Matched Filter Spectrum Sensing Technique for Various Fading Channels of Cognitive Radio Network

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Abstract

The emphasis of this research is spectrum sensing in cognitive radio, to recognize the presence of a primary user. Cognitive users are permitted to use the licensed spectrum when the primary user is unreachable. Matched Filter detection is created using the Additive White Gaussian Noise channel for local spectrum sensing. However, when a client comes across shadowing or fading phenomena, detection is impeded. Cooperative spectrum sensing is offered as a way to boost sensing performance. We employ cooperative spectrum sensing in AWGN, Rayleigh, and Rician fading channels. To offer a full picture of cooperative Matched Filter detection in numerous fading channels, centralized detection methods, varied data fusion rules, and closed form expressions are used.

Keyword –Cognitive Radio (CR), Primary User (PU), Secondary User (SU), Matched Filtering Detection (MFD), Signal-to-Noise Ratio (SNR), Probability of False Alarm (P_{fa}), Probability of Miss-Detection (P_{md}), Probability of Detection (P_d),Cooperative Communication (CC), Spectrum Sensing (SS), Additive White Gaussian Noise (AWGN).

I. Introduction

Due to the popularity of a variety of wireless equipments, like mobile phones, we have seen a massive increase in wireless communications during the previous ten years. As a result, there is a greater demand for high data rates, bandwidth, and spectrum use. [1] According to a research, limited spectrum is a critical element in the continuous growth of wireless services. As a result, a new technology known as "Cognitive Radio" has been developed to address the demand for high bandwidth and spectrum utilization. CR is a cutting-edge expertise that uses opportunistic spectrum access (OSA) to boost spectrum use and alleviate spectrum shortages. A CR is a wireless communication paradigm in which a wireless node adjusts its broadcast or reception parameters to avoid interference from authorized or unauthorized users. [2]

SU or unauthorized users are dealt with by CR by allowing the available "Spectrum gaps" to be used without causing interference. To take use of the spectrum holes, SU must constantly monitor the presence and absence of PU. More than 90% of the spectrum is underused or underutilized, as we all know. This method will make it easier to make better use of the spectrum. [3]

CC is a potential approach for increasing spectral efficiency and transmission coverage [11]. CC's main goal is to increase the performance of wireless networks or nodes. [4, 5] The goal of CC is to improve the wireless network by adding a third terminal to help with direct communication. Increase the Pd by using a relay as an intermediary terminal. This relay may make multi-hop transmissions in CC, which operate as a backup to the direct channel between sources and destinations. In CC, the destination D gets the signal generated by source S as well as relay overhearing information. This improves the spectral efficiency of each node while also increasing the reliability of direct connection. [7]

One of the primarily significant components of CR networks is SS. A CR can use SS to get information about its surroundings and spectrum availability. MFD is the most widely used SS approach.

In Matched Filter detection, signal s (t) is added with AGWN n(t) to maximize the SNR. In MFD, input y (t) is correlated (matching) with the input signal s(t). The output is evaluated with the threshold value to be able to make a decision. [6, 10]

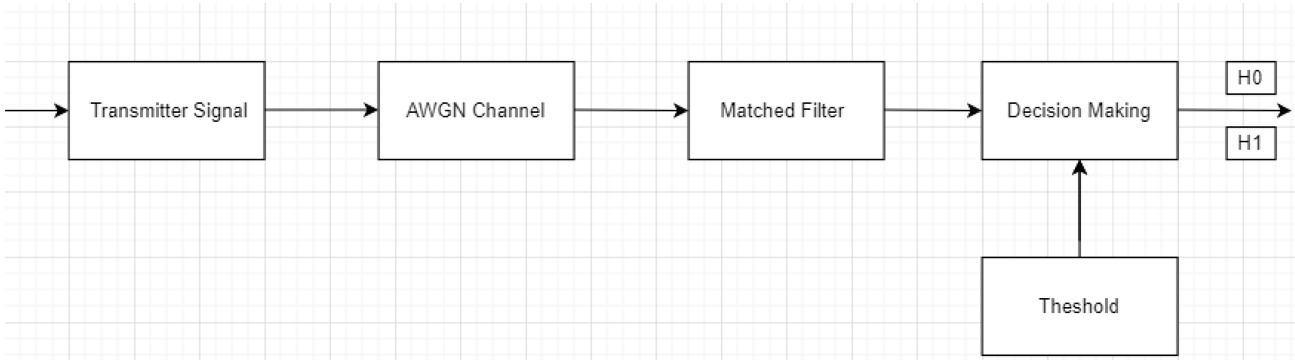

Figure 1: Block Diagram of Matched Filter

The main advantages of MFD are

- Less time is required to attain a high level of processing gain.
- Maximize the SNR

The main drawback of MFD is that it requires sensing receiver for every licensed user. If the SU has no accurate information then it works poorly. [12, 15]

II. System model

Path loss, multipath fading, and shadowing are all known to affect the radio channel between the receiver and the transmitter. By adding randomness into the received signal power, these channel obstructions can drastically degrade the MFD's performance [13]. The power of a received signal decreases with distance as it travels from the sender to the receiver, which is referred to as path loss. Shadowing, on the contrary, is caused by fast fluctuations in the strength of the received signal as a result of impediments in the propagation path.

Because they generate disparities over a wide range of distances, path loss and shadowing are examples of large scale fading. Multipath fading is a small-scale fading phenomenon that occurs when a signal is duplicated many times with different time delays and gains due to scattering, reflection, and diffraction [10]. Multipath fading can be described as an AWGN, Rayleigh, or Rician distribution, depending on the type of radio channel.

The spectrum white space, which is a empty slot in the PU spectrum, is used to detect a detector's decision. The binary hypothesis testing model distinguishes its presence or absence as follows:

H_0: PU absent
H_1: PU present

According to the H_0 hypothesis theory, there is unavailable prior information in the spectrum, only noise. As a result, it can be assigned to the SU. Primary signals, as well as noise, are present in the spectrum, according to the H_1 hypothesis. As a result, it cannot be assigned to secondary users because it would interfere with the PU [8]. Based on the presence and absence of PU, any received signal at CR user is delivered by

$$Y_i\,(t) = H_0 : n_i(t) \tag{1}$$

$$Y_i\,(t) = H_1 : h_i(t)\,x_i(t) + n_i(t) \tag{2}$$

Where yi (t) represents the received signal at the ith CR user and hi (t) represents the channel gain between the PU and ith CR user. ni (t) represents AWGN at the ith CR user, with the power spectral density Sn (f) = $N_0/2$ W/Hz. A test statistic T(x) is compared to a threshold to form the hypothesis. Pmd and P_{fa} are two measures that describe MFD performance. In SU, low P_{md} increases PU interference, while high P_{fa} increases the amount of missed spectral opportunity [9]. MFD's operation is described as follows:

$$Y[n] = \sum h\,[n-k]x[k] \tag{3}$$

Where 'x' is the unknown signal, which is convolved with 'h,' the MF impulse response that is matched to the reference signal in order to maximize SNR. With a non-coherent receiver, both real and imaginary components are required to fully characterize the signal. [13].

$$Y(n) = \sum_{n=0}^{N-1} w(n) \times x_p{}^*\ (n) \tag{4}$$

The value of y (n) is bigger than the threshold value (λ) when alternative hypothesis H_1 is true. During the P_d input signal, x (n) will be.

$$x(n) = s(n)h(n) + w(n);\ H_1 \tag{5}$$

This indicates that the detection is H_1 while H_0 is true. Now, during the P_{fa} input signal x (n) will be

$$x(n) = w(n), H_0 \tag{6}$$

The received signal y (n) can now be represented as, using equations (5) and (6).

$$y(n) = \sum_{n=0}^{(N-1)} [\,s(n)h(n) + w(n)] \times x_p{}^*\ (n) \tag{7}$$

The given equation can now be used to calculate the probability of PU detection indication for the MF detection method.

$$P_d = P[H_1/H_1] \tag{8}$$

$$P_d = P[y(n) > \lambda\,/H_1] \tag{9}$$

The final expression for P_d is,

$$P_d = Q\left(\sqrt{\frac{2E}{\sigma^2 w}}\ ,\sqrt{\frac{2\lambda^2}{w\sigma^2}}\right) \tag{10}$$

Where λ = threshold core figure and the Q (,) = Generalized Marcum Q Function.

$$Q\ (a,b) = \frac{1}{a^{(m-1)}} \int_b^{\infty} x^m\ e^{-\left(x^2+\frac{a^2}{2}\right)} l_{(m-1)}(ax)dx \tag{11}$$

I (m-1) ()= modified Bessel functions of the first kind of order, where a and b are non-negative real values and m is a positive integer (m-1) The supplied equation can now be used to determine the P_{fa} for the MF detection method.

$$P_f = P[H_1/H_0] \tag{12}$$

$$P_f = P[y(n) > \lambda\ /H_0] \tag{13}$$

From (11) and (12), the final expression for P_{fa} which is,

$$P_f = \exp[\frac{-\lambda^2}{E\sigma w^2}] \tag{14}$$

Where, λ= Threshold Value. exp ( ) = Exponential function. E = Input signal Power. σω2= Noise variance. Now, for the P_{md}, the decision is H_0 while H_1 is true.

$$P_m = P[H_0/H_1] \tag{15}$$

$$P_f = 1 - [y(n) > \lambda\ /H_1] \tag{16}$$

From equation (14), (15) the P_{md} for MF detection can be,

$$P_m = (1 - P_d) \tag{17}$$

$$P_m = 1 - Q\left(\sqrt{\frac{2E}{\sigma^2 w}}\ ,\sqrt{\frac{2\lambda^2}{w\sigma^2}}\right) \tag{18}$$

The AWGN signals' Power Spectral Density (PSD) is presented.

$$PSD_{AWGN}\ (f) = \frac{N_0}{2} \tag{19}$$

The noise signal N_0 is given by, and the AWGN channel Signal to Noise Power measured at the MF's output is given by

$$SNR = \frac{|s(t)|^2}{|N(t)|^2} \tag{20}$$

The nth PU's output noise power Pn is discovered to be

$$P_n = \frac{N_0}{2} \int_{-\infty}^{+\infty} |H_n(f)|^2\ dx \tag{21}$$

The calculated output signal power Ps of the nth PU is found to be

$$P_s = \int_{-\infty}^{+\infty} \left|H_n(f) s_i(f)^{ej2\pi ft} df\right|^2 \tag{22}$$

Now the SNR of the PU is simplified to SNR

$$SNR = \frac{2P_{is}}{N_0} \tag{23}$$

The PU signal above the noise was represented by the equation above. The MF acquisition process will yield Pfa and Pd, which may be calculated as:

$$P_{fa}^{MF} = 1 - (\frac{\lambda MF}{\sigma}, 2) \quad (24)$$

$$P_{d}^{MF} = Q(\sqrt{2n(SNR)}, \sqrt{\frac{\lambda MF}{2\sigma}}) \quad (25)$$

The non centrality constraint s2 = 2n (SNR) is the output of the filters in the I and Q branches at the accurate offset, where MF is the threshold value for MF. The central chi-square distribution of the MF correlation process has two degrees of freedom and a variance.

III. Simulation and Result

The performance measurement metrics Pd, Pfa, and Pmd = 1 - Pd are used to examine the performance of SS techniques. The ROC curve, which is a plot of Pd versus Pf or Pmd versus Pf, depicts the performance of a SS technology. The simulations were run on three different wireless fading channels: AWGN, Rayleigh, and Rician. Complementary ROC curves for different values of Pfa, Pd, and SNR are used to describe receiver performance.

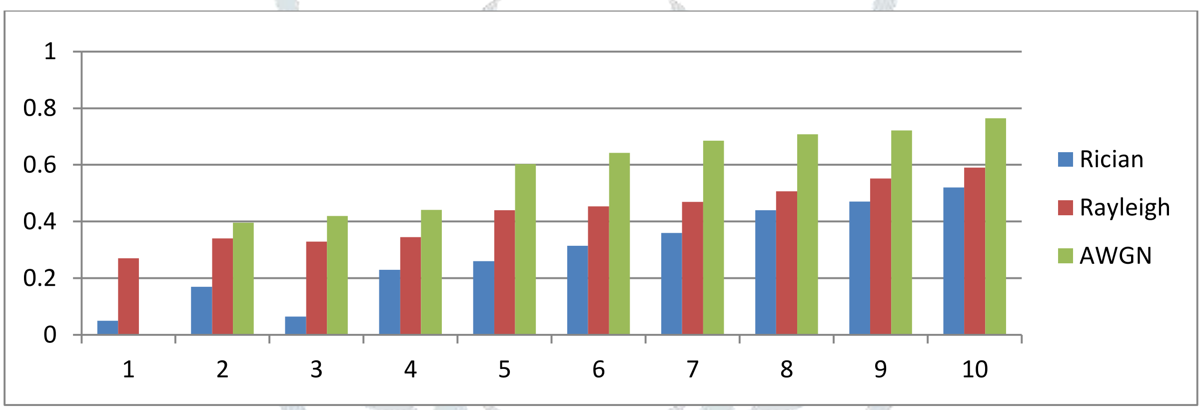

Figure 2: Analysis of Probability of Detection between all three channels

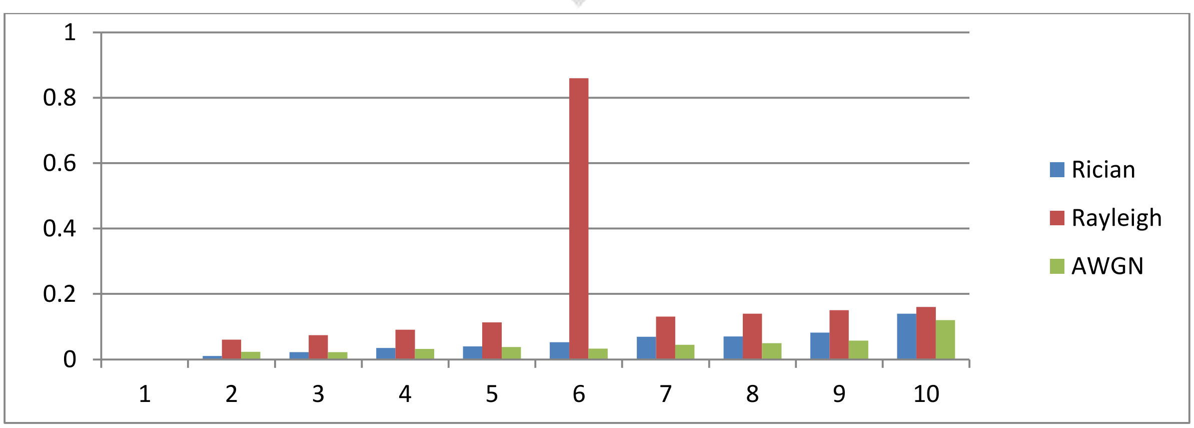

Figure 3: Comparison of Probability of False Alarm between all three channels

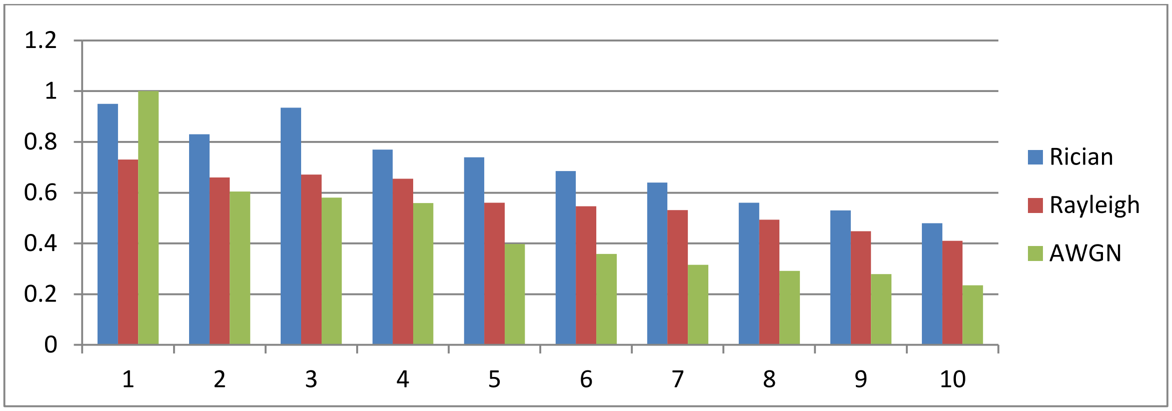

Figure 4: Comparison of Probability of Miss-Detection between all three channels

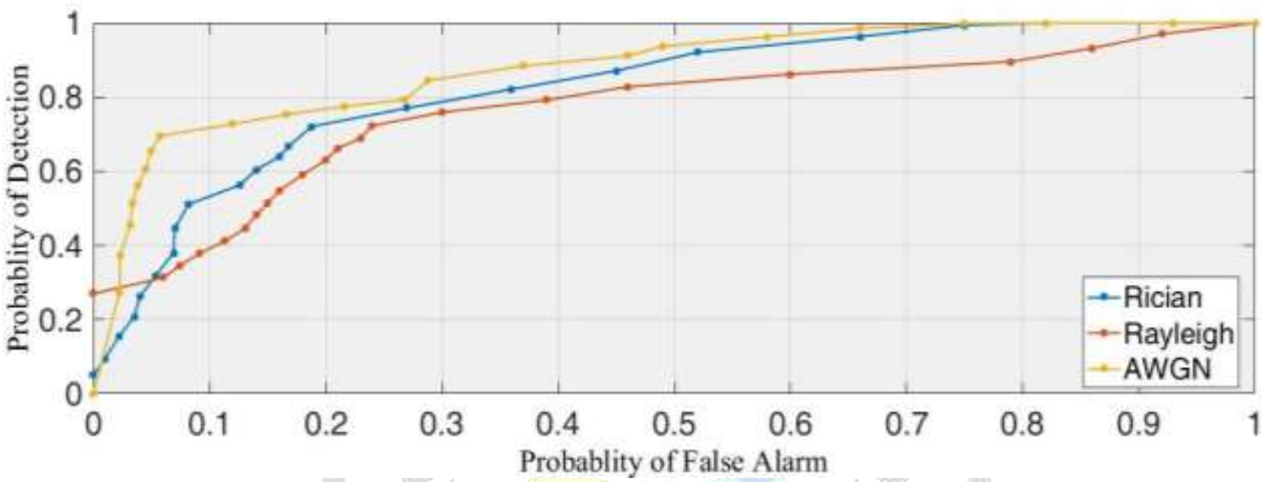

Figure 5: ROC curve among P_{fa} and P_d for Different Channels

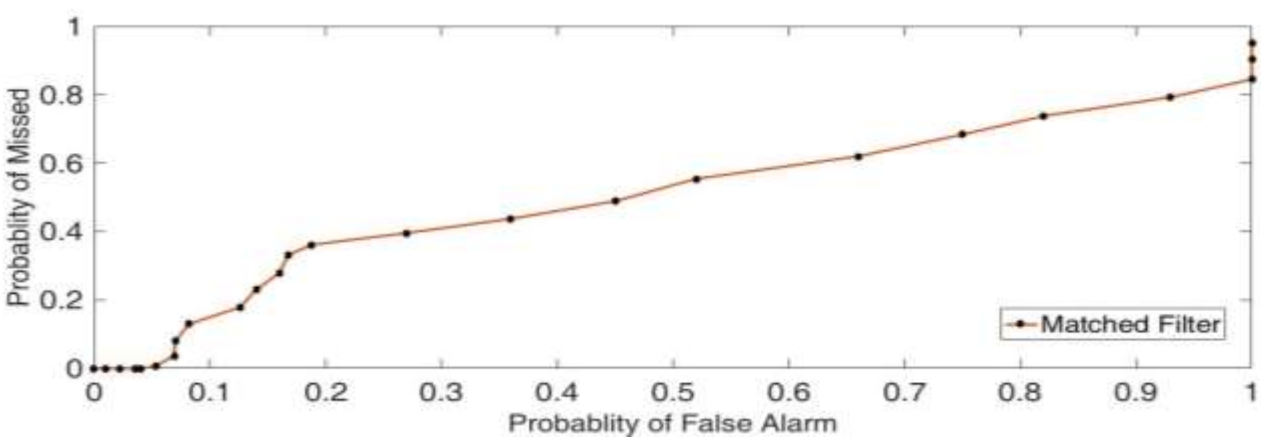

Figure 6: ROC curve between P_{fa} and P_{md} for Rician channel

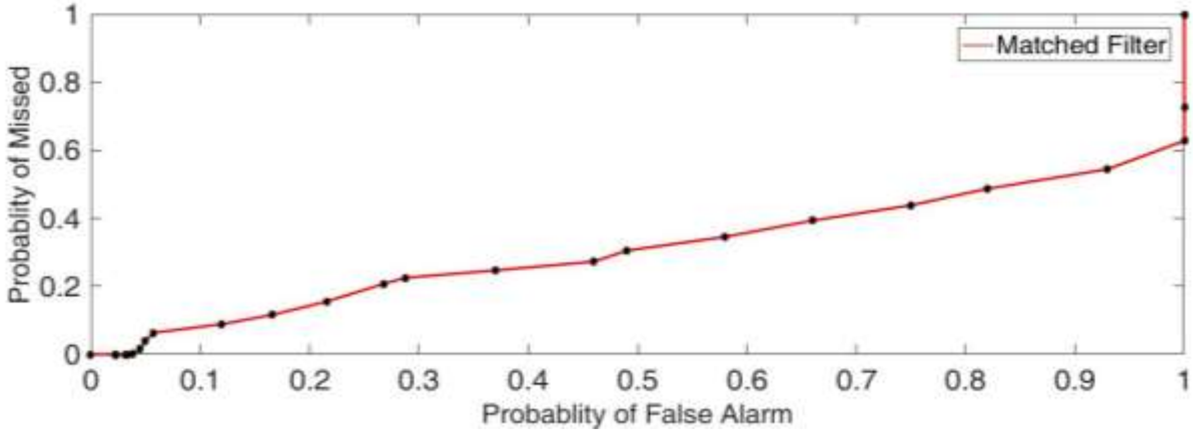

Figure 7: ROC curve between P_{fa} and P_{md} for Rayleigh channel

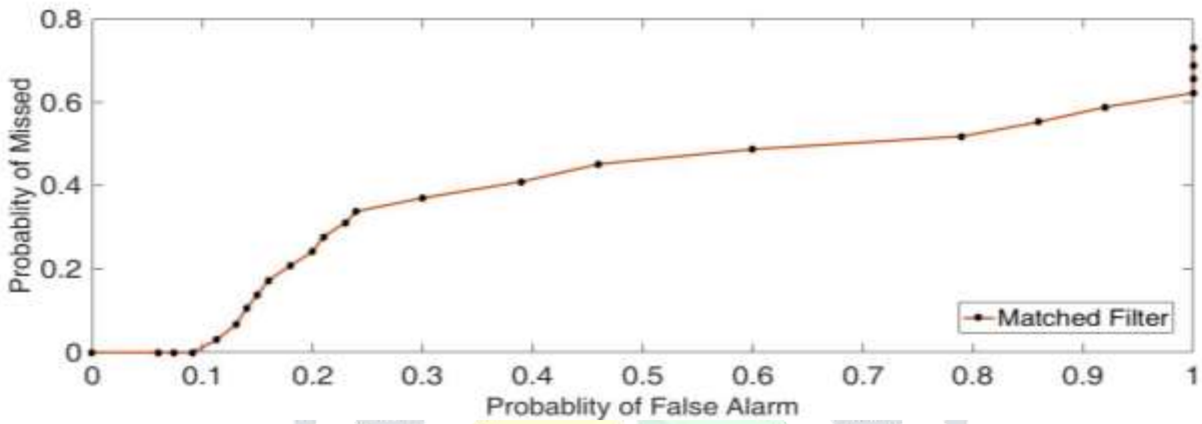

Figure 8: ROC curve between P_{fa} and P_{md} for AWGN channel

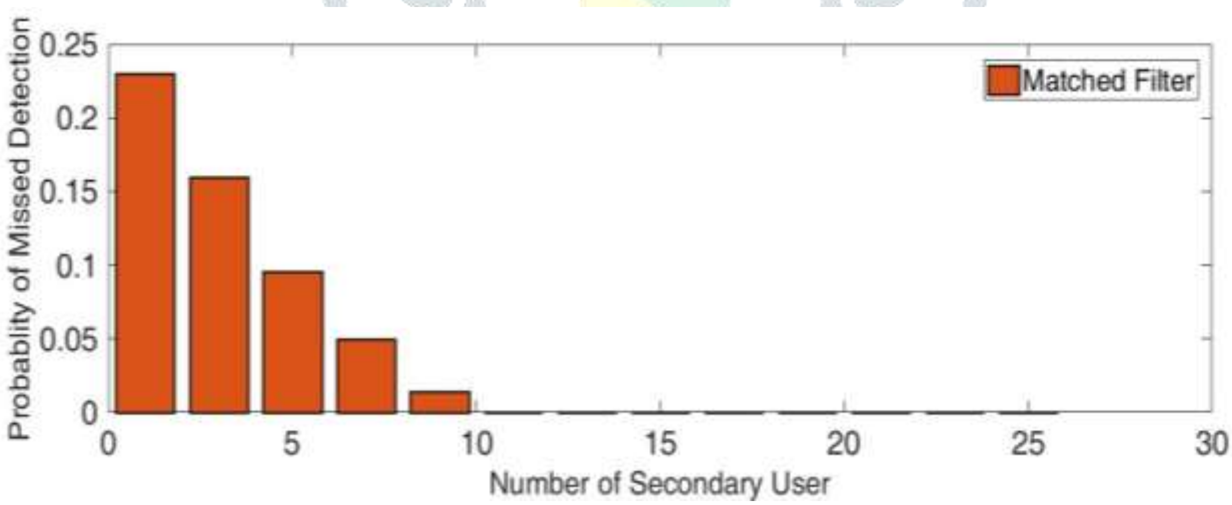

Figure 9: ROC curve between P_{md} and Number of SU

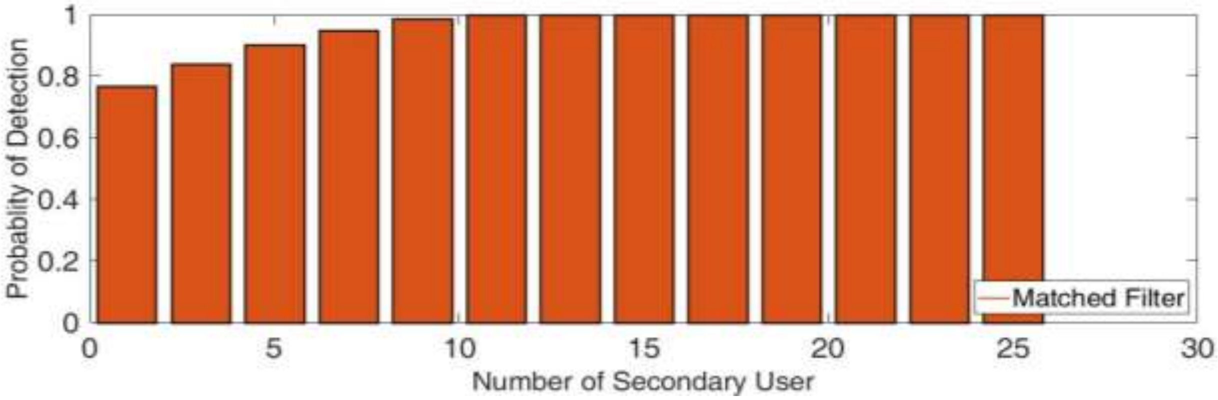

Figure 10: ROC curve between P_d and Number of SU

IV.Conclusion

Cognitive radio is a concept that uses opportunistic spectrum usage to make better use of the available spectrum. It's a fascinating and interesting notion. Sensing the available spectrum opportunities is one of the most critical issues in dynamic spectrum management.

The performance of MF Detection-based SS is demonstrated in this study using Wireless Fading channels such as AWGN, Rayleigh, and Rician. Over several wireless fading channels, closed form formulas for P_d and P_{fa} are analyzed. For this investigation, three performance indicators are used: P_d, P_{fa}, and SNR. It has been demonstrated that as the SNR value changes, the P_d increases in all channels. Thus, in a CR network, identification of the presence of the PU signal is the simplest task when utilizing MFD-based spectrum sensing technique, which has average computational complexity.

The comparison graphic clearly shows that among the variety of fading channels, Rician fading channels have a higher P_d than Rayleigh and AWGN fading channels. In comparison to previous research, the proposed strategy yields significantly superior outcomes. In CRN, the comparison of outcomes also aids in the quality assessment and channel selection. The work presented in this paper is thought to be beneficial in understanding the performance of a Cognitive Radio network over wireless fading channels.

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