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Implementation of Energy Detection Technique for Spectrum Sensing in Cognitive Radio using NS3

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***Abstract*— The increase in demand of the available spectrum has led to scarcity in the spectrum which is one of the current disadvantage that impairs further development in the field of wireless communication. The presence of vacancies in the radio spectrum requires fast, robust and accurate methods for their detection. Here, the vacancies are formed when the licensed user does not use his spectrum at a particular instant of time. This paper aims in implementing the Energy Detection Technique for Spectrum Sensing using open source simulation tool NS3. The main purpose of the proposal is to obtain comparative analysis of Energy Detection technique for different modulated signals which gives information about the presence or absence of Primary User (PU). The signals used in this paper for analysis are Orthogonal Frequency Division Multiplexing (OFDM), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). Simulation results show that probability of detection (Pd) can be increased at low Signal to Noise Ratio (SNR).**

***Index Terms*— Cognitive Radio, Primary User, Secondary User, Spectrum Sensing, Energy Detection.**

I. INTRODUCTION

A cognitive radio is an intelligent radio that will sense the unused frequencies in the spectrum band and allocates them to cognitive users in the network for a temporary use without causing any interference with the primary users of that spectrum [1].
In order to reduce the spectrum scarcity, cognitive radio (CR) has been introduced to implement the spectrum sensing and sharing to increase the spectrum efficiency so that the larger number of wireless users can be accommodated without creating a new RF spectrum band. The secondary CR network, which is software defined radio to work automatically according to their operating environment, the radio components are implemented in software rather than in hardware, therefore it is possible to adapt system configurations to any frequency to transmit and receive the data. It is important to note that the primary users (PUs) are authorized users of the licensed frequency band, and secondary users (SUs), who are not the PUs but want to use the licensed frequency band, are the cognitive users in CR networks. It is also worth to mention that allowing a secondary user to access the licensed spectrum (imposing some constraints on SUs) improves the spectrum utilization.

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As conventional and existing wireless communication networks are operating based on fixed spectrum assignment to the service providers and their users for exclusive use on a long-term basis result in spectrum scarcity, the CR technology uses the spectrum opportunities dynamically without creating harmful interference to licensed users. In order to fully realize the CR system, the detection of primary user signal is the most important and fundamental step. Therefore, CR system requires a signal processing for spectrum sensing implementation to detect both interference and the absence or presence of primary users.
Cognitive radio is a smart radio which is capable of autonomous reconfiguration by adapting to the communication environment. Since a cognitive radio operates as a secondary user which does not have primary rights to access any of the licensed frequency bands, it is necessary for it to dynamically detect the presence of primary users.
Spectrum Sensing: In order to avoid Interference, the spectrum holes are sensed. A spectrum hole (or also called white space) is a band of frequencies assigned to a primary user, but at a particular time and specific geographic location, the band is not being utilized by that user.
A recent spectrum occupancy measurement shows that a significant portion of the spectrum allocated to licensed services show little usage over time, with concentration on certain portions of the spectrum while a significant amount of the spectrum remains unutilized. Spectrum utilization can be significantly improved by adopting the concept of Dynamic Spectrum Access (DSA) where unlicensed or cognitive users (CUs) can temporarily utilize unoccupied bands but need to vacate the space (time, frequency or spatial) once the licensed or primary users (PUs) are detected as not to cause harmful interference.
Ultra-wideband (UWB) and cognitive radio (CR) are two exciting technologies that offer new approaches to spectrum usage. UWB is an underlay approach with restrictions on transmitted power levels; thus promotes coexistence with other existing radio technologies and operates over ultra wide bandwidth. In Fig. 1 Signal strength distribution is shown in geographical variations in the utilization of assigned spectrum ranges from 15% to 85% with high variance in time [2].

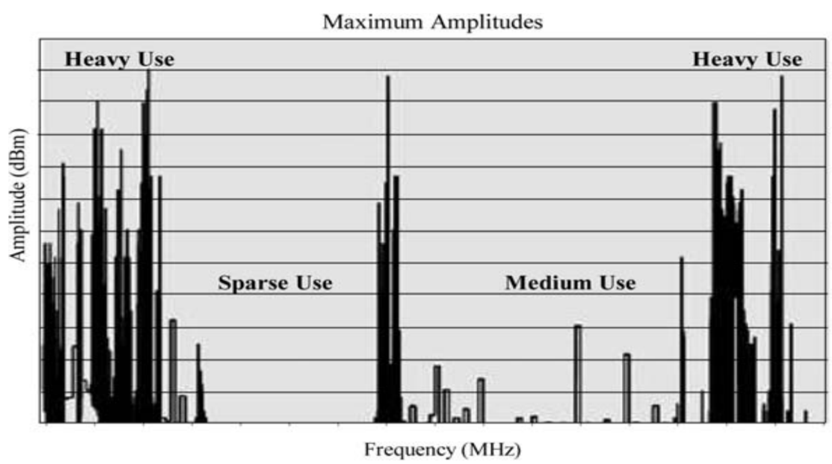

Figure1. Spectrum Utilization

II. SYSTEM MODEL

Energy detection is the widely used spectrum sensing method since prior knowledge of the licensed user signal is not required, performs well with unknown dispersive channels and it has less computational and implementation complexity and less delay relative to other methods.
However, this method relies on the knowledge of accurate noise power and hence is vulnerable to the noise uncertainty. Energy detection is optimal for detecting independent and identically distributed signals in high SNR conditions, but not optimal for detecting correlated signals. In this section we discuss the detailed implementation of energy detection as shown in Fig. 2[8]. The message from the user is modulated using any of the above mentioned modulation schemes.

A. Energy Detection Technique

The detection of PU is formulated as a binary hypothesis test between the following two hypotheses:

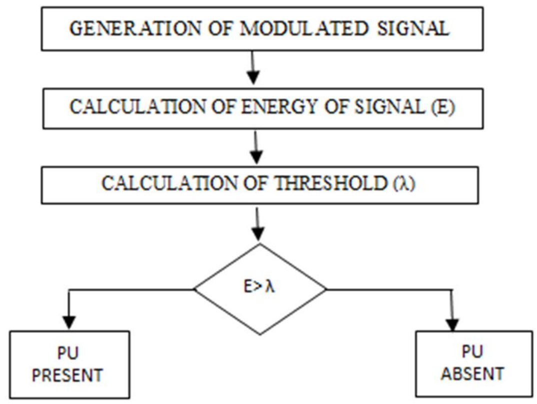

Figure 2. Flowchart of System Model

$$r_i(t) = \begin{cases} n(t) & H_0 \text{ (PU not detected)} \\ h(t).s(t) + n(t) & H_1 \text{(PU detected)} \end{cases}$$

where, $r_i(t)$ represents the signal received by a SU, s(t) is a signal of PU, channel gain is represented by h(t) and n(t) represents the zero mean Additive White Gaussian Noise(AWGN), H_1 and H_0 represents the hypothesis test of the existence and non-existence of PU, respectively[6][5]. As SU senses the signal r_i (t) of PU, it applies a filter of bandwidth W followed by a square law device and an accumulator. The output of the accumulator R is compared to a threshold λ and a local decision is made, H1 if R > λ, i.e., PU is present and H0 if R < λ, i.e., PU is absent [3][4]. The energy of the generated signal is calculated by squaring and adding the signal samples and dividing it by the number of samples and is given by the equation[3][7]:

$$E=\frac{1}{N}\sum_{n=0}^{N-1} y\,[n]^2$$

where, N is the number of samples, y[n] is the signal sample at n and E is the energy of signal. Calculation of threshold is done using the below equation:

$$\text{thr} = \left|\left(\sqrt{\left[\frac{2\sigma^4}{2N+1}\right]} * \log(p_f)\right)\right|$$

where, thr is the threshold, σ is the variance of modulated signal, N is the number of samples and p_f is the probability of false detection. Here threshold is calculated for each sample of the signal by making use of the variance of the signal sample and pf of each sample. Probability of false alarm is defined as the probability of stating absence of PU even when user is using the channel which leads to interference.

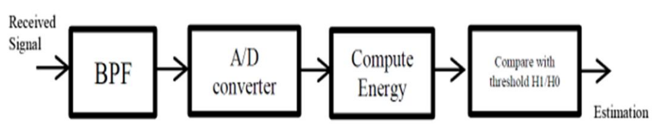

Figure 3. Block Diagram of Energy Detection Techniques

III. Results

A. Generation of signals

The above Fig.4 represents a binary phase shift keying signal (BPSK). In BPSK the transmitted signal is a sinusoid of fixed amplitude. It has one fixed phase when data is at one level and when the data is at the other level, phase is different by 180 degree.

The above Fig.5 represents a quadrature phase shift keying (QPSK). QPSK is a form of phase shift keying in which two bits are modulated at once, selecting one four possible carrier phase shifts(0,90,180 or 270 degrees).

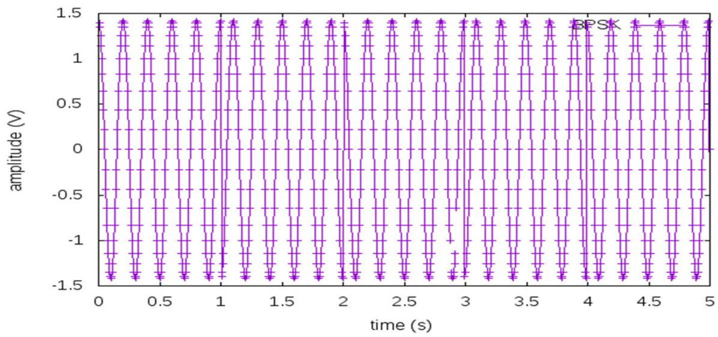

Figure 4. Generated BPSK signal

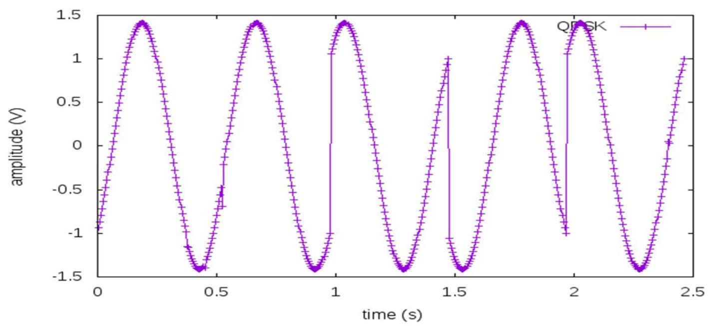

Figure 5. Generated QPSK signal

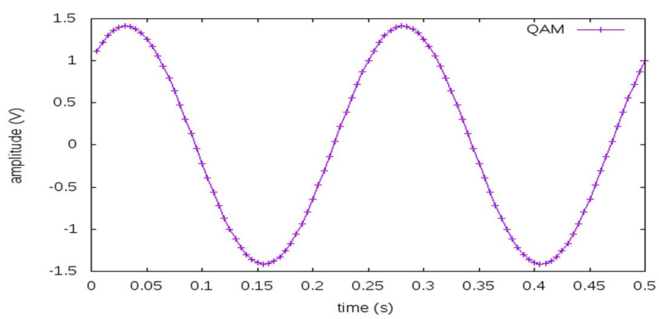

Figure 6. Generated QAM signal

The above Fig.6 represents a quadrature amplitude modulation (QAM). QAM is a method of combining two amplitude modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. QAM is used with pulse amplitude modulation in digital systems.

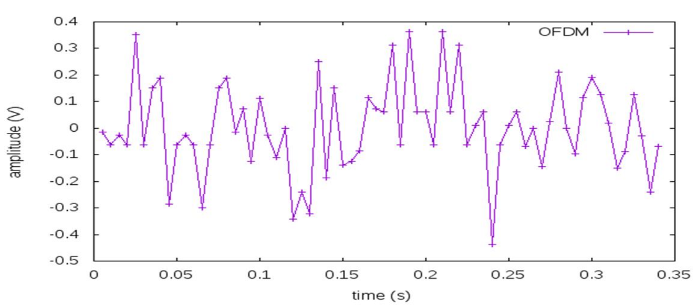

Figure 7. Generated OFDM signal

The above Fig.7 represents a orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM is a frequency-division multiplexing scheme used as a digital multi-carrier modulation method.

B. Plots of Theoretical Pd and Practical Probability of detection (Pd) v/s SNR

The probability of detection is the probability of determining the primary user's bandwidth which are not in use. SNR is the ratio of strength of an electrical or other signal carrying information to that of unwanted interference.

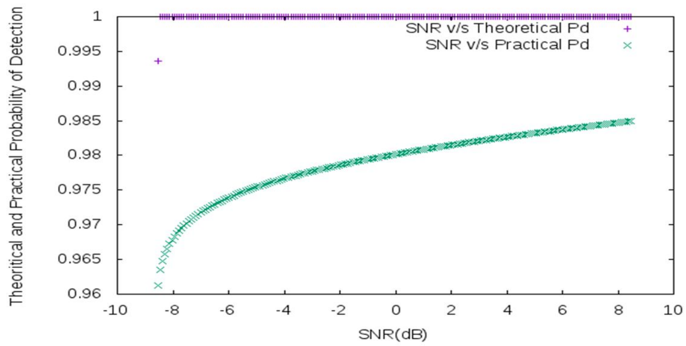

Figure 8. Theoretical Pd and Practical Pd v/s SNRfor BPSK signal

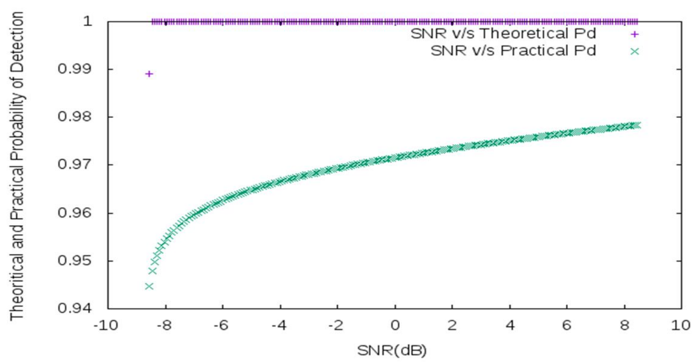

Figure 9. Theoretical Pd and Practical Pd v/s SNR for QPSK signal

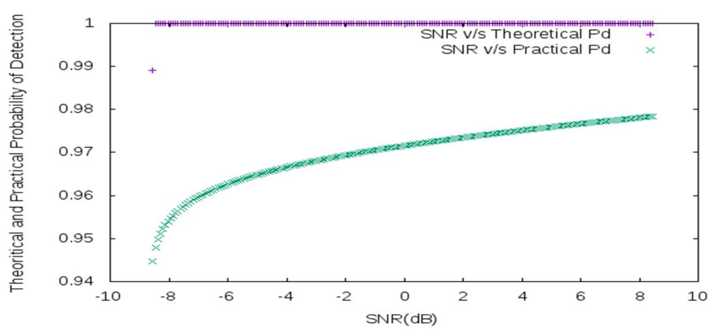

Figure 10. Theoretical Pd and Practical Pd v/s SNR for QAM signal

Fig. 8, Fig .9, Fig .10 and Fig .11 represents the plot of Theoretical and Practical probability of Detection for different values of SNR. In the above graphs we have assumed our theoritical Probability of detection to be 1 as it is maximum. Practically, low SNR implies that noise power is more than the signal power hence we have observed low Probability of Detetction, but as SNR increasses Probability of detecting the signal also increases which is clearly shown.

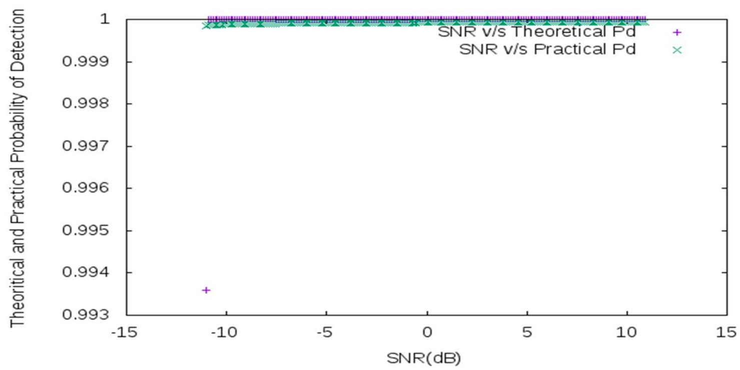

Figure11. Theoretical Pd and Practical Pd v/s SNR for OFDM signal

C. Plots of Probability of SNR v/s Probability of detection(Pd)

The Fig.12, Fig .13, Fig .14 and Fig .15 represents the plot of SNR(dB) v/s Practical Probability of Detection.

D. Plots of Signal to Noise Ratio (SNR) v/s Probability of miss Detection (Pm)

Probability of missed detection is the probability of failing to sense the free PU bandwidth. Probability of missed detection being inversely proportional to Probability of detection.

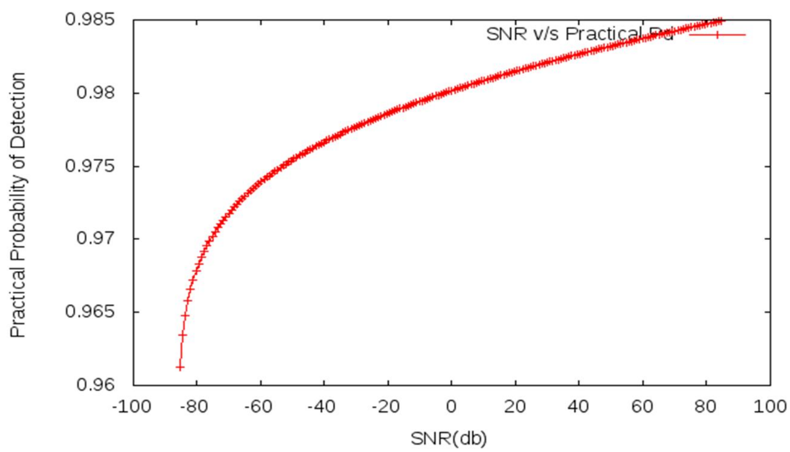

Figure 12. SNR v/s Practical Pd for BPSK signal

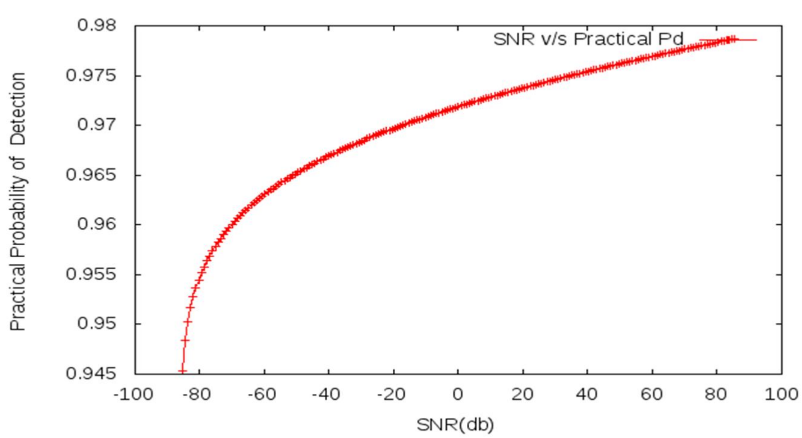

Figure13. SNR v/s Practical Pd for QPSK signal

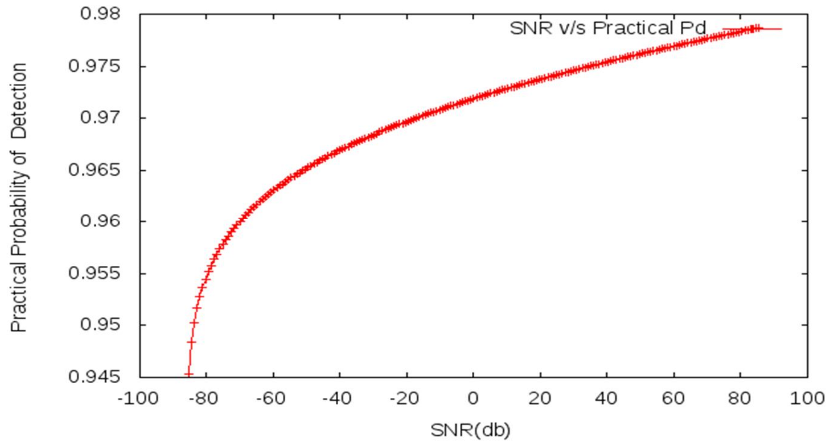

Figure14. SNR v/s Practical Pd for QAM signal

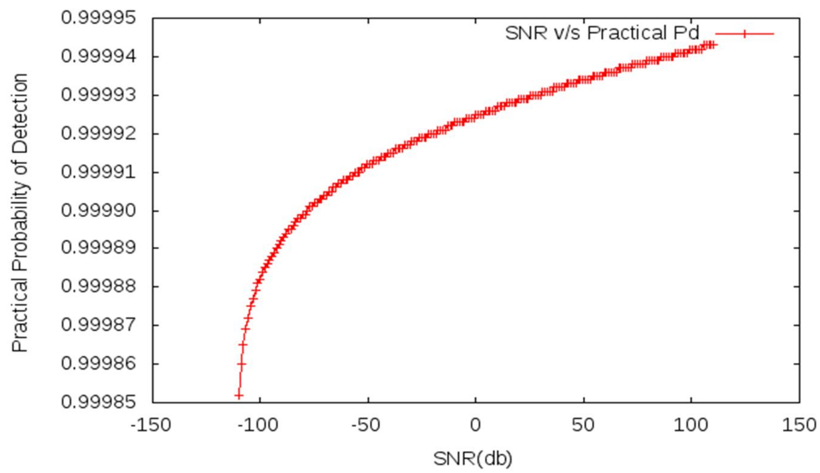

Figure 15. SNR v/s Practical Pd for OFDM signal

The Fig.16, Fig .17, Fig .18 and Fig .19 represents the plot of Practical Probability of Miss Detection(Pm) for different values of SNR(dB).

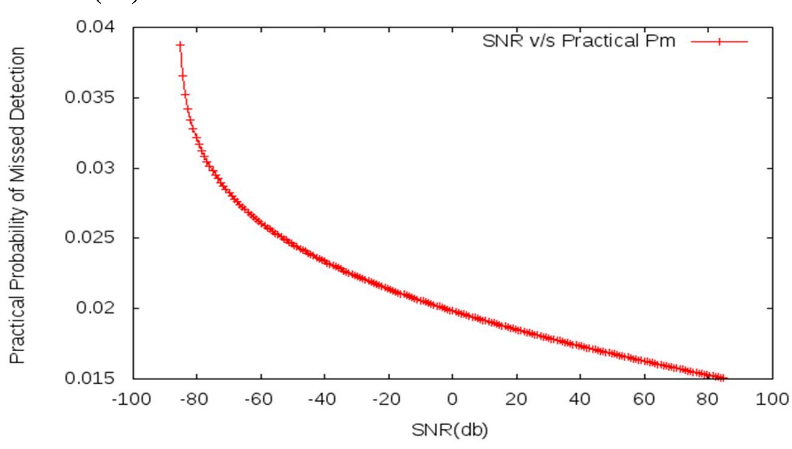

Figure16. SNR v/s Practical Pm for BPSK signal

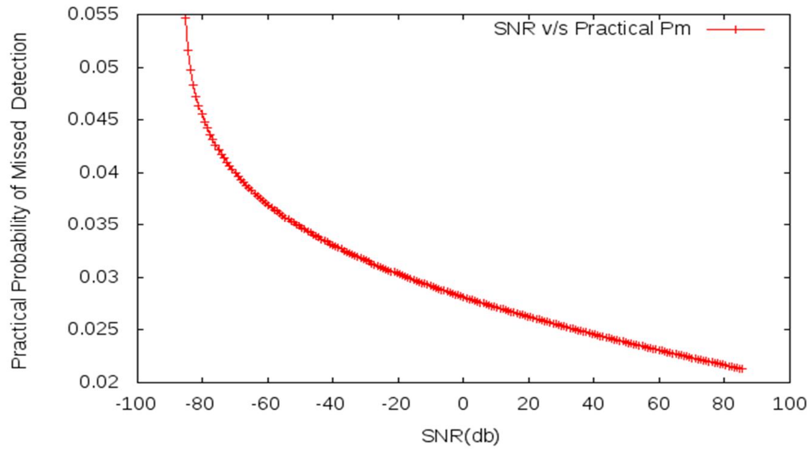

Figure17. SNR v/s Practical Pm for QPSK signal

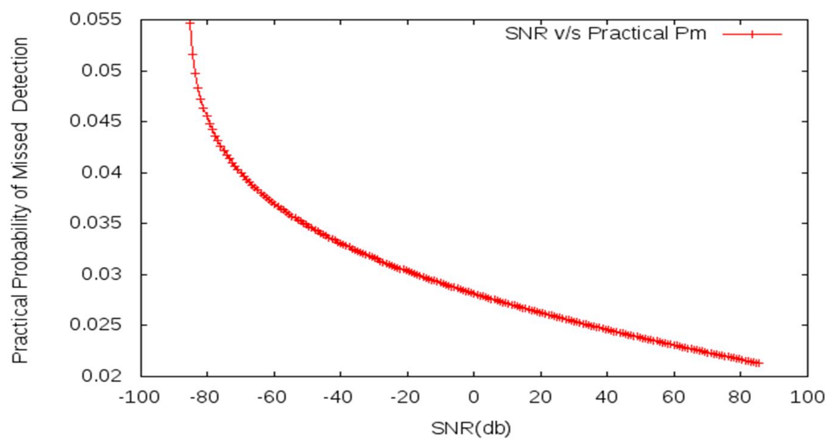

Figure18. SNR v/s Practical Pm for QAM signal

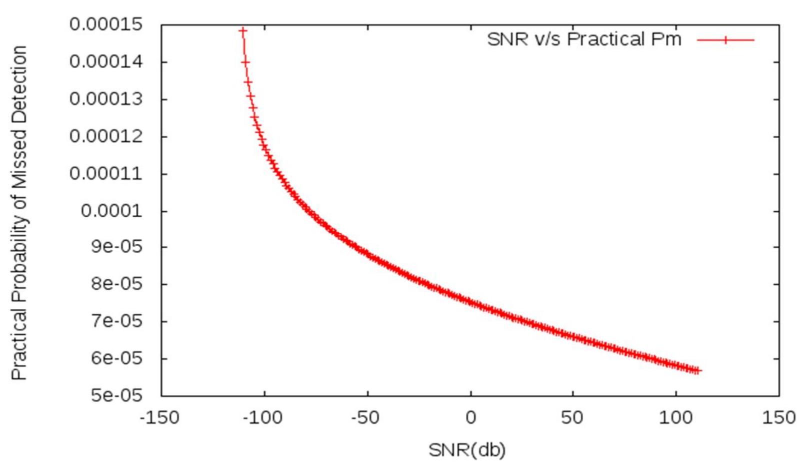

Figure19. SNR v/s Practical Pm for OFDM signal

TABLE I. VARIATION OF THEORETICAL, PRACTICAL PROBABILITY OF MISS DETECTION FOR SNR=-85DB

SIGNALS	SNR= -85 dB		
	Theoretical Pd	**Practical Pd**	**Practical Pm**
BPSK	1	0.962	0.038
QPSK	1	0.945	0.055
QAM	1	0.945	0.055
OFDM	1	0.99989	0.00011

IV. CONCLUSION

The sensing was implemented through energy detection technique cognitive radio using ns3 tool. The contribution of the paper are:

1. Comparative study of Spectrum Sensing in Cognitive Radio using Energy Detection method for different modulated signals.
2. To increase probability of detection at low SNR. This is achieved by comparative study of different modulated signal like: BPSK, QPSK, QAM and OFDM. It was observed that OFDM signal has the highest Probability of detection even at a low SNR.
3. Comparison between theoretical and practical probability of detection at different values of SNR.

It was observed that OFDM signal has the highest Probability of detection and lowest probability of missed detection even at a low SNR.

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