sequential-method of reporting on a single-channel. The presented scheme reduces the latency in Cluster head reporting and greatly improves the sensing-accuracy compared to the traditional method.

Chen et al. [21] discussed cooperative-spectrum detection method is able to produce more precise combination choice outcomes than single node selection. Cooperative sensing relies on a fusion center that collects and processes localized detection information or sensing findings in accordance to a predetermined records fusion rule before reaching a consensus on the present state of the channel. A reliable and accurate system relies heavily on the data fusion approach employed. They provide a concise overview of several well-established data fusion algorithms in CSS for cognitive-radio-networks and evaluate their performance.

Ye et al. [22] suggested an efficient-linear-weighted-cooperative-spectrum sensing scheme for clustering approach based CRN. Different weight levels would be allocated to cooperative nodes within that system based on the SNR of cognitive users as well as past sensing reliability. Furthermore, cognitive users could be grouped, and individuals with stronger channel conditions would be chosen as cluster heads to collect localized sensed data.

Mokhtar et al. [23] suggested a modified threshold dependent on a regulated false alarm probability, with anticipation of the innovative data fusion approach depending on a cluster system and detection in a manner of distribution. The suggested approach is tailored for enhancing channel errors in a heavily Rayleigh fading environment. They found that a two-stage method using distribution clusters and fusion node selection yielded a 0.42 percentage point gain in accuracy. The ROC curve analysis demonstrates a rise in detection probabilities as well as a decrease in false-alarms. In addition, there is a 0.95 increase in sensitivity.

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III. Model of Cooperative Spectrum Sensing

Energy detectors are being used as the local detecting node because of their ease of deployment. All the secondary nodes report to the fusion center and based on received data at the fusion center it gives the decision in terms of probability of detection.

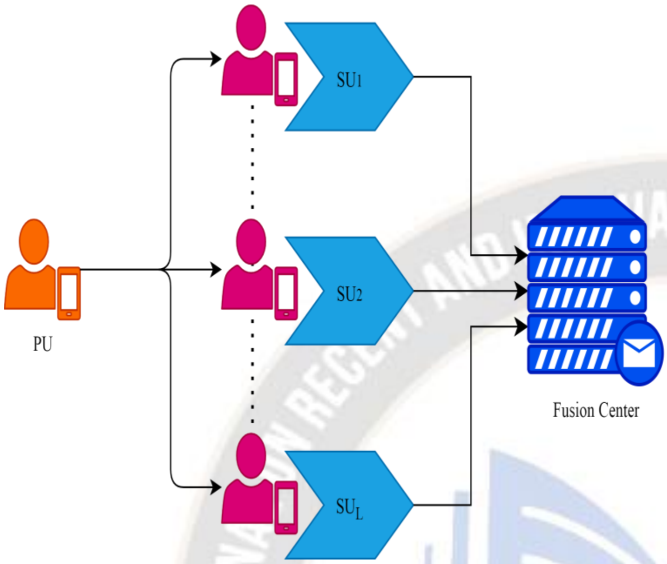

Figure 2. Structure of CSS Model

Figure 2 presents a schematic representation of a cooperative spectrum sensing model. At each local detecting node, a band-pass filter tends to reduce the incoming signal's intensity to prevent congestion, and then compared against a predetermined threshold value (λ). The compared results will be denoted by the two hypotheses: H0 represents that only noise is present where PU is absent, H1 represents that PU signals present with noise as below furnished expression [15], [24-25].

$$r(z) = \eta(z) \quad : H0 \qquad (1)$$
$$r(z) = x(z) + \eta(z) \quad : H1 \qquad (2)$$

In expression (1) $\eta(z)$is the additive white Gaussian noise (AWGN), where in expression (2) $x(z)$ is the primary signal and $r(z)$ represented the received signal at cognitive user or secondary user. Assume that there are L cognitive users in the system (j=1, 2, 3... L). The process of spectrum sensing requires N samples. When applied to cognitive spectrum sensing, the hypothesis holds for any arbitrary j.

$$r_j(z) = n(z) \quad : H0 \qquad (3)$$
$$r_j(z) = \acute{\alpha}_j x(z) + \eta_j(z) \quad : H1 \qquad (4)$$

Following two expressions are used to quantify the power and energy of each cognitive radio user.

$$E_j = \sum_{j=1}^{N} r_j^{\,2}\,(n) \qquad (5)$$
$$p_j(t) = \sum_{j=1}^{N} r_j^{\,2}\,(n)/N \qquad (6)$$

After completing their spectrum sensing, the j^th local node reports their findings through a reporting channel to the central fusion node. Individual node reporting will be done using either whole-energy statistics or a 1-bit representation.

A. Model of Centralized CSS (C-CSS)

Let's say the signal collected at the L^{th} secondary-user is denoted by $r_j(z)$ where j represents the number of participated SU's as shown in Figure 3. Likewise, the SNR is received at the L^{th} user, together with the energy that is received, and the threshold, are provided by $\|E_k\|$ and $\acute{\Lambda}_k$ accordingly. Cognitive radio network is governed by a central decision center which is in C-CSS [9]. Each individual secondary user takes part in the process of determining the spectrum that is available for usage in C-CSS. Following the completion of their respective local spectrum sensing procedures, all of the secondary users make a choice on a binary option on their own, and then they send their decision to a common fusion center. At the common fusion center, many distinct kinds of hard fusion schemes [12], [15-16], [19] such as the AND Rule and the OR Rule, are used in order to identify the empty spectrum.

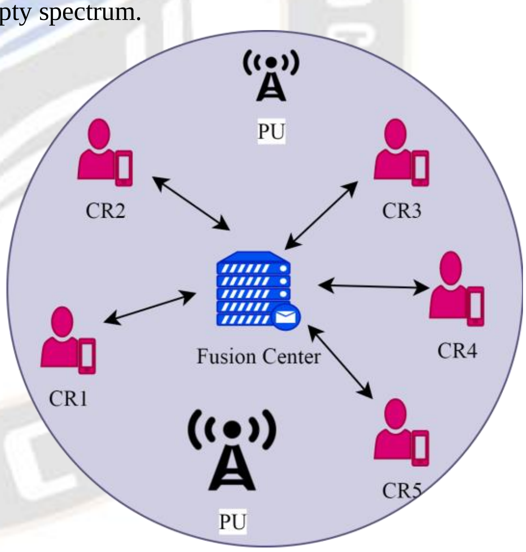

Figure 3. Structure of Centralized CSS Model [14]

B. Model of De-centralized CSS (D-CSS)

Figure 4 provides an illustration of Decentralized CSS structure. In a decentralized CSS model, every secondary user does their own unique energy detection and then transmits their findings to other secondary users so that they may reach a consensus over the likelihood of the presence of primary users in the spectrum [14]. In decentralized architecture, there is no central hub for fusion of information.

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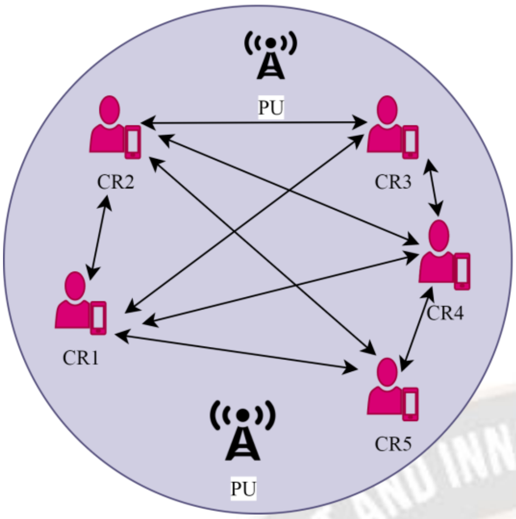

Figure 4. Structure of De-centralized CSS Model [14]

IV. PROPOSED METHOD

Figure 5 provides an illustration of the proposed conceptual system model for Cluster based Decentralized-CSS. The secondary users are segmented into distinct groups or clusters. Each secondary user in a cluster carries its own localized spectrum sensing, and then uses a fusion rule to share that information with the other secondary user (CH) in the cluster. Since a network is made up of multiple clusters, the primary users' presence is determined by the decisions made by each cluster and communicated between cluster heads.

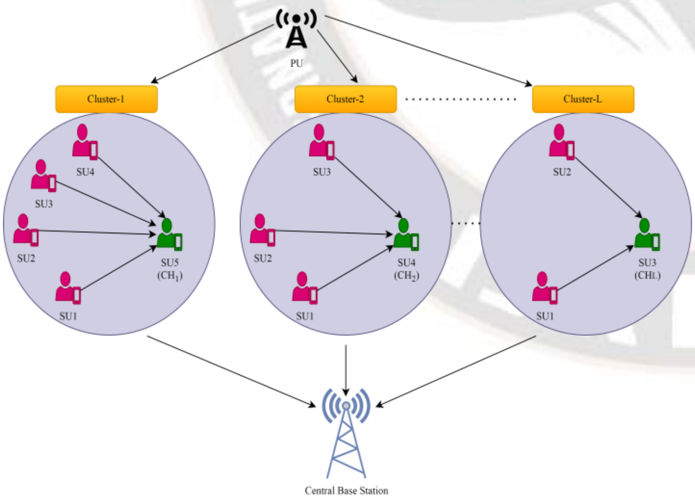

Figure 5. Cluster based decentralized CSS Model

The cluster distribution is set according to the network's overall size. The existence of a primary user in the D-CSS model can be determined by a two-stage judgment process that employs hard fusion criteria. By utilizing the AND rule at the cluster head and the OR rule at the central base station and vice-versa, we can determine whether the primary user exists or not.

4.1 *Proposed decentralized CSS*

The proposed decentralized CSS model's two stage fusion schemes are as follows.

- *Fusion Scheme AND—AND*

  By using the AND rule, the secondary users who were actively engaged inside the cluster combined their information with that of available secondary-users from the similar cluster. After that, the CHs of all of the participating clusters aggregate their own sets of individual data in order to arrive at a conclusive choice utilizing the AND rule.
- *Fusion Scheme AND—OR*

  Similarly, in this situation, the SUs of the cluster combined their knowledge via the scheme of the OR rule, and the clusters then pooled their unique findings in order to arrive at a global conclusion by the use of the AND rule.
- *Fusion Scheme OR--OR*

  In a manner similar to the previous example, the SUs of the cluster combined the information of all by using the OR-logic, and then every cluster communicated their separate outcomes in order to arrive at an overall decision by applying the OR-logic.
- *Fusion Scheme OR--AND*

  In a manner similar to the previous example, the SUs of the cluster combined the information of all by using the OR-logic, and then every cluster communicated their separate outcomes in order to arrive at an overall decision by applying the AND-logic.

4.2 *Flow chart of proposed decision mechanism for cluster based D-CSS Model*

As indicated in figure 6, there is a single cluster-head (CH) amongst secondary-users in each cluster. The four hard fusion techniques are used by each cluster's CHs to integrate secondary user results.

Finally, all CH choices will be combined at the same fusion center to determine PU's existence. The SUs that have acquired the most networking participation from a given PU could be used to estimate the cluster size. To inspect how well De-centralized CSS with clustered system works over two waves with diffuse-power fading channel, the spacing among the PU and SU is also calculated. This spacing varies according to the size of such network. The MATLAB tool-box such as a statistics and machine learning tool-box contains a segmentation method that may be used to categories all or

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most of the SUs in the network into distinct groups.

Each SU inside the cluster makes a determination about the status of PU by executing local-spectrum methods by comparing the energy value of each SU with the threshold value. Following that, the four single bit determination rule means the hard-fusion methodologies for cluster-based decentralized Co-operative spectrum sensing techniques are presented.

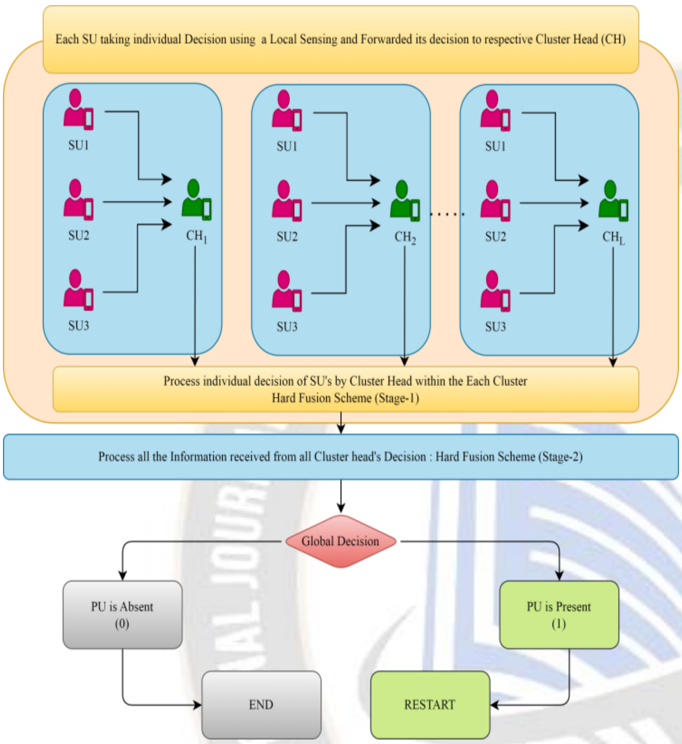

Figure 6. Cluster based decentralized CSS Model

V. MATLAB RESULTS AND ANALYSIS

Results from simulations of de-centralized CSS with clustered approach using multiple hard-fusion approaches in the presence of TWDP environment are discussed here. MATLAB-2021a is used to run simulations and get the results. Here we look at the behavior of the simulated graphs for the presented design using two step decisions by various fusion-rules under the TWDP-fading channel.

TABLE I. SIMULATION PARAMETERS FOR CLUSTER BASED D-CSS

Parameter	Value
Area	50 X 50
No. of secondary users	100
No. of iteration	10^5
Frequency	3 KHz
No. of sample	1000
Sampling rate	10^4
SNR range	-20 dB to -8 dB

Figure 7 illustrates the receiver operating curves highlighting the performance of AND logic, OR logic, Evidenced based CSS scheme [15] with proposed cluster based D-CSS using AND--AND logic, AND--OR logic, OR--AND logic, OR--OR logic under AWGN channel and TWDP channel respectively. Amongst all proposed rule, proposed fusion rule OR--AND rule provides a minimum chance of missing detection whenever the value of SNR (dB) less than -13 across the TWDP channel and vice versa AND logic under AWGN gives highest values probability of missed-detection and it implies efficiency incompatibility in a real scenario. For instance, as compared to the OR logic under AWGN channel [15], the likelihood of miss-detection of the suggested OR--AND logic decreased by around 6% when it was performed at an SNR value as mentioned in table I. As a result of the use of a de-centralized CSS using clustered approach in conjunction with a two-step decision mechanism, the aforementioned strategy is able to achieve a decreased missed-detection probability with the role of cluster head as well as individual decision taken by each secondary user within the cluster.

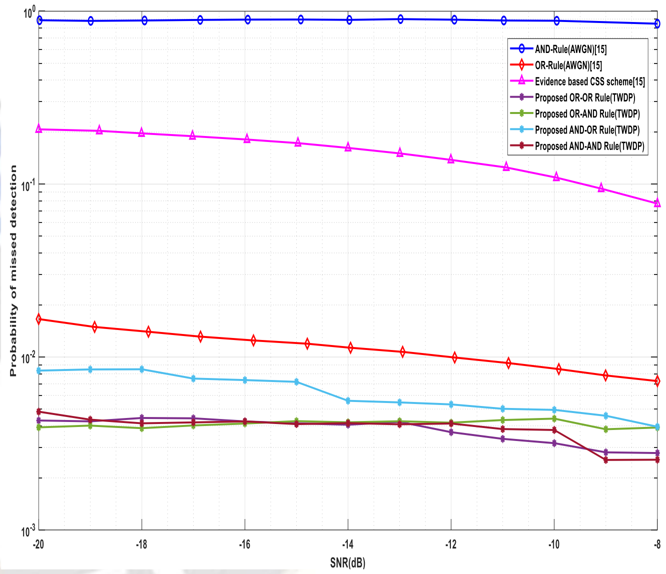

Figure 7. ROC Comparison between AND Rule, OR Rule, Evidenced based CSS scheme over AWGN Channel with Cluster based D-CSS over TWDP Channel

Figure 8 illustrates the receiver operating curves highlighting the performance of AND logic, OR logic, Evidenced based CSS scheme [15] with proposed cluster based D-CSS with AND--AND logic, AND--OR logic, OR--AND logic, OR--OR logic under Rayleigh channel & TWDP channel respectively. For example, over the Rayleigh channel condition, if the likelihood of false-alarm value is 0.2, the chances for detection value for 'OR' logic and 'AND' logic is 0.56 and 0.32 respectively. The proposed D-CSS model using four fusion rule over TWDP channel, if the likelihood of false-alarm value is 0.2, the detection probability value for AND--

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AND logic, AND--OR logic, OR--AND logic and OR--OR logic is 0.78, 0.81, 0.86 and 0.88 respectively. The approximate 10% improvement is observed while using OR--OR rule over TWDP channel. As compared to Evidenced based CSS scheme under Rayleigh channel, approximately 7% improvement is observed for proposed cluster based D-CSS model using four fusion rules over TWDP channel. Amongst all four fusion rules, OR--OR rule performs better at lower values for false alarm probability.

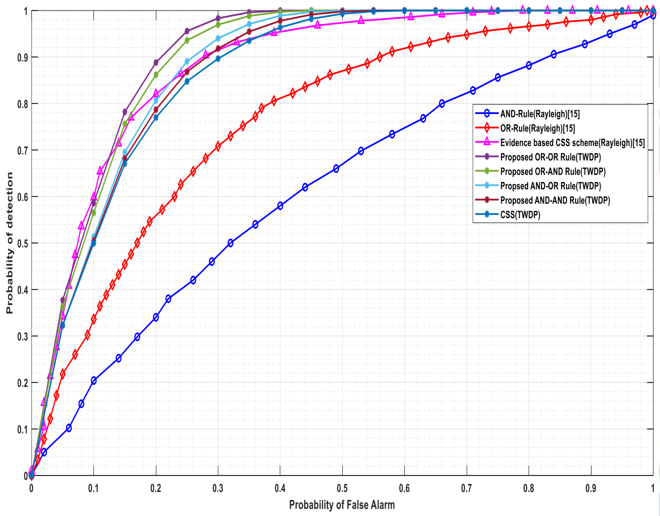

Figure 8. ROC Comparison between Centralized AND logic, AND--AND logic over Wei-bull Channel with proposed Cluster based D-CSS over TWDP Channel

Figure 9 shows the ROC curves highlighting the performance of Centralized AND logic, AND--AND logic [9] and proposed cluster based D-CSS with AND--AND logic, AND--OR logic, OR--AND logic, OR_OR logic, CSS scheme under wei-bull channel and TWDP channel respectively. The detection probability values over the Rician channel are always lower at SNR values ranging from -20 dB to -8 dB. For example, under the wei-bull channel condition, at -18 dB SNR value the detection probability value for centralized AND, AND--AND logic is 0.28, 0.54 respectively. While the proposed cluster based D-CSS over TWDP fading channel, at -18dB SNR value the detection probability value for AND--OR logic, OR--OR logic, AND--AND logic, OR--AND logic is 0.56, 0.56, 0.62, and 0.62 respectively. It can be observed that approximately 7% increases the detection probability for fusion rules over TWDP channel as compared to AND--AND rule over wei-bull channel.

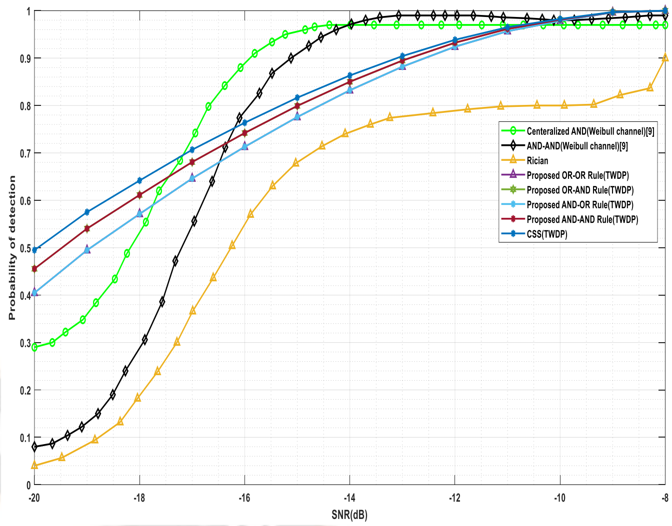

Figure 9. ROC Comparison between Centralized AND logic, AND--AND logic over Wei-bull Channel with proposed Cluster based D-CSS over TWDP Channel

VI. CONCLUSION

In search of a solution to the problem, non CSS over AWGN, Rayleigh, and Rician faded channel surroundings, many researcher studied and examined the cooperative spectrum sensing as a centralized and decentralized model over different fading channel such as AWGN, Rayleigh, Rician, Wei-bull channel. Cooperative spectrum sensing model overcomes the problems of hidden terminal problems and shadowing effects across the different fading environment conditions. In this article, an innovative approach for de-centralized co-operative spectrum sensing (D-CSS) using hard fusion schemes like AND--AND logic, OR--AND logic, AND--OR logic, OR--OR logic over two waves with diffuse power channels has been proposed. ROC curves like SNR vs. P_{md}, P_{fa} vs. P_d and SNR vs. Pd are simulated for the proposed scheme over TWDP fading channel and its compared with AND logic, OR logic over AWGN channel, AND Rule, OR rule, Evidenced based CSS scheme over Rayleigh channel, Centralized AND, AND--AND rule over weibull channel. Furthermore, the missed-detection probability of the proposed D-CSS model reduced by 6% when compared to the AND rule, OR rule, Evidence based CSS scheme over AWGN channel. The detection probability of the proposed D-CSS model over TWDP channel improved approximately 7% when compared to Evidenced based CSS scheme over Rayleigh channel. Also, the detection probability of the proposed D-CSS model using AND--AND rule improved 7% when compared to Centralized AND rule, AND--AND rule over Wei-bull channel condition. Amongst all four fusions scheme OR--AND rule, OR--OR rule over TWDP channel is performed better for cluster based D-CSS model.

In future, the performance of D-CSS method needs to investigate over the other fading scenario such as Nakagami fading channel. Also, the detection performance of the proposed D-CSS model needs to investigate with the variation in the number of participated SUs inside the cluster.

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