Cognitive Spatial Multiplexing Systems with Simultaneous Spectrum Sensing and Data Reception

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Abstract:- A multiuser cognitive communication system is considered under the existence of multiple primary transmissions where the spatial multiplexing mode of operation is implemented among the nodes. Simultaneous spectrum sensing and data reception is performed on the cognitive systems. In order to efficiently decoding the secondary data streams MMSE detection is carried out at the secondary receiver. At the remaining signal we also perform spectrum sensing to detect the presence of primary activity or not. The detection performance is plotted with the means of ROC curves. The probability of unexpected interference is estimated and also is minimized when the secondary vacate the channel.

Keywords:- *Cognitive Radio, Detection probabilities, Spectrum Sensing, Energy Detection, MMSE.*

I. INTRODUCTION

Spectrum management is simply the process of managing and controlling the use of radio frequencies in the electromagnetic spectrum to promote its efficient use. The main goal about this is to win a net social benefit. As the number of spectrum users is increasing day by day the spectrum management is considered to be a growing problem especially in this century.

By introducing the time serving usage of the frequency bands that are not heavily occupied and used by the licensed users, cognitive radio arises to be a captivating solution to spectral crowding problem. Cognitive Radio (CR) can be defined as a radio system that senses its electromagnetic environment and it have the capability of dynamically adjusting its radio operating parameters to modify the system operations for the improved performance. It can be simply clarified as a radio that is acquainted with environment around it and adjust their frequencies, waveforms, protocols etc.

The main sight of cognitive radio is related to autonomous exploitation of the locally unused spectrum for providing new specific paths and growth in the area of spectrum access. Other aspects of cognitive radio also includes the interoperability across several lattices, the roaming across borders while being able to remain in acquiescence with confined or local regulations, the adaption of the system, the transmission and reception parameters without the user intervention, and having the ability to grasp and follow actions and options. This can be only done by efficient spectrum sensing.

The accomplishment of spectrum sensing is highly related with the precision of the detection method used by the cognitive system. It's an important tool for finding the spectrum holes to efficiently transport the cognitive data while shielding the communication rank and grade of foremost service at the same time. In the conventional approach, the cognitive transmitter is performing the spectrum sensing in the first rigid time duration and then transmits its data in the remaining time duration.

This work is a new modus operandi of operation for protocol intention for cognitive networks is implemented using the spatial multiplexing transmission scheme. The novelty of this scheme is that the diverse single antenna minor nodes can in unison transmit their data streams to the corresponding diverse antenna minor receivers. The receiver can in unison perform the signal detection and spectrum sensing in the same frame duration. The signal detection is performed by MMSE detection method at the secondary receiver and spectrum sensing is performed by using the energy detector based method.

II. LITERATURE SURVEY

Many researchers have introduced various techniques related to the spectrum sensing having many applications in the real world applications. Generally finding out the ideal spectrum (the spectrum holes [1]) remains something difficult. Categorizing into two types: the quiet [2] and active [3] the area becomes more wide.

The quiet sensing method is the conventional one and is having certain drawbacks like capacity reduction. In order to overcome that the active method is introduced. A simultaneous spectrum sensing along with data reception is proposed in [4] where data is cancelled first by the secondary receiver and then senses the remaining signal. A single transmitter receiver scenario is proposed in [4] having only one primary node. Since it is imperfect for practical applications other methods are developed. In [3] and [5] both sensing and data reception is performed by sensing in some secondary nodes and data reception operation in other nodes.

The authors in [6] and [7] proposes a spatial isolation method mainly on antennas in a sense that some antennas are committed for sensing while others are devoted for data reception. But a large amount of self obtrusion arises there during sensing.

The concept of simultaneous spectrum sensing and data reception was studied in [8] for single antenna nodes and for multiple antenna nodes. These works uses the method of approximating the received signal as a Gaussian input using the central limit theorem.

Capitalizing the above results, here a new method of concurrent spectrum sensing and data reception is proposed. The secondary receiver performs the spectrum sensing upon the altogether signal reception from multiple transmitters. The spatial multiplexing modus operandi is implemented where all the peripheral transmitters send their data streams at the same instant in a given frame duration itself. Thus the self disruption problem can be avoided. The receiver bring into effective action of the MMSE detection approach to detect the secondary data streams. The optimum energy detector is used for the sensing process.

The rest of this paper is sorted and arranged as follows. In section III the system model along with the mode of operation is presented. The system is thoroughly analyzed. In section IV, the suggested configuration and its make-up is analogized with the simulation results. Finally in section V, the paper is concluded following the references.

III. PROPOSED METHODOLOGY

Considering a cognitive communication system, which is having m_c single antenna cognitive transmitters and receiver consisted of N ≥ m_c antennas operating under the presence of m_p single antenna primary nodes.

In the secondary system, the spatial multiplexing MIMO system which is used to maximize the transmission rate is considered and is implemented. The independent m_c data streams are transmitted at the same time by the subordinate nodes. An optimal and quite well organized detection layout, so-called the linear MMSE detection is performed at the secondary receiver. The intended practice is shown in below figure 3.1.

The way of operation of the considered system is consisting of three phases which are periodically alternating. They are namely the training phase, the data transmission phase and the spectrum sensing phase.

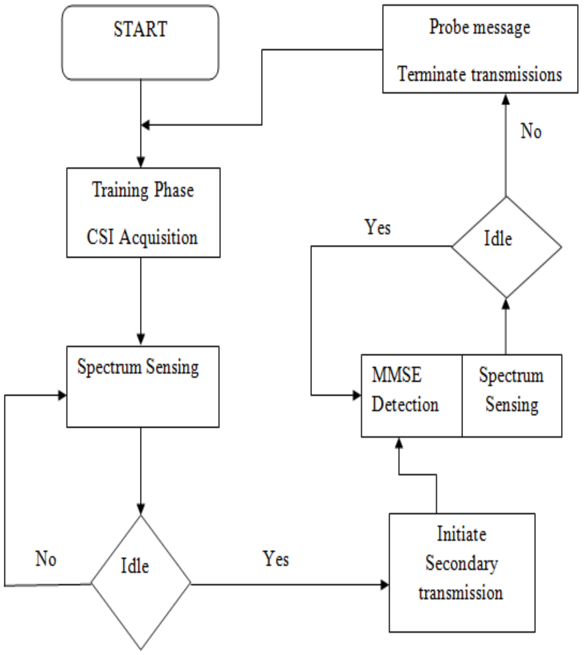

Fig 1:- Flowchart of the proposed scheme

In the training phase, all the nodes that are both the prime as well as the minor transmitters broadcast pilot signals. In order to earn the expeditious channel gains from both the chief and less important nodes the secondary receiver monitors the available spectrum resources. In order to win the channel gains between the primary nodes and themselves also all the secondary transmitters monitor the channel. The latter occurs to congruously reform their power in upcoming data juncture for potential transmission. It is assumed that the channel remains consistent and steady during the training stage. However, its level may vary in some time instances.

When the system enters the data phase, the subservient nodes remains dormant for one symbol time duration. At this time, the minor receiver senses the spectrum and captures the presence of primary activity whether it is present or not. No transmission task is performed by the secondary transmitters in the former case. This procedure is repeated up till the receiver senses the spectrum as unfilled. In the most recent case, the receiver broadcasts a enquiry message in order to take action on the secondary transmissions. Hence in the next symbol time instance, all active minor nodes may concurrently transmit their data streams. The MMSE detection is performed at the cognitive receiver and all the data streams are concurrently decoded.

The spectrum sensing stage is implemented after the taking away of all secondary signals from the received signal. The receiver also keeps track of the remaining signal for identifying the existence of principal activity. If the remaining signal is sensed unfilled, the procedure keeps on going up till the next training stage. If at the minimum one primary signal is detected at the remaining signal, then the receiver straight away broadcasts another message to tie up all secondary transmissions. An apt ceiling on the transmission power of the receiver is put to use in order not to cause unpredicted co-channel disruption to primary communications.

The channel is considered to be a Rayleigh fading channel and the mode of operation is having three phases.

A. Training Phase

At the time of the training phase, considering M orthogonal pilot sequences of length M symbols are assigned to both the primary and secondary nodes as such. The Zadoff Chu sequences are used as the pilot symbols.

The received pilot symbol can be expressed in the form:

$$y(n) = h(n)*s(n) + w(n) \qquad \cdots \quad (1)$$

Where, y(n) is the received pilot signal

h(n) is the channel matrix

s(n) is the transmitted signal

w(n) is the noise

Considering the practical network setups, the channel aging effect and the estimation errors are the two factors which are affecting the signals during the transmission through channels. These are occurring mostly for the reason that of the meteoric channel disparities occurring at back-to-back sample time instances mainly due to examples like fast fading conditions or user mobility issues.

Defining the channel aging effect as G and the estimation error as E, the equation (1) can be modified as:

$$y = G*s + E*s + w \qquad \cdots \quad (2)$$

B. Data Transmission Phase

Estimating the channel gains of all the signals from the training stage, the secondary receiver proceeds with the detection or decoding process of the concomitantly transmitted data streams.

The mean squared error of i^{th} received stream is formed as:

$$MSE_i = \mathrm{E}\left[|s_i - \emptyset_i^H\ y|^{\,2}\right] \qquad \cdots \quad (3)$$

Where $\emptyset_i$ is the optimum weight vector.

C. Spectrum Sensing Phase

The energy detector sensing method is selected as the optimum one since the channel gains, signal, and the noise variances are all well known. The use of numerous antennas at the secondary receiver can conquer the assessment precariousness and can ameliorate the accomplishment of the spectrum sensing.

From equation (2),

$$r = G_p * s_p + E_p * s_p + w \qquad \cdots \quad (4)$$

Where, r denotes the remaining received signal

G_p denotes the true channel matrix

E_p denotes the estimation error matrix

s_p denotes the transmitted signals from primary nodes

w denotes the noise.

The hypothesis test is formed as the energy of the signal.
The probability of detection is estimated using the equation (28) in [20].

$$P_d(\lambda) = Q_{NL}\left(\sqrt{\frac{2Ly\sigma_p^2}{N_0}}\ ,\ \sqrt{\frac{\lambda}{N_o}}\right) \qquad \cdots (5)$$

Where L is the tap length

σ is the variance

y represents the signal

For software implementation, $\frac{\lambda}{N_0}$ is taken as unity and y is taken as the minimum signal.

The probability of false alarm is estimated using the equation (34)

$$P_f(\lambda) = \frac{\gamma\left(NL, \frac{\lambda}{N_0}\right)}{\gamma(NL)} \qquad \ldots (6)$$

Taking NL as unity, in (6) the P_f can be estimated.

In order to stipulate a supreme energy threshold, we are using equation (35) in [20].

$$\lambda^* = P_f^{-1}(\tau) \qquad \ldots (7)$$

Where $\lambda^*$is the optimum energy threshold for a predefined target τ and P_f^{-1} is the inverse function of P_f.

The outage probability is explicated as the probability that the i^{th} stream falls below a certain threshold value. Using the equation (36) in [20] for outage probability and reducing the terms we get:

$$P_{out} = (1 - P_f(\lambda^*)) * \mathrm{SINR}(m) + (1 - P_d\ ) \qquad \ldots (8)$$

Where SINR (m) gives the signal to interference noise ratio value.

IV. RESULTS

The detection probability is plotted against the false alarm probability for various conditions. In figure 4.1, the curve is plotted for different L values whereas in figure 4.2 it is plotted for various numbers of primary nodes.

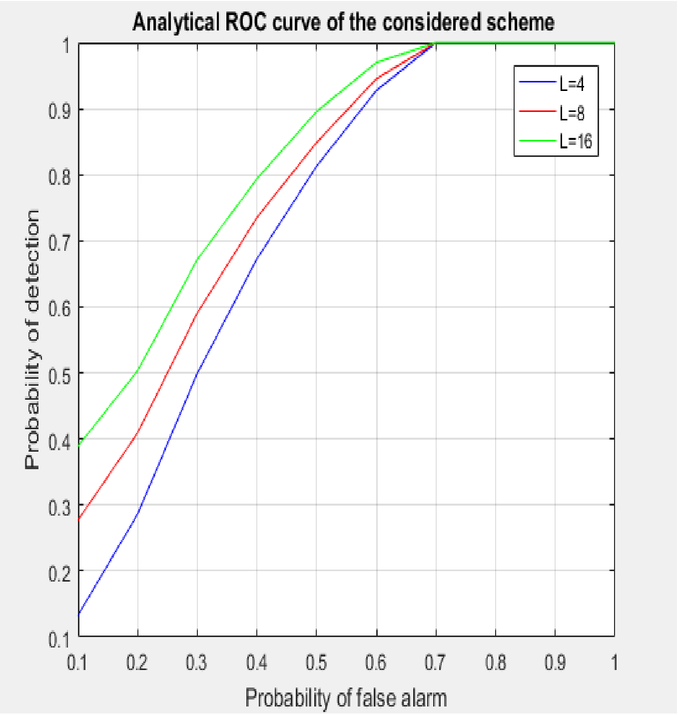

Fig 2:- Analytical ROC curve for the scheme for m_p = 4

The L is considered to be the tap length which is the length or distance between two adjacent blocks. In Fig. 4.1, the curve is plotted for various L values L = 4, L = 8 and L = 16. From fig. 4.1, the detection performance is increasing as the tap length increases. The curve is plotted by initializing and fixing a probability of false alarm value and estimating the corresponding probability of detection for several iterations and calculating the average of them. It has been done for the three different tap length cases.

In Fig. 4.2, the curve is plotted for various L values L = 8 and L = 32 with different number of primary nodes. Here also the process of plotting the curve is same as that of plotting the above figure. Considering two cases, one with the number of primary nodes as 2 and the other with number of primary nodes as 4. It is seen that the performance of detection probability against the false alarm probability is improving for higher number of receive antennas. This can be further boosted by increasing the number of samples.

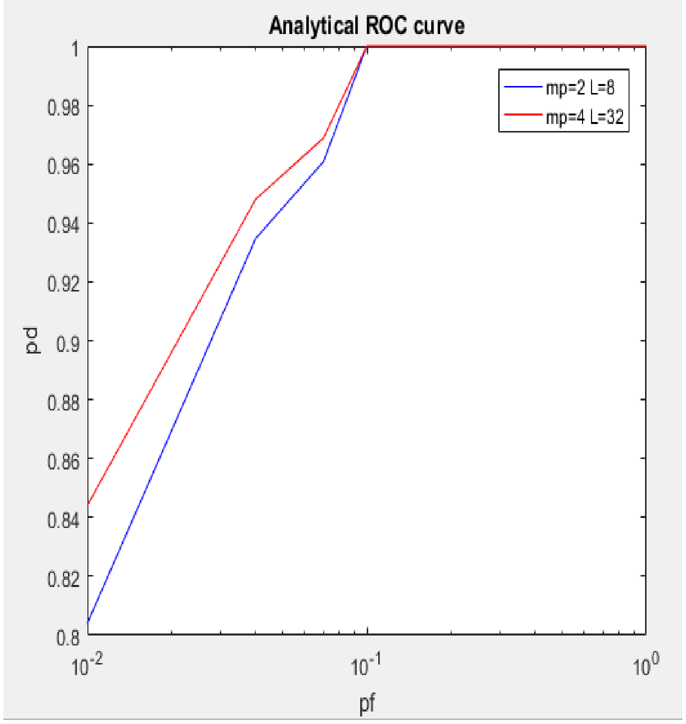

Fig 3:- Analytical ROC curve for the scheme for various number of primary nodes

In addition, the existence of more primary users depraves the fulfillment of the system because of the fact that adding more concealed signals would be imperceptible from noise. But, as the tap length of the systems have a large difference; the curve is obtained like this. Since as the tap length increases the detection performance increases.

In figure 4.3, the unconditional AUC is plotted against the SNR values of the primary nodes. Without knowing the probability values, the study of change of the detection and false alarm probability can be simply termed as the unconditional AUC. For plotting the curve, we have first defined a probability of false alarm as 0.02. Then calculate the corresponding detection probability using several iterations. Then changing the false alarm probability using equation (6), calculates detection probability for that using inverse q function. According to the change in tap length value, the false alarm probability along with detection probability changes. This change is indicated and with the help of unconditional AUC it is plotted for L = 4, L = 8 and L = 16. The detection performance is higher for large L value.

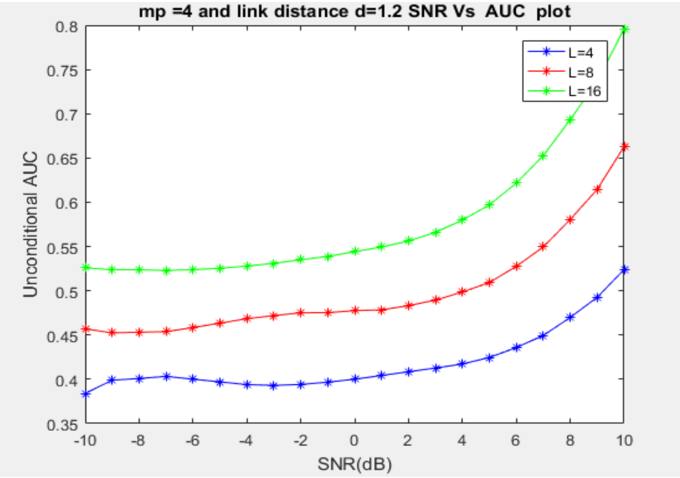

Fig 4:- Unconditional AUC vs. various SNR values of primary nodes

The detection probability is plotted against the various input Signal to Noise Ratio (SNR) values for the primary nodes in figure 4.4. The existence of more receive antenna elements increases the detection performance of the minor receiver as shown in figure 4.4. The curve is plotted for various tap length values L = 4, L = 8 and L = 16. While plotting detection probability against SNR values, the x axis is set to have the range given as -10 to 10. The corresponding detection probabilities are calculated and are plotted.

According to fig 4.4, the performance is maximum for high tap length values.

In figure 4.5, the CDF of the considered N*M MIMO system is plotted against various values of normalized outage threshold. The range of x axis is defined and CDF using inbuilt functions is plotted against this. As shown in the figure, the fulfillment exceeds for higher number of receive antennas with predetermined number of concurrently transmitting nodes because of the emerged diversity gain.

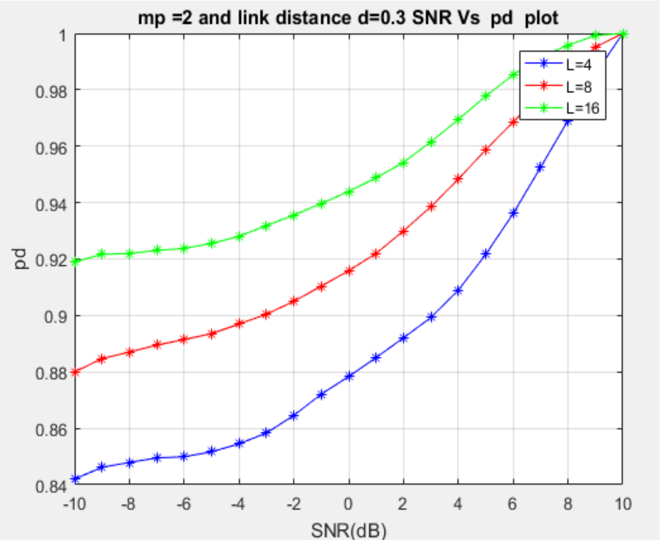

Fig 5:- Detection probability vs. various input SNR values for the primary nodes

In figure 4.6, the outage probability is plotted against the normalized outage threshold. The range of x axis is defined and outage probability using equation (8) is calculated and is plotted against this. Demonstrating the total outage performance of the system, the efficiency of the detection scheme plays a key role to outage probability. According to the results, there should not be so much difference between the performance plots of both.

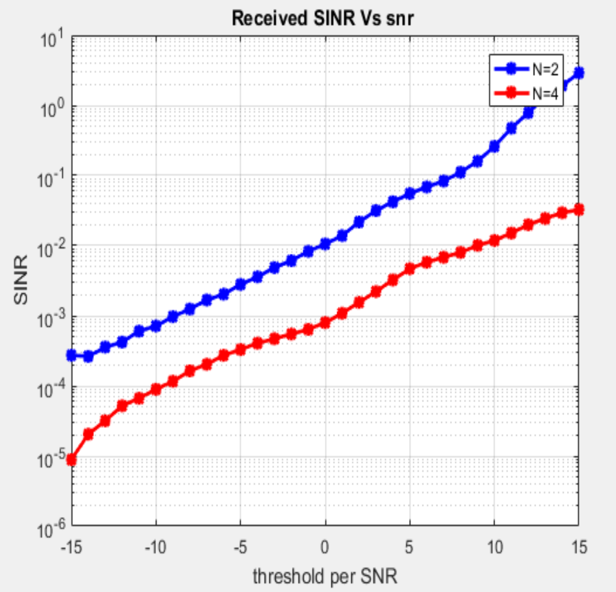

Fig 6:- CDF of the received SINR vs. various values of normalized outage threshold

The probability of unexpected interference at the primary nodes is illustrated in figure 4.7. While starting the project work it was assumed that the secondary user is not causing any interference to the major user. But from figure 4.7, it is clear that some unexpected interference is occurring at the primary nodes.

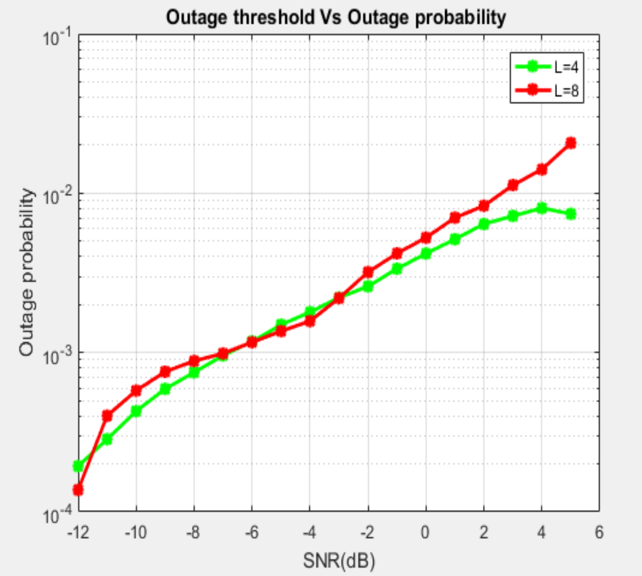

Fig 7:- Outage probability of the considered scheme vs. various values of normalized outage threshold

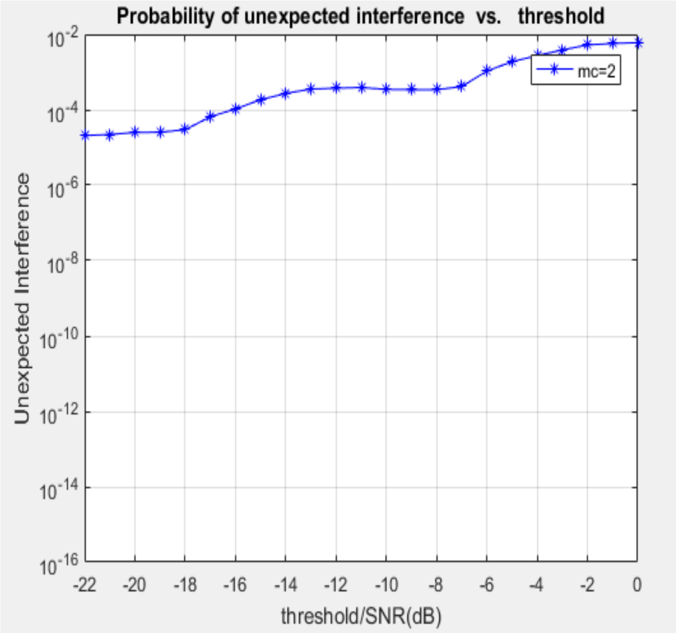

Fig 8:- Probability of unexpected interference vs. various values of normalized outage threshold

In order to reduce the unexpected interference, while vacating the channel the secondary performance is turned off. The probability of unexpected interference in both the cases where the secondary uses the channel and at the time when it vacates the channel is plotted in fig 4.8.

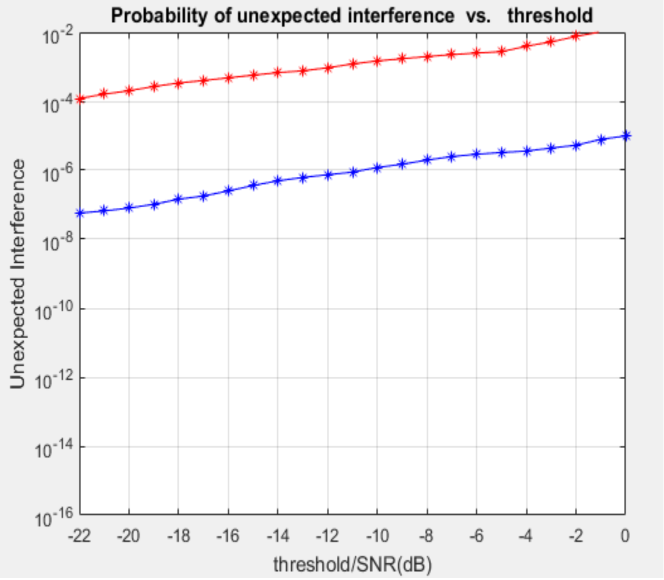

Fig 9:- Comparison of probability of unexpected interference when secondary occurs and vacates the channel

The red line indicates the case where secondary is active in the channel whereas the blue line indicates the probability of unexpected interference when the secondary vacates the channel. It has been proven from the plot that the interference level is reduced at the time when the secondary has vacated in order to give up the channel for the legitimate primary user.

V. CONCLUSION

A cognitive communication system is considered with the presence of multiple primary nodes or users. A new protocol is presented where the secondary receiver can simultaneously sense the spectrum and can receive data. The secondary receiver utilizes the MMSE detection for decoding/detecting the received data and it also uses the energy detector based spectrum sensing method for spectrum sensing. Considering the detection probability, false alarm probability, outage probability, SINR, the performance of the system was implemented using the ROC curves. It is proven that the tap length of the system plays a crucial role for the improved performance of the system. It was also demonstrated that the probability of unexpected interference was existing and is reduced at the time of vacating the channel to primary.

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