Simulation of Probability of False Alarm and Probability of Detection Using Energy Detection in Coginitive Radio

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Abstract
The rapid growth of wireless devices and application has contributed to huge demand for licensed and unlicensed frequency spectrum. However, recent studies exhibits that restricted spectrum assignment policy results in congestion for spectrum utilization under which considerable portion of the licensed spectrum is severely under-utilized. To address this problem, Cognitive radio is a paradigm for wireless communication in which network or a node changes its transmission and receiver parameters in order to communicate effectively and avoiding interference with licensed or unlicensed user. The main function of each Cognitive Radio User in CR network is to identify primary licensed user. This is attained by sensing RF environment and a process called Spectrum sensing Algorithm. In this paper the simulation of probability of false alarm and probability of detection is discussed.

Keywords
Cognitive Radio, Energy Detection, Primary User, Secondary User, Threshold

I. Introduction

Wireless communication has seen an emerging trend for the last few decades, it has been seen that there is a tremendous growth in the particular sector. With the increasing number of users scarcity of electromagnetic spectrum is obvious. Now to accommodate the increasing number of users in the limited spectrum available is a problem. With this thing into consideration, the Federal Communications Commission (FCC) published a report prepared by Spectrum Policy Task Force (SPTF) [1]. It is seen that there is significant inefficient spectrum utilization than the actual spectrum scarcity. Most of the allotted channels are not in use or most of the time; some are partially occupied while others are heavily used. It has been observed that present day the regulatory body manages spectrum under fixed spectrum management scheme. The problem of underutilization of allocated spectrum or the underutilized area is technically defined as a spectrum hole. A spectrum hole is band of frequencies assigned to the primary user but at a given instant of time these frequency bands are not being utilized and thus are free we also know them as white spaces [2]. All this is frequently observed under static spectrum allocation of spectrum.

In the Dynamic spectrum management the spectrum can be accessed in an opportunistic manner, this can be done using two techniques : SDR and CR. The only difference between the former and the latter lies in its reconfigurability. The SDR technique is for reconfigurable radio equipments whereas CR can reconfigure on its own. Here Cognitive radio (CR) dynamically aims to innovate the traditional fixed spectrum.

Therefore, SDR is a shift from conventional radio where functionality is provided in software. In SDR the modulation, demodulation and baseband processing all is done after programming in SDR. However characteristics can change if the software loaded in this radio is changed. Thus SDR can switch functions and operations because of reconfigurable software incorporated in it. SDR cannot reconfigure on its own. The software defined radio which has the capability to reconfigure on its own is defined as a cognitive radio . In other words we can say that CR is self aware, RF aware, user aware. It has high fidelity and is language technology adaptable with machine vision. The cognitive cycle helps CR to reconfigure them. In Cognitive cycle the CR follows these steps for reconfigurability i.e. Awareness, Perception reasoning and then Decision making.

In context to opportunistic spectrum sensing with cognitive radio's, it is to be noted that CR interacting with real time environment has the capability to dynamically alter its operating parameters such as transmitting power, carrier frequency, modulation and assimilates itself with the environment whenever there is statistical change in incoming radio frequency with the sole purpose to take advantage of the available spectrum without causing any interference to the licensed users.

Therefore, problem emerged as a result of fixed spectrum allocation can be resolved with the help of Cognitive Radio. This technology enables the access of the intermitted periods of unoccupied frequency bands called spectrum holes, thereby increasing spectral efficiency. Thus, in CR networks the task of CR users is to detect the licensed users, known as primary users (PUs), if present and identify the available spectrum if they are absent. This is usually achieved by sensing the RF environment, a process called spectrum sensing [3]. CR users should not cause harmful interference to PUs by either switching to unavailable band or limiting its interference with PU at an acceptable level. CR user should efficiently identify and exploit the spectrum holes for required throughput and quality-of-service (QoS). Thus, the detection performance in spectrum sensing is crucial to the performance of both primary and CR networks.

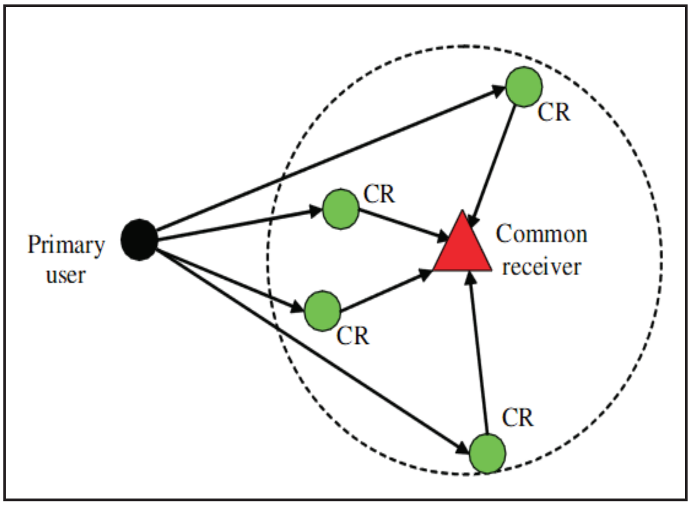

Fig. 1: Shows Spectrum Sensing Structure in Cognitive Radio Network

The detection performance can be primarily determined on the basis of two metrics: probability of false alarm and probability of detection. Probability of false detection denotes the probability of a CR user declaring that a PU is present when the spectrum is actually free. Probability of detection denotes the probability

ISSN : 0976-8491 (Online) | ISSN : 2229-4333 (Print)

of a CR user declaring that a PU is present when the spectrum is indeed occupied by the PU [3]. CR network can be categorized into three classes: underlay, overlay and interweave. Cognitive user needs to accurately detect whether the current band is occupied by a licensed user to ensure the licensed user's use of specific bands. Spectrum sensing algorithms in CR can be mainly divided into three types: energy detection, match filter detection, and cyclostationary detection. Among them , energy detection has been widely applied since its algorithm is simple, and it does not require transcendental knowledge of the licensed user's signals. Due to the interference factors, such as multipath and shadow effect of wireless channels, energy sensing conducted by single cognitive sensing node that has low signal-to-noise ratio (SNR) of the received signal may be unreliable [4].

II. Cognitive Cycle

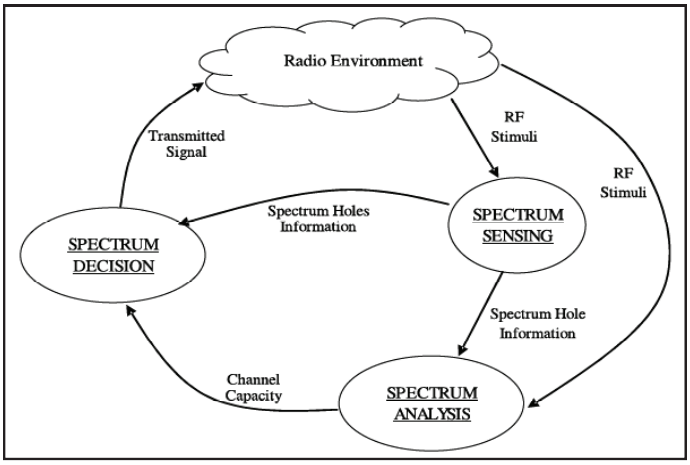

Fig. 2: Cognitive Cycle

Fig. 2 shows a basic Cognitive cycle [5]. A basic cognitive cycle comprises of following three basic tasks:

- Spectrum Sensing
- Spectrum Analysis
- Spectrum Decision Making

A. Spectrum Sensing

With sensing we mean real time wide band monitoring. In spectrum sensing the system is sensed and made aware of the parameters related to the radio channel characteristics. The availability of the spectrum is sensed keeping in view the transmitting power interference and noise. It is done across Frequency, Time, Geographical Space, Code and Phase.

B. Spectrum Analysis

Spectrum Analysis is based on spectrum sensing, it is rapid characterization of environment. In spectrum analysis the situation of several factors in the external and internal radio environment is monitored. It helps finding the optimal communication protocol and changing frequency or channel accordingly. It is also known as channel estimation.

C. Spectrum Decision Making

Spectrum Decision Making is based on spectrum analysis. The spectrum band to be used and its related parameters are sensed by spectrum analyzer and then spectrum decision maker give transmitted signal to the environment.

III. Cognitive Radio Architecture & Design

The network-centric cognitive radio architecture is aimed at providing a high-performance platform for experimentation with various adaptive wireless network protocols ranging from simple etiquettes to more complex ad-hoc collaboration. The basic design provides for fast RF scanning capability, an agile RF transceiver working over a range of frequency bands, a software-defined radio modem capable of supporting a variety of waveforms including OFDM and DSSS/QPSK, a packet processing engine for protocol and routing functionality, and a general purpose processor for implementation of spectrum etiquette policies and algorithms. There are two major subsystems in a cognitive radio, a cognitive unit that makes decisions based on various inputs and a flexible SDR unit whose operating software provide a range of possible operating modes. A separate spectrum sensing subsystem is also often included in the architectural a cognitive radio to measure the signal environment to determine the presence of other services or users. It is important to note that these subsystem do not necessarily define a single piece of equipment, but may instead incorporate components that are spread across an entire network. As a result, cognitive radio is often referred to as a cognitive radio system or a cognitive network. Fig. 3 shows a simplified architecture of cognitive radio network [6].

As shown, the cognitive engine tries to find a solution or optimize a performance goal based on inputs received defining the radio's current internal state and operating environment. The policy engine is in compliance with regulatory rule and other policies external to the radio. Cognitive radio (CR) enables much higher spectrum efficiency by dynamic spectrum access [7]. Therefore, it is a potential technique for future wireless communications to mitigate the spectrum scarcity issue. As unlicensed (secondary) users of the spectrum band, CR operators are allowed to utilize the spectral resources only when it does not cause interference to the primary (licensed) users, which entails continuous spectrum sensing in CR networks. Therefore, it becomes a critical issue in cognitive radio to reliably and quickly detect the presence of the primary users.

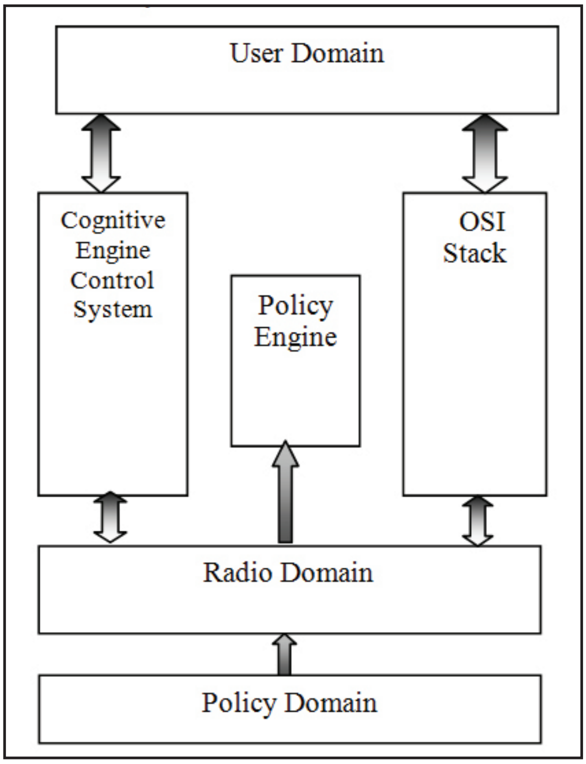

Fig. 3: Simplified Architecture of Cognitive Radio Network

A. Features that Cognitive Radios Can Incorporate to Enable a More Efficient and Flexible Usage of the Spectrum [8].

1. Frequency Agility:- The cognitive radio is able to change its operating frequency for its adaptation to the environment.
2. Dynamic Frequency Selection:- The cognitive radio senses signals from nearby transmitters to choose an optimal environment to work in.
3. Adaptive Modulation:- The transmission characteristics and waveforms can be reconfigured to exploit all opportunities for the usage of spectrum in an efficient way.
4. Transmit Power Control:-The transmission power is adapted to full power limits when necessary on the one hand and to lower levels on the other hand to allow greater sharing of spectrum.

Physical Architecture of Cognitive Radio Networks [9]

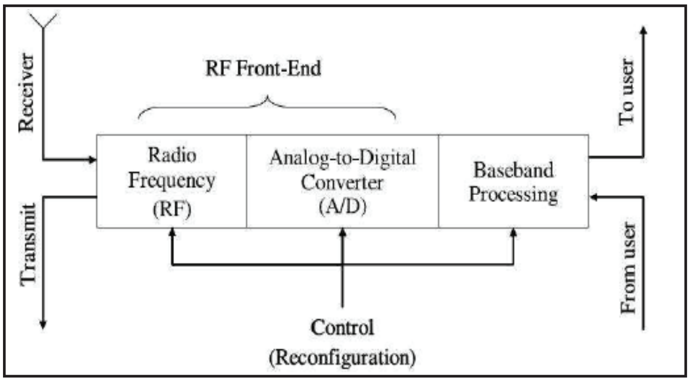

Fig. 4: Cognitive Radio Transceiver Architecture [14]

IV. Spectrum Sensing

The most tedious and crucial task to establish Cognitive radio Networks includes spectrum sensing. The spectrum Sensing technique aims to determine the availability of spectrum and the presence of the licensed users (PU). To allow reliable operation of cognitive radios, we must be able to detect precisely the spectrum holes at the link level. In practice, the unlicensed users, also called secondary users (SUs), need to continuously monitor the activities of the licensed users, also called primary users (PUs), to find the spectrum holes (SHs), which is defined as the spectrum bands that can be used by the SUs without interfering with the PUs. This procedure is called spectrum sensing[10]. There are two types of SHs, namely temporal and spatial SHs, respectively. A temporal SH appears when there is no PU transmission during a certain time period and the SUs can use the spectrum for transmission. A spatial SH appears when the PU transmission is within an area and the SUs can use the spectrum outside that area.

The sensing results basis helps SUs to obtain information about the channels so that they have access. However, the channel conditions may change rapidly and the behavior of the PUs might change as well. To use the spectrum bands effectively after they are found available, spectrum sharing and allocation techniques are important .As PUs have priorities to use the spectrum when SUs co-exist with them, the interference generated by the SU transmission needs to be below a tolerable threshold of the PU system[11] . Thus, to manage the interference to the PU system and the mutual interference among SUs, power control schemes should be carefully designed.

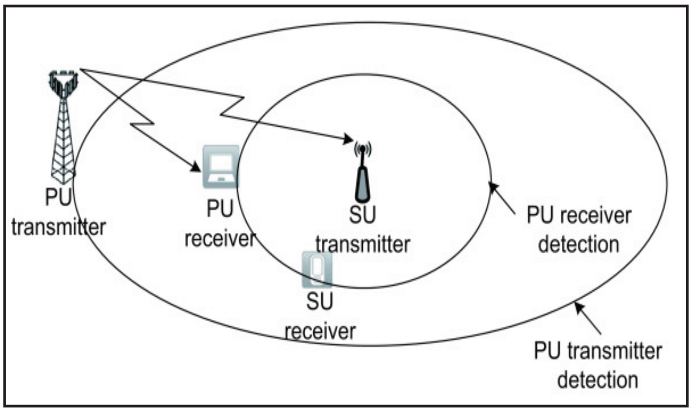

Fig. 4: Basic Principle of Primary Detection [14]

- PU transmitter is sends data to the PU receiver in a licensed spectrum band
- Pair of SUs intends to access the spectrum now to protect the PU transmission, the SU transmitter performs spectrum sensing
- The spectrum sensing by SU helps to detect whether there is a PU receiver in the coverage of the SU transmitter or not.
- However detection of PU receiver is difficult hence presence or absence of PU signal is done easily.
- As per figure the radius of PU transmitter and PU receiver detections are different, which lead to some shortcomings and challenges.
- It may happen that the PU receiver is outside the PU transmitter detection radius, where the SH may be missed. Since the PU receiver detection is difficult, most study focuses on PU transmitter detection.

A. Detection Theory

Assume a parametric measurement model $p(x|\theta)$ or $p(x;\theta)$, which is the notation that sometimes use in the classical setting.

In point estimation theory, estimate the parameter $\theta \in \Theta$ given the data x.

Now suppose that Θ_0 and Θ_1 forms a partition of the parameter space Θ:

$$\Theta_0 \cup \Theta_1 = \Theta, \qquad \Theta_0 \cap \Theta_1 = \emptyset.$$

In detection theory, to check which hypothesis is true

$H_0 : \theta \in \Theta_0$, null hypothesis

$H_1 : \theta \in \Theta_1$, alternative hypothesis

B. Rules of Detection

To design decision rule $\varphi(x)$: $X \rightarrow (0,1)$:

$$\Phi(x) = \begin{cases} 1, & decide\ H_1 \\ 0, & decide\ H_0 \end{cases},$$

which partition the data space X[i.e. the support of $p(x|\theta)$] into two regions:

Rule $\varphi(x)$: $X_0 = \{ x: \varphi(x) = 0\}$, $X_1 = \{ x: \varphi(x) = 1\}$.

Probability of false alarm and miss:

$P_{FA} = E_{X|\theta} [\varphi(X) \mid \theta] = \int_{x1} p(x \mid \theta)\, d_x$ for θ inΘ_0

$P_M = E_{X|\theta} [1- \varphi(X) \mid \theta] = 1-\int x_1\, p(x \mid \theta)\, dx$

$= \int_{x0} p(x \mid \theta)\, dx$ for θ inΘ_1.

Then, the probability of detection is:

$P_D = 1- P_M = E_{X|\theta} [\varphi(X) \mid \theta] = \int_{x1} p(x \mid \theta)\, dx$ for θ inΘ_1

According to the equations plot the Probability of Detection (Pd) vs. Probability of False Alarm (Pf)

Table 1: Probability of False Alarm vs Probability of Detection for SNR = -10 dB

Probability of False Alarm (Pf)	Probability of Detection (Pd)
0	0.7
0.1	0.87
0.2	0.93
0.3	0.95
0.4	0.96
0.6	0.98
0.8	0.99
1	1

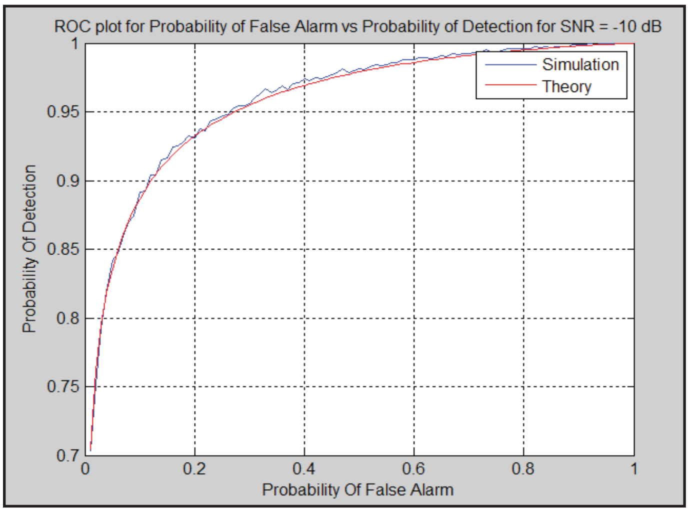

Fig. 5: ROC Plot for Probability of False Alarm vs Probability of Detection for SNR = -10 dB

VII. Conclusion

The computation done keeping in mind Pd (Probability of detection). It is seen that there is greater chances of false detection at higher Pd (Probability of detection) . the results show Probability of False Alarm vs Probability of Detection for SNR = -10 db.

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