SPECTRUM SENSING USING ENERGY HARVESTING ALGORITHM FOR COGNITIVE RADIO NETWORKS

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Abstract— Spectrum Sensing is the key challenge for Cognitive Radio Networks that allows the detection of primary user reappearance during secondary user transmission. The proposed Energy Harvesting Algorithm will detect the reappearance by sensing the change in the signal strength over a number of reserved tones in OFDM frame and this method also reduce the detection time of secondary receiver and decreases the frequency for spectrum sensing. The performance of Energy Harvesting Algorithm was evaluated by finding two parameters Probability of Detection and Probability of False Alarm and in presence of varying Secondary to Primary Power Ratio (SPR). Simulation result shows that probability of detection increases with increase in probability of false alarm. This method also gives high performance with reduces complexity compared to traditional methods. This algorithm also reduces complexity and comparison is done between energy harvesting algorithm and receiver statistic show that our algorithm shows enhanced performance for detection. These results are verified by MATLAB.

Index Terms— Cognitive Radio, Spectrum Sensing/Monitoring, Orothogonal Frequency Division Multiplexing (OFDM), Energy Harvesting Algorithm, Quiet Period, Detection Probability.

I. INTRODUCTION

In communication system, the Radio Frequency spectrum is access by Static Spectrum Access where the spectrum is fixed to licensed or primary users (PU) while secondary users (SU) or unlicensed users are prohibited for accessing those spectrums even when the primary users are unoccupied called Spectrum holes or White Space [12]. Hence there occur congestion in secondary user and also inefficient use of frequency spectrum in primary user. This leads to dynamic spectrum access which proposed a new technique called cognitive radio networks (CRN) in which secondary users (SU) can use the unoccupied spectrum of primary users (PU). The secondary user must have spectrum sensing capability to sense whether there is presence of PU prior to transmission. This provides spectrum efficiency and also increases the performance of the network. Cognitive radio network is an overlay network. In this method, secondary users will sense the spectrum of primary users if the PU spectrum is unoccupied, then SU can then use the spectrum for transmission, but at the same time SU must periodically able to detect signals from the primary users during which SU will remain silent and does not involve in transmission by monitoring the shared band to quickly vacate the occupied spectrum. If signal is not detected during sensing phase then SU continue in using the primary spectrum thus increasing throughput and Quality of Service (QoS). If signal is detected SU stops its transmission by vacating the occupied spectrum and choose another unoccupied spectrum. This will make the SU receiver to lose its synchronization with transmitter and also have reduced quality of services and throughput. During this process, the CR system takes a long time for detecting the reappearance of primary users and this interval is known as the sensing interval, during which the secondary user does not use the spectrum during this detection so it is called as Quiet Period (QP). They are different types of spectrum sensing such as Energy detection in which detection of primary signal is based on threshold value where if energy is above the threshold then there is presence of primary user, other technique can be matched filter, cyclostationary feature detection where all these technique require prior information and also have long quiet period [18].

Quiet period (QP) consists of two period first short period or energy detection where it measure energy level followed by feature detection where it take final decision [12]. In the IEEE 802.22 system, a quiet period consists of a series of consecutive spectrum sensing intervals using energy detection to determine if the signal level is higher than a predefined value, which indicates a non-zero probability of primary user transmission. The energy detection is followed by feature detection to distinguish whether the source of energy is a primary user or noise. This mechanism is repeated periodically to monitor the spectrum. Once the PU is detected, the SU abandons the spectrum for a finite period and chooses another valid spectrum band in the spectrum pool for communication. If the SU must periodically stop communicating to detect the emergence of the PU, two important effects should be studied. During quite periods, the SU receiver may lose its synchronization to the SU transmitter which causes an overall degradation in the secondary network performance and also degrades the QoS.

In order to decrease the quiet period and for efficient transmission secondary user will continue their transmission while simultaneously monitoring the presence of primary signal [16]. In Receiver statistics the detection is based on Low Density Parity Check

Code (LDPC) where it compares the error count with threshold value for the presence of primary users. Here the error count will combined with Additive white Gaussian noise (AWGN), so this makes receiver statistics difficult for detection. The proposed algorithm Energy harvesting algorithm allows effective sensing of primary user reappearance by two phase sensing and monitoring phase. This algorithm uses orthogonal frequency division multiplexing based cognitive radio because of bandwidth efficient and satisfy cognitive requirement such as interoperability, sensing and adapting to the environment, adjust its radio operational environment. Energy harvesting algorithm is done by sensing the change in the signal strength in the number of reserved tones in OFDM frame [1].

This algorithm does not required priori information about primary user and less complexity. The detection performance can be evaluated on the two basis probability of false alarm and probability of detection and this method also consider secondary to primary ratio (SPR). This evaluated result shows that there is high performance when compared to previous methods. This paper discuss about the OFDM based cognitive radio and the simulation result between probability of detection and probability of false alarm and with varying secondary to primary ratio.

In section II, the overall system model is discussed. In section III, the energy harvesting algorithm is summarized. In section IV, the parameters are analyzed and their evaluated results are given in section V.

II. METHODOLOGY

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique suitable for cognitive radio network because the reappearance of primary user is detected using the OFDM frame transmitted from primary user and it does not require waiting for the decoded bits. In Spectrum Sensing based Orthogonal Frequency Division multiplexing, secondary user is the Cognitive Radio user and should have the capability of sensing the environment and adaptable. Since OFDM satisfy the Cognitive Radio requirement spectrum sensing is done by using orthogonal frequency division multiplexing at the physical layer [11].

At the transmitter side of OFDM, the data is generated at baudrate and segmented into blocks, each blocks in then encoded and interleaved separately. After which constellation mapper is done, 16 QAM (Quadrature Amplitude Modulation) mapping is used since the signal contains both in-phase and quadrature information. After which reserved tone are added for each frame and transmitted along with the modulated data. By employing IFFT data is converted from frequency domain to time domain. Thus the nth time domain sample of the mth symbol can be expressed as given in (1). Where C(k, m) is the modulated data to be transmitted with k subcarrier and N_3 is the encoded complex data symbol.

$$S(n, m) = \frac{1}{\sqrt{N_s}} \sum_{k=-\frac{N_s}{2}}^{\frac{N_s}{2}-1} C(k, m) e^{\frac{j2\pi kn}{N_s}} \qquad (1)$$

In order to reduce Inter Symbol Interference the last N_g samples of the OFDM symbol is copied to the beginning of the symbol to form cyclic prefix (CP). While using cyclic prefix or guard bits. Thus, the initial transient remains within the CP so orthogonality is maintained. Thus OFDM frame consist of modulated data, reserved tones, cyclic prefix and time domain. Therefore the OFDM frame has a total time period of

$$N_t = (N_s + N_g + N_{RT})/F_s$$

Where, encoded complex data symbol and F_3 is the sampling frequency.

The channel used is Additive White Gaussian Noise (AWGN) with mean 0 and variance is 1. At the receiver side the inverse operation is done, the time and frequency synchronization is done by removing the cyclic prefix and OFDM symbol is converted from time domain into frequency domain using FFT and received data is equalized, demapping, deinterleaving, and decoding is done to generate the original data. Once FFT is done the reserved tones from different symbol are combined to perform energy harvesting algorithm.

In our model, we consider a cognitive radio network where PU will occupy a certain spectrum for transmission which is shared by secondary users. This spectrum is used by one SU called master node and remaining users are called slave node. The reappearance of PU is detected using the reserved tone in OFDM frame in the master node.

III. ENERGY HARVESTING ALGORITHM

During the OFDM frame generation before IFFT a number of reserved tones N_{RT} is reserved in each frame which helps the secondary user to detect the presence of primary user reappearance. Spectrum Sensing consists of two phase sensing and monitoring phase. This energy harvesting algorithm is done in monitoring phase where decision is taken whether there is presence of primary users signal. Sensing is done at the secondary receiver, after the receiver operation of OFDM such as removal of cyclic prefix and time to frequency domain conversion Energy Harvesting Algorithm is applied. In this algorithm the received tones from different OFDM symbol are combined to form one sequence of samples after which sliding window is applied.

Two consecutive equally sized windows is passed over the reserved tone where the energy of each sample is calculated and their ratio is evaluated which is called decision variable X_K and compared with the threshold that is calculated theoretically [1]. Thus this algorithm is based on the change in the reserved tones. Mathematically, the decision variable X_K can defined as given in (2).

$$X_k = \frac{U_k}{V_k} = \frac{\sum_{i=N+k}^{2N+k-1} |Z_i|^2}{\sum_{i=k}^{i=k+N-1} |Z_i|^2} \quad (2)$$

Where N is the number of samples per window, U_K is the energy of second window, and V_K is the energy of first window, and k is the integer. Whenever the parameter X_K is greater than the threshold then secondary user detect that there is presence of primary signal and secondary user must vacate the band, if X_K lesser than the threshold then both windows is assumed to have unwanted signal and secondary user need not to vacate and can continue its transmission. While the primary user appear second window will contain both primary signal and noise and first window will contain only noise so ratio of these two window will result in value greater than the threshold thus produce a spike when primary user is detected as shown in Fig.1.

The figure shows two scenarios where the ratio of the energy of two windows is less than the unity and thus contains only noise. In the other scenario the second window has energy greater than the first window since second window contain both primary signal and noise, whereas first window contain only noise and thus the ratio is greater than the threshold. Hence, the Secondary user must vacate the spectrum [16]. Therefore the signal at secondary receiver can be given by two hypotheses H0 and H1as given in (3) and (4).

$$Y(n) = w(n) \qquad \text{for H0} \quad (3)$$

$$Y(n) = S(n) + w(n) \qquad \text{for H1} \quad (4)$$

Where Y (n) is the received signal, w (n) is the AWGN of variance σ_w^2 and s(n) is primary user signal of variance σ_s^2.

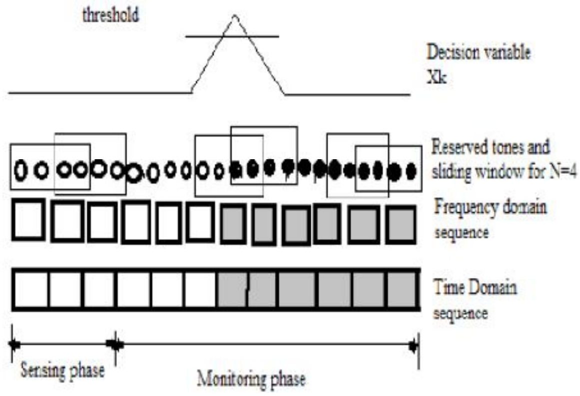

Fig.1. Energy harvesting algorithm

The hypotheses H0 is the absence of primary user and contain only noise and H1 is the presence of primary user contain both primary signal and noise. Since analysis is done in AWGN channel, by using energy harvesting algorithm we can define the hypotheses in terms of variance. The variance of first window is σ_v^2 and variance of second window is σ_u^2 and are defined as given in (4) and (5).

$$\text{H0:} \quad X_k = \frac{U}{V}, \; \sigma_u^2 = \sigma_v^2 \quad (4)$$

$$\text{H1:} \quad X_k = \frac{U}{V}, \; \sigma_u^2 > \sigma_v^2 \quad (5)$$

The hypotheses H0 happen when the variance of two windows are equal and hypotheses H1 take place when the variance of second window is greater than the first window.

IV. P_{FA} AND P_D EVALUATION

To verify the energy harvesting algorithm, we use the receiver operating characteristic (ROC) which is the tradeoff between probability of detection P_D and probability of false alarm P_{FA} is evaluated. Probability of detection denotes the probability of cognitive radio user declaring the presence of PU when the spectrum is occupied by the PU and probability of false alarm is the CR users probability declaring the presence of PU while the band is actually idle and vice versa. Thus P_{FA} and P_D for the given threshold can be defined as given in (5) and (6) respectively.

$$P_{FA} = \text{prob}\,[X_k > \gamma \,|H0] \quad (5)$$

$$P_D = \text{prob}\,[X_k > \gamma \,|H1] \quad (6)$$

Once the primary signal is available in the spectrum the second window contain power of primary signal and power of noise and thus their variance will consider SPR, it is the secondary to primary power ratio [5]. Thus whenever secondary to primary power ratio (SPR) increases the detection probability decreases.

V. SIMULATION RESULT

The simulation is done in MATLAB software where energy harvesting algorithm is evaluated through the analysis of P_{FA}, P_D, SPR. This algorithm uses OFDM (orthogonal frequency division multiplexing) system where the data is generated at a baudrate of 9.6 kHz. The data generated are converted to 100 symbols with each symbol having 96 bits. The number of reserved tones N_{RT} = 4 and data is modulated by 16 QAM mapper and the cyclic prefix N_g =16 bits that is the last 16 bits is placed at the first 16 bits location of the frame in order to eliminate inter symbol interference. The number of samples taken in each window is 4. Fig.2. shows the primary users spectrum with the baudrate of 9600 bits. After the spectrum creation, orthogonal frequency division multiplexing (OFDM) intialization is done consecutively orthogonal frequency division multiplexing (OFDM) frame is generated which consits of data, time domain sequence, cyclic prefix, and reserved tones and transmitted over the additive white gaussian noise (AWGN) channel.

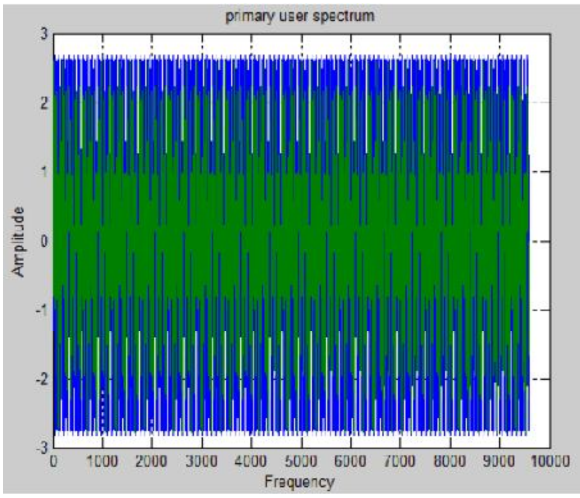

Fig.2. Primary user spectrum

The reserved tones are combined for the analysis of energy harvesting algorithm. The reserved tone in OFDM frame for the given input is shown in Fig.3.

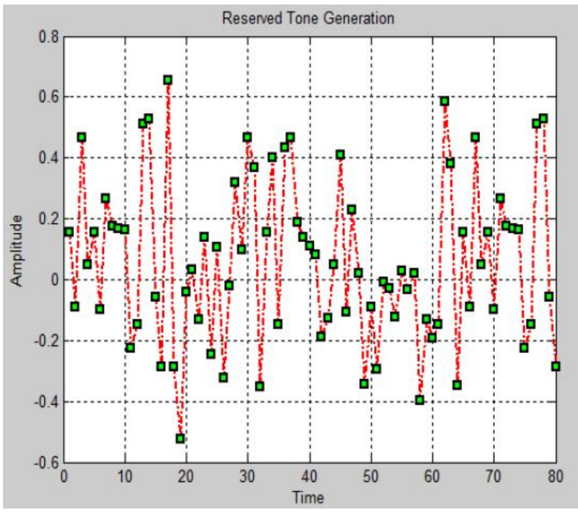

Fig.3. Reserved tone inserted in OFDM frame

The algorithm is analyzed using the receiver characteristics where the detection probability is varied with the secondary to primary power ratio (SPR) for four different value of probability of false alarm P_{FA}. SPR is related to primary to secondary noise ratio such that PNR (dB) = SNR (dB) – SPR (dB).This show the ability of detection probability P_D to detect the presence of primary signal with varying SPR keeping the probability of false alarm constant. Whenever the probability of false alarm increases there is decrease in probability detection. As the result the energy harvesting algorithm show high detection probability for the small value of SPR and thus gives high performance. Fig.4. shows the result of the detection probability verses secondary to primary power ratio for four different values of probability of false alarm 0.025, 0.05, 0.075, 0.1.

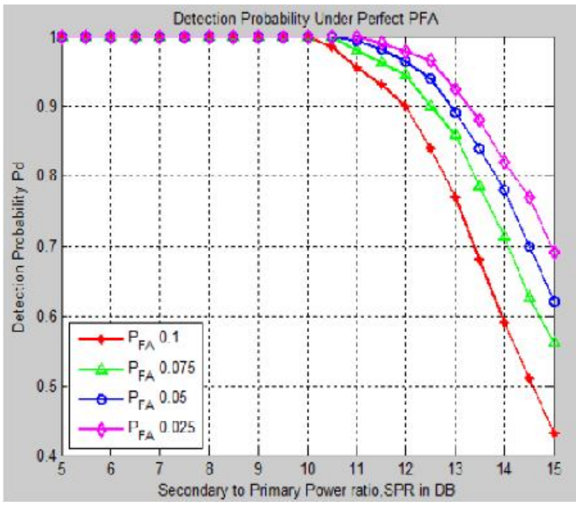

Fig.4. Probability detection at fixed probability of false alarm.

Another analysis of receiver operation charateristics is done between probability of false alarm P_{FA} and the detection probability for different values of SPR as shown in Fig.5. The detection probability should decrease with increase in SPR and thus the simulation result shows that at SPR=11 dB there is maximum probability of detection and as the SPR increases to 15dB the detection probability also decreases. This result an enhanced performance of secondary user to detect the presence of primary user signal.

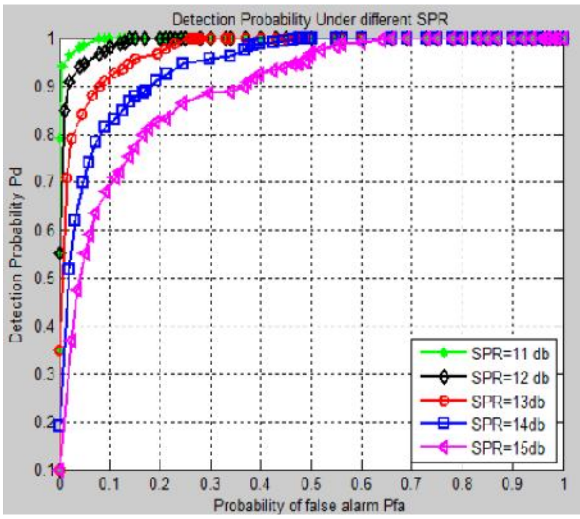

Fig.5. Probability of detection under different SPR.

The performance of energy harvesting algorithm and receiver statistics is compared in Fig.6. and it is shown that energy harvesting algorithm shows good performance when compared to receiver statistics. The reappearance of primary signal is detected faster. Fig.6. Comparison between energy harvesting and receiver statistics.

CONCLUSION

Thus, by using energy harvesting algorithm for OFDM based cognitive radio networks the reappearance of primary user signal is detected faster since it does not require waiting for the decoded bits. This algorithm also reduces complexity and does not require prior information when compared to traditional technique. In order to analysis the proposed algorithm we derived the detection probability and the probability of false alarm P_{FA} for AWGN channel. This algorithm also improves the performance of OFDM based cognitive networks by improving the detection probability by enhancing the Probability of false alarm P_{FA} and with increase in SNR.

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