OFDM Signal Detection Based on Auto-Correlation and Kurtosis

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Abstract: The spectrum sensing problem has augmented new scenarios with cognitive radio and opportunistic spectrum access concepts. It is one of the most challenging issues in cognitive radio systems. In this paper, we present a novel technique to sense and blindly detect OFDM signal based on auto-correlation and kurtosis. We carryout performance analysis of the proposed approach at various channel conditions and effect of increase in sample length of the sensed signal. Further, threshold value to decide the existence of OFDM signal is calculated. In addition, for 100 % detection rate, we perform an analysis of various pilot allocation strategies in OFDM signal and consequently its effect on detector performance. Detector performance improves further by using frequency spaced – all time (combo-pattern) pilot allocation in OFDM signal by 1dB to 3dB as compared with lattice and block type pilot allocation strategies. Experimental results show that the proposed approach can be successfully used to detect OFDM signal blindly in cognitive radio with 0 % false alarm rate.
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1. Introduction

The need for higher data rates is increasing as a result of the transition from voice-only communications to multimedia type applications. Given the limitations of the natural frequency spectrum, it becomes obvious that the current static frequency allocation schemes cannot accommodate the requirements of an increasing number of higher data rate devices (Yucek and Arslan, 2009). As a result, innovative techniques that can offer new ways of exploiting the available spectrum are needed. Cognitive radio arises to be an attracting solution to the spectral overcrowding problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licensed users (Mitola and Maguire, 1999), (Federal Communications Commission, 2005).

One of the most important components of the cognitive radio concept is the ability to measure, sense, learn, and be aware of the parameters related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. In cognitive radio terminology, primary users can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, secondary users, which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user or not and to change the radio parameters to exploit the unused part of the spectrum.

The determination of empty spectrum is typically done by spectrum sensing and is a critical challenge in cognitive radios. In particular, (i) spectrum sensing has to reliably determine the presence or absence of ongoing licensed transmissions, and (ii) sensing of multiple radio channels (possibly spanning several hundreds of MHz) has to be done as fast as possible.

In the communication spectrum, a number of primary users as well as secondary users may exist. Further, each primary user may have its own communication characteristics for signal transmission like bandwidth, modulation type and transmitter power to achieve various transmission data rates. Spectrum sensing is traditionally understood as measuring the spectral content or measuring the radio frequency energy over the spectrum. Whereas, cognitive radio is considered as a more general term that involves obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency, and code. It also involves determining what types of signals are occupying the spectrum including the modulation, waveform, bandwidth, carrier frequency, etc. However, this requires more powerful signal analysis techniques with additional computational complexity (Yucek and Arslan, 2009).

In this paper, we assume that the primary user is employing OFDM based communication system for signal transmission and our aim is to sense the spectrum for detection of an OFDM signal in the radio spectrum based on auto-correlation and kurtosis characteristics of the sensed signal. In literature, a plethora of techniques can be found for signal detection in radio spectrum based on energy, match filters, cyclostationarity properties and etc. Since, we are interested in detecting OFDM signal in radio spectrum, so we will focus only on OFDM signal detection techniques.

This paper makes the following contributions;

- Analysis of the auto-correlation based detector for OFDM signal detection under varying channel conditions
- Analysis of the kurtosis based detector for OFDM signal detection under varying channel conditions
- Development of an improved detector to detect OFDM signal blindly in cognitive radio
- Effect of increasing sample length on probability of detection for OFDM signal
- Performance analysis of the proposed approach by considering different pilot allocation strategies in OFDM signal.

The remaining paper is organized as follows; we present a brief review of spectrum sensing techniques in Section II. Section III describes the model for sensed OFDM transmitted signal and the derivation to calculate auto-correlated signal. Section IV contains detail about the proposed OFDM signal detection technique. In section V, we provide results and discussion. Section VI concludes the carried out current research work.

2. OFDM Detection Methods

2.1. Lit. Review

At present, spectrum sensing is still in its early stages of development. A number of different methods have been proposed for identifying the presence of signal transmissions which can be categorized based on energy detection, matched filter and cyclostationarity based methods. Since most of emerging and next-generation communications and broadcasting systems are orthogonal frequency division multiplexing (OFDM) based, detecting OFDM waveforms is of great importance (Arash et al., 2012). Therefore, the detection method separating OFDM signal from other single carrier signal or random noise is very essential. Detection schemes for amplitude modulation and frequency modulation have been studied extensively in last two decades (Hang et al., 2008). In this section, some of the most common spectrum sensing techniques used in cognitive radio are described.

Energy detector based spectrum sensing approach is the most common used because of its low computation and implementation complexities including OFDM signal (Datla et al., 2007), (Lehtom¨aki et al., 2005). Further, it is more advantageous because receivers do not need any knowledge on the primary users' signal. The primary signal is detected by comparing the output of the energy detector with a threshold which depends on the noise present in the signal (Urkowitz, 1967). Some of the challenges with energy detector based sensing include selection of the threshold for detecting primary users. Further, its performance is not robust to noise and is known to be poor at low SNRs (Maleki et al., 2010). Moreover, energy detectors do not work efficiently for detecting spread spectrum signals (Yucek and Arslan, 2006).

Waveform and Matched filter based techniques have also been used for spectrum sensing. These methods are applicable to systems with known signal patterns and their main advantage is to achieve a certain probability of false alarm in short time (Proakis, 2001), (Quan et al., 2008). In the presence of a known pattern, sensing can be performed by correlating the received signal with a known copy of itself (Tang, 2005), (Proakis, 2001). In practical spectrum sensing scenarios, however, we seldom have full knowledge of the primary transmitter's signal at the detecting receiver. In an OFDM system, one can use the pilots embedded in the symbols and attempt to detect the signal using a filter matched to these pilot tones. The limitation of this strategy in real systems is that pilot tone values are usually pseudo randomly coded and hence not known to the receiver. Thus, simply adding the output of the matched filter from consecutive symbols will not necessarily improve performance. In fact, it could have a negative impact on the detection performance of the system. A similar detection strategy proposed in (Chen, 2008) auto-correlates consecutive OFDM symbols to exploit identical pilot sequences that are embedded within each symbol. This method is also not practical as deployed systems seldom repeat identical pilot sequences from one OFDM symbol to the next.

Cyclostationarity feature detection method exploits the cyclostationarity features of the received signals for detecting primary user transmissions (Han et al., 2006), (Kim et al., 2007). Periodicity in the signal or in its statistics like mean and autocorrelation results in cyclostationarity features (Gardner and WA, 1991). Further, cyclic features can be induced deliberately to assist spectrum sensing like the cyclic prefix inserted in the OFDM signal and detection reliability increases as the cyclic prefix length of the signal increases (Tu et al., 2007). However, many OFDM systems do not add a cyclic prefix or a sufficiently long one due to spectral flatness and throughput considerations (www.wimedia.org).

Some researchers in (Oner and Jondral, 2007), (Lunden et al., 2008) attempt to extract the cyclic frequency corresponding to the sampling rate for the OFDM systems. These both OFDM signal detection techniques are based on the cyclostationarity of the signal; they do not exploit any knowledge about the embedded pilots. Instead, they treat the OFDM signal like a pulse-amplitude-modulated waveform which degrades the performance of these methods upto 5 dB in some cases (Zahedi-Ghasabeh et al., 2010). In contrast, some researchers aim to exploit the cyclostationarity signatures of an OFDM symbol realized from its embedded pilots (Sohn et al., 2007) and (Sutton et al., 2008). However, they assume that the pilot signal is unchanged over consecutive OFDM symbols.

In ref (Goh et al., 2007), authors have developed several criteria based on the time domain periodicity introduced by the cyclic prefix in DVB-T OFDM symbol. Vladimir Sebesta et al. (2011) have proposed an approach to detect OFDM signal using cyclic auto-correlation function. Authors claim that the detector is able to detect an OFDM signal in the case of multipath propagation, inexact frequency synchronization and without time synchronization. In addition to this, S. Chaudhari et al. (2009) have introduced a method to detect OFDM signal based primary user using its autocorrelation coefficient. Further, authors apply the maximum likelihood estimate of the autocorrelation coefficient in the low signal-to-noise ratio (SNR) regime. In addition to this authors claim that cooperative spectrum sensing between secondary users provides diversity gains including reduction in delay and the amount of data needed in identification of the underutilized spectrum. Auto- correlation based OFDM signal detection works well but their performance is affected badly in the degrading environment.

Kurtosis based spectrum sensing has also been performed in cognitive radio (Suresh et al., 2012). Suresh et al. (2012) have used kurtosis, a fourth order statistic to detect primary user signal. In their techniques, they have not considered the scenario for detection of OFDM signal.

In this paper, we perform an analysis of auto-correlation based signal detection for OFDM signal corrupted with noise at various SNRs. We conclude from our experimental results that performance of auto-correlation based method for OFDM signal detection decreases abruptly with increase in signal noise. Further, signal corrupted through 0 dB AWGN or more, it becomes very difficult to detect the primary user signal peak because of number of spurious peaks. Additionally, kurtosis value of OFDM signal is very small because of identically independent distribution of OFDM symbols. Further, kurtosis value of only noise signal (Gaussian distribution) is also zero. So, it is very difficult to distinguish primary user OFDM signal from noise signal, if we apply kurtosis statistic directly on OFDM signal. Based on our experimental analysis, in the proposed technique, we first take auto-correlation of the sensed signal and then measure kurtosis of the obtained auto-correlated signal. This improves the probability of OFDM signal detection better than auto-correlation OFDM signal detection methods. Moreover, we do not employ assumption of synchronization between primary user transmitter and secondary user receiver. Effects of various pilot allocation strategies and length of sample sequence on OFDM signal detection are explored. This is one of the major contributions in this paper.

In our experimental study, we intend to detect WIBRO OFDM signal and assume that primary user is employing the following OFDM transmission characteristics; IEEE 802.16e, frequency bandwidth 2.3 GHz, max mobility 60 km/hr, cell coverage ~ 1 Km, data rate about 25 Mbps and modulation scheme QAM. Further, cyclic prefix is inserted in OFDM symbols to avoid inter symbol interference. In addition to this, pilot signal is also embedded in OFDM signal to achieve channel equalization. We also study various strategies for pilot allocation in OFDM signal and its consequent effect on OFDM signal detection in cognitive radio.

2.2. Cyclic Auto-Correlation Based Spectral Analysis

In this sub-section, auto-correlation based OFDM methodology is descried in detail. OFDM signal detection through cyclic auto-correlation is based on non-zero autocorrelation property.

Let x(t) be an OFDM signal in time domain, and in each frame assume that length of the useful symbol data is T_d and cyclic prefix is T_c for an OFDM system. To derive the test statistic for auto-correlation based OFDM signal detector, H_0 represents the null hypothesis means that there is no OFDM based primary user signal present, and H_1 be the OFDM based primary user is active.

The cyclic auto-correlation of a signal may be estimated through the following mathematical expression;

$$R_{xx}(t,\tau) = E\{x(t+\tau/2)x^*(t-\tau/2)\}$$
$$R_{xx}(t,\tau) = \sum_{\alpha} R_{xx}^{\alpha}(\tau)e^{j2\pi\alpha t} \quad (1)$$
$$R_{xx}^{\alpha}(\tau) = < R_{xx}(t,\tau), e^{-j2\pi\alpha t} >, \quad < \cdot > = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}(\cdot)dt$$

Where, α is cyclic frequency.

2.3. Kurtosis Cumulative Distribution Function (cdf) of Random Sample

In this sub-section, we intend to calculate kurtosis cdf of random sample sequence of length n. We perform the experiment for 200,000 times and calculate kurtosis (k(i)) of random sample n. we then calculate kurtosis cdf by considering various levels (values) and plot cdf versus value range. The obtained kurtosis cdf against random sample of different length (1-4 frames) is plotted in figure 1. From our experimental analysis, we observe that false alarm rate can be reduced upto 0.5 x 10^{-5} with resolution of 2.5x10^{-6}. Considering the required false alarm rate, from figure 1, we can obtain and set a threshold for kurtosis based signal detection. In this experimental study, we keep false alarm rate 0% by setting threshold greater than 0.15.

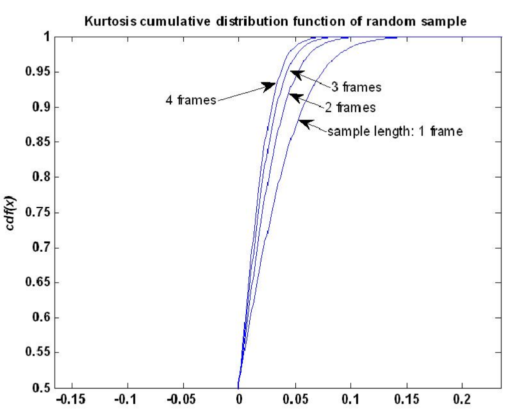

Figure 1. Plot of kurtosis cdf of random sample of various lengths

2.4. Kurtosis Based Spectral Analysis

The kurtosis, k for a circular zero means random variable x is defined as;

$$k = E\left[|x|^4\right] - 2\left(E\left[|x|^2\right]\right)^2 \quad (2)$$

It can be deduced that the kurtosis of a Gaussian random variable is close to zero while it is non-zero for a non-Gaussian random variable [30]. This implies that the kurtosis can be considered zero under hypothesis H_0, and non-zero under hypothesis H_1. The magnitude of the kurtosis, therefore, serves as a good candidate for the decision statistic of the binary hypothesis test.

3. Derivation of Mathematical Expression for Auto-Correlation

We consider a discrete-time (sampled) complex baseband model as shown in figure 2. Assume that x is a received vector of length N that consists of an OFDM signal plus noise, i.e.

$$x = s + n$$

where s is a sequence of K consecutively transmitted OFDM symbols, and n is a noise vector. The noise n is assumed to be zero-mean circularly symmetric complex Gaussian with variance σ^2. Each OFDM symbol consists of a data sequence, and a cyclic prefix (CP). Further, each symbol in OFDM sensed signal may or may not possess pilot signal depending upon the used pilot allocation strategy. In this research work, we consider AWGN channel in order to study the most important fundamental aspects of OFDM signal detection. In practice one cannot know exactly when to start the detection. That is, the receiver is not synchronized to the transmitted signal that is to be detected.

We derive a closed-form expression to calculate auto-correlation of sensed OFDM signal. The key observation for deducing the optimal detector based on kurtosis of auto-correlated signal is that OFDM lies in a certain subspace, owing to the structure introduced by the insertion of stationary pilots and by the repetition of data in CP.

Auto-correlated signal of an OFDM signal can calculated using the mathematical expression given in equation 3.

$$R_{xx}(l) = \frac{1}{N}\sum_{n} x(n)x(n+l) \quad (3)$$

where $R_{xx}(l)$ is the auto-correlated signal of OFDM signal x(n) by shifting x(n) through l samples (i.e. x(n+l)).

Equation 3 can be expressed more explicitly by visualizing autocorrelation of x(n) at symbol level;

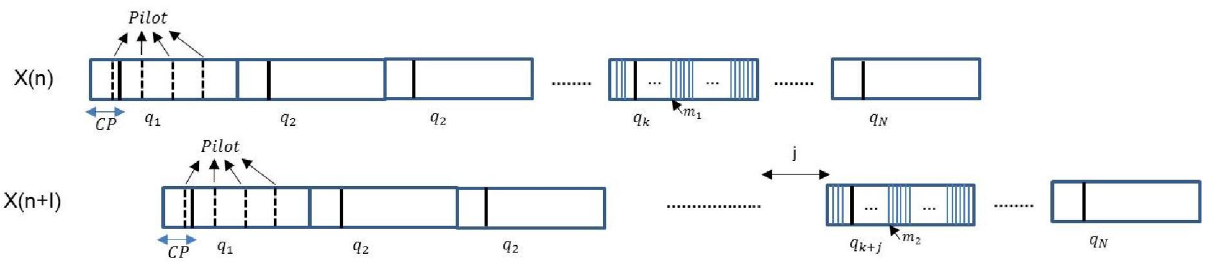

Figure 2. Model for N Samples of the Received OFDM Signal

$$R_{xx}(l) = \frac{1}{N}\sum_{n} q_k(m_1) \begin{cases} q_{k+j}(m_1+m_2) & if\ m_1+m_2<L \\ q_{k+j+1}(m_1+m_2-L) & if\ m_1+m_2 \geq L \end{cases}$$

where q_k and q_{k+j} represent symbols located at 'k' and 'k+j' in OFDM signal.

$$n = kL + m_1 \ and\ l = jL + m_2,$$

$$0 \leq m_1 < L, \text{ and } 0 \leq m_2 < L$$

$$R_{xx}(l) = \frac{1}{N}\sum_{k}\sum_{m_1} q_k(m_1) \begin{cases} q_{k+j}(m_1+m_2) \\ q_{k+j+1}(m_1+m_2-L) \end{cases}$$

$$E\left[R_{xx}(l)\right] = \frac{1}{L}\sum_{m_1} E\left[\frac{1}{k}\sum_{k} q_k(m_1) \begin{cases} q_{k+j}(m_1+m_2) \\ q_{k+j+1}(m_1+m_2-L) \end{cases}\right] \tag{4}$$

First we solve the sub-fraction on right hand side;

$$\mathrm{E}\left[\frac{1}{k}\sum_{k} q_k(m_1) \begin{cases} q_{k+j}(m_1+m_2) \\ q_{k+j+1}(m_1+m_2-L) \end{cases}\right]$$

$$= \frac{1}{k}\sum_{k} E\left[q_k(m_1) \begin{cases} q_{k+j}(m_1+m_2) \\ q_{k+j+1}(m_1+m_2-L) \end{cases}\right]$$

$$= \frac{1}{k}\sum_{k} R_{qq}(m_1, m_2) = R'_{qq}(m_1, m_2)$$

This implies that

$$\mathrm{E}\left[R_{xx}(l)\right] = \frac{1}{L}\sum_{m_1} R'_{qq}(m_1, m_2) \tag{5}$$

The model and method which we present is valid for any value of K. Generally, the detection performance will improve with increasing K. However, choosing a very large K in practice may cause problems. Thus, our model is mostly useful for quite moderate values of K.

We present here an example to visualize that kurtosis value of auto-correlated signal calculated from OFDM signal is non-zero (very high as compared to kurtosis value of random signal) whereas, kurtosis value directly calculated from OFDM signal is zero (0.094). To generate OFDM signal through simulation, we use the following parameters; create a random sequence of integers (value 0 to 15), apply QAM modulation with M equals to 16, FFT size 1024, 768 sub-carriers for data, 64 for pilot signal, 192 sub-carriers as guard interval, CP size 128 (8% of FFT size). Communication system based on these parameters generate OFDM symbols q_1 and q_2 having length of 1052 data components with cyclic period L=2π/N. OFDM signal coefficients for symbols q_1, q_2 and corresponding auto-correlated signal coefficients are plotted in figure 3. Further, we compute the kurtosis value for both OFDM symbols q_1 and q_2, and have found kurtosis value of randomly distributed data coefficients in OFDM symbol is approximately zero (0.094). Furthermore, correlated signal of both symbols q_1 and q_2 by sliding symbol q_2 over q_1 with a factor of l is calculated and auto-correlated signal result is averaged out for 1000 iterations. We calculate kurtosis value for averaged auto-correlated signal using equation 6, and assess that kurtosis value is much greater than zero (36, compared to threshold value used to detect OFDM signal in cognitive radio).

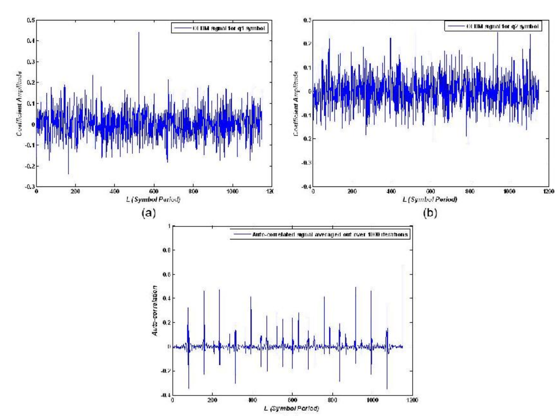

Figure 3. Signal Coefficients are Plotted; a) Sub-Plot of Real Coefficients of q_1, b) Sub-Plot of Real Coefficients of q_2, c) Correlated Signal of Symbol q_1, q_2, Averaged Out Over 1000 Iterations.

4. The Proposed OFDM Signal Detection Technique

Since, performance of auto-correlation based techniques to detect OFDM signal decreases when the sensed signal is highly corrupted, i.e. 0 dB or more AWGN. Further, kurtosis based techniques have been used to sense spectrum for cognitive radio but cannot be employed directly to OFDM signal. This is because the OFDM symbols in the sensed OFDM signal are independent, identically distributed in a similar fashion to Gaussian distribution. The kurtosis value of a random variable is zero; either the random variable is an OFDM signal or noise. Here, the key point is that if the randomness in OFDM symbols could be removed then it may be possible to employ kurtosis based techniques to detect OFDM signal even in highly noisy environment. This is one of the important objectives in the current research. Keeping in view of the above mentioned facts, we propose an intelligent technique for OFDM signal primary user detection in cognitive radio based on cyclic auto-correlation and kurtosis. In the proposed technique, we first calculate auto-correlation of the sensed signal to detect primary user transmitting OFDM signal in cognitive radio. Auto-correlation removes the phase randomness in OFDM symbols and we exploit this advantage and detect the OFDM signal by calculating kurtosis value of the auto-correlated signal. The schematic flow chart of the proposed technique is shown in figure 4.

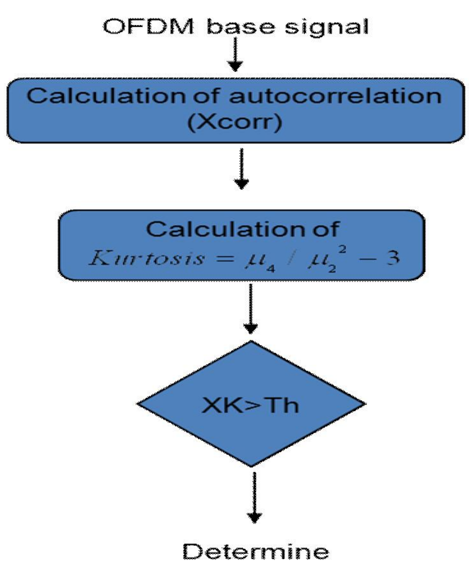

Figure 4. Flowchart of the Proposed Technique

We use the following mathematical expression to calculate the kurtosis value from auto-correlated signal.

$$Kurtosis(XK) = \frac{\mu_4}{\mu_2} - 3 \qquad (6)$$

The procedure of the proposed technique to detect the OFDM signal in cognitive radio is described below;

- Sensed signal x(t)
- Calculate the Auto-Correlation Function (Xcorr) considering each symbol for the complete sensed signal x(t) using equation 1
- Calculate Kurtosis value based on auto-correlation function Xcorr through equation 3
- If the value of kurtosis (XK)is larger than a threshold, then OFDM signal exist, otherwise specific band is free
- Threshold value can be defined by using kurtosis value (XK) based on noise
    - Threshold = average of noise XK + 3(standard error of noise XK) by considering 8 frames of OFDM sensed signal.

In the following section, we make analysis of the OFDM signal corrupted through AGWN at various SNRs and performance of the proposed technique to detect primary user transmitting OFDM signal by considering different pilot allocation schemes.

5. Results and Discussion

In this section, we perform the analysis of the proposed technique to detect OFDM signal by varying spectrum sensing time, signal corrupted at various SNRs, and different pilot allocation strategies. In our simulations, we do not need synchronization of both primary user transmitter and secondary user receiver at symbol level. Whereas, all cyclostationarity analysis based spectrum sensing techniques in cognitive radio assume that both primary user transmitter and secondary user receiver are synchronized at symbol level.

5.1. Auto-Correlation Based Analysis of OFDM Signal

A typical example of pilot allocated WIBRO OFDM signal corrupted through 0dB AGWN is shown in figure 5. From OFDM signal plot shown in figure 5, it may be observed that the signal coefficients are randomly distributed. Further, real coefficients of a sensed corrupted OFDM signal and central portion of its corresponding auto-correlation plot are shown in figure 6. To calculate kurtosis value of auto-correlated signal, we consider only central portion of auto-correlated signal to avoid the effects of power and CP peaks in the first half and end effects in the right half of the auto-correlated signal. We have calculated kurtosis value of both plots shown in figure 6 and have found that kurtosis value directly calculated from OFDM signal is ~ 0 (0.094), whereas, kurtosis value of auto-correlated signal of OFDM signal is 720. Since, Gaussian white noise is also randomly distributed; by considering the OFDM signal as noise only, we have also performed analysis of the only noise signal by finding its kurtosis value. From our experimental analysis, we conclude that kurtosis value of auto-correlated noise signal is very small, i.e. close to 0. This is because auto-correlation of Gaussian white noise has peak at zero only and kurtosis value of auto-correlated signal using equation (2) and (3) will result zero. Based on the above mentioned analysis, a sensed signal will be declared as an OFDM signal if its auto-correlated kurtosis value is high enough.

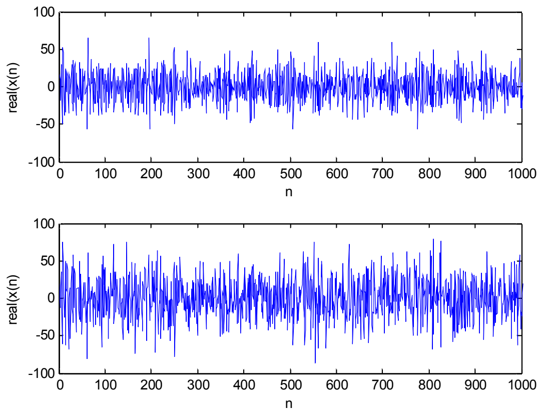

Figure 5. Plot of Real Coefficients of Two Different Frames of Wibro OFDM Signal Corrupted Through 0dB AWGN

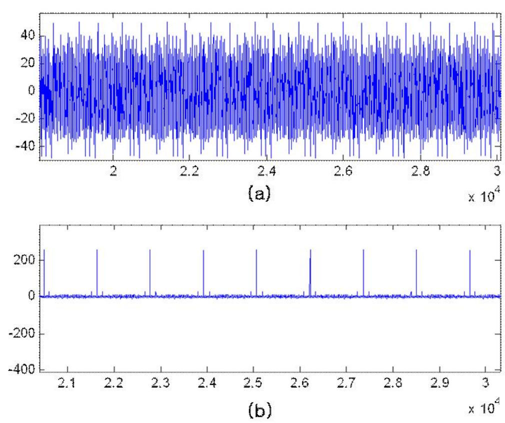

Figure 6. Plot of an OFDM Signal and Its Auto-Correlation. a) Sub-Plot of Real Coefficients of an OFDM Signal Corrupted Through -5dB, b) Sub-Plot of Auto-Correlated Signal of (a)

We perform experimental analysis of the obtained OFDM signal by considering two scenarios and measure its auto-correlation kurtosis (XK) value; at various SNRs and by increasing number of frames to calculate XK value. We average out the obtained results for 20 iterations. Obtained results for XK are shown in figure 7. From figure 7, it may be observed that auto-correlation kurtosis value of sensed OFDM signal corrupted with same AGWN increases by increasing spectrum sensing time. Further, with increase in noise in the OFDM transmitted signal reduces the auto-correlation kurtosis value for a fixed duration spectrum sensing. It may be concluded that keeping in view of channel conditions, proper sensed signal length may be used to calculate the XK value.

Detector threshold is calculated from XK value of noise signal only to decide the presence of an OFDM primary signal using the following relation;

Th = Threshold calculated from noise XK + α

Where, α is positive fraction used as margin on safe side (low FAR) to correctly identify the sensed signal even in a severe channel condition. Further, based on our experimental analysis, we fix threshold equal to 0.25 heuristically to decide whether the sensed spectrum signal is primary user OFDM signal or noise (free spectrum band). This can be further explained that if the XK value of a sensed signal over 8 frames is greater than 0.25, the detector declares that a primary user OFDM signal is present otherwise the sensed spectrum is vacant.

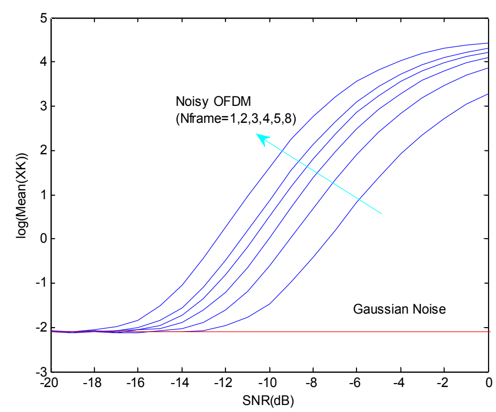

Figure 7. Effect of Channel Noise on Auto-Correlation Kurtosis Value of OFDM Signal

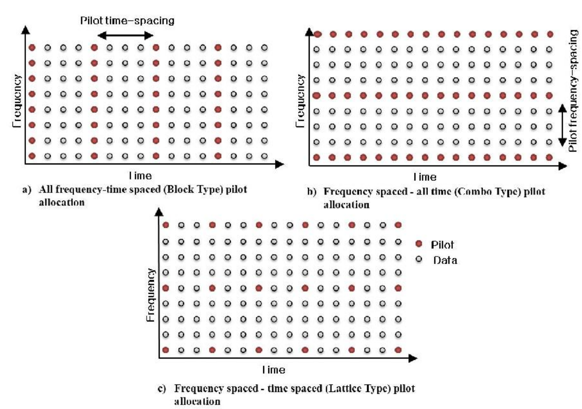

Figure 8. Different Possibilities for Pilot Allocation

5.2. Performance of the Proposed Technique Against Various Pilot Allocation Strategies

Pilots can be allocated in spaced intervals of time and frequency as illustrated in figure 8. We also perform experimental analysis of the proposed approach by considering three scenarios for pilot allocations; all frequency – time spaced (block type), frequency spaced - time spaced (lattice type) and frequency spaced – all time (combo type) pilot allocations in the OFDM signal. In practical systems, actually it's impossible to achieve 0% FAR or 100% detection rate. We have performed experiments for 1000 times to detect the primary user through the proposed approach based on XK value and found 100% detection rate. Based on our experimental analysis, in the current research work, we fix false alarm rate to 0 % and carryout performance analysis of the proposed approach at various SNRs and by increasing sample size (number of frames). Obtained results are averaged out over 100 iterations. Considering the block type pilot allocation strategy in the OFDM transmitted signal, auto-correlated signal of the Wibro OFDM signal corrupted through -5dB AWGN is shown in figure 9. Further, performance of the proposed approach at various noise degradations and sample length is shown in figure 10. From figure 10, it may be observed that by increasing sensed signal length, performance of the detector can be improved depending upon the application. Results obtained through the proposed approach by employing block type pilot allocation strategy in OFDM signal are summarized in table1.

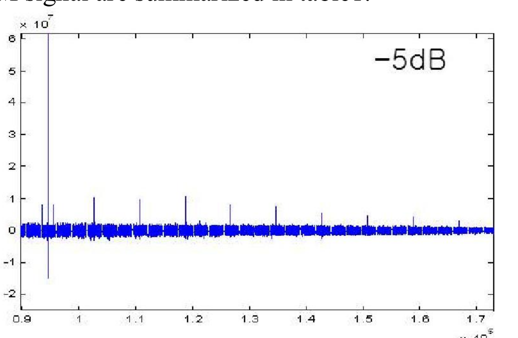

Figure 9. Auto-Correlated Signal of WIBRO OFDM Signal with Block Type Pilot Allocation Strategy and Corrupted Through -5dB Noise

Table 1. Effect of number of sample frames on SNRs range for block type pilot allocation

Frame Number	1	2	3	4	5	8
FAR=0%	-5dB	-7dB	-8dB	-9dB	-10dB	-11dB

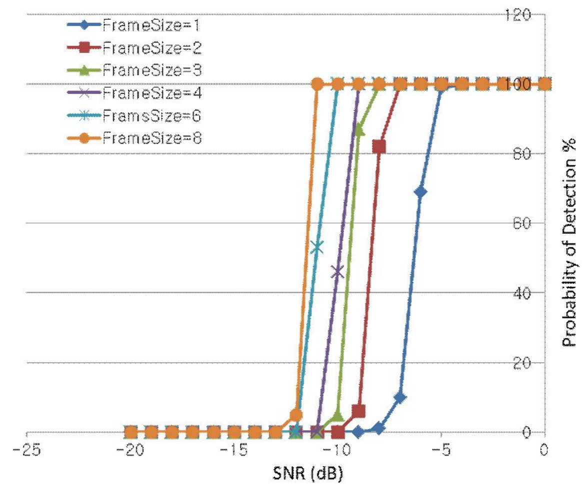

Figure 10. Performance of the Proposed Approach at 0% FAR for Block Type Pilot Allocated WIBRO OFDM Signal

For lattice type pilot allocation strategy in OFDM signal, auto-correlated signal is shown in figure 11 and results obtained through the proposed approach for FAR 0% are shown in figure 12. It may be observed from figure 12 that performance of the proposed detector is increased. From results, it can be ensured that for 100 % detection rate, SNRs range reduces by 1dB through lattice pilot allocation in OFDM signal as compared to block type pilot allocation strategy in OFDM signal. This may be due to the fact that in block type pilot allocation strategy, all symbols in sub-frames may contain either pilot or data only. Whereas, considering lattice type pilot allocation strategy, few symbols in each frame contain both pilot and data, and others comprise of data only. Obtained results using this pilot allocation strategy are summarized in table 2.

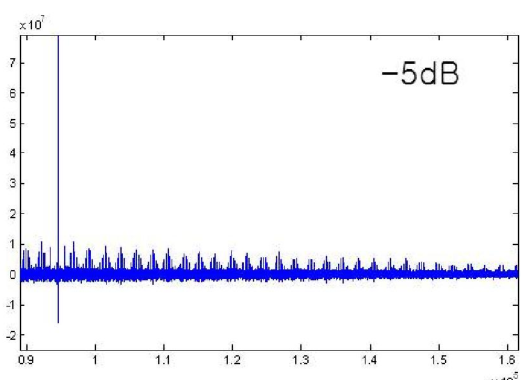

Figure 11. Auto-Correlated Signal of WIBRO OFDM Signal with Lattice Type Pilot Allocation Strategy and Corrupted Through -5dB Noise

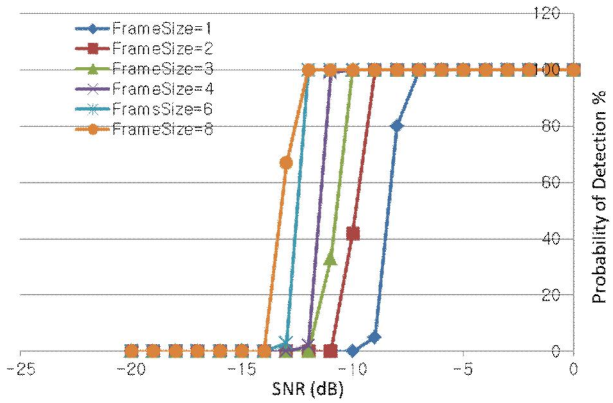

Figure 12. Performance of the Proposed Approach at 0% FAR for Lattice Type Pilot Allocated WIBRO OFDM Signal

Table 2 Effect of number of sample frames on SNRs range for lattice type pilot allocation

Frame Number	1	2	3	4	5	8
FAR=0%	-7dB	-9dB	-10dB	-11dB	-12dB	-12dB

Table 3 Effect of number of sample frames on SNRs range for combo type pilot allocation

Frame Number	1	2	3	4	5	8
FAR=0%	-9dB	-10dB	-11dB	-12dB	-13dB	-14dB

In third scenario, we perform experimental analysis of the proposed technique by considering combo type pilot allocation in the OFDM transmitted signal. Auto-correlated signal and obtained results through the proposed technique at FAR 0% for OFDM signal with various channel conditions are shown in figure 13 and figure 14, respectively. It may be noted from figure 14 that performance of the proposed detector is improved as compared to block or lattice type pilot allocation strategies. Further, it can be confirmed that for 100 % detection rate, SNRs range reduces by 2dB through combo type pilot allocation in OFDM signal as compared to lattice type and 3dB as compared with block type pilot allocation in OFDM signal. Obtained results using this pilot allocation strategy are summarized in table 3. This performance improvement as compared to other two pilot allocation strategies is due to the fact that each symbol in a frame comprises of both data and pilot. Further, uniform pilot distribution in OFDM signal makes it possible to detect an OFDM signal by relaxing the assumption of primary user transmitter and secondary user receiver synchronization, and does not require any priori information about the OFDM signal transmission system.

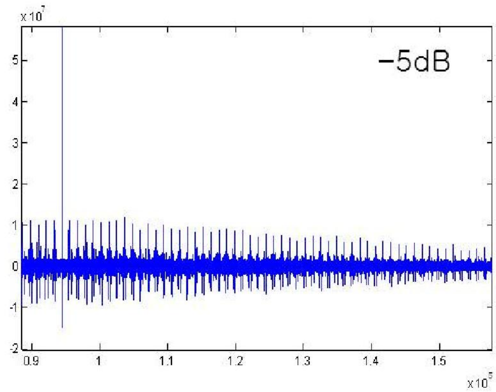

Figure 13. Auto-Correlated Signal of WIBRO OFDM Signal with Lattice Type Pilot Allocation Strategy and Corrupted Through -5dB Noise

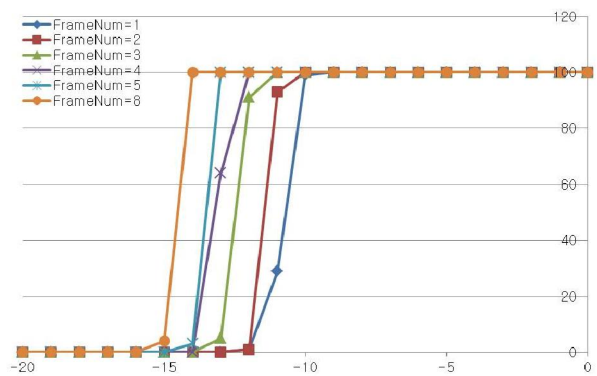

Figure 14. Performance of the Proposed Approach at 0% FAR for Combo Type Pilot Allocated WIBRO OFDM Signal

6. Conclusions

An intelligent and improved OFDM signal detection based on the auto-correlation and kurtosis is analyzed. To detect OFDM signal in spectrum sensing with 100 % detection, a threshold is defined based on noise auto-correlation kurtosis. Performance analysis of the proposed techniques has been carried out by increasing the length of sample sequence of the sensed signal. Different scenarios have been considered for pilot allocation in the OFDM signal to study its effect on detector varying channel conditions. From results, it may be observed that detector performance increases with increase in sample length and by employing combo type pilot allocation in OFDM signal transmission. Promising detection results for OFDM signal shows the efficacy of the proposed approach. In future, we intend to extend our approach to detect OFDM signal from an unknown primary user transmission system.

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