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Analysis of factors influencing the performance of Cognitive Radio Networks

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Abstract – The increased number of wireless devices has led to spectrum hungriness. OFCOM and FCC found this and paved way for a new technology named Cognitive Radio (CR). The CR is a Software Defined Radio (SDR) that is self-organizing. This CR divides the spectrum into licensed band and unlicensed bands. The licensed band constitutes the Primary User (PU) and the unlicensed band the Secondary User (SU). The CR works eventually with managing frameworks like spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. Of this, spectrum sensing is important since wrong sensing leads to inefficient spectrum usage. Hence it becomes mandatory to analyze the parameter that helps for proper utility of radio environment. Thus a CR has to be built keeping an eye over the parameters. Thus this paper rolls down the analysis over several parameters and the uplink and downlink transmissions.

Index terms – Cognitive Radio (CR), software defined radio (SDR), Primary User (PU), Secondary User (SU).

I. INTRODUCTION

A CR is defined as a radio that is aware of its environment and the internal state and any stored pre-defined objectives that can make and implement decisions about its behavior. The basic idea of CR networks is that the unlicensed devices (also called cognitive radio users or secondary users) need to vacate the band once the licensed device (also known as a primary user) is detected. CR networks, however, impose unique challenges due to the high fluctuation in the available spectrum as well as diverse quality of-service (QoS) requirements. Spectrum sensing is a basic functionality in CR networks, and hence it is closely related to other spectrum management functions as well as layering protocols to provide information on spectrum availability. The idea of cognitive radio was first presented officially in an article by Joseph Mitola III and Gerald Q. Maguire, Jr in 1999. CR is one of the new long term developments taking place in radio communications technology. The first phone call over a CR network was made on Monday, 11 January 2010 in the Centre for Wireless Communications at the University of Oulu using CWC's cognitive-radio network, CRAMNET (Cognitive Radio Assisted Mobile Ad Hoc Network), which was developed by CWC researchers.

The cognitive architecture constitutes of primary network and CR network components as shown in figure 1. The primary network is referred to as an existing network, where the primary users (PUs) have a license to operate in a certain spectrum band. If primary networks have an infrastructure support, the operations of the PUs are controlled through primary base stations. Due to their priority in spectrum access, the PUs should not be affected by unlicensed users (SUs). The available spectrum bands are distributed over a wide frequency range, which vary over time and space that are used by the users. Thus, each user shows different spectrum availability according to the primary user (PU) activity.

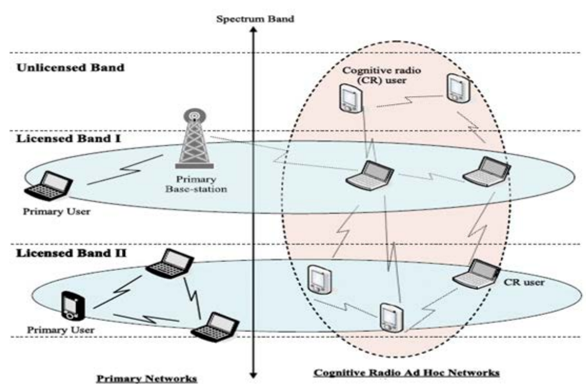

Figure 1 Cognitive architecture

CR has two properties that makes it more friendly; Cognitive capability and reconfigurability. Cognitive capability is the ability of the radio technology to capture or sense the information from its radio environment. By this, the portions of the spectrum that are unused at a specific time or location can be identified and also the best spectrum and appropriate operating parameters can be selected. It categorizes its functions into four main domains as shown in figure 2.

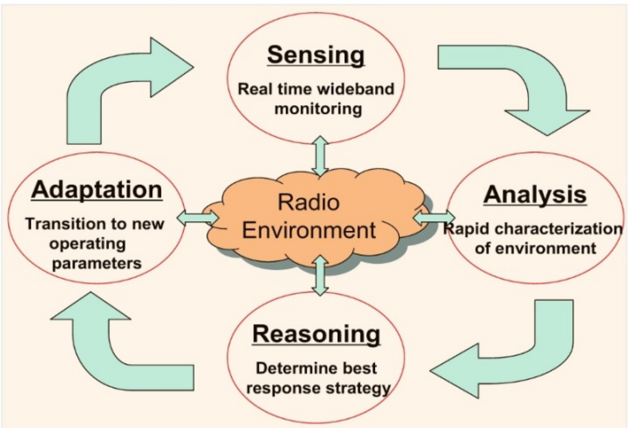

Figure 2 Cognitive Cycle

CR with dynamic spectrum access capability has got several challenges apart from transmitting/ receiving data to ensure quality of service (QOS) in the wireless environment. Further the additional challenges of CR in the DSA environment can be divided into three major categories: Primary sensing, Preswitching synchronization, fast switching. Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase.

CR spectrum sensing methodology must allow time slots when it does not transmit to enable the system to detect other signals. Spectrum Analysis is based on spectrum sensing which is analyzing the situation of several factors in the external and internal radio environment (such as radio frequency spectrum use by neighboring devices, user behavior and network state) and finding the optimal communication protocol and changing frequency or channel accordingly. It is also known as channel estimation.

Spectrum sensing falls into two categories such as non co-operative spectrum sensing and co-operative spectrum sensing. The non co-operative occurs when a CR acts on its own. For e.g. Energy detection, Matched filter detection, Cyclostationary detection. Sensing will be undertaken by a number of different radios within a CR network in a co-operative spectrum sensing. A central station will receive reports of signals from a variety of radios in the network and then combine decision by some particular fusion rule.

Matched filtering is an optimal method for detection of PUs when a known signal is transmitted. This requires less time to achieve high processing gain and probability of false alarm and mis detection due to coherent detection. A non-coherent detection technique is the Energy detection technique in which no details of pilot data is needed. It is based on some function of the received samples which is compared to a predetermined threshold level. By exploiting the Cyclostationary features of the received signals, the primary user transmissions cab ne detected. Such a detection technique is referred as Cyclostationary feature detection technique. Hidden node problem, Increase in agility, reduced false alarms, more accurate signal detection are few merits of this technique.

Hidden incumbent problem is one of the major issues that have to be monitored. Consider two CR nodes (A and B) that communicate in a frequency channel. If an incumbent D starts transmitting near A in the same frequency channel as A, upon detecting the primary incumbent A initiates the channel switching process by dynamically choosing a new channel that is available from its local spectrum report and migrates to the new channel. The problem here is that the receiver may have a primary device C that already operates in the new frequency channel in its vicinity but outside the region of A (hidden incumbent scenario). The primary A does not have any knowledge about this frequency utility. Finally, A ends up being in the new channel and node B will exist in the old channel resulting in synchronization failure and loss of communication.

Figure 3 below depicts the above mentioned where the primary devices gets acted upon by the secondary devices. There results the communication and synchronization failure due to this hidden node incumbent problem.

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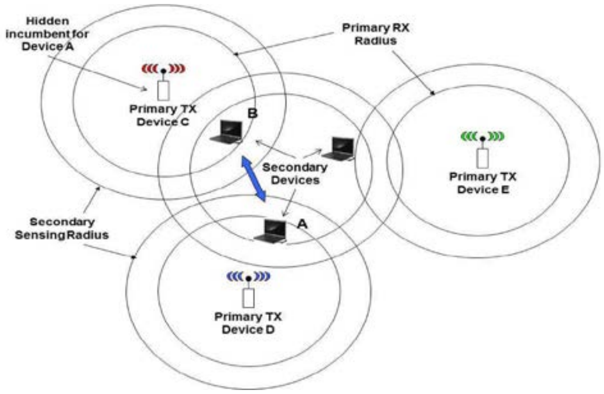

Figure 3 Hidden incumbent scenarios

I. DESIGN

Incumbent sensing/detection are one of the main aspects of a CR network. From other CR communications and a primary incumbent communications often energy, noise and interference detection are used. And thus it becomes necessary to develop a modified approach for accurate sensing/detection.

The detection threshold is defined as the number of errors (in a certain sensing duration) exceeding the value of which signifies the presence of primary incumbent. If the threshold is set too low, the CR may incur a high number of false alarms (i.e., detecting the existence of primary incumbent while the incumbent is actually not present) and if the threshold is set too high, there may be a high probability of misdetection (missing to detect the primary when it is present). Dynamic thresholding scheme that adapts to the time-varying wireless environment is required to be opted.

In order to execute these techniques, several constants are used for evaluation. The constants used here include: number of users, time bandwidth factor, path loss, constant loss, threshold levels, signal-to-noise ratio, error rate, ambient temperature, Boltzmann constant etc. Basically the analysis deals with the probability of false detection, probability of misdetection, threshold with total error rate and probability of bit error with signal-to-noise ratio. These parameters have got a special and important implication over the network. These are ought to be chosen such that it accounts for better performance. First the analysis is made for the Probability of False Alarm and Probability of Misdetection. The required parameters are initialized first and then formulate the AND rule i.e., PdAnd=0 and the time constant Pf is given. The signal is added along with a carrier. A SNR is defined here that gives the signal strength. Once these are made, local spectrum sensing is carried out using any detection technique. The channel used here is the Additive White Gaussian noise channel. The test strategy is made such that if for j users, the value are greater than lmdba. If it is yes then detect=detect+1, if not end. It becomes essential to analyze the signal-to-noise ratio after the performance analysis of false alarm, misdetection, and threshold.

The analysis of signal-to-noise ratio is compared with bit error rate. The required input parameters are initialized first. A random source is used which acts upon the input signal. The input signal is encoded by a channel encoder. The channel modulation is performed with the help of any modulation technique. After modulation, the noise gets introduced in the channel and to explore this matched filtering technique is used. Channel decoding is done to retrieve the signal back. Simulation is done for the above and the plot is made between Bit Error rate and Signal-to-noise ratio.

The capacity for a given number of CR users both in terms of uplink and downlink becomes necessary for analysis. The power used at base station for transmission, the rate at which the transmission occurs, the q factor, the gain of both transmitter and receiver all these influence the capacity factor. Computation of capacity and computation of active SUs both are evaluated predominantly with respect to the number of SUs. First the cell parameters are given that includes outer radius, interference radius for the primary and secondary users. The rate at which transmission occurs is also given. The propagation parameters i.e. the transmission power at the base station, the gain of antenna at the transmitter, the gain of the antenna at the receiver. After this the receiver power is noted. The average ratio of users and the average interference power is obtained. Then simulation is carried for computation of capacity and active number of secondary users.

II. SIMULATION AND RESULTS

The performance analysis of spectrum sensing of CRN are carried out and done using the platform MATLAB. The performance analysis of each is performed and the inferences are made accordingly with stipulated values of reference.

First the analysis of probability of false alarm and mis detection is analyzed. Based on the results obtained from the test

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strategies it can be observed that SNR and the random distance has got a direct impact over the number of CR users. The simulated results show that it varies with respect to different SNR values and the corresponding distance. For the same distance or same SNR value with varied distance and SNR, the simulated result with respect to CR's varies. The following figures 4 and 5 with SNR db 5 and 15 with a distance of 7:0.1:8 respectively is shown below.

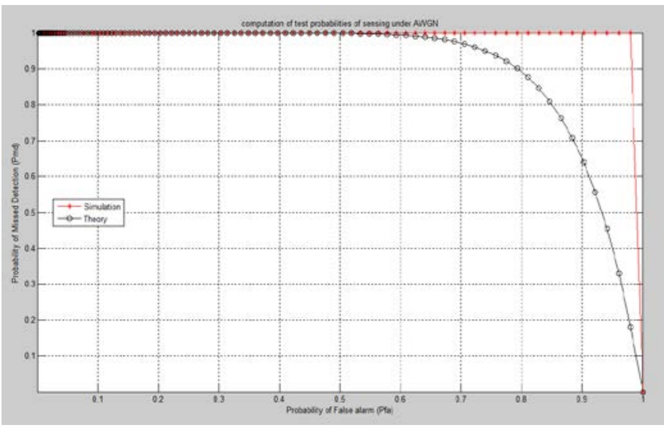

Figure 4 Computation of Test Strategies (SNR 5db)

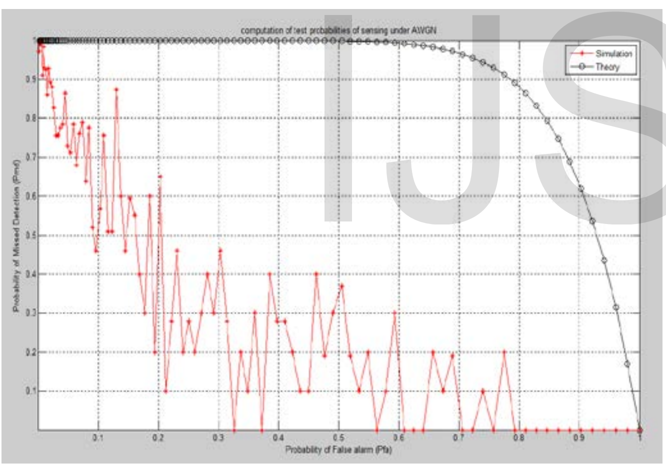

Figure 5 Computation of Test Strategies (SNR 15db)

Next the analysis of bit error rate is performed. The evaluation of relation between bit error rate and SNR was formulated by using a modulation scheme and a plot is made for it with the coded channel error and the uncoded channel error. The errors tend to vary for the coded and uncoded channel error. The following figure 6 shows the corresponding output.

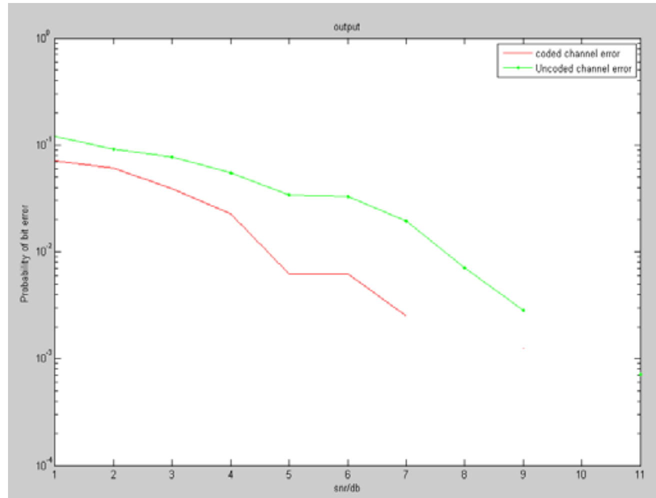

Figure 6 Probability of Bit Error Rate

For the evaluation of capacity, plot is made between the numbers of SUs and SU capacity per active SUs (bits/s/Hz). In the analysis of computation of capacity, the uplink quotient with varied rates and q are inferred to be in correlation with the downlink of same rates and q as of uplink. The downlink is analyzed with the power at base station in Watts, such that it helps to know the capacity with respect to amount of power consumed. This is been analyzed with R=0.1, 0.3 0.5 bits/s/Hz, P_{BS}=10W and R=0.2, 0.4, 0.6 bits/s/Hz, P_{BS}=15 W. The following figures 7 and 8 show them respectively.

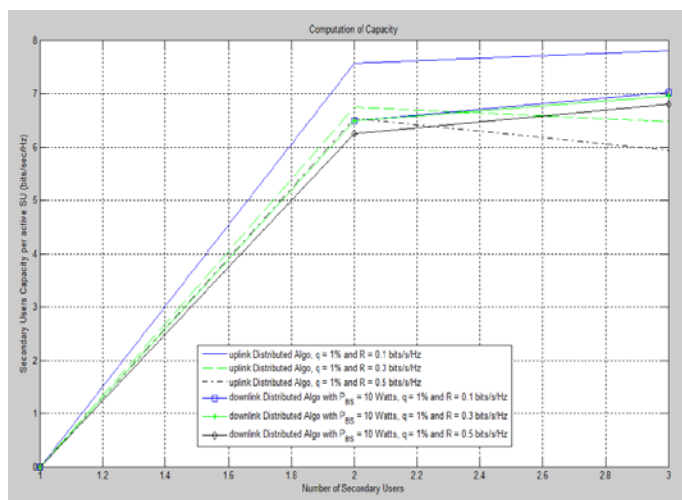

Figure 7 Computation of capacity with R=0.1, 0.3, 0.5 bits/s/Hz, P_{BS}=10W

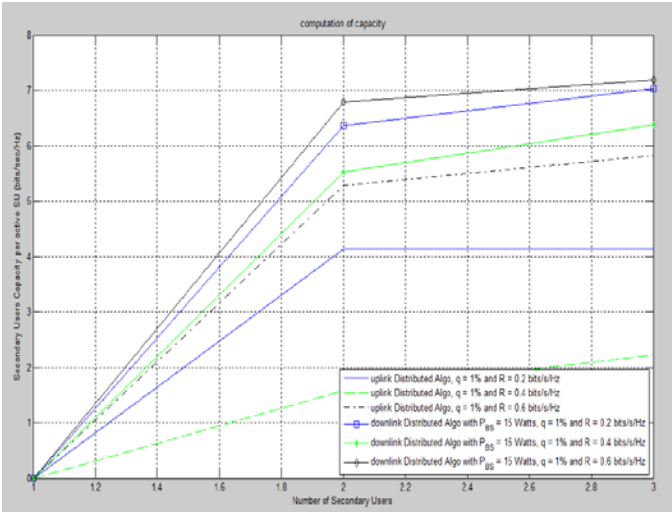

Figure 8 Computation of capacity with R=0.2, 0.4, 0.6 bits/s/Hz, P_{BS}=15 W

The next execution is made for the capacity utility between the number of SUs and active number of SUs. As like the computation of capacity, this is also made with varying R and P_{BS} rates. The uplink and downlink level varies greatly with that of varying R and P_{BS}. The active users are picked upon by those which currently get involved in transmission. It is analyzed with R=0.1, 0.3 0.5 bits/s/Hz, P_{BS}=10W and R=0.2, 0.4, 0.6 bits/s/Hz, P_{BS}=15 W. The following figures 9 and 10 show them respectively.

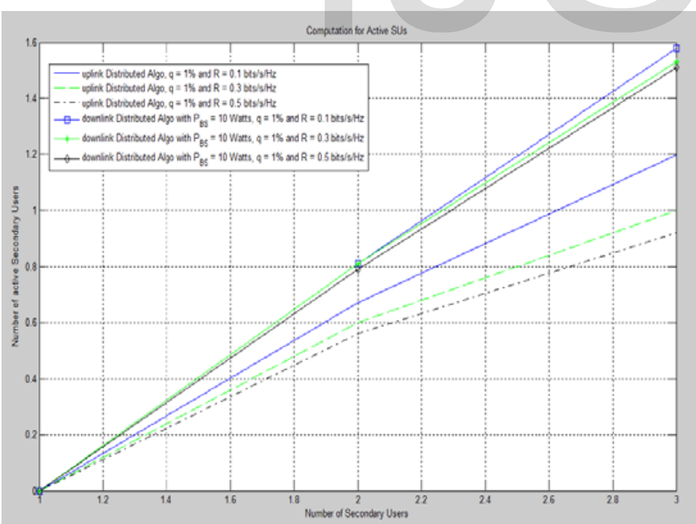

Figure 9 Computation for active users with R=0.1, 0.3, 0.5 bits/s/Hz, P_{BS}=10W

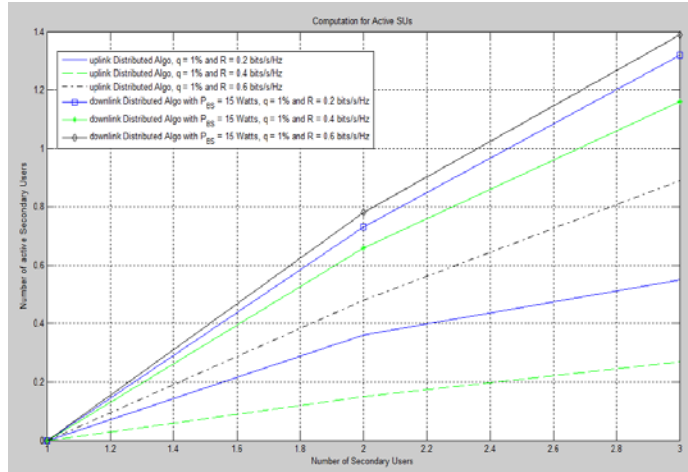

Figure 10 Computation for active users with R=0.2, 0.4, 0.6 bits/s/Hz, P_{BS}=15W

III. CONCLUSION

As explained in the section above finally the analysis of the probability of false alarm, probability of misdetection, the variation of total error rate with respect to the threshold, signal-to-noise ratio and bit error rate are done. The inferences out of these performance analyses are made correspondingly. Apart from this, analysis over the capacity and number of active users in accordance with that of the power used for transmission, the rate of transmission and mainly the number of users in the network are also carried out. The outcome of these evaluations brings out that the number of users, threshold taken for reference, the signal-to-noise ratio level, power at transmitter and receiver and gain of transmitter and receiver play a vital role in CR for the SU to act properly using the PU band.

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