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Cyclostationary FFT Accumulation (FAM) Technique Analysis Using Wi-Fi and Wi-Max Preamble for Spectrum Sensing

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Abstract: *The most stimulating problem for ultra-wideband (U-WB) signals is the sensing of cyclostationary signals in cognitive radio. Licensed user's signal must be efficiently detected by cognitive radio as well as in low signal to noise ratio (SNR) and diverse environment conditions. This paper proposes a technique for the detection of ultra wideband signal in such scenarios. To deal with this problem, cyclostationary FFT accumulation technique has been developed with low bit error rate (BER) and less complexity. Obtained graph of wi-fi and wi-max signal with low SNRs versus BER shows the successful recognition of primary user signal and cyclostationary FAM method is equally suitable for wi-fi and wi-max due to negligible difference in BER.*

Keywords: *Spectrum sensing, OFDM signal, Cyclic spectrum, QAM, Cyclostationary FFT accumulation.*

1. INTRODUCTION

To reduce the effect of spectrum scarcity, cognitive radio is best approach to exploit the available radio frequency spectrum. Cognitive radio (CR) is considered as an advanced type of software define radio (SDR) method. CR performs various functions in addition with SDR such as spectrum sensing, spectrum sharing, spectrum mobility and spectrum management. It is the major issue to sense the spectrum without knowing the parameters of primary user (PU) in a noisy and overcrowded environment. Almost all the wireless signals are cyclostationary in nature such as sinusoidal carriers pulse trains repeating codes, modulation technique, cyclic prefixes, mean and autocorrelation vary cyclically w.r.t time. CR can easily access the white holes dynamically without affecting the secondary user signal using statistical property of wireless signal. Some methods of spectrum sensing are matched filter and energy detection.

The matched filter technique performs the signaldetectionafter knowing the parameters of PU signal as signal shape, frame size, modulation technique etc. An energy detection method detects the vacant slots by comparing the estimated power with predetermined threshold value [5]. Hence, these methods don't perform efficiently under poor signal to noise ratio environments. When signal is greatly ruined by noise, inequity between presence and absence of signal is difficult.

In this paper, we intend a different approach to these methods is FFT accumulation detection method, for wi-fi and wi-max OFDM signal. This method is based on the detection of cyclic autocorrelation function (CAF) peaks which are due to cyclic prefixes. The pilot symbol is randomly generated which yields zero correlation [7]-[8]. This technique gives trustworthy approximation of signal's parameters.

The rest of the paper is structured as follow. Section II introduces the wi-max and wi-fi OFDM signal investigation. The proposed model for wi-fi and wi-max signal detection is explained in Section III. FAM estimation of cyclic spectrum is described in Section IV. Numerical results are shown in Section V and finally the conclusion is drawn in Section VI.

2. WI-MAX OFDM ANALYSIS

An orthogonal frequency division multiplexing (OFDM) is a modulation scheme that uses multiple carriers to transmit data. Each of these carriers could be modulated using any variation from BPSK to N-QAM. The basic idea is to split the data to be transmitted over multiple lower rate channels to make it more robust but getting higher bit rates in the overall transmission. Such a scheme has been improved by defining orthogonality between the used carriers and allowing them to be closer to each other and reducing the needed bandwidth.

The cognitive radio system requires spectrum sensing that are usually implemented by means of the FFT. OFDM has an FFT machine that in many cases could be shared for spectrum sensing algorithms. This allows the manipulation of individual carriers as a strategy to reduce the current bandwidth. This is where adaptability of OFDM resides, making possible to modify power on individual carriers, suppressing any of them, modulation order and even the spectrum shaping. This flexibility allows to getting an added advantage of available frequency spots, since it is possible to adapt the transmission to the size of the spot. In fact multiband OFDM uses scattered free spots to allocate transmission thanks to the ability to pick and shape carriers to be used [4].

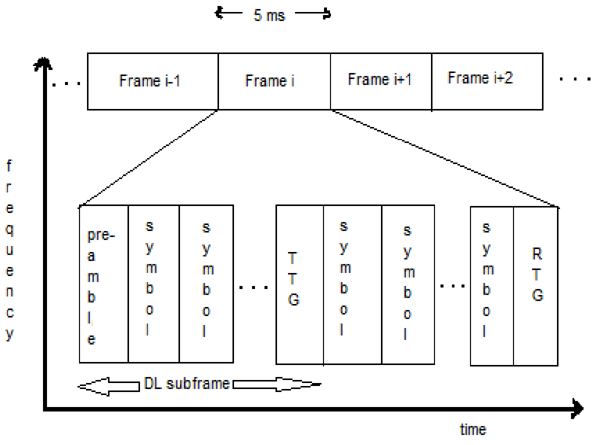

Fig. 1: TDD wi-max frame structure.

All wi-max equipments support only 5ms frame [11] [9]. The frame starts with preamble as a first signal, used for time and frequency synchronization. In OFDM signal three type of subcarriers are used: null carriers for guard band, pilot carrier for estimation and data carriers to send informatory signal [7]-[8]. OFDM signal is also esteemed by it strength against multipath and this is accomplished by defining cyclic guard intervals as part of its structured design. This feature is inclined to be easily modified to meet different environments. Fig. 1 represents the TDD frame structure of IEEE 802.16e.

3. PROPOSED MODEL

For very high speed applications, a spectrum sensing technique should require less computation time and should have less complexity. Thus, there is a scope for development of a fast and less complex spectrum sensing technique by some modifications to the existing techniques.

In this paper, cyclostationary technique is applied to wi-fi and wi-max signal derived from preamble by making some assumptions of primary user signal to detect the spectrum. FFT accumulation technique is applied to the incoming wi-fi and wi-max signal which reduces the complexity. 64-QAM modulation is used in which 6 bits are transmitted per symbol.

Initially, we define the autocorrelation function as cognitive sensing node. This idea originates from the instance of having a pulse modulation of single magnitude like $+/-1$ that after square hide any ghost line but the dc one. Then the transformation $\mathrm{y(t) = x(t).x(t-\tau)}$ promises spectral lines for $\mathrm{m.f_0}$ where m is a numeral.

$$m_y^a =< y(t)e^{-j2\pi at} > \quad (1)$$

$$=< x(t).x(t-\tau)e^{-j2\pi at} >\neq 0 \quad (2)$$

The spectral correlation purpose definition comes from the basic idea of discovery the middling power in the frequency domain as $R_x(t) = |x(t)|^2$ If the correlation in the frequency domain among the shifted forms v(t) and u(t) has to be found then the appearance becomes,

$$R_x^0(\tau) =< u(t)v*(t) >=< |x(t)|^2 e^{-j2\pi at} \quad (3)$$

Furthermore, the power spectral density (PSD) could be imagined as passing the signal x(t) by a narrowband pass filter and scheming the average power, where the filter is simulated all over the band. In the limit, the bandwidth (B) of the filter methods zero:

$$S_a(f) = \lim_{B\to 0}\frac{1}{B} < |h_B(t)\otimes x(t)|^2 >^n \quad (4)$$

$$S(f) = \int_{-\infty}^{\infty} R_x(\tau)e^{-j2\pi ft}\,d\tau \quad (5)$$

$$S_x^a(f) = \int_{-\infty}^{\infty} R_x^a(\tau)e^{-j2\pi ft}\,d\tau \quad (6)$$

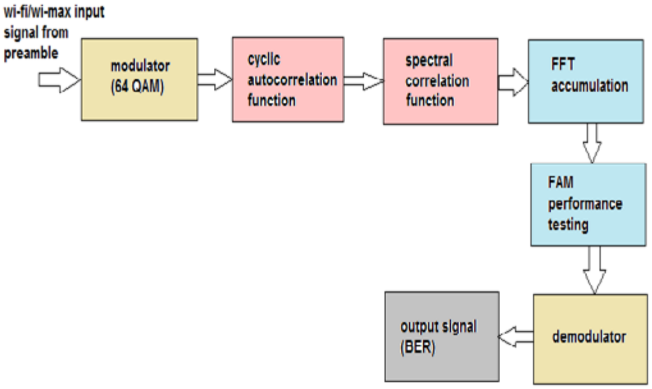

Fig. 2: Proposed model.

Moreover, the strip spectral correlation analyzer (SSCA) and FFT accumulation (FAM) are both under the time-smoothing organization. The SCD function of x[n] is definite as $S_x(f) = \sum_{k=\infty}^{-\infty} R_x^a(k)e^{-j2\pi fk}$ by means of the discrete Fourier transform, where:

$$R_x^a(k) = \lim_{n\to\infty}\frac{1}{2N+1}\sum_{n=-N}^{N}[x(n+k)e^{-j2\pi a(n+k)}][x(n)e^{-j2\pi an}] \quad (7)$$

Lastly, FAM presentation could be examined by FFT accumulation test bench, capable of outputting a value that designates the attendance of a particular signal like 802.11a in cognitive radio unit. The production has to be a ratio metric defined since wireless indications does not promise fixed signal energy levels. A good expedient output could be the summary of the peaks where introductions should seems and also comprise the pilot's peaks.

Table 1: OFDM parameters for wi-fi and wi-max signal.

S. No.	PARAMETER	WI-FI	WI-MAX
1.	SNR (db)	20	20
2.	Bits per symbol (bps)	1,2,4,6	1,2,4,6
3.	Modulation technique	64 QAM	64 QAM
4.	FFT	64	256
5.	No. of symbols	200	67
6.	No. of frames	200	138
7.	Data carrier	48	192
8.	FAM sampling frequency (hertz)	2 X 10^7	4 X10^6

4. FFT ACCUMULATION ESTIMATION

FAM contains hamming window for capturing in a time length Δ_ta piece of the received signal x[n] which is the outcome of x(t), sampled atf_s. Approximation of $S_x^a(n,f)_{\Delta t}$ is achieved over this time of length (t). This calculation is achieved iteratively over consecutive smithereens in the time domain until satisfactory results for a summation of several $S_x^a(n,f)_{\Delta t}$ contents the request, in terms of time of calculation and objective to meet.

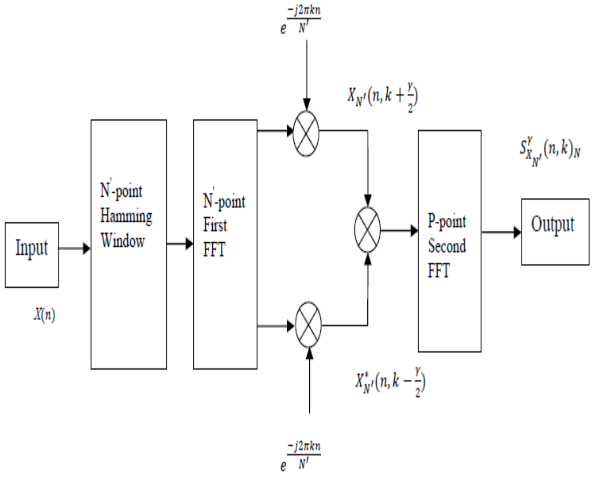

Fig. 3: FFT accumulation method.

The FAM method works as follow:

1) Important parameters are initialized from the data sequence.
2) The value of L and N is determined as the resolution in sampling frequency and frequency and compromise in computational efficiency and minimizing cycle leakage and aliasing respectively, which is defined by $N^l = \frac{f_s}{\Delta f}$ and $L = \frac{N^l}{4}$
3) Envelop is estimated by sliding N point FFT and then applied to data in L samples.
4) Complex conjugate is found out and determined the value of P according to cyclic frequency$\Delta\alpha$.
5) Simulation is chosen as $P = \frac{F_s}{L\Delta\alpha}$

To test the presence of signal, a hypothesis test is formalized.

H1: x(n) = s(n)h + w(n)
H2: x(n) = w(n)

Based on the values of threshold H1 is declared as presence of signal and H2 is considered as a vacant band.

5. SIMULATION RESULTS

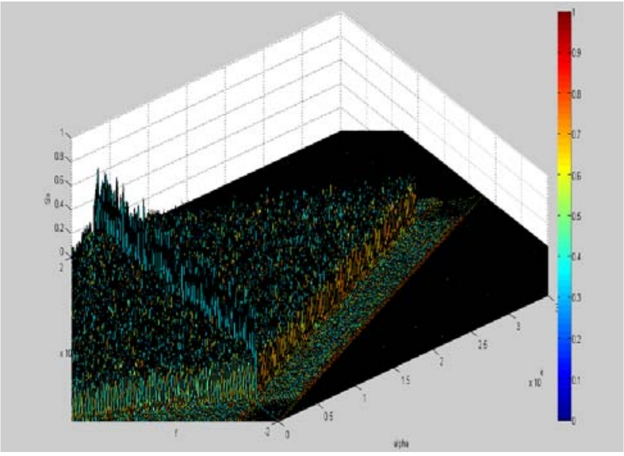

Fig. 4: Power spectral density of wi-max signal using 64 QAM.

Fig. 4 shows the surface plot of positive cyclic frequencies of power spectral density (PSD). The pilot subcarrier peaks can be seen over-hanged well above the data subcarrier floor in arrays of three then two and finally one. To ensure the pilot subcarrier peaks are clearly identifiable, the results averaged over 120 OFDM symbols.

Fig. 5 is generated by the FAM estimator. The Fig. demonstrates a clearly identifiable pilot subcarrier cyclostationary pattern. This is the signature that is exploited when classifying Wi-Fi/Wi-Max waveforms. The pilot subcarriers spectral lines are not identifiable in upper part of each Fig. and clearly discernable in lower part of each figure.

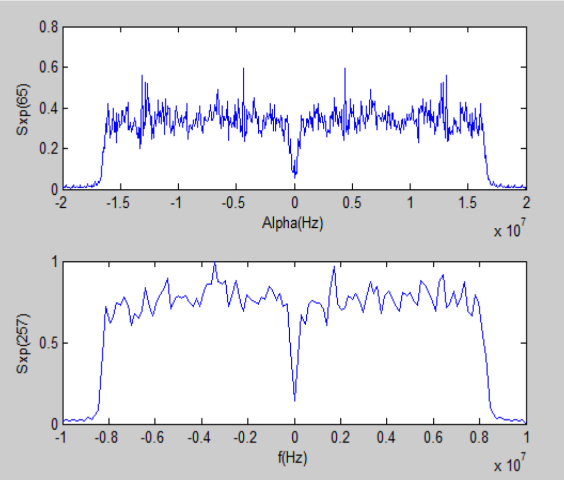

Fig. 5(a). normalized frequency of wi-fi signal at 6bps.

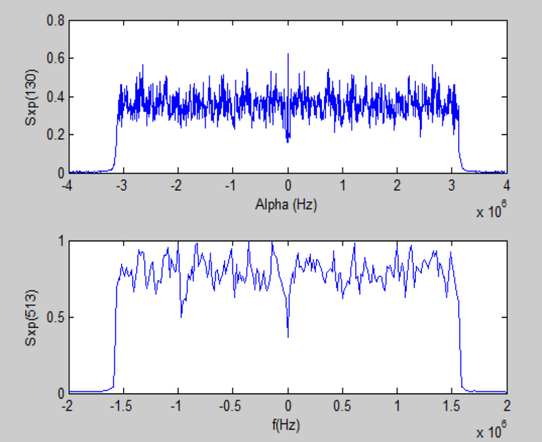

Fig. 5(b). Normalized frequency of wi-max signal.

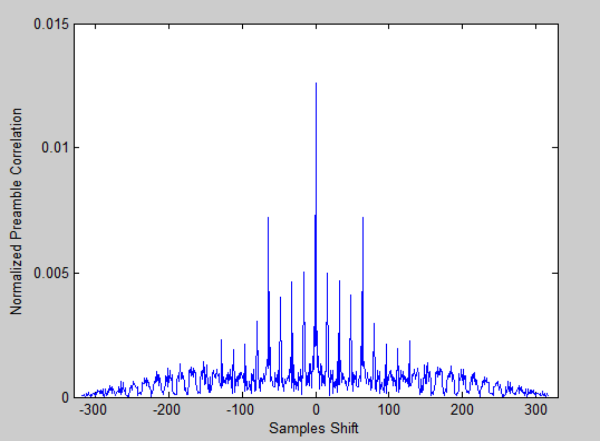

Fig. 6(a). Normalized sum of magnitude square using 6bps (wi-fi).

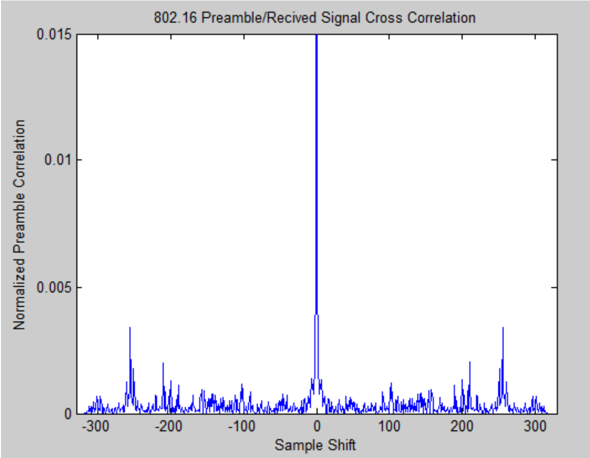

Fig. 6(b). Normalized sum of magnitude square using 6bps (wi-max).

Fig. 6 shows the cross correlation between Wi-Fi/Wimax compliant preamble sequence versus a received signal from the noisy AWGN channel. Each sample preamble is comprised of 320 samples, which equates to the entire preamble sequence (short and long training sequences).

Table 2: Difference in BER for wi-fi and wi-max for n-QAMs at same SNR.

SNR (dB)	BIT ERROR RATE							
	2-QAM		4-QAM		16-QAM		64-QAM	
	WiFi	Wimax	WiFi	Wimax	WiFi	Wimax	WiFi	Wimax
1	0.0578	0.0620	0.1284	0.1856	0.2610	0.2625	0.3370	0.3372
2	0.0219	0.0252	0.0798	0.1157	0.2093	0.2127	0.3015	0.3024
3	0.0074	0.0078	0.0405	0.0626	0.1618	0.1659	0.2607	0.2588
4	0.0003	0.0010	0.0144	0.0215	0.1181	0.1193	0.2174	0.2173
5	0	0	0.0021	0.0046	0.0786	0.0827	0.1709	0.1746
6	0	0	0.0002	0.0005	0.0428	0.0474	0.1330	0.1350
7	0	0	0	0	0.0159	0.0198	0.0968	0.1000
8	0	0	0	0	0.0051	0.0057	0.0645	0.0669
9	0	0	0	0	0.0007	0.0010	0.0361	0.0382
10	0	0	0	0	0	0	0.0116	0.0169
11	0	0	0	0	0	0	0.0043	0.0053
12	0	0	0	0	0	0	0.0006	0.0008

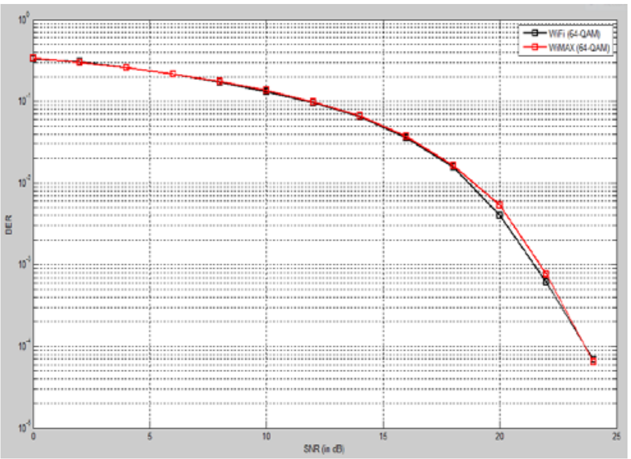

Fig. 7. Difference in BER at same SNRs for wi-fi and wi-max signals at 64 QAM.

Modulation used in our simulations is QAM with different constellation size or bits-per-symbol. Simulations were done for Wi-Fi and Wi-Max systems individually, with 4 symbol sizes of QAM, *viz.*, 2, 4, 16 and 64. Noise considered in our simulations is the Additive White Gaussian Noise (AWGN) with zero mean and variance $N_o/2$ per dimension, where N_o (Power Spectral Density of Noise) varies with respect to the signal-to-noise ratio for different configurations accordingly. For 64-QAM, a difference of 0.0053 (at most) in terms of BER performance is observed between the Wi-Fi and Wi-Max systems.

Of all the modulations, spectral efficiency of 64-QAM is best and thus it is more desirable. Spectral efficiency of 64-QAM is 6 bits/sec/Hz, i.e., it transmits 6 bits per second using 1 Hertz of bandwidth. Rest of the schemes, i.e., 16-QAM, 4-QAM and 2-QAM, have spectral efficiency of 4 bits/sec/Hz, 2 bits/sec/Hz, and 1 bits/sec/Hz, respectively.

As seen from Table 2, the BERs for 64-QAM systems at SNR of 8 dB is comparable to the BER for 2-QAM systems at SNR of 1 dB. Thus, we need an increase of 7 dB in signal power above noise power to transmit and receive 5 more bits/Hz, which is acceptable as the increase is power is linear and not exponential.

Also, if we have SNR >= 12 dB, all systems behave equally in terms of BER performance and in this case we can use 64-QAM system (Wi-Fi or Wi-Max) without any error overhead.

6. CONCLUSION

Cyclostationary spectrum sensing technique is devised to detect OFDM signals in a noisy (AWGN) environment with less complexity. For very high speed applications, a spectrum sensing technique should require less computation time and should have less complexity. The proposed system has less computation time and less complexity. The proposed system was compared with existing spectrum sensing techniques in terms of bit error rate performance.

The validity of the proposed spectrum sensing technique has been done using Wi-Fi and Wi-Max systems. As seen from the simulation results, there is a minor increase in the BER of a Wi-Max system when compared to a Wi-Fi system at same SNR. This difference or increase in BER of the Wi-Max system is tolerable as the communication range of a Wi-Max system is far better than that of a Wi-Fi system at same SNR. Also, Wi-Max being a wideband system can handle more users than Wi-Fi which is a narrow band system.

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