NOVEL PILOT BASED SPECTRUM SENSING ALGORITHM

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Abstract- Spectrum scarcity is an unresolved problem due to static frequency allocation. Adapting a spectrum sensing algorithm to utilize unused primary user's spectrum to secondary user is a promising solution. This paper proposes a Pilot based Spectrum Sensing (PSS) algorithm to sense the pilot tones on OFDM based primary user signal. The algorithm consists of two stages namely coarse and fine stage to senses the presence of primary user even at worst sensing cases like time offset and higher noise gain. On each iteration, PSS algorithm decides the channel hypothesis based on the outcome of the two stages. Moreover, only pilot tones on the received signal are sensed which ensures the security of primary user information. Features such as precise sensing interval, power level comparison, low pass filter, correlation coefficient and sliding window process are considered in PSS algorithm. Performance analysis of PSS algorithm through simulation indicates reduced false alarm probability and improved probability of detection.

Keywords- Primary User, Cognitive Enhanced Secondary User, Pilot Based Spectrum Sensing.

I. INTRODUCTION

Heterogeneous network is driven by an unpredictable revolution to guarantee ubiquitous high speed data service along with existing voice communication. The growing traffic burden, necessity of superior coverage and the potential demand for spectrum have resulted in frequency reuse phenomenon. When same set of frequency is assigned to primary and secondary users who are spatially apart, frequency reuse happens. Due to mobility these two different users may come into same spatial coverage. Thus frequency reuse scenario in-turn leads to severe interference and QoS degradation for primary users. Even though primary users are the dominant network users, they often experience service degradation due to the exponential growth of secondary users. To handle such situation, the secondary user must sense the channel and acquire knowledge about primary user.

Cognitive radio, a channel sensing technique is a boon to many emerging networks. Cognitive radio technology assists secondary user in opportunistic usage of resource when the channel is idle. It aids the secondary user to sense the channel, learn the statistics of primary user and dynamically and autonomously adjusting the radio parameter to mitigate interference, improve interoperability and enhance throughput.

The most preliminary task of secondary user is to test the idleness of the channel with respect to signal metrics of the received primary user signal. This task is accomplished with many spectrum sensing methods like energy level detection, cyclostationary base sensing and waveform based sensing method. Less complex energy detector does not need any knowledge about primary user signal characteristics. The energy of received signal is compared with a threshold value. If received signal is weaker than the threshold, channel of interest is decided as idle and vice versa. Threshold of energy detection scheme is determined based on noise floor value. Cyclostationary sensing is based on periodic nature of the received signal at the secondary user entity. Intentionally introduced bits at transmitter end or periodic phase shifts assist this type of spectrum sensing. In waveform based spectrum sensing, known patterns like preamble, midamble and regularly inserted pilot symbols are added at transmitter entity. These added overheads serve the secondary user to ensure channel status. Many literatures are available which combined the two to three spectrum sensing technology to mitigate the corns of one another. However, combining different technique for a single aim may lead to huge system complexity.

The basis for the proposed PSS algorithm is waveform based spectrum sensing algorithm. The pilot pattern of transmitted primary user's signal is learnt and compared with the known copy of locally generated reference pilots. Power level, frequency component or the level of correlation between the local pilot signal and received signal is compared to analyze the presence of primary user over the channel of interest.

Proposed PSS algorithm senses the channel by tracking the pilot tones on received signal. The proposed algorithm treats the received signal over two different stages namely coarse and fine stage. In coarse stage, power of received signal is compared with the power of locally generated reference pilots. If received power is greater than the power of reference pilots, received signal must contain higher power pilots, modulated data and channel noise. This leads to the predication of busy channel. Else, received signal is supposed to contain random noise which leads to the conclusion of idle channel. In the coarse stage, high power received signal is correlated with local pilot pattern to ensure either the signal is really a modulated one or just a high frequency random noise. The rest of this paper is organized as follows. Section II presents a brief overview on pilot model and spectrum sensing hypothesis. Section III elaborates on proposed pilot based spectrum sensing algorithm, while section IV evaluates the simulation results. Section V sets the conclusion.

II. SYSTEM MODEL

Orthogonal frequency division multiplexing (OFDM) is a multi-access technique which is being adopted in a great degree over existing techniques. Primary and secondary users are considered to adapt LTE modulation standards.

A. OFDM System

Primary user's raw data undergoes convolutional coding, 16-QAM process, pilot insertion and serial to parallel conversion. Then the 64 parallel symbols are transformed into orthogonal frequency domain signal using Inverse Fast Fourier Transform (IFFT). After IFFT block, the time domain signal $x(n)$ can be written as

$$X(k) = \text{IFFT}\{x(n)\} \quad (1)$$

$$X(k) = \sum_{k=0}^{N-1} x(n)\, e^{\frac{j2\pi kn}{N}} \quad (2)$$

where $x(n)$ denote the n^{th} symbol of the total OFDM symbol in time domain, $X(k)$ refers the frequency domain signal over an orthogonal subcarrier k and N implies the total number of subcarriers. $X(k)$ is then converted to RF frequency and transmitted over erroneous additive white gaussian noise channel.

At secondary sensing unit, received signal undergoes front end conversion which is formulated as

$$Y(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k)\, e^{\frac{-j2\pi(k+\Delta k)(n+\Delta n)}{N}} + w(n) \quad (3)$$

where $(k + \Delta k)$ and $(n + \Delta n)$ represents the possibility of frequency and time offset in the received signal respectively. $w(n)$ is considered as additive white Gaussian noise with zero mean and unit variance. These offsets may lead to synchronization error while tracking the beginning of the data symbols with reference to pilot tones.

B. Pilot model:

Pilot tones are the uniformly spaced reference symbols or tones, inserted after fixed number of data symbols as shown in fig. 2(b). In general, pilot does not contain net information rather they serve paramount purposes such as control, equalization, continuity, supervisory and receiver synchronization [6]. Proposed system follows regular pilot insertion scheme in which defined pilots are inserted after a fixed number of data symbol. Also powers of pilot tones are considered to be higher than the power of data symbols. At transmitter entity, pilot symbols are inserted after every 12 data symbols. Obviously at the secondary user's sensing unit, local pilot sequence is generated and pilot symbols are separated by 12 symbol interval as illustrated in fig. 2(a). As both primary and secondary users follow LTE signal standards, secondary users are inherently familiar with the pilot insertion pattern of primary user. Thus secondary users are capable of generating the local reference pilot from the knowledge of predefined pilot sequence of primary OFDM signal. With respect to self-generated reference pilots, two metrics of received signal are compared. They are power level and correlation coefficient. Based on the level of correlation between received signal and locally generated pilot pattern and the power level between them, decision are made resulting in any one of the hypothesis.

C. Spectrum Sensing Hypothesis:

Well-known, two important hypothesis test of spectrum sensing can be formulated as

$$\mathcal{H}_o : Y(n) = w(n) \quad (4)$$

$$\mathcal{H}_1 : Y(n) = x(n) + w(n) \quad (5)$$

The test statistics $\mathcal{H}_o$ denote the absence of primary user over the channel of interest and $\mathcal{H}_1$ refers the presence of primary user over the channel of interest. Also the performance of spectrum sensing algorithm can be determined by two probability analyses like probability of detection P_d and probability of false alarm P_f. P_d is the probability of identifying the channel as busy, when the channel is truly busy. P_d can be formulated as

$$P_d : (\mathcal{H}_o | \mathcal{H}_o) \text{ or } (\mathcal{H}_1 | \mathcal{H}_1) \quad (6)$$

$$P_f : (\mathcal{H}_1 | \mathcal{H}_o) \text{ or } (\mathcal{H}_o | \mathcal{H}_1) \quad (7)$$

P_f is the probability of detecting the channel of interest as busy, when it is truly idle. P_f must be minimum to prevent underutilization of transmission opportunity.

III. PILOT BASED SENSING ALGORITHM

Aim of this algorithm is to ensure the presence and absence of primary user over the channel of interest. The first stage of the algorithm undergoes coarse detection which has power level comparator. It coarsely detects the absence of primary user by comparing the power of received signal with the power of locally generated reference pilots.

Let $P(n)$ be the locally generated reference pilots as shown in fig. 2(a). Initially, the received signal $Y(n)$, which could be either noise or primary user signal is fed into the power level comparator. At the power level comparator, the power of the received signal is compared with the power of the locally generated reference pilots for a limited sensing interval τ_T where τ_T is given as

$$\tau_T = 2\tau_P + \tau_D \quad (8)$$

where τ_P is the pilot tone duration and τ_D is 12 data symbol duration.

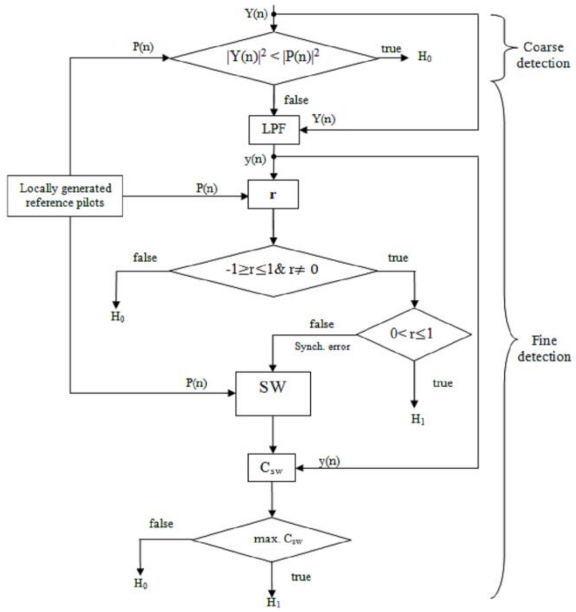


Fig. 1: Pilot based Spectrum Sensing (PSS) Algorithm

If the power of the received signal is less than the power of the locally generated reference pilots for a defined interval τ_T, the test statistics is made to be $\mathcal{H}_o$ and the channel is determined as an idle channel. i.e., pilots are supposed to have higher power and obviously weak received signal implies the absence of pilot and data in the received signal. Thus

$$|Y(n)|^2 < |P(n)|^2 \rightarrow \mathcal{H}_o \quad (9)$$

With this hypothesis prediction, test statistics decide the channel state as idle. Hence proposed pilot based spectrum sensing algorithm terminates at the coarse detection stage by deciding the absence of primary user. On the other hand, if the received signal is a primary user's signal over the defined sensing interval τ_T, the power of received signal will be greater than the power of the locally generated reference pilots. i.e., the received primary user signal has pilot, data and channel introduced noises. Hence

$$|Y(n)|^2 > |P(n)|^2 \rightarrow \mathcal{H}_1 \quad (10)$$

This decision predicts the presence of primary user over the channel of interest. Following this prediction, the received signal undergoes the fine detection stage and algorithm flows further to correlate the pilot tones on the received signal with locally generated reference pilots. Low pass filter with a cutoff frequency of pilot tone is incorporated in fine stage to remove the higher noise component above the pilot tone. After this, coefficient correlation (r) between received signal $y(n)$ and local reference pilots $P(n)$ is calculated over a limited time interval τ_T.

The coefficient correlation between received signal and locally generated reference can be formulated as

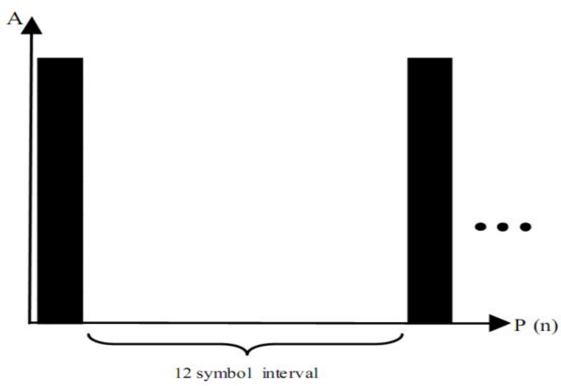
$$r = \frac{\frac{1}{n}\sum_{n=0}^{N-1}\left[y(n).P(n) - \bar{y}(n).\bar{P}(n)\right]}{C_y.C_P} \quad (11)$$

where $\bar{y}(n)$ and $\bar{P}(n)$ are the mean value of received signal and local pilot signal respectively. Also correlation coefficient obeys $-1 \geq r \leq 1$.

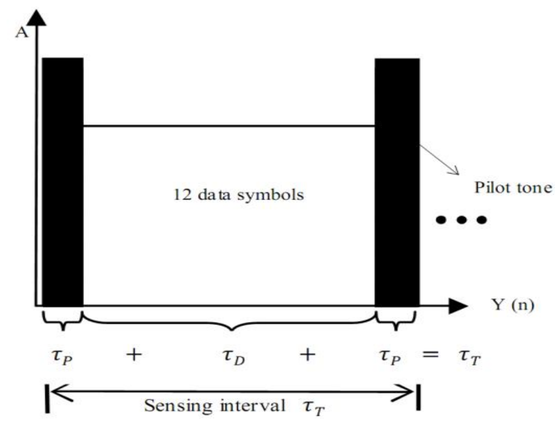
N is the total number of symbols over the sensing interval τ_T. The values of C_y and C_P are termed as

$$C_y = \sqrt{\frac{1}{n}\sum_{n=0}^{N-1}\left[y(n)^2 - \bar{y}(n)^2\right]} \quad \text{and} \quad C_P = \sqrt{\frac{1}{n}\sum_{n=0}^{N-1}\left[P(n)^2 - \bar{P}(n)^2\right]} \quad (12)$$

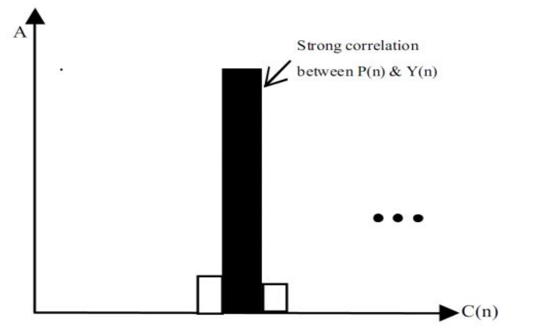
The value of r directly implies the presence and absence of primary user over the channel of interest. positive value of r implies strong correlation, negative value of r implies weak correlation and zero r value implies null correlation between received signal and pilot signal.



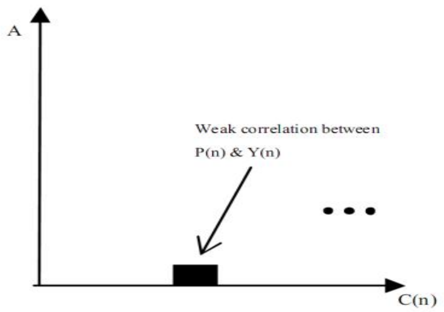
a. Locally generated reference pilots



b. Received signal and sensing interval



c. Maximum correlation between P(n) & Y(n) on perfect synchronization



d. Poor correlation between P(n) & Y(n) on perfect synchronization

Fig. 2: Representation of local pilot, received signal and synchronized P(n) & Y(n)

The first decision box in fine stage checks for two different cases at same instant i.e. it checks whether r lies between -1 and 1 but not exactly equal to 0. If the above condition is false, test statistics turns out as $\mathcal{H}_0$ and the received signal is not LTE-OFDM modulated primary user signal but a mere noise signal which escaped through LPF.

On the other hand, if the case $-1 \geq r \leq 1$ and $r \neq 0$ is true, the following decision box checks for the condition $0 < r \leq 1$. If it is again true, r holds positive value which represents strong correlation between y(n) and P(n) as illustrated in figure 2(c). This value ensures the presence of primary user over the channel of interest and test statistics is decided as $\mathcal{H}_1$. Alternatively, if $0 < r \leq 1$ is false, there exist weak correlation between received y(n) and P(n) as depicted in figure 2(d). Hence similarity between received signal and local reference pilots is minimal. This is due to the time offset in the received signal which in-turn failed to match with the locally generated reference pilots. To handle such time offset scenario, sliding window process is implemented following the false case of the algorithm. The sliding window is shifted to $\tau_T + 1$ different positions to attain maximum correlation (C_{SW}) between locally generated pilots and received signal. Maximum value of C_{SW} is inferred as presence of primary user over the channel of interest. In contrast, if correlation between y(n) and P(n) is minimum, the test hypothesis turns out as idle channel. Out of these 3 different decision boxes and two distinct stages, any one condition turns out to be the state of pilot based sensing algorithm for every τ_T interval.

IV. PERFORMANCE ANALYSIS

In this section, performance of pilot based spectrum sensing algorithm is studied through simulation and probability of detection and probability of false alarm are compared for various SNR and sensing time. Performances are examined using Matlab tool. The proposed algorithm is formulated under Monte Carlo simulation. Proposed algorithm had undergone 10000 Monte Carlo simulations over an Additive White Gaussian Noise channel. In the simulations, for each sensing time of 2, 4, 6 and 8 ms, probability of detection is plotted over varying SNR ranging till 20 dB.

Longer the sensing period, higher will be the chance of detecting the channel as busy when it is actually busy and vice versa. Fig. 3. depicts the improvement in detection probability with lesser SNR but with a longer sensing time. This is due to the fact that the perfect knowledge about the channel is acquired on lengthy sensing time. For the sensing time of 8 ms, probability of detection has reached 1 with minimal SNR requirement of 6 dB. Thus proposed pilot based sensing algorithm requires lesser SNR with a penalty of longer sensing time. Evidently fig. 4. illustrates the false alarm probability Vs SNR over a varying set of sensing time.

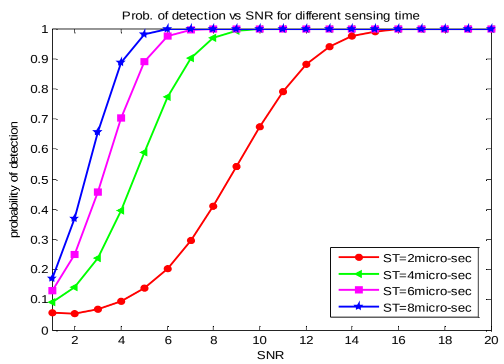


Fig. 3. Probability of detection Vs SNR for various sensing time

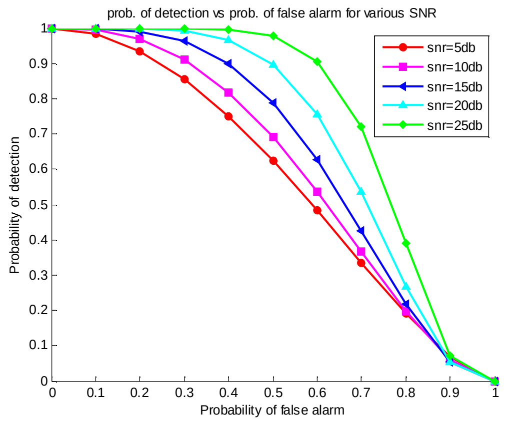


Fig. 4. Performance of PSS for various SNR

Lesser the sensing time, more will be the false alarm probability, i.e. for 6 dB of SNR and 8ms of sensing time, probability of false alarm is 0 whereas for the same 6 dB of SNR and 2 ms of sensing time, probability of false alarm is 0.86 which is unacceptable.

Thus the above results manifest the minimum false alarm probability at an appreciable SNR with a penalty of trice the sensing time.

CONCLUSION

In the proposed PSS algorithm, presence of pilot signal is checked through four different feature over a defined interval. Based on these checks, decisions are taken throughout the algorithm to determine the presence of primary user over the channel of interest. Each stage of algorithm are designed to alleviate the worst case effects of sensing namely, detecting the dominant channel noise power as pilot power of primary user, detecting the unsynchronized primary user signal as noise signal and deciding the high frequency traces of neighboring channel component as presence of primary user. Proposed pilot based spectrum sensing algorithm with sliding window process mitigates the chance of detecting the busy channel as idle one, thereby greatly reducing false alarm probability and ameliorating the probability of detection with respect to different sensing time.

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