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Spectrum Awareness for Cognitive Radio Oriented Wireless Networks

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ABSTRACT

At a time in licensed spectrum most of allocated channels are completely free, some are partially used, and some are heavily used. Solution of this revolve around better spectrum management. i.e. if a licensed spectrum can be used by an opportunistic user when main user is idle.CR (Cognitive Radio) is a novel technology to solve the spectrum sharing problem and allow secondary users to use spectrum on opportunistic basis, but it is currently a big challenge for spectrum management system. The reason for that is the need for self-adaptability and flexibility of the CR. As CR must sense its operating environment by changing its paraments so that spectrum hole can be exploited.SDR is an emerging technology that provide platform for reconfigurable radio system.In this research paper, the performance of the system is studied in terms of overall probability of error while sensing operation is going on. Also, recommends certain rules and regulation to carry out efficient spectrum utilization.

1. INTRODUCTION

EM radio spectrum being invaluable natural resource is underutilised. This is continuously causing problem in expansion of new wireless services and increasing number of new applications which demands this resource. Increasing demand of wireless services leads to spectrum scarcity in modern digital world. Studies shows that most of the spectrum for which licensed has been allocated is not utilised properly, causing an artificial scarcity. Moreover, the position of the Spectrum hole continuously changes with time and location.Spectrum being natural limited resource require careful and cautious utilization. This leads to licensing of spectrum by governmental agencies [1,2].

Being a promising and capable solution to scare radio spectrum, Cognitive radio (CR) seems to be future of all wireless services. CR build a predictive model based on intelligence sensing of radio spectrum and based on past analysis it tries to find out holes in spectrum for efficient utilization. CR is built on Software Defined radio (SDR). SDR offer multi-standards, multiservice and multiband operations defined by software.Sensing of radio band is called spectrum sensing (SS) [3]. SS plays a critical role in overall CR operation by avoiding interference and allowing quick & reliable detection of licensed user.Majority of spectrum sensing algorithm revolves around energy detection because of simplicity and flexibility [4].

2. LITERATURE REVIEW -COGNITIVE RADIO

Cognitive radio (CR) has emerged as an incredibly capable solution to tone down spectrum shortage in radio frequency spectrum. CR optimizes the spectrum utilization by finding out spectrum holes in sensed frequency band and utilized them. Therefore, it is important to understand how it works.

Joseph Mitola used term CR first time [5]. He defines “CR as a radio capable of analysing the environment (as channels and users), learning and predicting the most suitable and efficient way of using the available spectrum and adapting all of its operation parameters”.

Joseph Mitola coined term SDR in 1992. Software defined radio operate in wide band of frequencies and for a wide range of parameter. All these frequency band and parameterdepends upon type of application in hand. The major advantage with SDR is it can change its parameter based on application with the help of software [6].

As per definition of FCC: A ‘‘Cognitive Radio’’ interact with environment of operation and based on interaction changes its transmission parameters.

Spectrum sensing techniques revolves around finding spectrum hole and differentiating main and opportunistic user [7,8]. Here, main user is also called as primary user and opportunistic user as secondary user. In order to find the effectiveness of detection scheme, some performance parameters for each SS technique is defined. These are:

- Probability of making correct decision
- Probability of making false decision
- Probability of not making decision

Spectral vacancies in the spectrum band can be determined by the following ways [9]

- Periodically sensing the spectrum for free band.
- Separate transmitters are required to determine the spectrum availability.
- Using temporal and spatial information to have a clear information using database of recorded frequencies.

Only CR architecture and functional components don't completely explain each and every aspect of CR. To provide fundamental cognitive capabilities CR architecture is integrated with machine learning.Based on the available primary user information CR uses different approaches [10]. They are:

1. Spectrum Overlay
    1.1. Cooperative Sensing
    1.2. Non-Cooperative Sensing
2. Spectrum Underlay
    2.1. Interference Based Sensing

There are four major tasks of a CR which it must have to fulfil. They are as follow:

1. Spectrum Sensing: This is done to find the presence of white space in radio band.
2. Spectrum Management: maintaining quality and robustness of services.
3. Spectrum Mobility: radio spectrum management during inter channel and intercell transfer.
4. Spectrum Sharing: resource sharing by robust and fair scheduling methods among the coexisting users.

CR has following advantages over a primitive radio [11]:

1. Scan the radio frequency spectrum in order to detect the spectrum hole.
2. Manages the unutilized frequency spectrum.
3. Spectrum utilization increase significantly.
4. While scanning the channel CR system ignores heavy used channels use the unutilized channel to improve spectrum utilization.
5. Increase throughput of network with good quality of service.

3. SPECTRUM SENSING IN COGNITIVE RADIO

The key functionality of CR is efficient SS so that as soon as there are an opportunity to use the unutilized spectrum is arises, it can be utilize by CR and if PU return to the band then secondary user has to either leave the band or need to reconfigured its transmission parameters in order to protect the licensed user or, if possible, move to another available spectrum hole.White space or Spectrum holes can be of two time i.e. over a period of time and over a period of frequency.In radio spectrum frequency band are classified in three categories [12,13] :

• Black Space: should be always avoided, since contain high interference user.
• Grey Space: low interference user.
• White Space: free band only noise may present also called spectrum hole

On the bases of spectrum occupancy information SS can be done by three main approaches. These can ne categories as:

1. Database and geo-location-based sensing of spectrum.
2. Sensing at primary user
3. Sensing locally at Secondary user.

Figure 3.1 show general classification of SS techniques Depending on the method of sensing

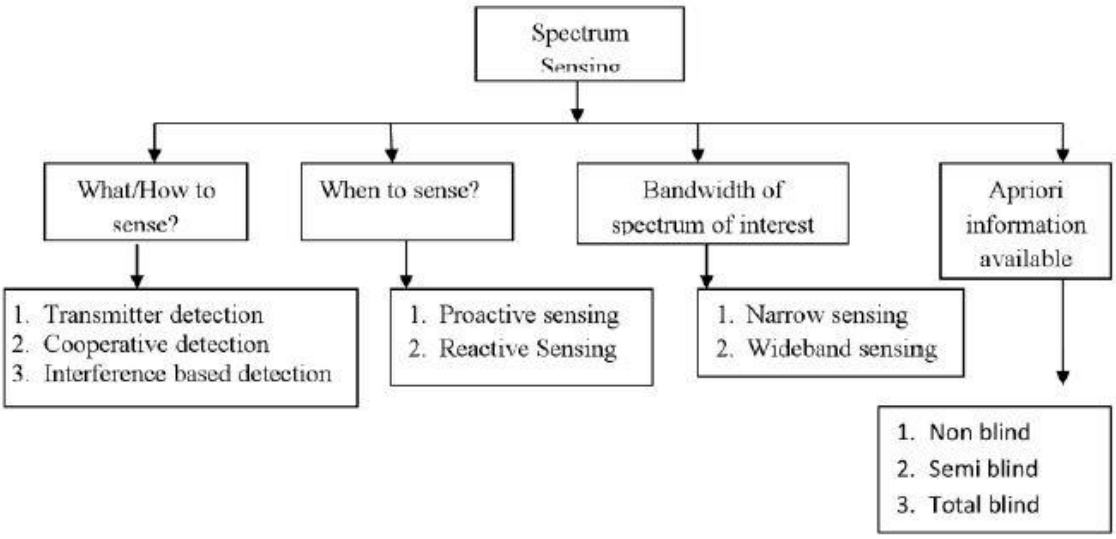

Figure: 1: Broder classification of techniques of spectrum sensing

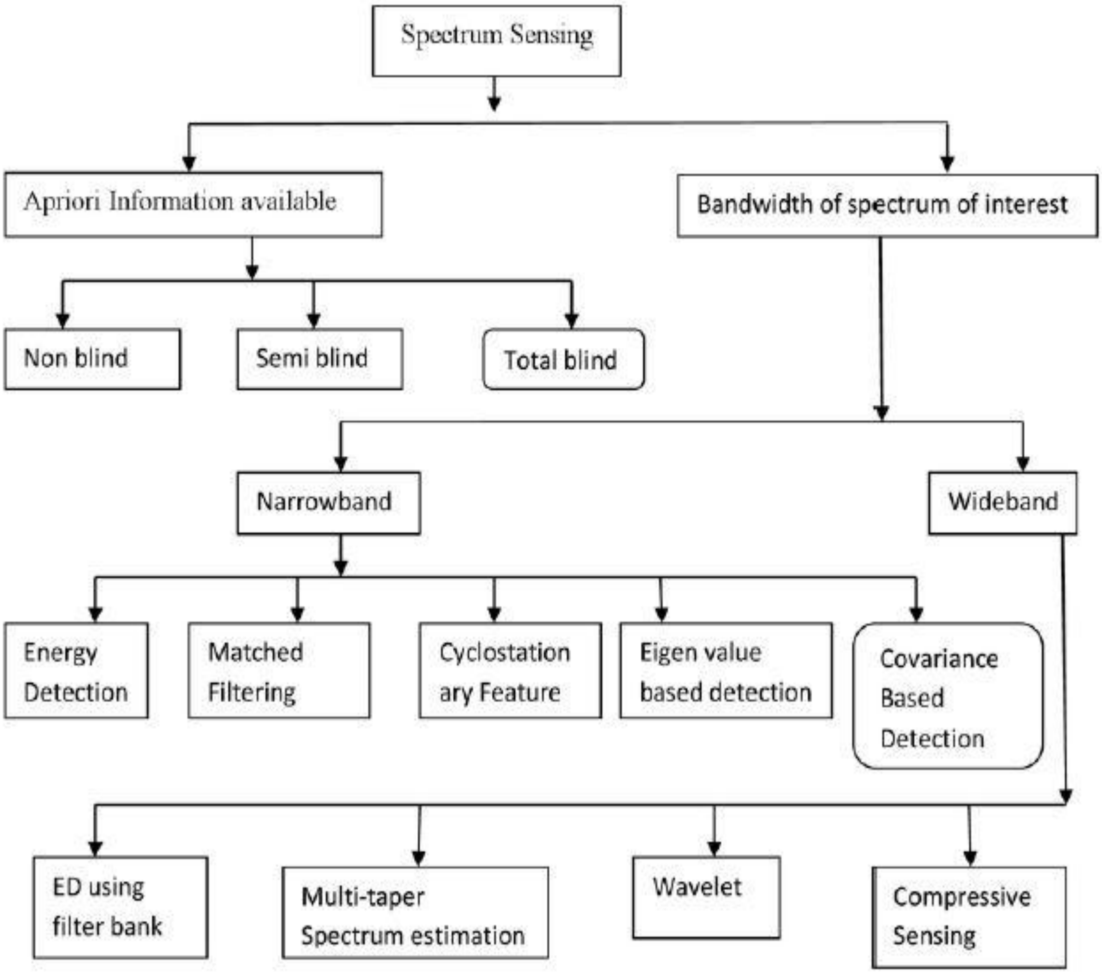

Figure 2: Classification spectrum sensing techniques based on primary transmitter

Comparison of different detection techniques: Figure 3 shows comparative analysis of detection method based on transmitter in terms of accuracy and operational complexity. Among all described techniques matched filter-based detection has highest complexity and highest precision. Similarly, the lowest complexity and lowest accuracy is offered by energy detection method [14,15].

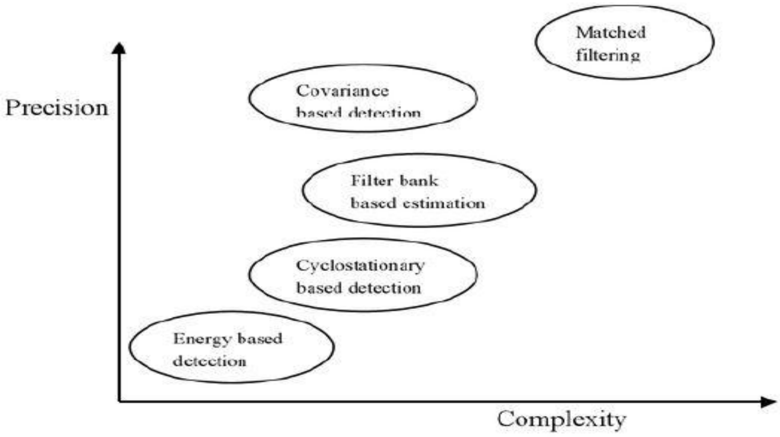

Figure 3: complexity Vs precision of different transmitter detection methods

ISSUES AND CHALLENGES IN SPECTRUM SENSING

3.1 Challenges in Non-Cooperative Sensing

- Lower Sensitivity of detecting lower power PU signals. Like for TV signal it is supposed to detect signal up to -21 dB because of fading and shadowing. In dynamic scenario these requirements increased by 30–40 db.
- Lower flexibility; since high flexibility is required to be adaptive with changing external radio spectrum in both time and space. Higher flexibility ensures better changing parameters as per requirement.
- Hidden main user issue; if primary user is just outside specified area in that situation SU ignore it.
- Sensing based on fewer parameters
- Performance degradation if other SU's network is present nearby. In such condition system performance degrades with increasing interference

3.2 Challenges in Cooperative Sensing

- Channel commands are required to achieve cooperation; which always acts as channel overhead. This data/information transmitted through control channel.
- Decision time more, since require mutual agreement on sensed data
- Increased miss detection as a result of multiple agencies, also called as correlated shadowing.
- Information management becomes hectic as amount of data increase as a result of increased in participating secondary users, this effect system performance in multiple ways.

4. MATHEMATICAL MODEL OF ENERGY DETECTION

Mathematically, if a cognitive user that wants to find the availability of primary user signal. To find the presence of primary user by means of energy detector we compare detected power of first user with threshold defined to detect any transmission from primary side.

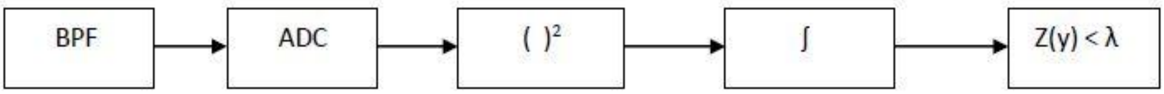

Fig. 4: Block Diagram of Traditional Energy Detector

From Figure 4 the band first filter allows only signals of particular band to pass through it which further digitized by second stage of analog to digital convertor (ADC). Squared version of this digitized signal further integrated to get energy estimate over complete sensing duration [16]. This digitized signal further compared with predefined and precalculated threshold of estimated energy to detect presence of primary user (PU) in desired band. The estimated detection is a semi blind detection method because it doesn't require signature of the primary signal. But estimated detection requires knowledge of the channel noise to define a threshold [17,18].

On basis of above discussion two thesis can be framed out of this as
$A(e)= C(e) \qquad X_0$ (4.1)
$B(e)=A(e)+w(n)X_1$(4.2)

where
B(e) is the received signal at the secondary user
A(e) is PU signal with zero mean and variance σ_s^2
C(e) is channel noise with AWGN characteristics

Where X_0 indicates absence of PU or a condition when band can be allocated to opportunistic users, where's X_1suggest presence of PU and in that condition, band has to been dedicated to PU only.
Over AWGN channel detection probability (P_d) and probable rate of false alarm can be formulated as under
P_d=Prob(Z(B>λ_d|X_1)
P_d=1/2(λ_d−μ1/σ_1) (4.3)
P_{fa}=Prob(Z(B>λ_{fa}|X_0)
P_{fa}=1/2(λ_{fa}−μ_0/σ_0)   (4.4)

Probability of misdetection P_m is another important parameter. P_m is high means decision of energy detector is wrong; in case of presence it is showing absence and vice-versa.
P_m=1−P_d(3.8)

5. RESULTS

Results are simulated by computer simulation in MATLAB 2013a. For simulation purpose some values of parameters used in research work are assumed. These are targeted value of P_d is taken 0.9 - 0.95 for CDR scheme and targeted value of P_{fa} is taken as 0.01 for CFAR scheme. SNR range is taken from -20 dB to 0 dB. For certain noise, noise power is assumed to be completely known (σ_n^2=1).

P_d and P_{fa} trade-off analysis: First two figures show the trade-off between P_d and P_{fa} and these results also illustrate that the performance of the ED start degrading below a critical value of SNR.

Sensing Error Probability (P_e): Figure 5 to 9 shows the analysis of P_e for both certain and uncertain noise and also includes analysis of P_e with different value of threshold.

Results are generated by computer simulation in Matlab2013a. Figure 5 illustrate that energy detector with the decision threshold (λ_f) obtained from CFAR criteria, works well in high SNR conditions but as the value of SNR decrease probability of detection decrease dramatically but when the decision threshold is $\lambda_d$then P_d meet the targeted value. But figure 6 illustrate that for the same decision threshold the probability of false alarm is high in low SNR region, this leads to a trade-off between P_d and P_{fa}. Figure 5.1 shows that two curves intersect each other at a point, SNR at this point is called critical SNR, beyond this critical SNR, both the curves meet the preferred value of probability, whereas below this critical value a trade-off exists between P_d and P_{fa}.

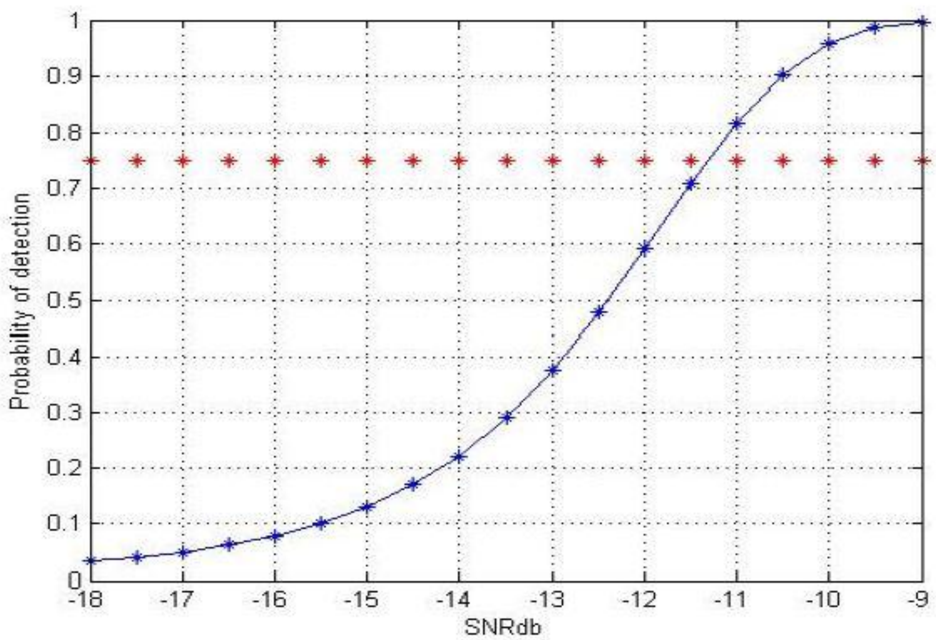

Fig. 5: Probability of detection for the two thresholds obtained from CFAR criteria and CDR criteria.

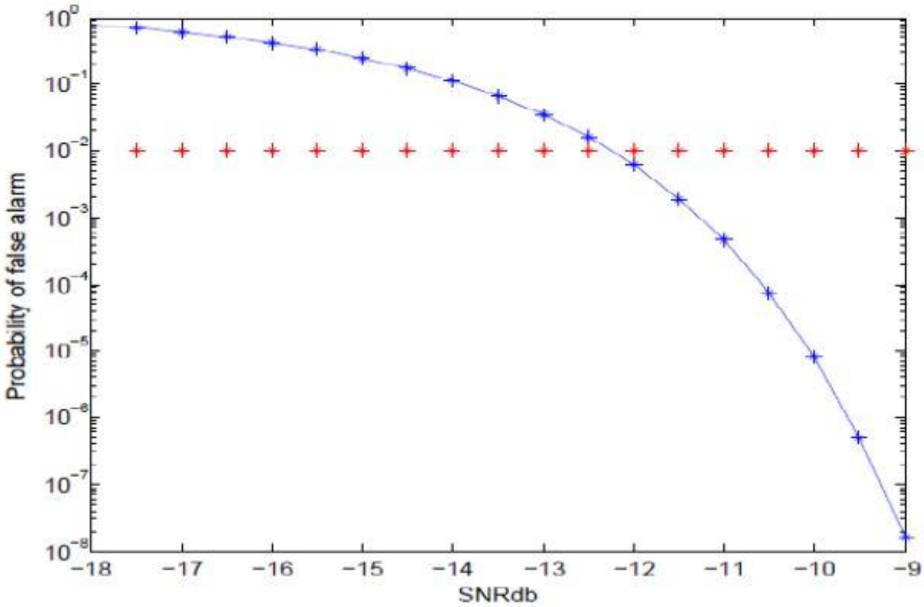

Fig. 6: False alarm Probability for the two thresholds obtained from CFAR criteria and CDR criteria.

Traditional energy detector calculates the threshold by targeting the Pfa which doesn't require knowledge of SNR therefore when SNR is below the particular SNR value, performance of the energy detector deteriorates. If the SNR of the channel is more than critical value than there are two options, if it is mandated to cause the least interference with the primary user than λ_{fa} can be chosen as decision threshold. But if high throughput is required from the secondary network than λ_d can be chosen as decision threshold.

Assumption for simulation are listed below
• Platform used: Matlab
• Noise power: 1 (completely known environment)
• P_{fa} = 0.01 for constant false alarm scenario
• P_d = 0.9 for constant detection scenario
• P_m= .01 over complete range from 0 to -25 dB.
Simulation parameter for analysis of constant detection scheme in noisy environment
• Uncertainty factor= 1 to 1.4
• SNR= 0 to -25

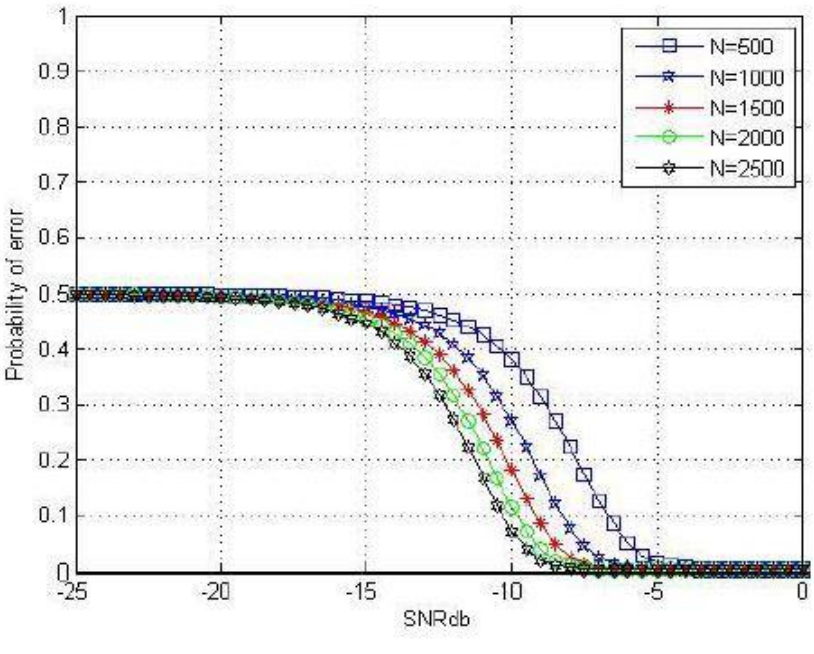

Fig. 7: Error probability in constant false alarm rate.

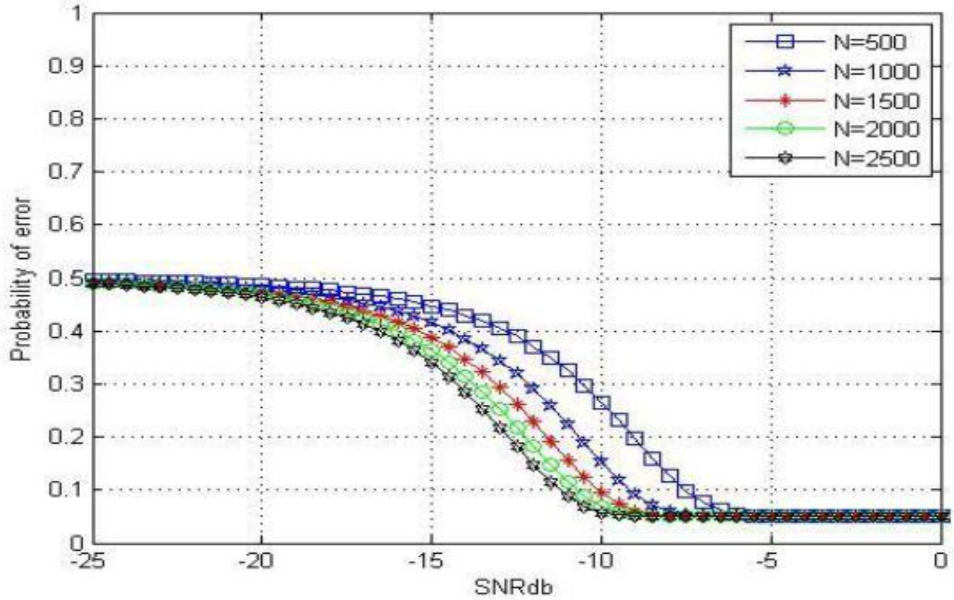

Fig. 8: Error probability for constant detection scheme Vs. SNR

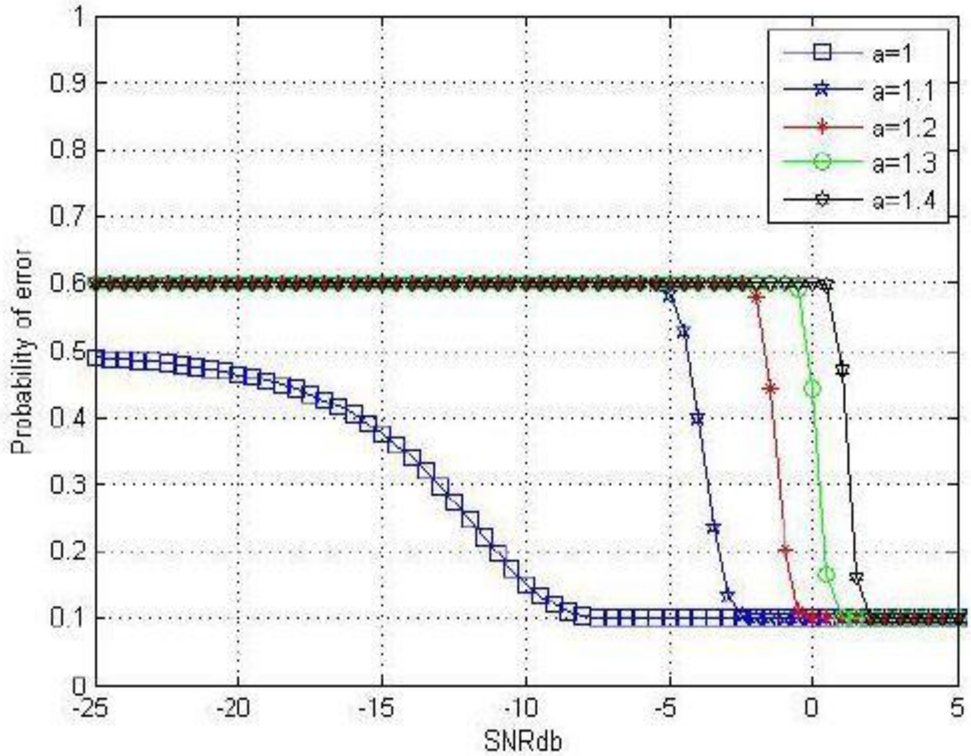

Figure 9: shows false rate increases as we increase uncertainty probability.

CONCLUSION

In this paper, performance of the energy detector at low SNR is analysed. For better performance there is always trade off to have low false alarm probability and high detection probability, i.e. if energy detector getting high P_d at low SNR than for the same SNR P_{fa} is also high resulting into higher error probability. Achieving a low error probability in all scenario whether it may be noise or desired was the motivation of this work; which has been successfully achieved.Analysis done here for both scenario (noise and known) shows improved performance when results for a defined test case has been simulated for both the cases i.e. error probability using detection rate as constant and false alarm rate as constant. Both yield a much lower error and improved performance drastically. This work analyses the sensing error probability and explore some situations that really helpful in real time scenarios. This work can further be used in order to obtain batter probability of error.

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