Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 2, No. 1, February : 2023

# ANALYSIS OF THE MATCHED DETECTOR'S PERFORMANCE UTILISING AWGN AND OFDM UNDER LOW SNR REGION

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***Abstract:*** To serve the tremendous demand for wireless applications, Cognitive Radio (CR) is investigated. CR technology is capable of accessing licensed users' spectrum dynamically. In this paper, the spectrum sensing method Matched Detector (MD) is analyzed under channel environment additive white gaussian noise (AWGN). MD is also performed for orthogonal frequency division multiplexing (OFDM) systems to utilize spectrum more efficiently under low SNR like -25 dB and -30 dB here. Low range SNR are focused over here due to Prior to the data sent by Primary users, the received signal is used to analyse the performance of MD. Results are validated based on parameters like various SNRs, Probability of detection, probability of false alarm. These parameters are studied practically and theoretically for each model.

***Keywords:*** Cognitive Radio (CR), Matched Detector (MD),Probability of detection, Probability of false alarm

## 1. Introduction

Radio resources are very limited while the available radio spectrum is already occupied by all its licensed users. Due to the rapid growth of wireless users, there is a huge demand for wireless applications. In research [1], It has been found free slots in the licensed user's spectrum. Cognitive Radio (CR) is developed in Mitola's thesis [2,3] which is the smart radio access of the licensed user's spectrum dynamically when there is no transmission going on through primary user (PU)'s signals. CR suits best to serve the demand of wireless users [4]. CR networks enable the secondary user (SU)'s when there is a white space or PU's spectrum is idle for further transmission [5]. All SU's transmit their signal using a licensed band (PU's Spectrum) without disturbing the PU's signal. There is the main task of CR is to sense the PU's spectrum before utilising by SUs. There are various spectrum sensing techniques available based on which we can select the best suitable spectrum sensing technique.

Figure 1 shows the entire cognitive radio process cycle. The spectrum sensing is based on results of probability of detection ($P_D$) and probability of false alarm ($P_{FA}$). In spectrum sensing, probability of miss detection ($P_{MD}$) causes interference to PU while $P_{FA}$ decreases the spectrum efficiency [5,6]. For efficient utilisation of spectrum, spectrum sensing technique should maximize the $P_D$ , minimize the $P_{FA}$ and avoid the $P_{MD}$. There are many different spectrum sensing methods available. Based on Primary User (PU)'s information is not available, partially available or available, one can select the best spectrum sensing technique for cognitive radio users [7-12].

TV channels conversion happened from analogue to digital, white space is created in spectrum. There is a IEEE 802.22 Wireless Regional Area Network (WRAN) standard used for utilising TV white spaces [13]. Instead of single spectrum sensing, Cooperative Spectrum Sensing (CSS) technique is also used. In CSS, a decision is not taken by a single CR user but based on distributed or centralized type of approach used.

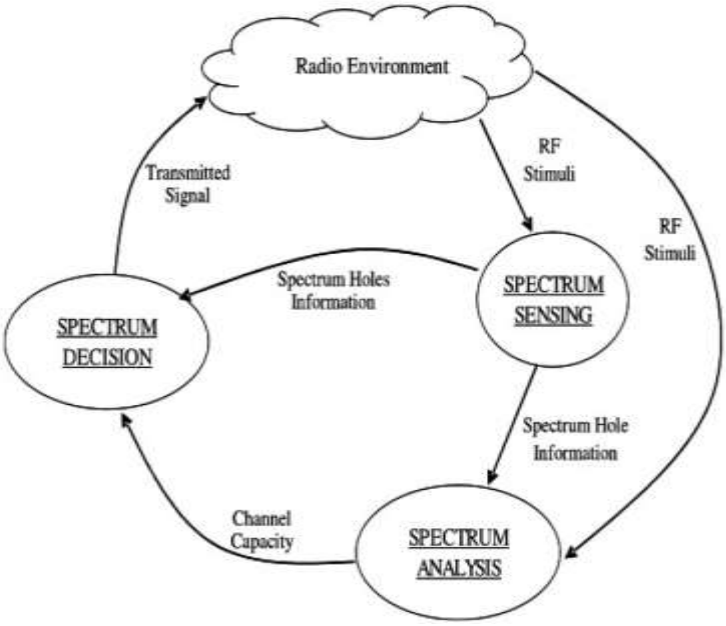


Figure 1 Cognitive Radio Cycle

**2. Background Theory**

In [14], MD is studied for identification of PU's signal and also recognizes the power level of PU' signal. Comparative study of energy detection spectrum sensing techniques for CR networks under different channel environments like AWGN , Rayleigh fading channel in [15] and SNR is chosen -1 dB , 4 dB , 7 dB and 9 dB to simulate ROC parameters. Spectrum sensing based on cooperation among SUs is used to improve detection of PU's signal [16]. In a cooperative environment, a number of CR users/ SUs made grouping based on their observations [17]. In CSS, centralized approach, SUs sense the channel and send their observations to Fusion Centre [18].While in CSS , distributed approach, SUs decision does not depend on Fusion Centre but each SU takes their decision itself only[19]. To increase probability of detection with relevant probability of false alarm, SU's data is weighted where algorithm can find errors of SU without relevance of malicious effect on it [20].

In [21], all transmitter based spectrum sensing techniques are analyzed like Energy Detector, Matched Detector and Cyclostationary Feature Detection. In [22, 23], improved ED is shown with a dynamic threshold for increasing probability of detection at -20 dB SNR. In [24], IEEE 802.22 WRAN standard parameters are analyzed for cognitive radio networks.

**3. System model**

Here MD is designed under AWGN channel environment and OFDM environments which are represented by their system models respectively in section 3.1 and 3.2.

**3.1 Spectrum Sensing using Matched Detector in AWGN channel**

Under Additive White Gaussian Noise channel, cognitive radio networks use matched detector spectrum sensing.The system model is designed below through Eq.(1) with two hypothesis :

Hypothesis 0 (H0) : y= n &

Hypothesis 1 (H1) : y= n + x , x is a known pilot vector and w is a noise (1)

while using known value of x, we can perform matched filter operation as

$\tilde{y} = X^H y$ (2)

Now put value of Eq. (2) in Eq. (1) to both hypothesis and estimated results are given as,

H 0: $\tilde{y} = X^H y = X^H n = \tilde{n}$

H 1 : $\tilde{y} = X^H y = X^H (x + n) + ||x||^2 \tilde{n}$ (3)

In Eq. (3) noise $\tilde{n} = X^H n$ which is Gaussian Random Variable with mean 0 & variance $||x||^2 \sigma_n^2$

Now to determine PU's signal, test statistics to decide H1 & H0 is in Eq. (4) ,

$$\tilde{y} \geq \gamma \Rightarrow H1$$
$$\tilde{y} < \gamma \Rightarrow H0 \quad (4)$$

Probability of false alarm $P_{FA} = P_r(\tilde{y} \geq \gamma | H0) = Q(\frac{\gamma}{||x|| \sigma_n})$ (5)

Probability of detection $P_D = P_r(\tilde{y} \geq \gamma | H1) = Q(\frac{\gamma - ||x||^2}{||x|| \sigma_n})$ (6)

where threshold $\gamma$ can be calculated using $\gamma = ||x|| \sigma_n Q^{-1}(P_{FA})$.

**3.2 Spectrum Sensing using Matched Detector in OFDM systems**

Orthogonal Frequency Division Multiplexing (OFDM) is a key broadband wireless technology and it has a large transmission bandwidth which leads to significantly higher data rates. Several WI-FI and Wireless Local Area Network (WLAN) standards are based on OFDM. For cognitive radio networks operating in an OFDM Rayleigh fading channel, matched detector spectrum sensing is employed. The system model is designed below through Eq.(7) with two hypothesis :

H0 : y= n &
H1 : y= XH + n = x+n (7)

where x= XH and X is a known diagonal matrix and H is N*1 DFT coefficient vector , x is deterministic and known signal, using x , one can perform matched filtering as $\tilde{y} = x^H y$

The result corresponding to both hypotheses is given as,

$$H0: \tilde{y} = x^H y = x^H n = \tilde{n}$$
$$H1: \tilde{y} = x^H y = x^H(x + n) = ||x||^2 + \tilde{n} \quad (8)$$

In Eq.(8) , $\tilde{n} = x^H n$ is again Gaussian random variable with mean zero and variance $||x||^2 \sigma_w^2$

test statistics to decide H1 and H0 is,

$$\tilde{y} \geq \gamma \Rightarrow H1$$
$$\tilde{y} < \gamma \Rightarrow H0 \quad (9)$$

for Eq. (9) $\gamma$ can be selected as $\gamma = ||x|| \frac{\sigma_w}{\sqrt{2}} Q^{-1}$ (PFA )

Probability of false alarm $P_{FA} = P_r(\tilde{y} \geq \gamma | H0) = Q(\frac{\sqrt{2}\gamma}{||x|| \sigma_w})$ (10)

Probability of detection $P_D = P_r(\tilde{y} \geq \gamma | H1) = Q(\frac{\gamma - ||x||^2}{||x|| \frac{\sigma_w}{\sqrt{2}}})$ (11)

Eq.(10) & Eq.(11) are used to calculate $P_D$ and $P_{FA}$ for spectrum sensing using OFDM environment for CR users.

**4. Simulation Results**

In this paper, Matched Detector has been analyzed using various channel platforms and techniques. Performance parameters like Probability of Detection ($P_D$) , Probability of False Alarm ($P_{FA}$), number of CR users on a network for cooperative spectrum sensing , different range of SNR and error probability are focused and simulated.

### 4.1 Performance Analysis of Matched Detector using AWGN channel

Matched detector is simulated for the AWGN channel environment here. Figure 2 shows SNR vs. Probability of detection ($P_D$) results. It has been analysed for different ranges of Probability of false alarm from $10^{-6}$ to $10^{-1}$. In figure 2 ,SNR is varied from -20 dB to +20 dB . Results say that when SNR is increasing from -20dB to +20 dB, $P_D$ is increasing from 0 to 1. It shows for a higher value of SNR, there are better results for $P_D$, nearer to 1 value. In Figure 2, the ROC curve for a matched detector under the same scenario, is plotted using simulated and analytical results for different SNR values. $P_D$ and $P_{FA}$ are calculated using Eq. (5) and Eq. (6) shown in section 3.1. In this ROC curve, simulated and analytical results are matched for SNR values like -20 dB, -10dB , 0 dB and 10 dB . Results are proved that the performance of the matched detector is better for SNR value 10 dB compared to -20 dB , -10 dB. and 0 dB.

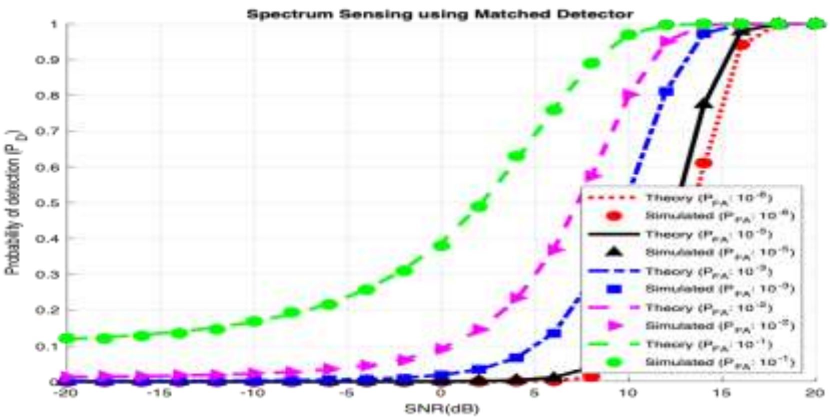


Figure 2 SNR (dB) Vs. Probability of detection ($P_D$) graph for $P_{FA}$ :$10^{-6}$ to $10^{-1}$

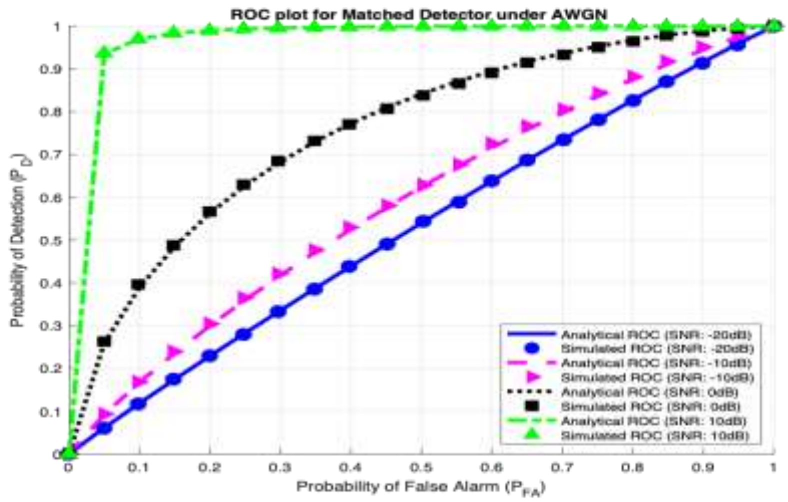


Figure 3 Probability of False Alarm ($P_{FA}$) Vs. Probability of detection ($P_D$) graph for SNR : -20 dB to 10 dB .

### 4.2 Performance Analysis of Matched Detector using OFDM systems

OFDM technique has been added to the previous section 4.1 with Matched Detector spectrum sensing for cognitive radio network environments shown in Figure 4. Using OFDM, spectrum sensing can be done under the worst SNR scenario like -25 dB & -30 dB .There is also advantage of OFDM Matched Detector spectrum sensing technique to utilize the available spectrum efficiently due to orthogonality in carrier signal. Figure 5 shows OFDM Matched Detector spectrum sensing technique under Cooperative Spectrum Sensing (CSS) heterogeneous environment. All algorithms of CSS , perform similar results in terms of $P_D$ and $P_{FA}$ with SNR range -30 dB to -15 dB (low SNR region).

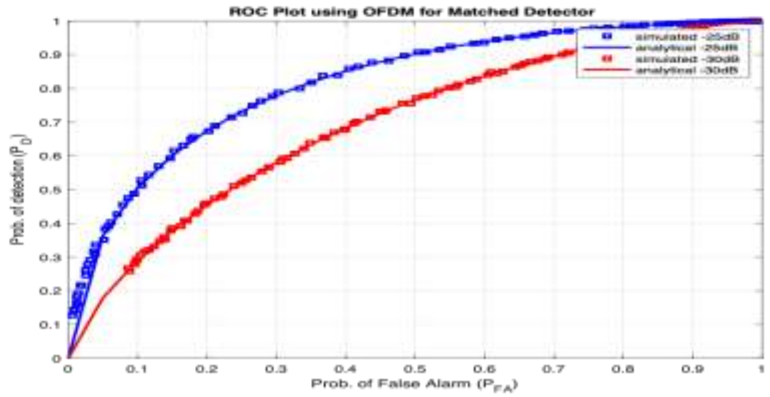


Figure 4 Probability of False Alarm ($P_{FA}$) Vs. Probability of Detection ($P_D$) for OFDM Matched Detector for SNR -25 & -30 dB .

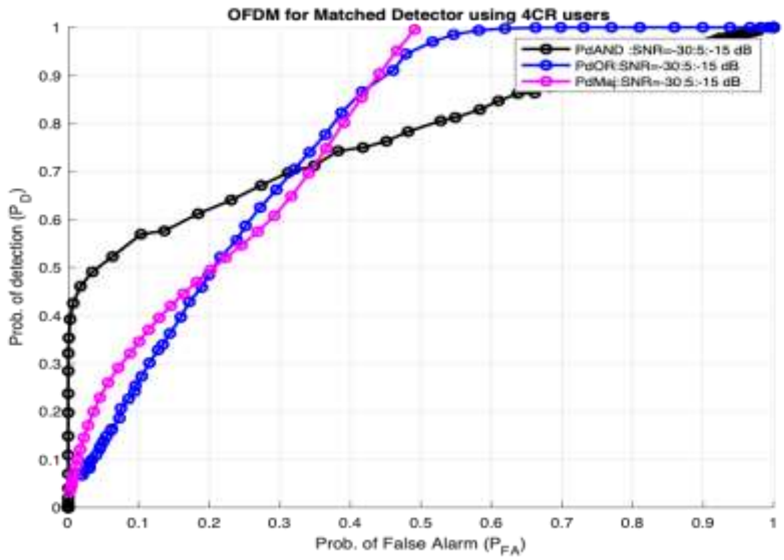


Figure 5 With CSS: Probability of False Alarm ($P_{FA}$) Vs. Probability of Detection ($P_D$) for OFDM Matched Detector for SNR -30: 5: -15 dB .

## 5. Conclusion

In this paper, Matched Detector spectrum sensing technique is analyzed under AWGN environment. Further, OFDM has also been added to sense the spectrum under lower SNR regions. The different parameters like Probability of Detection ($P_D$) , Probability of False Alarm ($P_{FA}$ ), are tested in this different channel environment. Results have also been compared with Cooperative Spectrum Sensing (CSS) heterogeneous environment. It states that using CSS, performance of detectors has increased with OR logic. When the Detector operates in low SNR zones, its output is lowered. When there is a good SNR, the detector performs better in terms of PU signal detection and 0 error probability for Cognitive Radio Networks. In this paper, it's targeted on SNR like -10 dB to -30 dB( low region) and obtained good results practically and theoretically. Detector is targeted Matched Detector in this paper for all performance parameters analysis. Matched Detector required PU's signal prior information to generate reference signal.

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