Chapter 5
Performance Evaluation

5.1 Overview

The proposed model is de-centralized co-operative spectrum sensing using clustering approach by two-stage hard-decision strategies and the simulation is carried out over two-waves with diffuse power channel. In this chapter, performance evolution is considered for two clusters only. While, the creation of nodes there is one primary-user (PU), number of secondary-users (SUs) is vary for each simulation scenario to check the performance of important benchmarks of cognitive radio such as, missed-detection probability, detection-probability, false-alarm-probability. As per proposed model there are two clusters and each clusters have different number of secondary-users inside it which is perform the localized energy-detection spectrum sensing individually to declare or give judgment for the existence of the primary-user (PU). The available secondary-users (SUs) inside each cluster decide its own cluster-head (CH) based on which SUs have maximum received energy level from PU. At the first stage, cluster-head will combine the received individual decisions from the SUs by using modified hard-decision-schemes either AND decision / OR decision within the cluster. In the second stage, each cluster will combine its first level decision of each cluster and make a global or a final decision by using modified hard-decision-schemes either AND decision / OR decision. Therefore the final existence of the primary user (PU) is decided based on the above two-stage decision strategies such as AND_AND logic decision, OR_AND decision, OR_OR decision, AND_OR decision. For the performance evolutions of proposed de-centralized co-operative spectrum sensing with clustering approach, we have used the MATLAB R2021a platform for obtaining the simulations results like random generation nodes (i.e. -PU, SUs, CHs) within fixed defined area, SNR Vs. missed-detection probability, false-alarm-probability Vs. detection-probability, SNR Vs. probability-detection, false-alarm-probability Vs. missed-detection probability for different values of K and delta (Δ) for individual modified hard-decision strategies. Also, we have used some MATLAB tool boxes such as signal-tool-box for band pass filter, statistics and machine-learning tool-box for the creation of clusters using k—mean’s algorithm, radar tool-box, phase-array tool-box, statistic tool-box for calculating the distance between the primary-user and secondary-users (SUs). At last the simulated results are compared with centralized co-operative spectrum sensing (C_CSS) with OR decision strategy over two-waves with diffuse-power channel, AWGN, Rician, Rayleigh and wei-bull channel to evaluate the performance analysis of the proposed D_CSS model.

5.2 Simulation Scenario – Creation of Nodes

Figure 5.1 shows that a cluster is constructed through participating secondary users in the communication environment. According to our proposed cluster-based DCSS, we considered two clusters for the simulation results. The number of secondary users is divided into these two clusters based on received energy levels and the distance between each SU and PU. The primary user is indicated by a red color asterisk-marked in the following result. Secondary users of cluster-1 are indicated by blue color symbol as a star while in cluster-2 SU’s are indicated by pink color symbol as a star. 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. Below diagram shows the total number of 100 SU’s and 1 primary user which are scattered in the dimension of the area that is 200x200. For the different simulation scenario the number SU’s will vary for analyze the performance of the suggested D_CSS model with clustering approach.

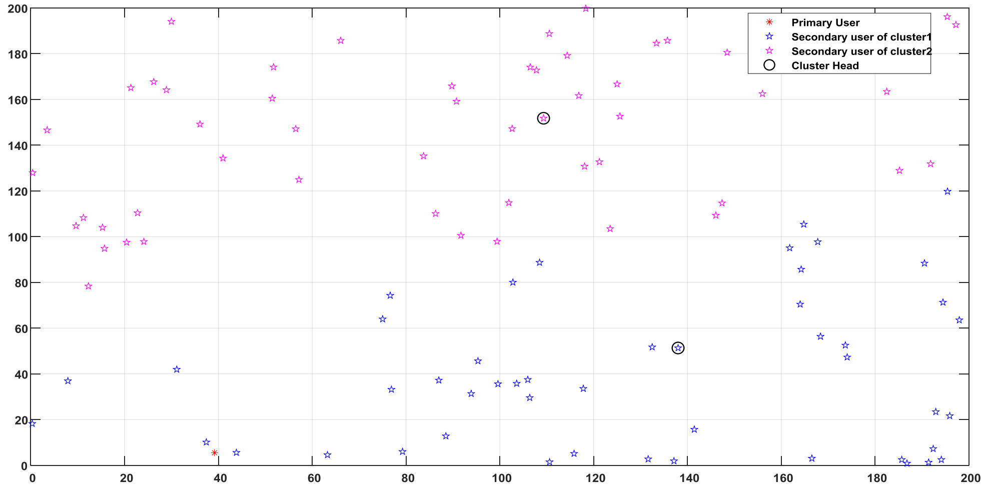

Figure 5.1: Creation of users and formulation of cluster

5.3 Simulation Results and Discussion

The detection likelihood is a crucial statistic for evaluating and comparing the performance of the suggested D_CSS clustering-based co-operative spectrum sensing over two-waves with diffuse power fading. Missed detection probability is significantly and negatively related to detection probability. Having a low likelihood of detection, results in a high possibility of miss detection which misleads the CR user to leave the channel when the primary user is trying to utilize it. The Receiver - operating characteristic (ROC) is utilized to evaluate the effectiveness among signal-to-noise ratio: SNR and P_{md}. In this simulation, we consider the system parameter: average signal to noise ratio (SNR), Area boundary for PU, SUs and cluster-head (CH), number of secondary-users (L).

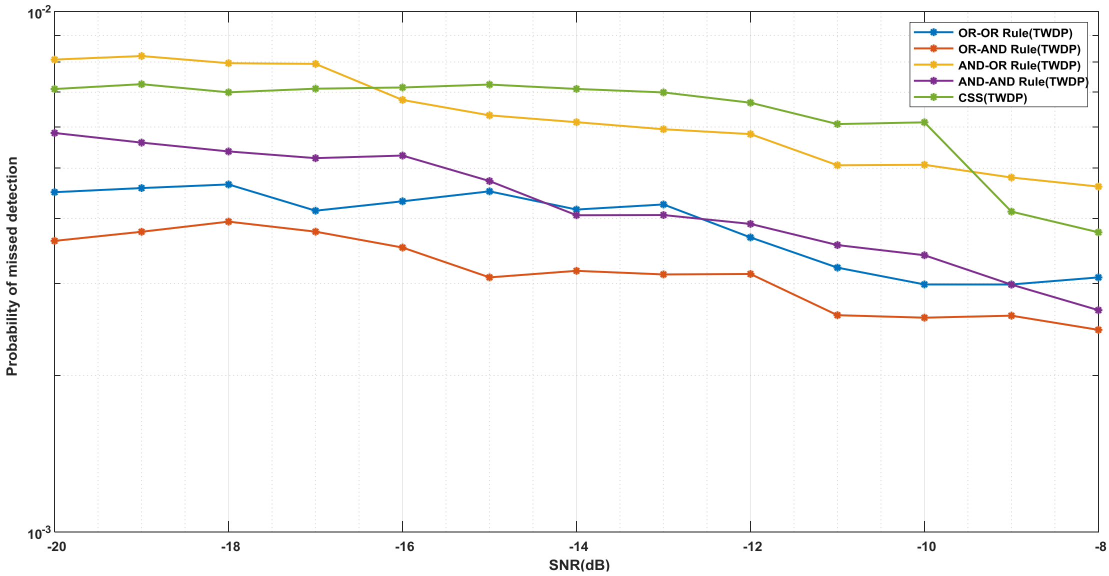

Figure 5.2: SNR versus P_{md} over TWDP fading channel (L=25)

ROC graphs 5.2 and 5.3 shows the missed-detection probability versus SNR variation range between -20dB to -8dB for number of secondary users 25 and 50 respectively.

From the figure 5.2 we clearly observed that the P_{md} values are always minimum value for any SNR value for OR_AND decision logic. It has been also observed that centralized-CSS with OR logic over TWDP fading environment the P_{md} values is higher between the SNR range -16dB to -10dB as compared to the other decision rules. From the figure 5.3 it is clearly observed that the there is a change in P_{md} values for all the decision logics. But, OR_AND decision logic gives minimum P_{md} values if the SNR values between -20dB and -11dB.

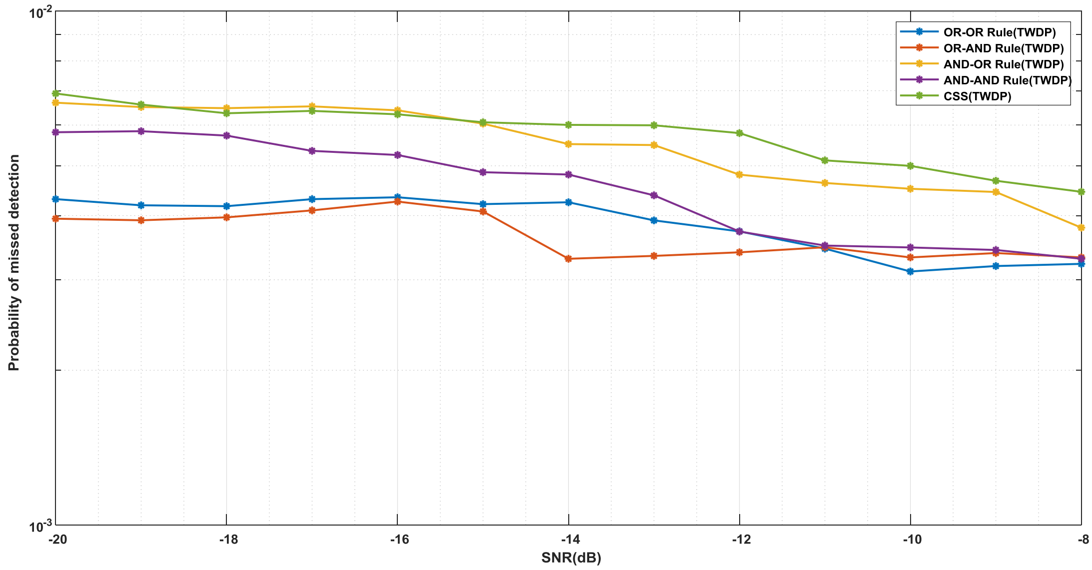

Figure 5.3: SNR versus P_{md} over TWDP fading channel (L=50)

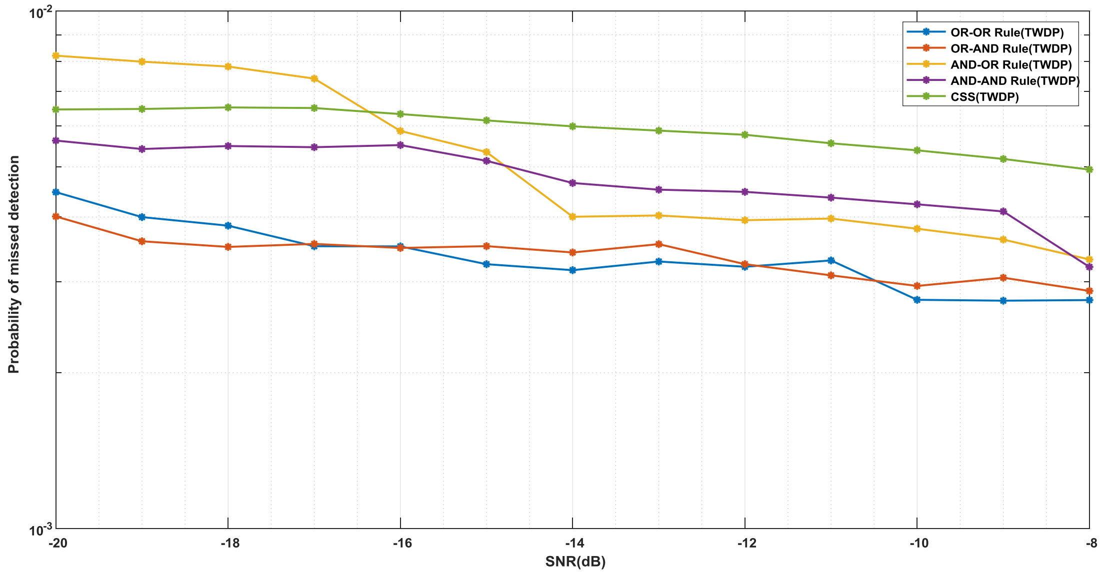

Figure 5.4: SNR versus P_{md} over TWDP fading channel (L=75)

Figure 5.4, 5.5, and 5.6 shows the performance analysis of missed-detection probability over different values of SNR over TWDP fading channel for the number of secondary-users (L) is 75, 100 and 200 respectively. From the graph 5.5, it has been observed that the P_{md} values are reduced for AND_OR logic as compared to previous scenarios when secondary-users are 25 and 50. Also, the P_{md} values for centralized-CSS are higher when the SNR range is between -16dB to -8 dB. From the ROC graph 5.6, it is clearly observed that the P_{md} values for OR_AND decision logic is always attains a minimum values as compared to other decision logics. The ROC graph 5.6 shows the high values of P_{md} when it is compare with scenario when the number of SUs is 100. Form the simulation graph of figure 5.7, it has been observed that the values P_{md} is always higher in case of centralized-CSS with OR logic over TWDP fading channel. Also, OR_AND decision scheme achieves minimum P_{md} values as compared to other decision schemes when the SNR values are between -20db to -10dB.

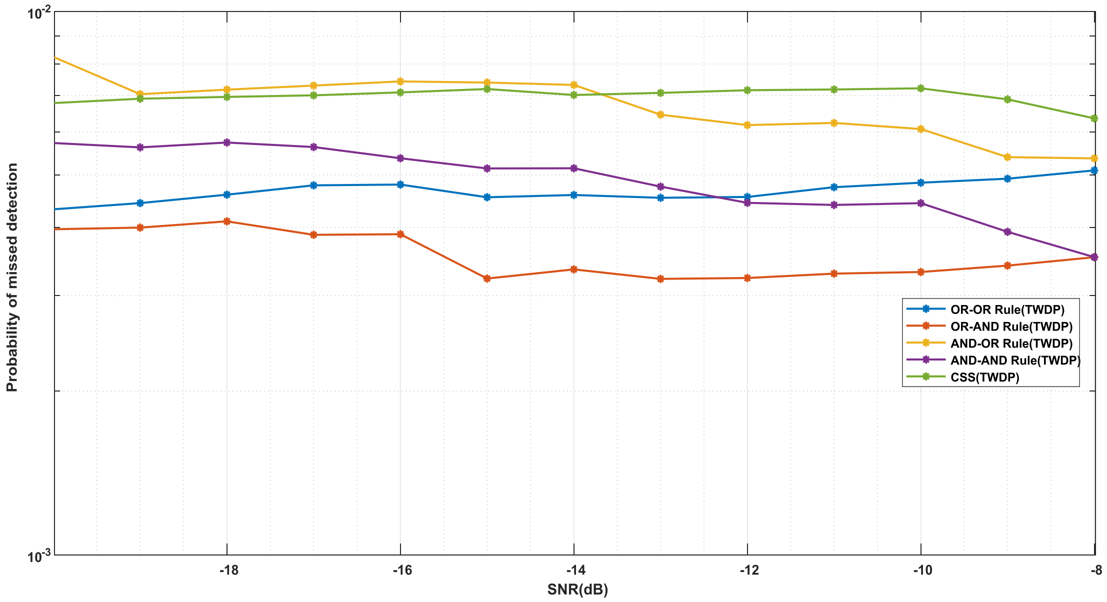

Figure 5.5: SNR versus P_{md} over TWDP fading channel (L=100)

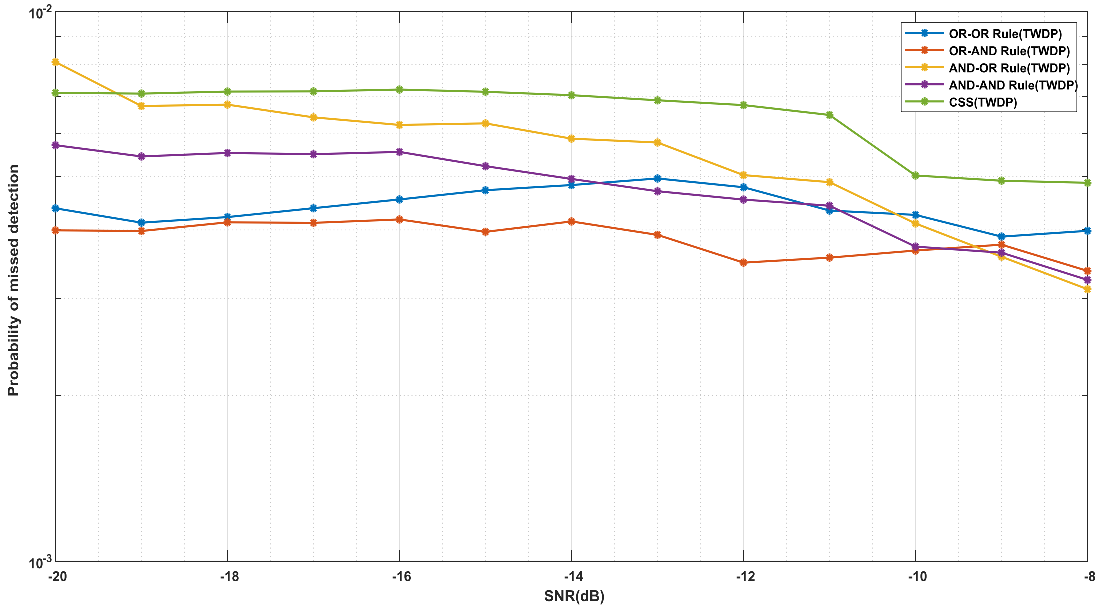

Figure 5.6: SNR versus P_{md} over TWDP fading channel (L=200)

Above all the ROC graphs shows that OR_AND decision logic attains minimum P_{md} values as compared to other decision logics. Furthermore we can summarizes from all the simulation graphs that to achieve the minimum missed-detection probability the number of secondary-users should be more so that it gives comparative better result. Also, if we achieve the minimum missed-detection probability than detector performance is increased because the relation between P_{md} and P_d is inversely proportional to each other. Also, P_{md} values are always minimum for the suggested de-centralized model using clustering approach as compared to centralized-CSS model with OR-logic over two-waves with diffuse power channel due to idea of making a decision with clustering approach and two-stage hard decision logics. In the centralized-CSS available total numbers of secondary-users are taking a decision about the PUs availability with combining all the individual decision received at common fusion center (FC). If there is a large number of SUs in C_CSS model than there is complexity process increases at the fusion-center as well as over-head in channel is also increased.

Figure 5.7 is simulated ROC results P_{fa} versus P_d for the suggested de-centralized co-operative spectrum sensing over two-waves with diffuse-power with modified hard-decision logics for the number of secondary-users (SU's) are 100.

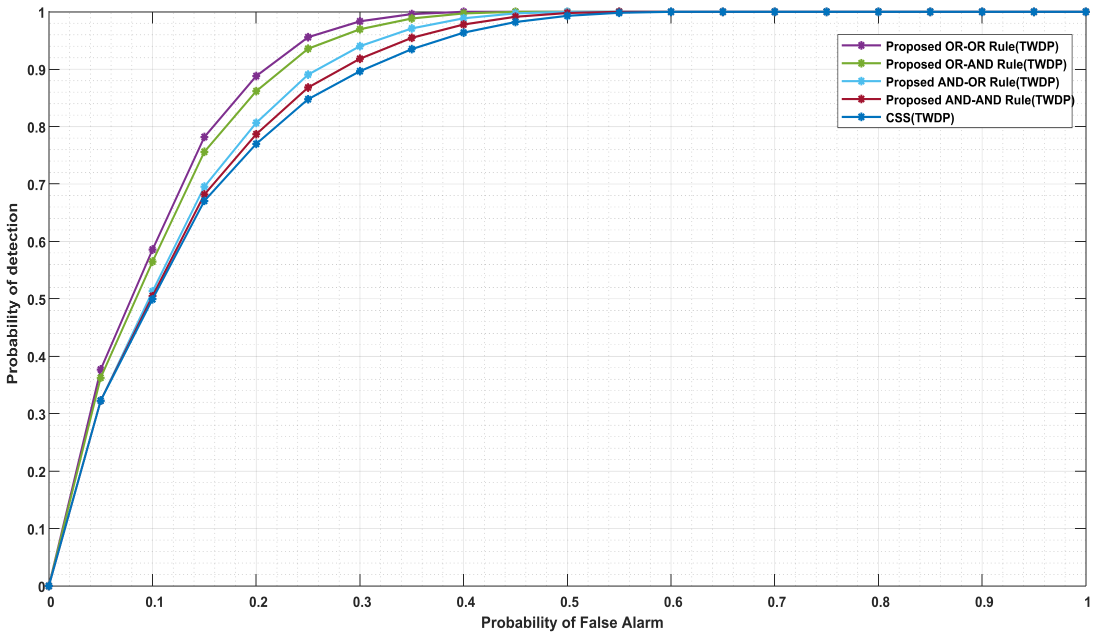

Figure 5.7: ROC of P_{fa} versus P_d over TWDP fading channel (L=100)

From the ROC in figure 5.7, when the false-alarm-probability value (P_{fa}) is 0.05 the detection-probability value is 0.32 for centralized-CSS, AND_AND decision, AND_OR decision, 0.36 for OR_AND logic 0.37 for OR_OR logic under two-waves with diffuse-power channel for the number of SU's are 100 which performs the decisions using modified hard-logic. For example, when false-alarm probability is 0.1 then the detection-probability values are 0.50, 0.51, 0.56 and 0.58 for the suggested AND_AND decision, AND_OR decision, OR_AND logic and OR_OR logic respectively. When P_{fa} value is 0.1, the detection result value for centralized-CSS with OR_logic is 0.49. So, it is clearly observed that the suggested de-centralized-CSS methodology improves the detection values as compared to centralized-CSS approach while P_{fa} value is 0.1. Also, we can state that the suggested OR_OR logic strategy enhance the detection-probability as compare to other logic strategies.

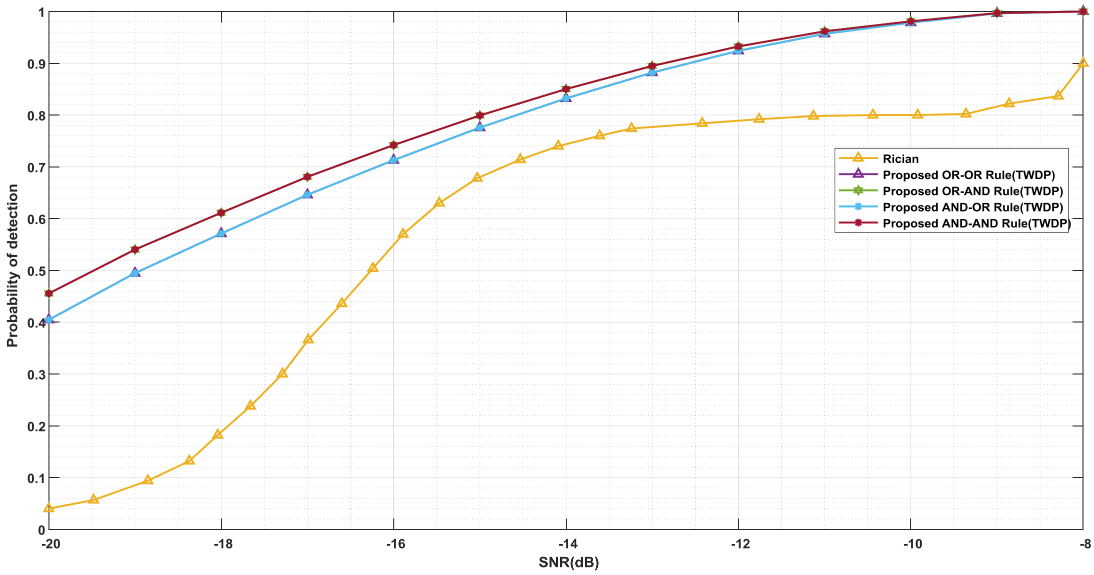

Figure 5.8: ROC of $SNR(dB)$ versus P_d over TWDP fading channel (L=100)

Figure 5.8 highlighted the detection performance of de-centralized-CSS under TWDP fading scenario with different modified hard-decision logics with centralized-CSS approach under the Rician fading channel. For example, when SNR value is -18 dB than the detection-probability is 0.18 for Rican channel and 0.57 for AND_OR as well as OR_OR logic strategy, 0.61 for OR_AND as well as AND_AND logic strategy. From these comparative values we can say that the detection performance improves in the suggested de-centralized-CSS over two-waves with diffuse-power channel with compared to centralized-CSS approach under the Rician fading channel. Also, the AND_AND decision logic and OR_AND decision logic shows higher probability-detection among other decision logics. To achieve 0.8 values of detection-probability the minimum SNR requirement is -15 dB for the suggested model while centralized-CSS approach under the Rician fading requires minimum SNR value -12 dB.

5.4 Comparative Performance Analysis

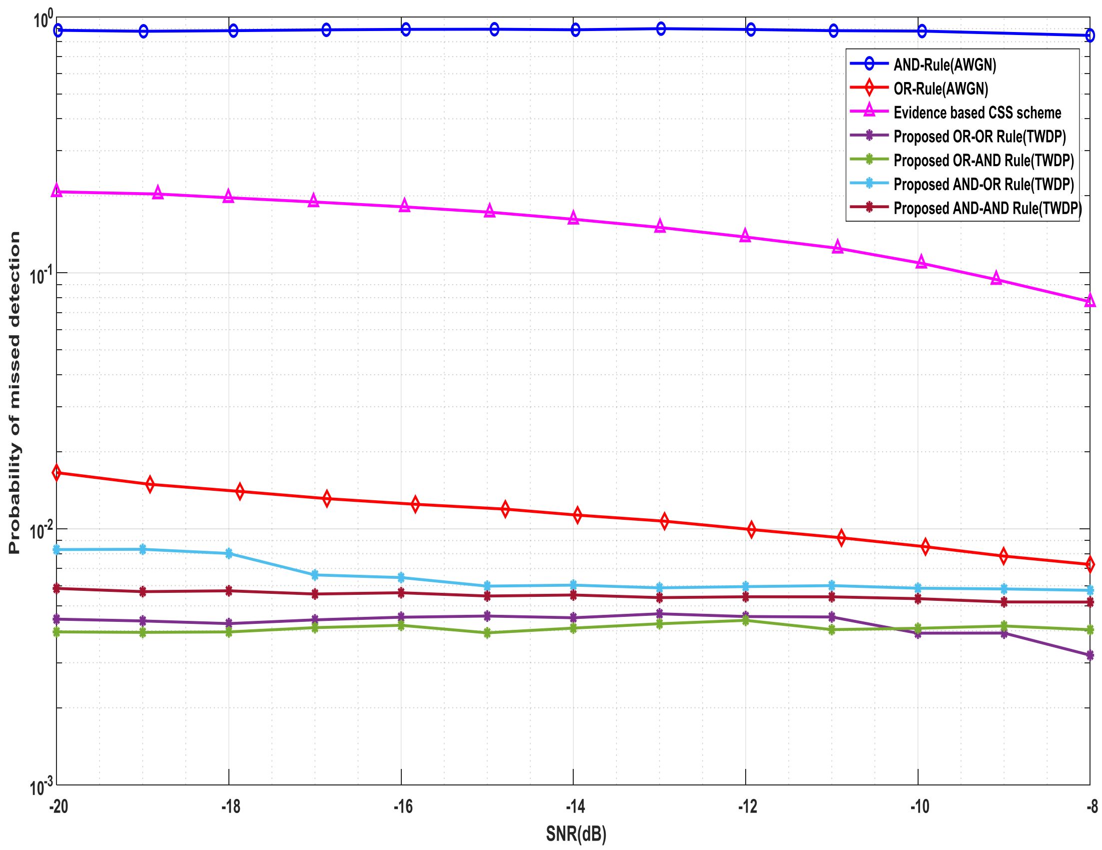

Figure 5.9: ROC comparisons of $SNR(dB)$ versus P_{md} (L=100)

Figure 5.9 highlights the performance comparisons between conventional hard-fusion strategies using AND as well as OR decision criteria over AWGN scenario, Evidence-based CSS methodology over AWGN scenario with suggested four decision methods using de-centralized co-operative spectrum sensing using clustering approach under the influences of two-waves with diffuse-power scenario. The P_{md} values for OR_AND decision rule over two-waves with diffuse-power channel is attains minimum while AND strategy over AWGN channel attains a maximum due to inadequate performance in the real practical situations. From the below furnished Table 5.1 values of as Miss-Detection-Probability (P_{md}) over SNR ranges between -20dB to -8dB, The proposed de-centralized-CSS approach with clustering strategy achieves the minimum miss-detection probability due to implementations of two-stage hard-decision (i.e. OR_AND) methodology with introduction of cluster head (CH) which minimizes the over-head of channels.

SNR (dB)	Miss-Detection-Probability (P_{md})						
	AND Decision (AWGN) [109]	OR Decision (AWGN) [109]	Evidence-based-CSS approach [109]	OR__OR logic (TWDP)	OR__AND logic (TWDP)	AND__OR logic (TWDP)	AND__AND logic (TWDP)
-20	0.8831	0.015	0.2073	0.0044	0.0039	0.0082	0.0058
-18	0.8851	0.014	0.1966	0.0042	0.0039	0.0080	0.0057
-16	0.8923	0.014	0.1810	0.0045	0.0041	0.0064	0.0056
-14	0.8990	0.011	0.1619	0.0044	0.0040	0.0060	0.0055
-12	0.8931	0.009	0.1381	0.0043	0.0042	0.0059	0.0054
-10	0.8851	0.008	0.1090	0.0040	0.0040	0.0058	0.0053
-8	0.8422	0.007	0.077	0.0032	0.0040	0.0057	0.0051

Table 5.1: Miss-Detection-Probability (P_{md}) values at different SNR (L=100)

Figure 5.10 highlights the performance comparisons between conventional hard-fusion strategies using AND as well as OR decision criteria over Rayleigh scenario, Centralized--CSS methodology over TWDP faded scenario with suggested four decision methods using de-centralized co-operative spectrum sensing using clustering approach under the influences of two-waves with diffuse-power scenario. It clearly observed from the figure 5.10 and tabular data of table 5.2, the suggested OR_OR decision logic with de-centralized co-operative spectrum sensing using clustering strategy gives the highest detection performance with compared to all other decision strategies.

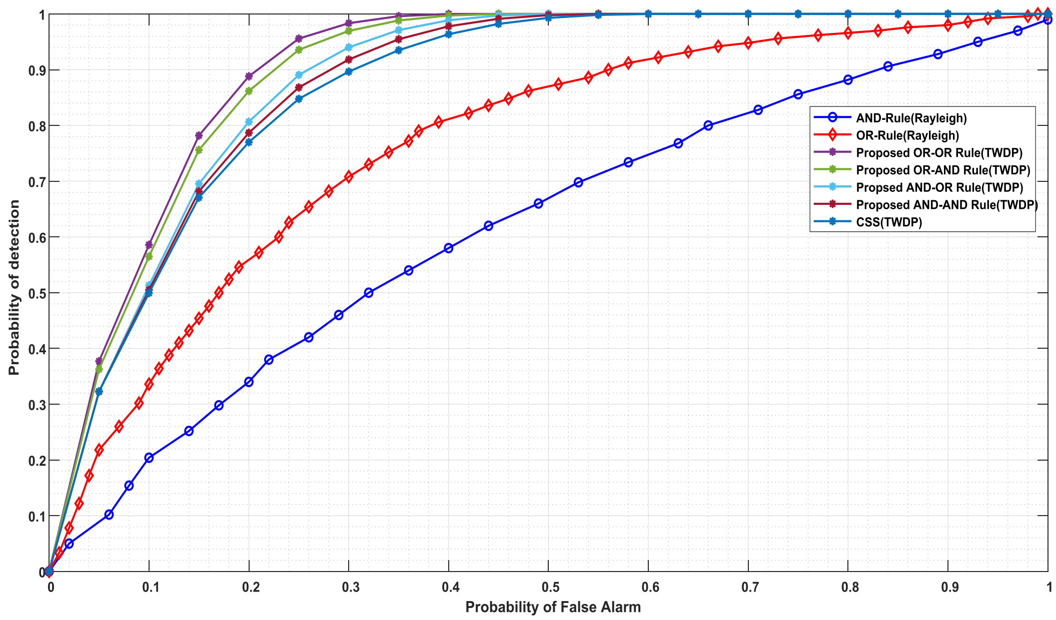

Figure 5.10: ROC comparisons of P_{fa} versus P_d (L=100)

P_{fa}	Detection-Probability (P_d)						
	AND Decision (Rayleigh) [109]	OR Decision (Rayleigh) [109]	C_CSS (TWDP)	OR__OR logic (TWDP)	OR__AND logic (TWDP)	AND__OR logic (TWDP)	AND__AND logic (TWDP)
0.1	0.2040	0.3360	0.4993	0.5859	0.5649	0.5131	0.4993
0.2	0.3400	0.5460	0.8065	0.8880	08617	0.8065	0.7868
0.3	0.4600	0.7080	0.9401	0.9834	0.9696	0.9401	0.9182
0.4	0.5800	0.8060	0.9887	1.0000	0.9887	0.9870	0.9887
0.5	0.6600	0.8740	1.0000	1.0000	1.0000	1.0000	1.0000
0.6	0.7340	0.9220	1.0000	1.0000	1.0000	1.0000	1.0000
0.7	0.8280	0.9480	1.0000	1.0000	1.0000	1.0000	1.0000
0.8	0.8820	0.9660	1.0000	1.0000	1.0000	1.0000	1.0000
0.9	0.9280	0.9800	1.0000	1.0000	1.0000	1.0000	1.0000

Table 5.2: Detection-Probability (P_d) values at different P_{fa} (L=100)

For example, when false-alarm probability values is 0.1, the detection values are 0.20, 0.33, 0.49, 0.58, 0.56, 0.51, and 0.49 for AND—logic, OR—Logic over Rayleigh channel, C_CSS approach, OR_OR, OR_AND, AND_OR and AND_AND decision schemes respectively. To achieve the detection-probability more than or equal to 0.9 the false-alarm probability values should be 0.58 for AND—logic and 0.56 for OR—Logic over Rayleigh fading scenario. When compared to the suggested method that achieves the detection probability greater than 0.9 at only 0.25 value of P_{fa}. It clearly indicates that there is less chances of wrong detection about the existence or availability of PU in case of the suggested de-centralized-CSS using clustering strategy can be used.

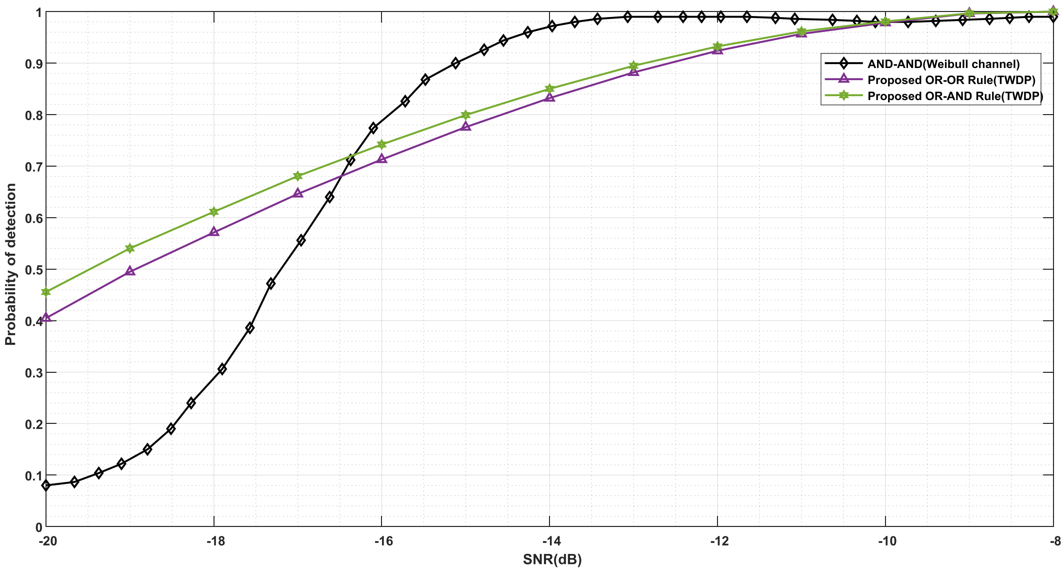

Figure 5.11: ROC comparisons of SNR versus P_d (L=100)

Figure 5.11 highlighting the comparative performance of the de-centralized co-operative spectrum sensing using clustering strategy by two-stage decision methods (i.e. – OR__OR, OR__AND) under two-waves with diffuse-power channel with AND__AND logic over wei-bull channel [108]. Here we have considered total 100 number secondary-users (SUs) for the above simulation scenario. For example, at -18dB SNR value, the detection probability value for AND__AND logic over wei-bull channel 0.29, 0.57 for OR__OR strategy, and 0.61 for OR__AND strategy over two-waves with diffuse-power channel. Also, the proposed approach improves the detection-performance approximately up to 30% between the SNR values -20dB to -17dB as compare to that AND__AND logic over the wei-bull fading scenario.

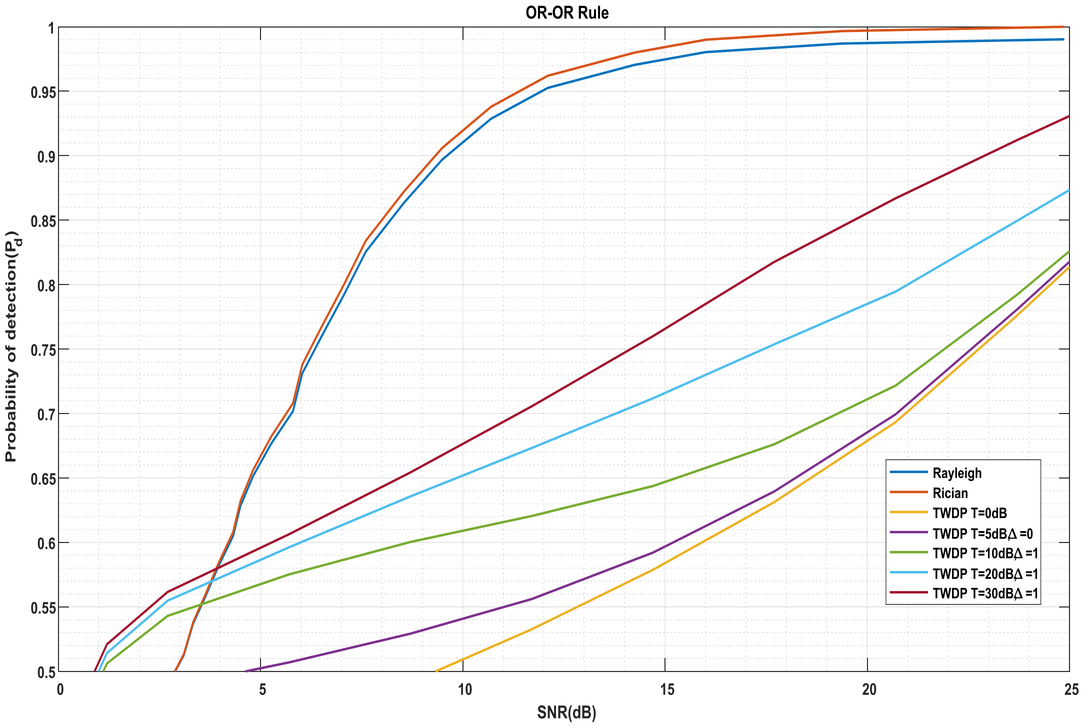

Figure 5.12: $P_{d_{TWDP}}$ versus SNR for different values of T and $\Delta = 1$ (OR__OR)

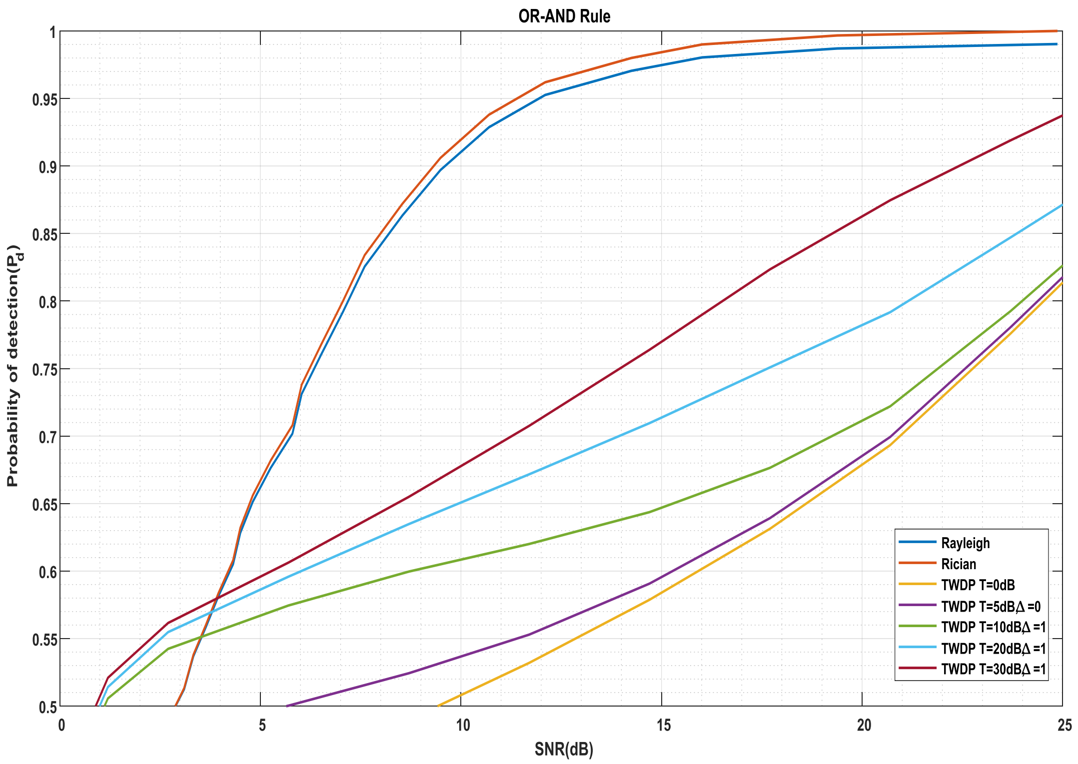

Figure 5.13: $P_{d_{TWDP}}$ versus SNR for different values of T and $\Delta = 1$ (OR__AND)

Figure 5.12 and 5.13 highlighting the sensing performance under fading scenario where u_1 = 0.75 and u_2 = 0.15 and the ratio of average power to specular component power (T) varies from 10dB to 30dB. Above simulation is carried out for OR__OR and OR_AND decision methods. The simulation results show that as the values of T is increases, the detection performance is increases and it moves towards the Rician channel. Due to this reason the performance of the detection will change abruptly when SNR value cross the 15dB value.

In the particular scenario in the special cases,

1) $T = 5\ dB\ and\ \Delta = 0$, a minimum required SNR 24 dB to achieve P_d = 0.8,
2) $T = 10\ dB\ and\ \Delta = 1$, a minimum required SNR 23 dB to achieve P_d = 0.8
3) $T = 20\ dB\ and\ \Delta = 1$, a minimum required SNR 21 dB to achieve P_d = 0.8
4) $T = 30\ dB\ and\ \Delta = 1$, a minimum required SNR 18 dB to achieve P_d = 0.8

From this results we deduced that the minimum SNR requirement for achieve for achieving detection-probability can be decreased by 25 %, which indicates that the energy is saved by the secondary users during the signal transmission with the cluster-head and would increases the overall performance of the detector.