Australian Journal of Basic and Applied Sciences, 10(12) July 2016, Pages: 17-25

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Power Spectral Estimation of Beacon Signal from Primary Base Station for Effective Spectrum Sensing in Cognitive Radio Networks

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ARTICLE INFO

Article history:
Received 26 April 2016
Accepted 21 July 2016
Published 30 July 2016

Keywords:
Cognitive radio (CR), spectrum sensing, beacon signal, channel state information (CSI).

ABSTRACT

Cognitive radio is considered as one of the most eminent technology to overcome the spectrum underutilization problem. It pays a way, to discover the white space in the surrounding environment. In CR network authorized (licensed) user is supplied with enormous channel to meet its demand. At an instant of time, when the channel is idle, the unauthorized (unlicensed) user can claim that frequency band by getting proper authentication from the licensed user. This process of discovering the idle spectrum can be done by spectrum sensing method. A few literature surveys reveals that sensors are used to perform the function of spectrum sensing but it may fail while considering for a multiple user network due to interference. In this paper, we focus on transmitting a beacon signal from primary base station to secondary base station to detect the available spectrum resources. We have proposed a network model for a open system with transmitting beacon signals. The sensing of signal is carried with the help of cyclostationary feature of beacon signals which is transmitted periodically and updated in the channel state information by primary base station (PBS). Finally, the simulations are carried with generating different beacon signals for same interval of time. Simulation results reveal that sensing accuracy is improved while transmitting more beacon signals in the short interval of time with fixed SNR. Power spectral estimation of various detection techniques and traffic load metrics due to transmission of more beacon signals in the CR network also discussed in detail in this paper.

INTRODUCTION

The unexpected growth in the wireless communication meets an unpredictable increase in the spectrum resources. Most of the services provided by the radio environment include TV broadcasting, military, medicine, cellular networks etc., make use of these resources. Since the utilization of these spectrum bands is in peak which may leads to spectrum scarcity. A current technology which is in practice to tackle this problem is cognitive radio (CR). This allows the secondary users to use the spectral bands of the authorized primary users by getting proper authentication from the primary user whereas authorized user have the full right to access the respective frequency band. But the cognitive radio network (CRN) is considered as a complex architecture when compared to other networks because of its software defined radio platform (Hanwen Cao, *et al.*, 2009). Later with automatic computing property which has been introduced in CR made it easier. Its aim is to identify the white spaces in the CR network using any access method and to allocate the detected idle spectrum to the unauthorized users without causing any harmonic interference to the primary users (PU) (Liang, Y.C., 2008). For a homogeneous network, a parallel sensing concept has been proposed in which each secondary user is provided with a sensor. In non-homogeneous environment, a aggregation rule is considered at the access point (AP) to choose the optimal channel (Le Thanh Tan and Long Bao Le, 2014). Hence, the above said literature

To Cite This Article: S Thamizharasan and D. Saraswady., Power Spectral Estimation of Beacon Signal from Primary Base Station for Effective Spectrum Sensing in Cognitive Radio Networks. ***Aust. J. Basic & Appl. Sci.,*** *10(12): 17-25, 2016*

survey reveals that sensors play a vital role in sensing, but error may occur in most of the cases which affects the sensing performance of the system because the identification of white spaces rely on sensing results.

In this paper, we use a concept of applying beacon signal to avail the spectrum opportunities with the help of channel state information (CSI) which indicates occupancy nature of the primary user. Beacon signal is widely used in all kinds of wireless system because it is independent of user signal and does not depend on modulation types. Consider a network with a primary user and multiple cognitive users, in such case beacon signal is send before transmission to claim the channel which may affect the performance of the system due to channel fading (Hyoil Kim and Kang G. Shin, Fellow, 2008). To avoid such interference, an ad-hoc network is designed in which the channel information is located in the centralized base station (CBS) (Mai Vu, S.S. Ghassemzadeh and Vahid Tarokh, 2008). In (Le Thanh Tan, 2011), the signal transmission regarding the availability of spectrum takes place in the MAC sub layer rather disturbing the activities of any other layers in the network whereas MAC protocol uses a channel sensing algorithm to discover the spectrum opportunities. The research works undergone in MAC protocol to distribute the channel resources to the unauthorized users without inferring the performance of the PUs (Michael Timmers, *et al*., 2010).

Now we have incorporated a scenario, with a single primary base station (PBS) which acts as a head for M number of primary users (PUs) and a secondary base station (SBS) which serves as a head for N number of secondary users (SUs) in which there is no direct link between the SUs to PUs but they communicate via the base station. In this paper, we focus on transmitting the beacon signal from primary base station (PBs) to secondary base station (SBs) to detect the spectrum holes in the radio environment. These beacon signals which are transmitted are detected using cyclostationary feature detector analysis. Experimental works are done to improve sensing accuracy of the network by transmitting various beacon signals for the same interval of time and their detection probabilities are compared.

Paper Organization:

The rest of the paper is organized as follows. Network model and algorithm are discussed briefly in Section II. Simulation results and conclusion was discussed in Section III and Section IV respectively.

II. Netwrok Model And Algorithm:

In this section we discuss about the network model and spectrum sensing algorithm for a CR network.

A. Network Model:

Let us consider a network with 'M' number of primary users such as M={PU_0,PU_1,…,PU_M} which are operating in the specified licensed band in the cognitive radio environment. These users have a communication link with the primary base station (PBS) in order to inform about the spectrum opportunities to the surrounding system. Likewise, 'N' secondary users (SUs) N={SU_0,SU_1,…,SU_N} also linked with the secondary base station (SBS) which acts as a master communicating node for the secondary users by sending a request signal to the primary base station (PBS).

B. Spectrum Sensing:

It is assumed that the system works in a heterogeneous condition in which primary base station (PBS) can be located at any point in the system without any restriction based on distance between the two nodes, coverage area etc., because here sensing takes place with the help of a beacon signal which could not be affected by these factors since SNR is minimum for beacon signal.

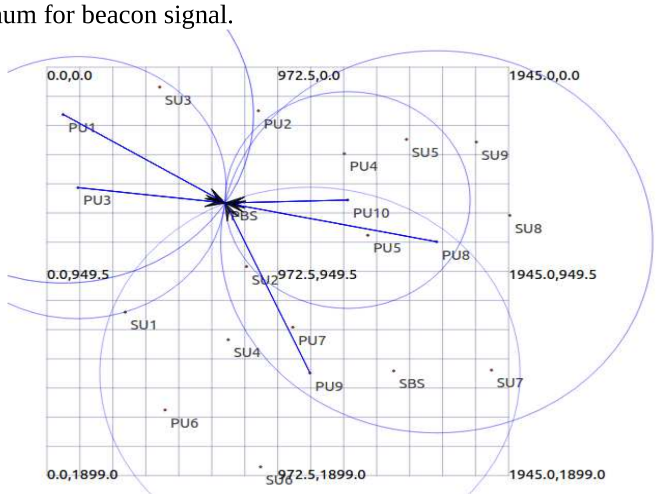

Fig. 2: Representation of sending beacon signal from PU to PBS.

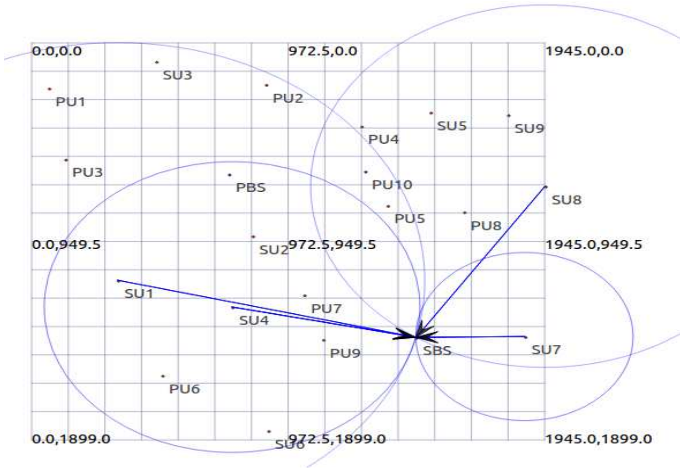

Fig. 3: Representation of SUs requesting SBS for channel state information.

We consider a system in which primary base station (PBS) sends a signal to M primary users that to update their channel information. The primary users in the network sends beacon signal which contains channel state information to PBS as in Fig.2. Meantime, it is assumed that SUs send request signal to SBS to access the idle channel which is illustrated in Fig.3. When SUs requesting SBS for accessing idle spectrum, SBS send request signal to PBS to detect the beacon signals which contains spectrum availability information and in turn PBS acknowledges SBS with channel status which is depicted in Fig.4 and Fig.5 respectively. Thus, SBS periodically monitor the channel state information on request and acknowledge the secondary users to access the available idle spectrum which is illustrated in Fig.6. By observing the activities of primary users in the network channel status is updated periodically in the vector table using cyclostationarity in the received beacon signal. The vector table representing busy or idle band of primary users that is assumed in this model is represented in Table1. The vector table representing the 6 PUs in which PU_3 and PU_5 are idle and remaining PUs are busy during the request given by SBS.

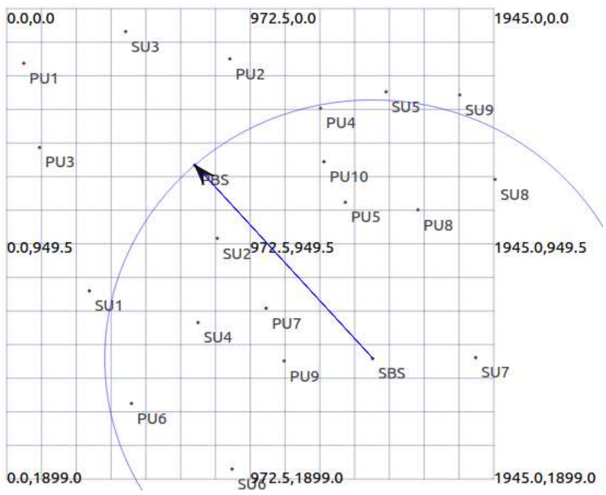

Fig. 4: SBS sending channel status request to PBS.

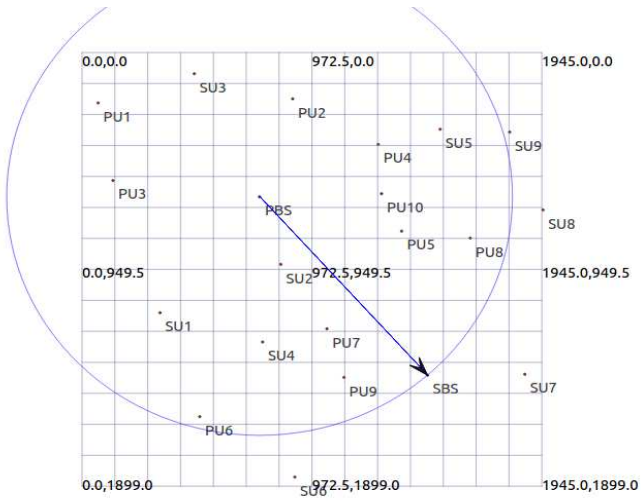

Fig. 5: PBS acknowledging SBS with channel information

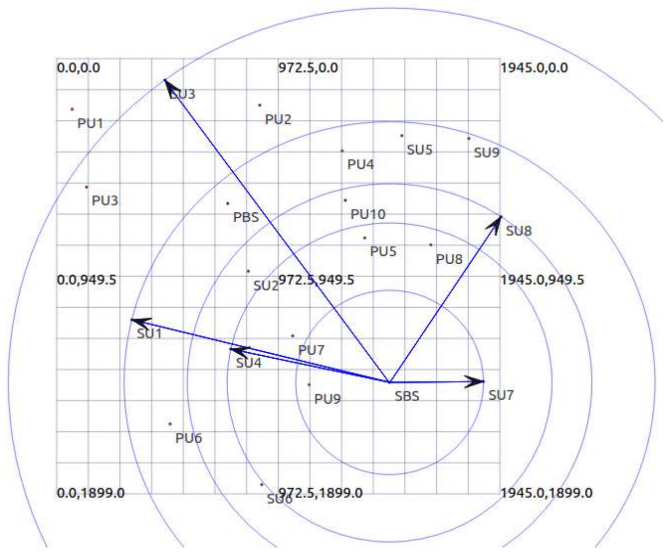

Fig. 6: Allocation of idle channels to SUs through SBS.

Table 1: Channel State Information

Primary User(PU)	Status
PU_1	1
PU_2	1
PU_3	0
PU_4	1
PU_5	0
PU_6	1

C. Beacon signal Estimation:

A cyclostationary based sensing is used in this model since it finds advantage for detecting primary user transmission and exploiting the cyclostationary features of the received signal (Mitola, I.J. and J. Maguire, 1999). Let the signal x(t) is said to be cyclostationary which exist in wider band and its autocorrelation function is given as,

$$R_x(t,\tau) = E\{x(t+\tau/2)x^*(t-\tau/2)\} \quad (1)$$

Where, t is the time interval at particular time lag τ. These time intervals can be studied using Cyclic Autocorrelation Function (CAF).

$$R_x(\tau,\alpha) = \lim_{\Delta t \to \infty} \int_{-\Delta t/2}^{\Delta t/2} x(t+\frac{\tau}{2}) x^*(t-\frac{\tau}{2}) e^{-j2\pi\alpha t} dt \quad (2)$$

Whereas α denotes the cyclic frequency and Δt be the time span. The frequency domain equivalent of CAF is given as,

$$S_x(f,\alpha) = \lim_{\Delta f \to 0} \lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\Delta t/2}^{\Delta t/2} \Delta f X_{\frac{1}{\Delta f}}(t, f+\frac{\alpha}{2}).X^*_{1/\Delta f}(t, f-\frac{\alpha}{2}) dt \quad (3)$$

Where, $X_{\frac{1}{\Delta f}}(t,v) = \int_{t-1/2\Delta f}^{t+1/2\Delta f} x(u) e^{-j2\pi vu} du$ (4)

Where Δf is the bandwidth of the signal and v is frequency of the signal. The cyclo-stationary based detection algorithm allows us to differentiate the noise from the primary user signals (Mitola, I.J. and J. Maguire, 1999). The cyclic correlation function is mainly used for detecting the generated beacons which have been present in the given spectrum. The cyclic spectral density of the received signal can be expressed as,

$$S(f,\alpha) = \sum_{T=-\infty}^{\infty} R_y^{\alpha}(T) e^{-2\pi fT} \quad (5)$$

Where, $R_y^{\alpha}(T) = E[y(n+T)y*(n-T)e^{j2\pi\alpha n}]$ (6)

The cyclic frequency α is a feature for identifying the transmitted signal. It must be equal to the transmitted signal x(t).The beacons produced here are decoded using a detector circuit where several spectral components are cross correlated at various frequencies to extract original signal.

D. Algorithm:

The frequency carriers of the signal which are correlated using certain predefined function which gives the location of the beacons. This process takes place in the detector. These beacon signals are then converted into time domain using Inverse Discrete Fourier Transform (IDFT). Flowchart of the proposed algorithm is depicted in Fig.7.

The steps for proposed algorithm are as follows:

Step1: Let us consider the set of primary user as PU_i, where i={1,….,M}, with K channels and the secondary users as SU_j, where j ={1,….,N} and the channel availability can be represented as,

$$\sum_{K=1}^{M} C_N^K \quad (7)$$

Step2: Consider ΔT be the time slot at which beacon signal is send at the regular intervals.

$$T = \max_i T_i \quad (8)$$

$$T_i = \sum kPU_i T_{ik}, T_{ik} \quad (9)$$

Where, T is the time interval at which the beacon signal is sent

T_i is the sensing time of PU_i on channel k.

Step3: Considering the i^{th} channel condition by,

$$C_N^K = \begin{cases} PU_i(H0); i \neq 1; PU_{i\,idle} \\ PU_i(H1); i = 1; PU_{i\,busy} \end{cases} \quad (10)$$

Step4: If PU_i is idle, return the beacon signal with ACK.

Step5: m^{th} bit of K^{th} channel in the vector table is encoded and updated in channel state information.

Step6: Send the encoded information to SBS

Step7: Vector table is periodically received by SBS

Step8: If the vector table i^{th} PU is idle, allocate the idle spectrum to SU on request.

Step9: If the vector table of i^{th} PU is busy, then update the channel state information and send to SBS periodically.

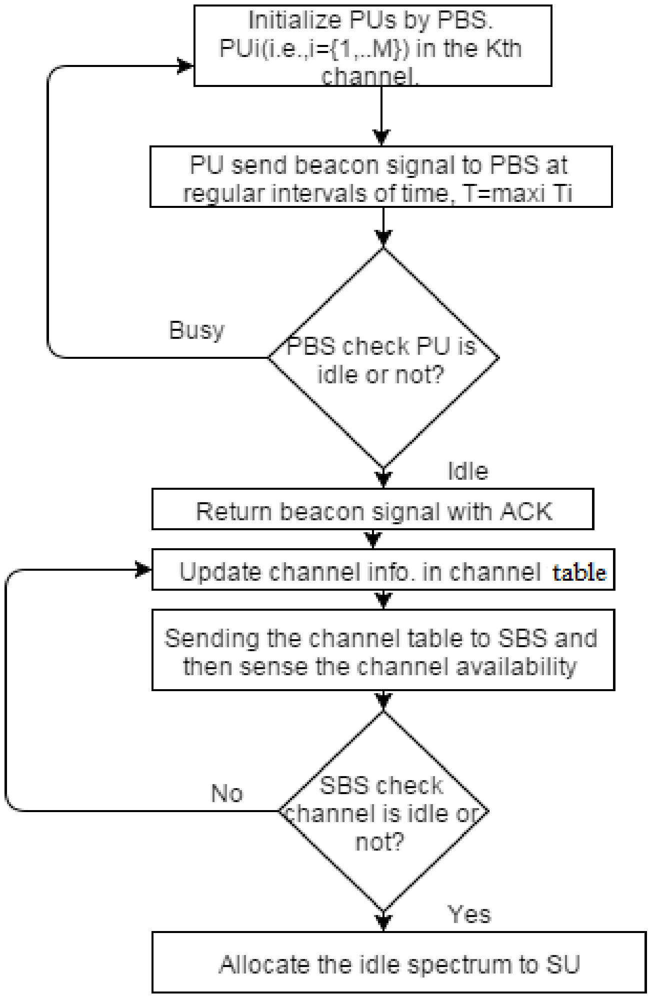

Fig. 7: Flow Chart

III. Simulation Results:

In this model, beacon signals are periodically sent to PUs in regular interval of time which periodically senses the usage of spectrum in frequency band. The performance metrics are carried by generating various beacons with same interval of time and sensing of signal is carried out using cyclostationary feature in the signal transmission. Fig.8 represents the sensing accuracy curve of sending 4, 8, 12 and 16 beacons for 60sec duration with 10 primary users in the network.

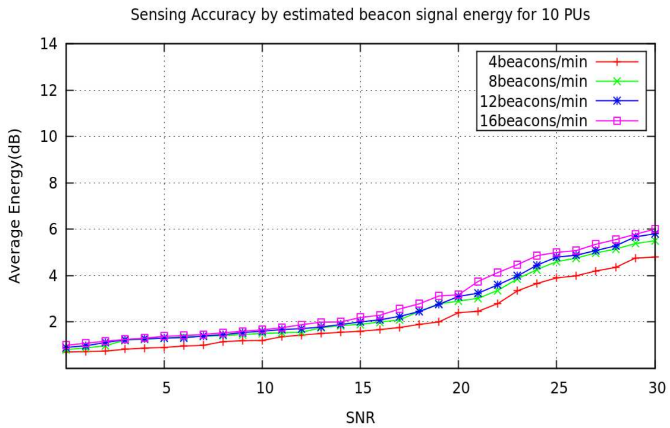

Fig. 8: Sensing accuracy curve for 10 PUs with different beacon signals

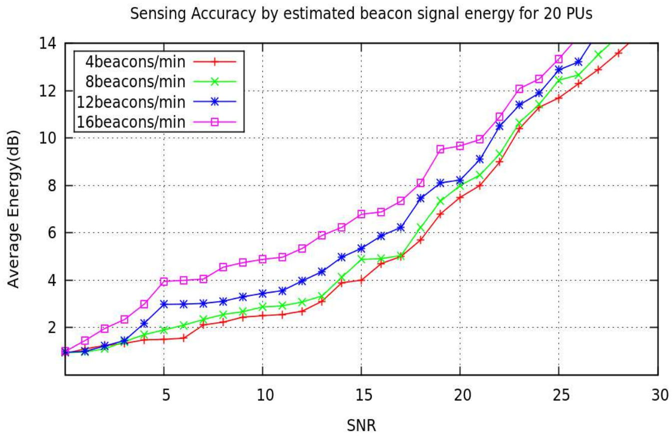

Fig. 9: Sensing accuracy curve for 20 PUs with different beacon signals.

The performance characteristics with similar beacon signals for same duration of time are done with 20 PUs and 30 PUs in the network is illustrated in Fig.9 and Fig.10 respectively. Spectrum accuracy can be achieved even with more number of PUs present in the network with detecting beacons. On comparison, independent of the number of secondary users in CR network, fair sensing accuracy can be deprived with transmission of more beacon signals.

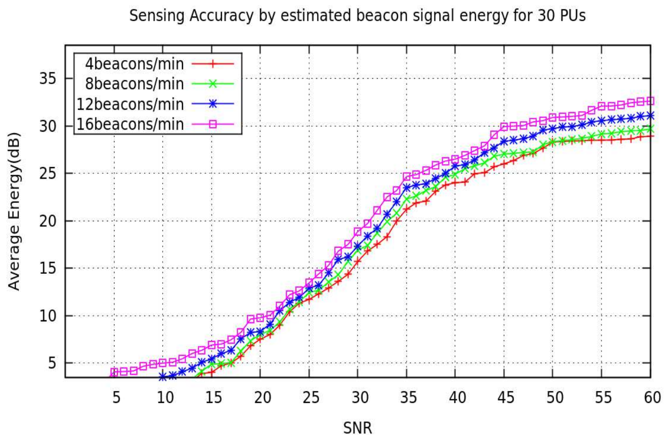

Fig. 10: Sensing accuracy curve for 30 PUs with different beacon signals.

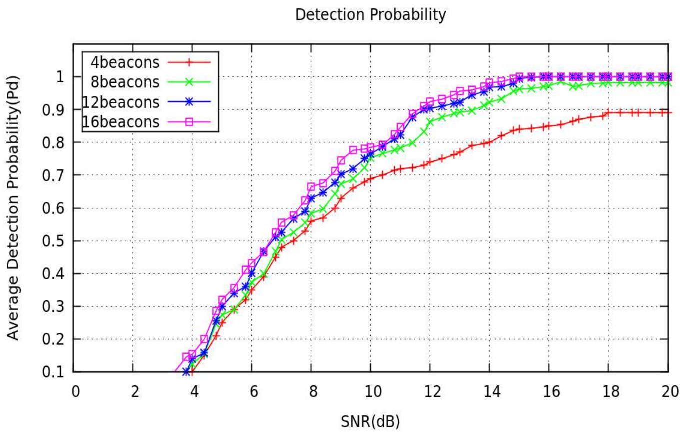

Fig. 11: Detection Probability curve for different SNR.

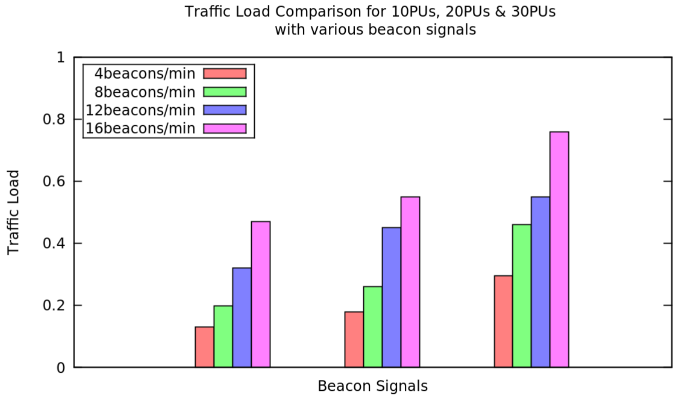

Fig. 12: Comparison of Traffic Load for 10 PUs, 20PUs & 30 PUs in CR network.

From the simulation results, it is clear that the sensing accuracy of PU in the networks gets improved with more number of beacon signals but result in traffic overload in the network. Since increasing the number of beacon signal results in fair sensing but the CR networks congested with traffic because more beacons are sent to PUs during short interval of time.

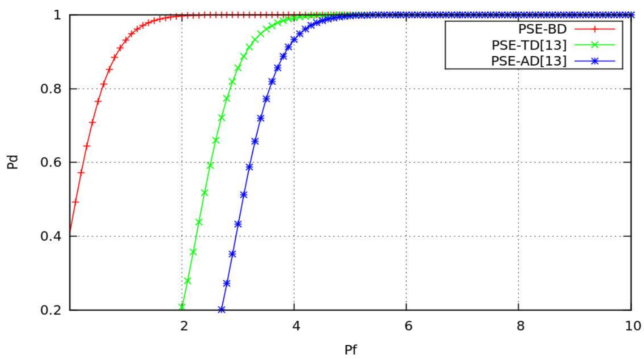

Fig. 13: Prob. of detection versus prob. of false alarm

The probability of detection with different SNR value of the beacon signal is shown in Fig.11. The fair detection of spectrum is achieved with transmitting 16 beacon with reliable SNR compared with 4, 8 & 12 beacons for same SNR value. The number of beacon signal sent during a specified interval of time is also limited to achieve fairness in traffic condition. The traffic load metrics for using 4, 8, 12 and 16 beacons is shown in Fig.12. The traffic load comparison of CR network considering 10 PUs, 20 PUs and 30PUs implies that traffic load is high for 16 beacon signals comparing with 4, 8 and 12 beacon signals since more beacon signals is generated by different primary users within a short interval of time. The probability of detection versus probability of false alarm for different power spectral estimation is depicted in Fig.13. The proposed power spectral estimation of beacon detection (PSE-BD) improves the detection probability comparing with detector used for true (PSE-TD) and average method (PSE-AD) (Thamizharasan, S., *et al*., 2013).

Conclusion:

Cognitive Radio, which is one of the very opportunistic spectrum usages, has become a promising concept. One of the important aspects in CR is spectrum sensing. In this paper, the spectrum sensing concepts are evaluated with transmission of beacon signals by the PUs and thereby finding the autocorrelation function of the signal to identify the spectrum accuracy and probability of detection by power spectral estimation. Simulations are carried with considering different beacon signals for different SNR values in the proposed network scenario. Simulation results reveals that generating more beacons signal by PUs in the CR network will improves the efficiency of sensing mechanism although more beacon signals results in creating traffic load in the network. The proposed power spectral estimation of beacon detection (PSE-BD) improves the detection probability comparing with detector used for true and average method. Hence, considering the number of beacon signal transmission for certain interval of time by the PUs will considered for limitations in the network such that it will not degrade the system performance due to more traffic load in the CR network.

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