PERFORMANCE COMPARISON OF CYCLOSTATIONARY AND AUTOCORRELATION DETECTORS FOR LTE

A Project Report

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MAHESH DUBEY

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THESIS CERTIFICATE

This is to certify that the thesis titled **Performance Comparison Of Cyclostationary And Autocorrelation Detectors for LTE**, submitted by **Mahesh Dubey**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master Of Technology**, is a bonafide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. Devendra Jalihal
Research Guide
Professor
Dept. of Electrical Engineering
IIT-Madras, 600 036

Place: Chennai

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ABSTRACT

This projects involves comparative analysis of various detectors such as energy ,Autocorrelation detector ,ACAE detector and cyclostationary detector .This thesis will provide the brief knowledge about cyclostationarity and lte OFDM signals. This thesis mainly concentrate on the indepth analysis of autocrrelation and cyclostationary detector under specific condition.This covers two broad sections ,one is domain analysis of cyclostationary detector and second part is to analyse the performance of autocorrelation and cyclostationary detector for LTE OFDM frame structure . We evaluated the performance of detectors by mainly focusing on two parameter of lte OFDM frame namely cyclic prefix and pilot signals .This thesis also analyze the impact of known and unknown primary signal information at secondary user on detection performance of detectors .

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CHAPTER 1

INTRODUCTION

1.1 Cognitive Radio

Wireless communication systems rely on the use of scarce resources, most notably the radio frequency spectrum. The dramatic increases in the number of wireless subscribers, the advent of new applications and the continuous demand for higher data rates call for flexible and efficient use of the frequency spectrum. Cognitive radios have been proposed as a technology for dynamic spectrum allocation . Cognitive radios sense the radio spectrum in order to find temporal and spatial spectral opportunities and adjust their transceiver parameters and operation mode accordingly. Spectrum sensing has to be done reliably in the face of propagation effects such as shadowing and fading. Moreover, the level of interference caused to the primary (legacy) users of the spectrum must be maintained at a tolerable level.

1.2 Detectors

There are various detectors which are available to detect the presence of primary signals over a given spectrum. Among them major detectors are energy detector ,autocorrelation detector and cyclostatinory detector .Over here performance of various detector is studied . Analysis of their comparative performance is executed . In this thesis measure focus was on Cyclostationary detector and autocorrelation detector . This thesis covers the the performance of the detectors with respect to varying frame size of LTE signal .

1.3 Organization Of Thesis

Property of cyclostationary signal is explained in chapter 2.It also covered Cyclic Autocorrelation Function ,Spectral Correlation Density and FAM algorithm .

Chapter 3 explained about basics of LTE OFDM signal.It covers Review of various detectors .Those detectors are energy, ACAE, autocorrelation and cyclostationary detector .It also conclude the performance comparison of various detector .

Chapter 4 provides the result related to domain analysis of cyclostationary detector .It also highlights the lte signal detection using cyclostationary detector and itâĂŹs performance under varying conditions.

Chapter 5 covers the performance analysis of autocorrelation and cyclostationary detector under varying conditions, such as known/unknown CP ,varying frame length etc .

Chapter 6 highlights the conclusion of thesis and provides future scope of thesis .

CHAPTER 2

Cyclostationary Feature Analysis

2.1 Cyclostationary Process

A cyclostationary process is a signal having statistical properties that vary cyclically with time. A cyclostationary process can be viewed as multiple interleaved stationary processes

An important special case of cyclostationary signals is one that exhibits cyclostationarity in second-order statistics (e.g., the autocorrelation function). These are called wide-sense cyclostationary signals, and are analogous to wide-sense stationary processes. The exact definition differs depending on whether the signal is treated as a stochastic process or as a deterministic time series.

2.2 Cyclic Autocorrelation Function

A wide sense cyclostationary signal's mean $\mu_x(t)$ and autocorrelation $R_x(t_1, t_2)$are periodic with at least one cyclic period ,T. An ergodic signal's mean and autocorrelation can be estimated from a large number of samples Gardner (1994).

$\mu_x(t)$=$\mu_x(t+T)$

$R_x(t_1, t_2) = R_x(t_1 + T, t_2 + T)$

Now moving autocorrelation in frequency domain ,second order periodicity ,$R_x^\alpha(\tau)$,can be expressed as follows,where the α is a cyclic frequency .

$R_x(t, \tau) = \Sigma R_x^\alpha(\alpha, \tau) e^{j\alpha t}$

$R_x^\alpha(\alpha, \tau) = \lim_{N\to\infty} \sum_{t=0}^{N-1} R_x(t, \tau) e^{-j\alpha t}$

$R_x^\alpha(\tau)$ is defined as cyclic auto correlation function .

2.3 Cyclic Spectrum And Spectral Correlation Density

Another important terminology related to cyclostationary signal processing is spectral correlation density i.e. SCD .While designing the cyclostationry detector sometime it is preferred to operate in frequency domain ,which will be discuss in letter chapter . The Fourier transform of cyclic auto-correlation function is called cyclic spectrum .the expression is given as follow .

$$S_x(\alpha, \omega) = \Sigma R_x^{\alpha}(\alpha, \tau) e^{-j\alpha\tau} .$$

Cyclic statistics have been used as a tool for exploiting cyclostationarity in several application including communications,signal processing etc .

2.4 FFT Accumulation Method

As modern communication system waveforms have increased in complexity, a need arose for computationally efficient methods of producing the SCD of these signals, if their cyclic properties were to be exploited. An algorithm was developed in Roberts and Brown (1991) that addressed this need. Two classes of cyclic spectral analysis algorithms were identified as frequency smoothing algorithms and time smoothing algorithms. While both classes of algorithms are effective at estimating a signal SCD, the time smoothing approach is considered to be more computationally efficient. Within the time smoothing class of algorithms,Roberts and Brown (1991) developed two computationally efficient algorithms: the FAM and Strip Spectral Correlation Algorithm (SSCA) .among the two ,FAM algoritham is discussed over here .

Consider there are N input data samples. From the input sample data, arrays of the lengths N_0 are formed. The starting point of each succeeding row is offset from its previous row by L samples. The value of L is chosen to be $N_0 = 4$ since it allows for a good compromise between maintaining computational efficiency and minimizing cycle leakage. The value of N0 to be determined according to the desired frequency resolution , and is given by

$$N' = \frac{[fs]}{[\Delta f]}$$

N_0 is chosen to be the power of 2 to take the advantage of FFT algorithm without making use of zero-padding. Thus we can form $P = \frac{N}{L}$ rows. A hamming window is applied across each row, then fast Fourier transformed and down converted to base-band. Now we got an 2-D array where columns representing the constant frequencies. Each column now is point-wise multiplied with conjugate of every other column. Each resultant vector now contains P elements and is fast Fourier transformed. The lower frequency half is placed into the final Cyclic spectral plane at appropriate locations. These implementation steps are shown in the block diagram Fig. 2.1.

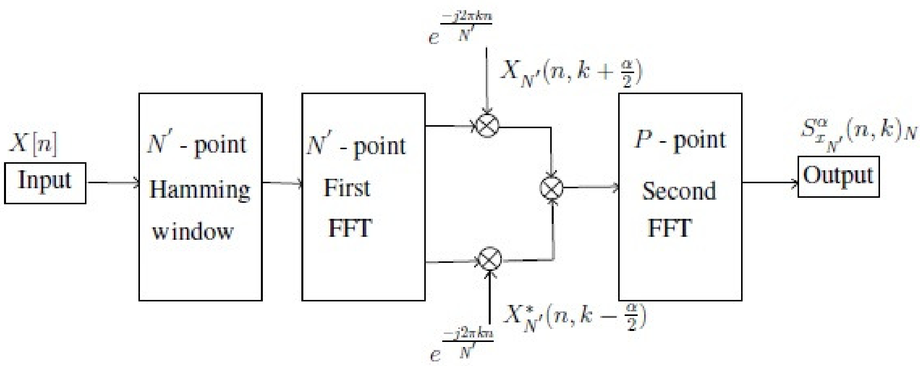

Figure 2.1: FAM Block diagram

CHAPTER 3

Review Of LTE OFDM And Detectors For LTE Signals

LTE is a standard in wireless communications for high-speed data transfer rates. The standard is developed by the 3GPP (3rd Generation Partnership Project). The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency-division duplexing (FDD) and time-division duplexing (TDD). It uses Orthogonal frequency Division Multiple Access (OFDMA) on the downlink (DL) and Single Carrier- Frequency Division Multiple Access (SC-FDMA) on the uplink (UL). In this thesis, we consider the detection of Downlink signals using the Cyclostationary property of OFDM signals.

3.1 Basics Of OFDM

Orthogonal frequency-division multiplexing i.e. OFDM is a method of encoding digital data on multiple carrier frequencies. Effectively, the original bandwidth W of the high rate bit stream R is segmented into L subbands of bandwidth W/L. The subcarriers are separated by an optimal distance within the frequency band, referred to as orthogonality, to avoid inter carrier interference. This is accomplished through the effective use of digital signal processing techniques such as FFT and Inverse FFT (IFFT) in the baseband, prior to RF modulation. To illustrate the orthogonal subcarrier separation, Fig. 3.1 shows the frequency response of adjacent subbands in a FFT. To visualize orthogonality, notice that when the response of any one subband is at its maximum, the collection of spurious responses from all the remaining subbands is zero Schnur (2009).

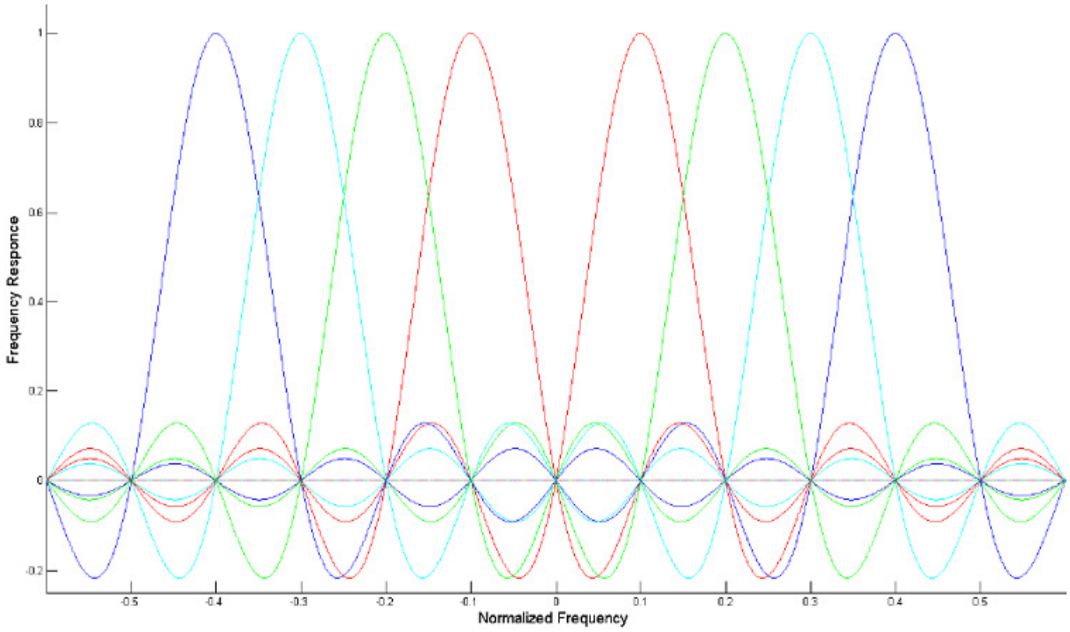

Figure 3.1: OFDM subcarrier spacing

3.2 OFDM Block Description

The process of OFDM modulation is depicted in Fig. 3.2 as mentioned above orthogonality in OFDM sub carrier is obtain equivalently through IFFT .ouput of OFDM symbol is given as follow

$x[n] = \sum_{k=N/2}^{N/2-1} X_k e^{j2\pi kn\Delta f}$

where N is number of subcarrier and X_k is a data symbol .

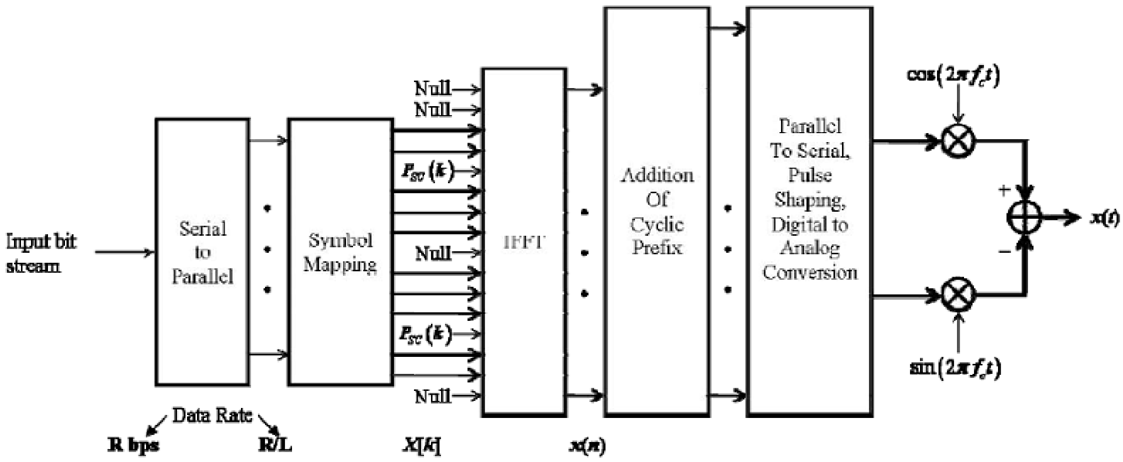

Figure 3.2: OFDM block description

3.3 CP and Pilots in OFDM

3.3.1 Cyclic Prefix

The CP is a portion of the higher index IFFT output samples. These samples are copied and appended to the OFDM symbol as the leading portion. The purpose of the CP is to prevent ISI among OFDM symbols during transmission through a multipath fading channel; CP size is dependent on channel conditions.

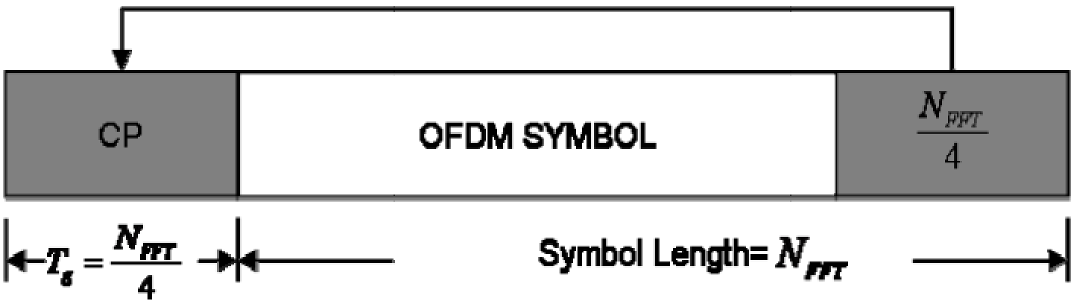

Figure 3.3: Cyclic prefix arrangement in OFDM symbol

3.3.2 Pilot Subcarriers

Typically, not all of the IFFT inputs are utilized as data subcarriers. A certain number of subcarriers are used as pilot subcarriers for channel estimation.Additionally, numerous lower and upper end subcarriers are set to zero to reduce adjacent channel interference. The number of pilot and null or guard subcarriers depend on the size of the IFFT and the standard governing the communication system.The pilot subcarriers transmit a pseudo-random sequence that is known by the receiver. This allows for determination of channel conditions and therefore which baseband modulation technique to employ. The pseudo-random pilot sequence will be an important feature for system identification.

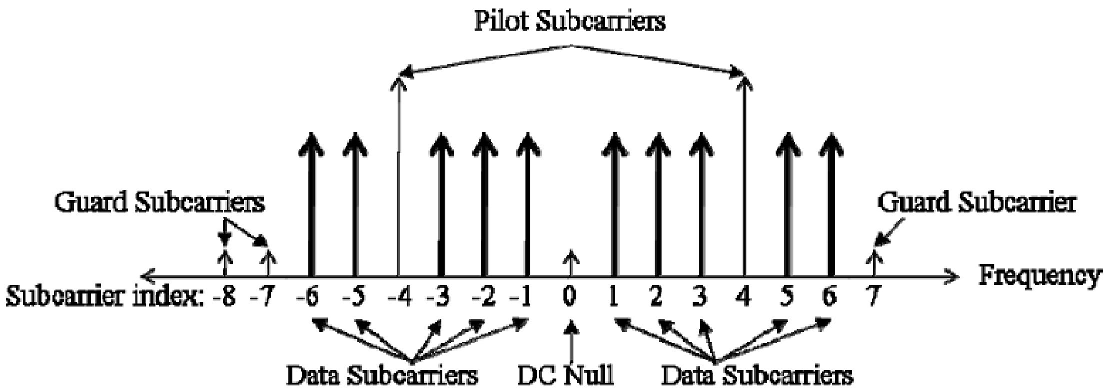

Figure 3.4: Pilot subcarrier arrangement in OFDM symbol

periodicity introduced by CP or pilots is utilized for cyclostationary detection ,which will be discussed in subsequents chapters .

3.4 Signal Detection

Signal detection theory is a means to quantify the ability to discern between information-bearing patterns (called stimulus in humans, signal in machines) and random patterns that distract from the information (called noise, consisting of background stimuli and random activity of the detection machine and of the nervous system of the operator) There are various detectors which are available to detect th e presence of primary signals . among them major detectors are energy detector ,autocorrelation detector and cyclostationary detector.

3.5 Energy Detector

This is a very basic detection technique also known as radiometer.The energy detector measures the energy received during a finite time interval and compares it to a predetermined threshold.the energy detector works well for almost all the cases,but it is not optimal detector .Energy detector is frequently used for coarse sensing to narrow down the region of detection Poor and Larsson (2012).

for N input received sample data test statistic is given as follows

$T.S. = \frac{1}{N}\sum_{n=1}^{N} {X_n}^2$

Consider the hypothesis

$H_0 : -x(n) = w(n)$

$H_1 : -x(n) = s(n) + w(n)$

When the signal is absent, the decision statistic has a central chi-square distribution with 2N degrees of freedom. When the signal is present, the decision statistic has a central chi-square distribution with the same number of degrees of freedom. If N is large the central limit theorem can be used to approximate the test statistic as $N(m, \sigma^2)$ that is Gaussian with mean m and variance σ^2

$\Delta : N(\sigma_w^2, \frac{(\sigma_w^2)^2}{N})$ under H_0

$\Delta : N(\sigma_s^2 + \sigma_w^2, \frac{(\sigma_s^2+\sigma_w^2)^2}{N})$ under H_1

And the threshold for energy detector is given as follows ,

$\gamma = \sigma_w^2(1 + \frac{Q^{-1}(P_{fa})}{\sqrt{N}})$

3.6 Autocorrelation Detector

In this detector autocorrelation of received signal is taken as a Test Statistic.Chaudhari *et al.* (2009) for a given x as received data sample and M as a size of data sample mathematically test statistic is represented as follows

$T.S. = \frac{\frac{1}{M}\sum_{t=0}^{M-1} Real(x(t)x^*(t+T_d))}{\sigma^2{}_z}$

where T_d is delay time which is same as symbol time and $\sigma^2{}_z$ is obtain as follow

$\sigma^2{}_z = \frac{1}{2(M+T_d)}\sum_{t=o}^{M+T_d-1} |x(t)|^2$

Probability of false alarm for autocorrelation detector is given as

$P_{fa} = P(T.S. > \gamma | H_0)$

$= \frac{1}{2}\text{erfc}(\sqrt{M}.\gamma)$

where γ is threshold value for detector . For any detector in most of the cases P_fa is known .From where threshold is evaluated to calculate the probability of detection .for autocorrelation threshold is given in terms ofP_fa as follow

$\gamma = \frac{1}{\sqrt{M}} erfc^{-1}(2P_{fa})$

Finally the probability of detection is given as follows ,

$P_{fa} = P(t.s. > \gamma | H_1) = \frac{1}{2}\text{erfc}(\sqrt{M}.\frac{\gamma-\rho_1}{1-\rho_1^2})$

As mentioned above this scheme requires knowledge of T_d (symbol length or FFT size of LTE signal frame) , which is not always available with secondary detector . So with the knowledge of T_d ,autocorrelation has a best performance among the compare detectors .this will be explain in detail in subsequent chapters.

3.7 Autocorrelation Based Advance Energy Sensing Detector

ACAE is combination of autocorrelation detector and energy detector .Considering DVB OFDM signal received by a LTE-Advanced eNodeB with spectrum sensing.it is referred from Zhao and Guo (2010). consider following hypothesis

$H_1 : r(n) = x(n) + \eta(n)$

$H_0 : r(n) = \eta(n)$

ACAE spectrum sensing algorithm can be described as two steps. Step 1: Calculating following equations as shown in Fig. 3.5

$\varepsilon(N_d) = \sum_{n=0}^{N_{cp}-1} |r(n + N_d) - r(n)|^2$

$\varepsilon_r^{def} = \frac{1}{K}\sum_{k=1}^{K}\sum_{n=0}^{N_{cp}-1} |r(n + kN_{cp}) - r(n)|^2$

where

N_{cp} -CP size N_d -size of data in a frame K -Number of segment in a frame .

finally Test Statistic is derived as follow

$T.S. = \frac{\varepsilon(N_d)}{\varepsilon_r^{def}}$

probability of false alarm can be given by

$p_{fa} = e^{-N_{cp}\gamma}(e^{N_{cp}\gamma} - \sum_{k=0}^{N_{cp}-1} \frac{(N_{cp}\gamma)^k}{k!})$

And probability of detection can be obtain as

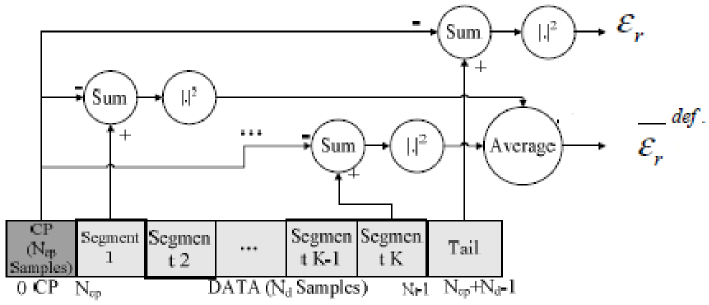

Figure 3.5: ACAE

$$p_{fa} = e^{-\frac{(\sigma_d^2+\sigma_n^2)}{\sigma_n^2}N_{cp}\gamma}\left(e^{\frac{(\sigma_d^2+\sigma_n^2)}{\sigma_n^2}N_{cp}\gamma} - \sum_{k=0}^{N_{cp}-1}\frac{(\frac{(\sigma_d^2+\sigma_n^2)}{\sigma_n^2}N_{cp}\gamma)^k}{k!}\right)$$

where γ is threshold and σ_d is signal variance and σ_n is noise variance .

3.8 Cyclostationary Detector

A process x(t) is second-order cyclostationary if its mean and autocorrelation are periodic in time. Thus, for a cyclostationary process, the cyclic autocorrelation function (CAF) is nonzero for a set of cyclic frequencies $\alpha \neq 0$. Here, we concentrate on signals that exhibit conjugate cyclostationarity such as OFDM signals. The conjugate cyclic autocorrelation function at cyclic frequency α can be estimated as.refer Ala-habshana and Venatesan (2010)

$$R_x^\alpha = \frac{1}{N}\Sigma_{n=0}^{N-1}x(n)x^*(n-\tau)e^{\frac{-j2\Pi\alpha n}{N}}$$

$$R_x^\alpha = R + \varepsilon(\alpha)$$

in which $\varepsilon(\alpha)$ is the estimation error. Here, τ is lag parameter in the autocorrelation. In practice, values of the CAF are seldom exactly zero and decision has to be made whether the value presents a zero or not.If the cyclic autocorrelation does not exist, R=0 and $R_x^\alpha = \varepsilon(\alpha)$, which is asymptotically normal zero mean complex random variable .now

$$R_x^\alpha = X(\alpha) + jY(\alpha)$$

where $X(\alpha)$ and $Y(\alpha)$ ara normal distribution zero mean random variables. For vector of zero mean random variables ,an estimate of the covariance matrix can be computed as

$$\Sigma = \begin{bmatrix} E[X^2] & E[XY] \\ E[XY] & E[Y^2] \end{bmatrix}$$

where elements of the matrix is calculated as follows

$$E[X^2] = \frac{1}{N}\sum_{k=0}^{N-1} Real(R_x^{\alpha_k})^2$$

$$E[XY] = \frac{1}{N}\sum_{k=0}^{N-1} Real(R_x^{\alpha_k}) * imag(R_x^{\alpha_k})$$

$$E[Y^2] = \frac{1}{N}\sum_{k=0}^{N-1} imag(R_x^{\alpha_k})^2$$

Finally the test statistic for the cyclostationary detector is given as follows . Detailed derivation is provided in appendix A.

$$T.S. = (R_x^\alpha)\Sigma^{-1}(R_x^\alpha)^T$$

Fig.3.6 is a representation of cyclostationary detector.

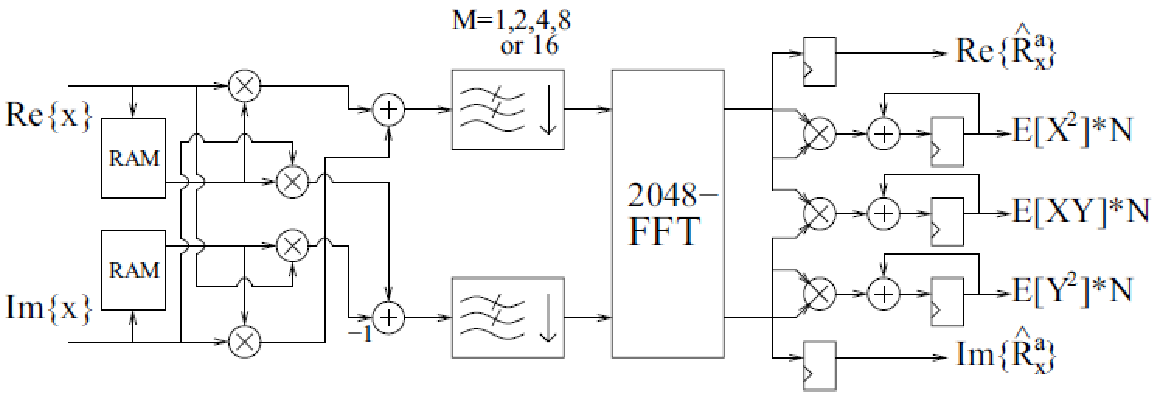

Figure 3.6: Cyclostationary detector block diagram

This is designed for the fix α ,same approach can be use for generalization of cyclo-stationary detector .refer Dandawate and Giannakis (1994)

3.9 Comparative Performance Of Various Detector

As discussed, various detectors are available for spectrum sensing. This section will provide the comparative performance analysis of this detectors. Among this detector energy detector is simple and least complex detector . But at low snr energy detector has worst performance as compared to other other detectors . Hence it is not useful for spectrum sensing for highly noisy environment .

3.9.1 Comparison Between ACAE And Cyclostationary Detector

For a given sensing time the performance of this two detector is obtain. Under the situation where primary signal parameter such as CP size,Frame length or pilot signal position etc. are known to the secondary user .Performance of ACAE is better than cyclostationary detector .But in reality secondary user hardly gets any information of primary signal in cognitive environment .In that case in general cyclostationary detector is better than ACAE .

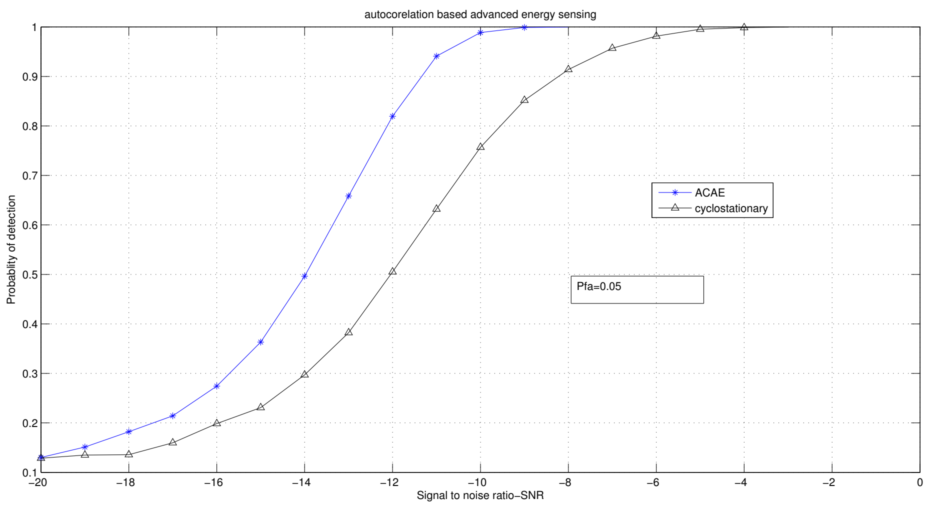

Figure 3.7: Comparison of ACAE and cyclostationary detector under known primary signal

Fig. 3.7 gives comparative performance analysis of two detector under known primary signal condition .

3.9.2 Comparison Between Autocorrelation And Cyclostationary Detector

Now the performance of autocorrelation and cyclostationary detector are obtain. Similar to ACAE under the situation where primary signal parameter such as CP size,Frame length or pilot signal position etc. are known to the secondary user .Performance of Autocorrelation detector is better than cyclostationary detector .but in reality secondary user hardly gets any information of primary signal in cognitive environment .In that case in general cyclostationary detector is better than autocorrelation .

Fig. 3.8 gives comparative performance analysis of two detector under known primary signal condition .

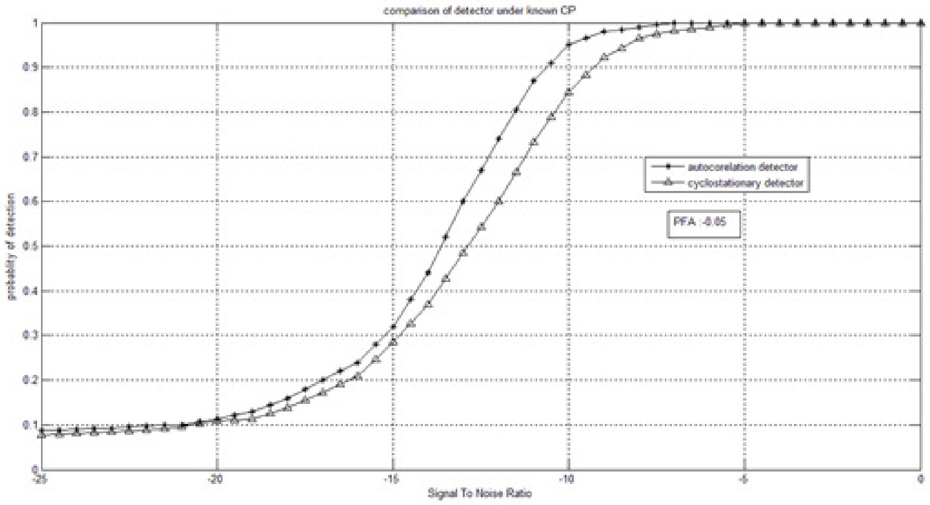

Figure 3.8: Comparison of Autocorrelation and cyclostationary detector under known primary signal

Unknown primary signal case is exploited in subsequent chapter. Subsequents chapter will give more elaborated analysis of autocorrelation and cyclostationary detector.

CHAPTER 4

Domain Analysis Of Cyclostationary Detector

For cyclostationary detector Test Statistic can be derived in time as well as in frequency domain .But it is observed that for the same signal samples, performance of the cyclostationary detector in this two domain will be drastically different .For some signal frame structure time domain analysis will provide better performance while in some other signal frame structure frequency domain analysis will provide better performance .Here two different cases are studied and their domain performance is analyzed .

In cyclostationary detector cyclic autocorrelation function(CAF) and spectral correlation density(SCD) plays the main role in analyzing the Test statistic in time and frequency domain respectively .Detector performance is directly depends on how well the values of CAF and SCD at cyclic frequencies are distinguishable then neighbouring values .Gardner (1988)

4.1 CAF And SCD In The Presence Of Only Pilot Signals

Let's consider the LTE OFDM frame structure having only pilots signal as a periodic component .in general periodicity of pilots signal will be exploited for detector design .

Fig. 4.1 represents spectral correlation density and Fig. 4.2 represents cyclic autocorrelation function for signal having periodicity induced by pilot signal only .

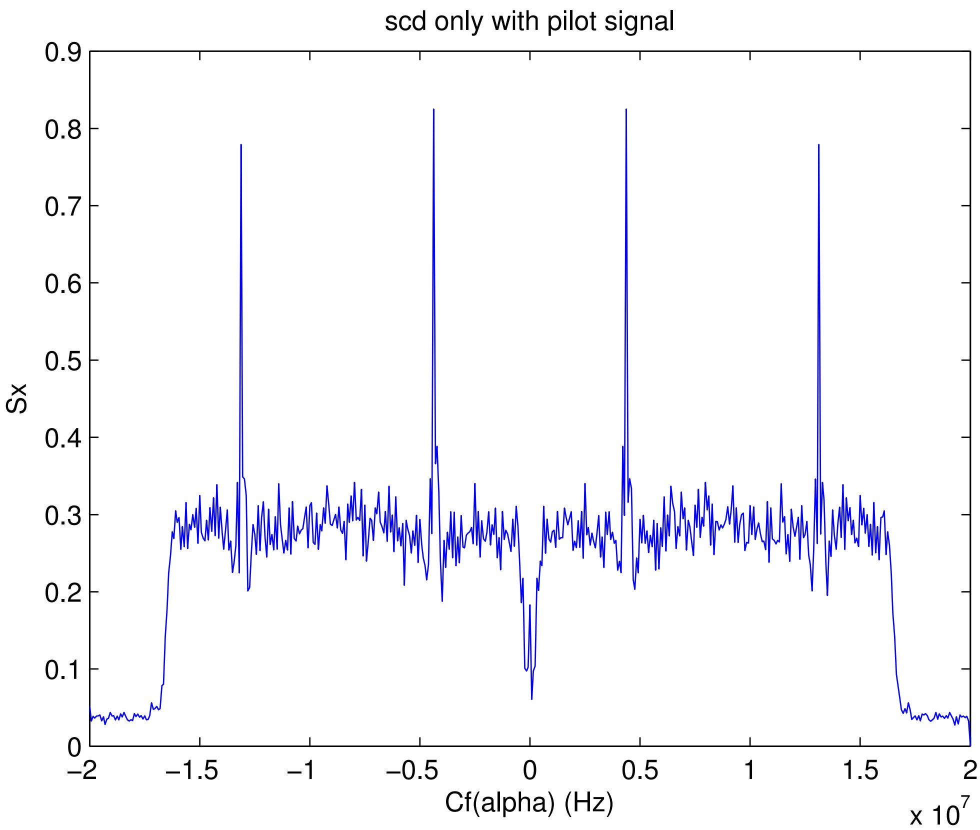

Figure 4.1: SCD for pilot signal

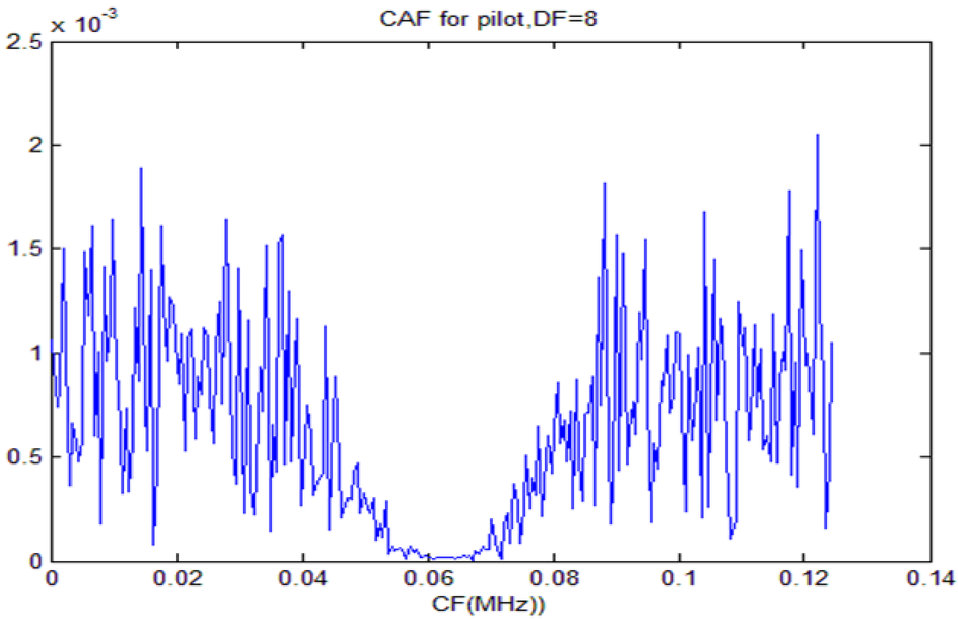

Figure 4.2: CAF for pilot signal

As seen from Fig. 4.1 and Fig. 4.2 for proper periodic data like pilot signal,which are repeating in every frame , SCD based detection will provide better performance than CAF based detector .As can be seen in SCD plot at cyclic frequency and it's harmonic points , well distinguishable peaks are obtain which is not the case in CAF plot for same signal .

Finally one can say that for signal possessing the periodicity of type pilot signal i.e. Signal having regular periodic components ,frequency domain or Spectral correlation density(SCD) based cyclostationary detector is considered to provide better detection performance .

4.2 CAF And SCD In The Presence Of Cyclic Prefix Only

Now let's consider the LTE OFDM frame structure having only Cyclic prefix i.e. CP as a periodic component .Similar to the previous case periodicity of Cyclic prefix will be exploited for detector design

Fig. 4.3 represents spectral correlation density and Fig. 4.4 represents cyclic auto-correlation function's graph for signal having periodicity induced by Cyclic Prefix only.

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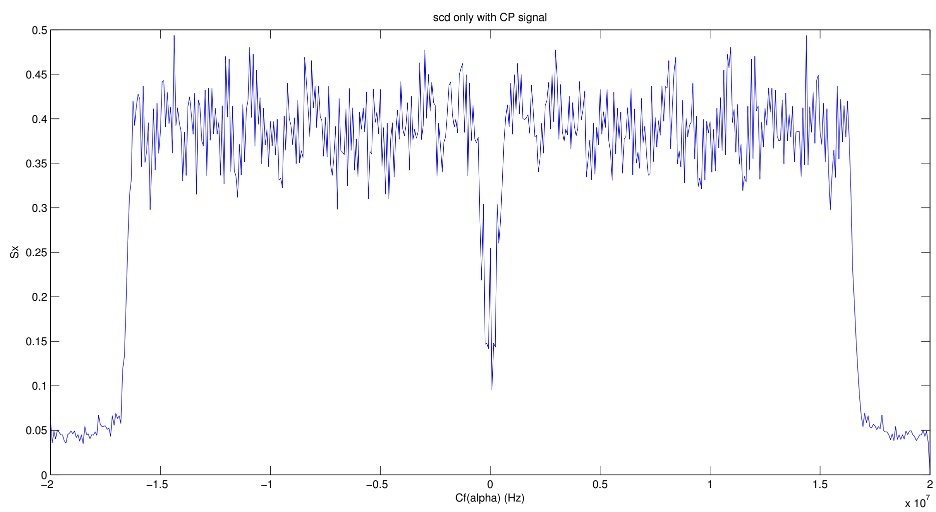

Figure 4.3: SCD for Cyclic prefix

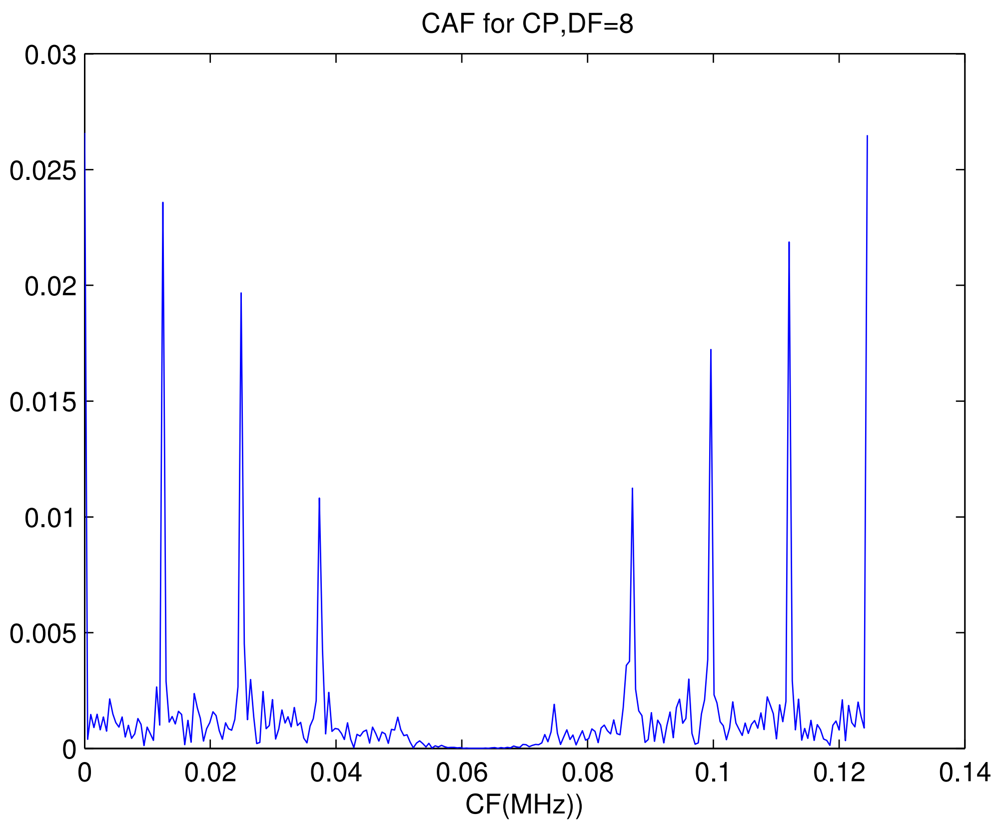

Figure 4.4: CAF for cyclic prefix

Unlike to previous case as seen from the above two plot for pattern based periodic data symbols like Cyclic Prefix,which are different in every frame, CAF based detection will provide better performance than SCD based detector .as can be seen in CAF plot, at cyclic frequency and it's harmonic points well distinguishable peaks are obtain which is not case in SCD plot for same signal . one can say that for signal possessing the periodicity of type Cyclic Prefix i.e. signal having pseudo periodic components ,time domain or cyclic autocorrelation(CAF) based cyclostatinoary detector will provides better detection performance .

Finally it can be concluded that for signals having pilots signals as periodic component ,frequency domain cyclostationary detector should be preferred while for signals having cyclic prefix as periodic component ,time domain cyclostationary signal detection should be executed in order to obtain the better detection performance .

4.3 LTE Signal Detection

section 4.3 include the basics lte signal detection using cyclostationary detection technique .it briefs the impact of various factor on detection performance .use of CAF to differentiate between lte and wifi OFDM signal also demonstrated .

4.3.1 Detection Performance With Decimation Ratio

In detection theory ,detection performance improved as the sample size grows .as sample size (N) increases ,it reduces the variance of Test statistic ,which eventually reduce the area of intersecting region of two hypothesis . time interval for which data is collected is related to decimation ratio as follows v.and Marko Kosunen and Huttunen (2009)

$T_d = \frac{M*N_{fft}}{F_s}$

fig. 4.5 and fig. 4.6 indicates the impact of decimation on CAF .

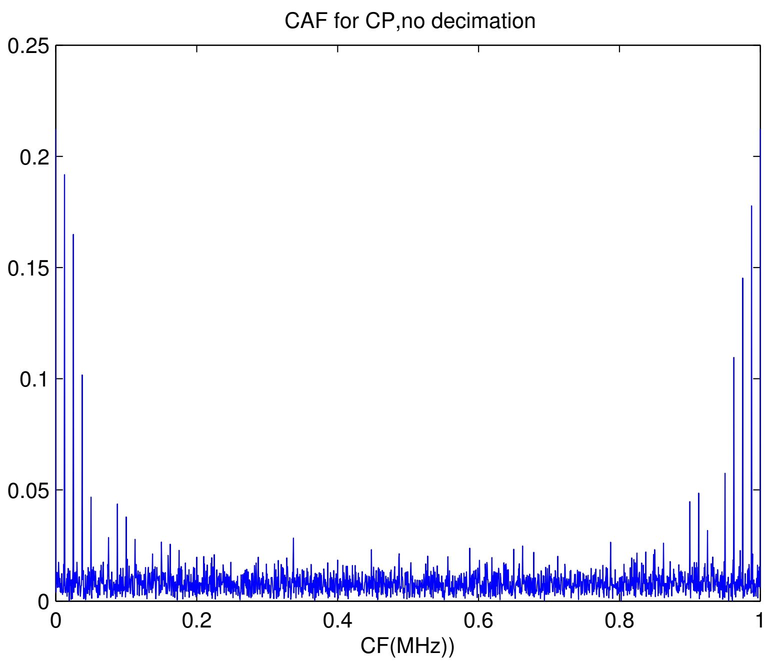

Figure 4.5: CAF without decimation ratio

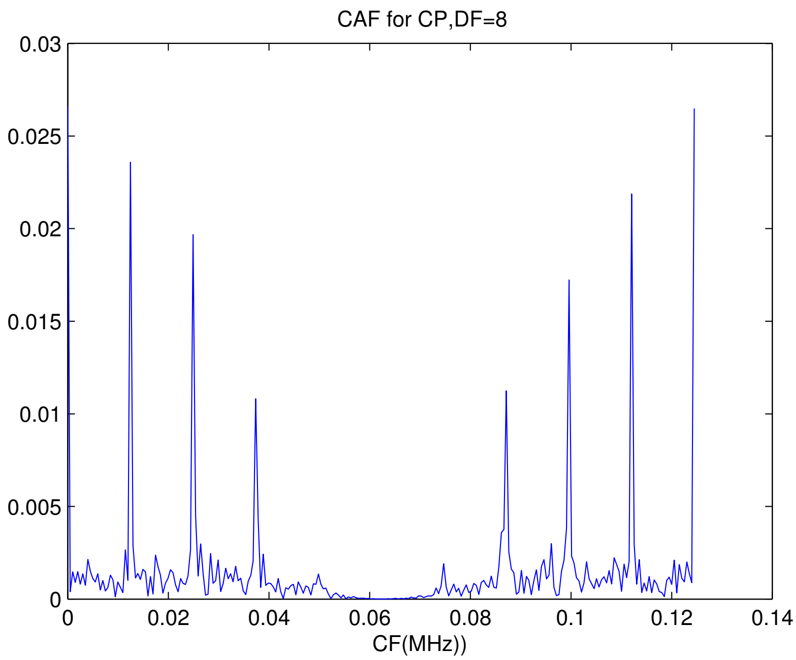

Figure 4.6: CAF with decimation ratio M=8

detection performance of cyclostationary detector for Varying decimation ratio can be visualized in figure 4.7 .

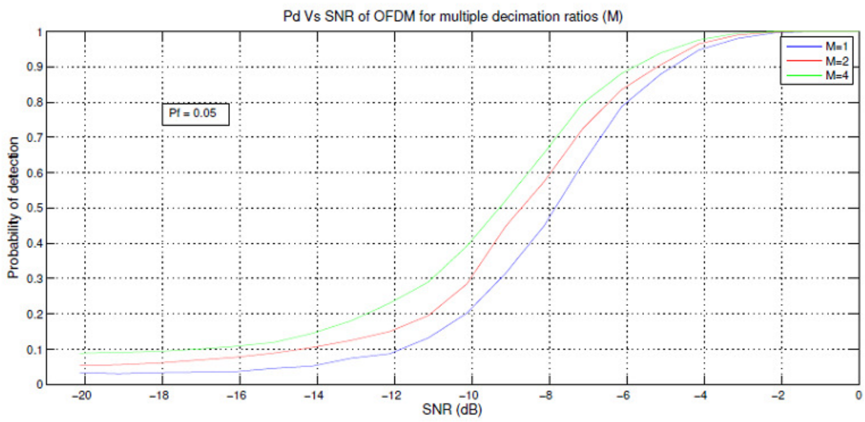

Figure 4.7: Detection performance for varying decimation ratio

4.3.2 Detection Performance In Multipath Channel

considering the 3 tap channel having coefficient [0.9 0.4 0.2] .the resultant CAF is expressed as follows

$$R_y^\alpha = (\sum_{n=0}^{L-1} |h(n)^2|) * R_x^\alpha$$

as from above equation it is evident that caf gets scaled due to multipath components.figure 4.8 illustrate the performance deterioration in the presence of multipath channel.

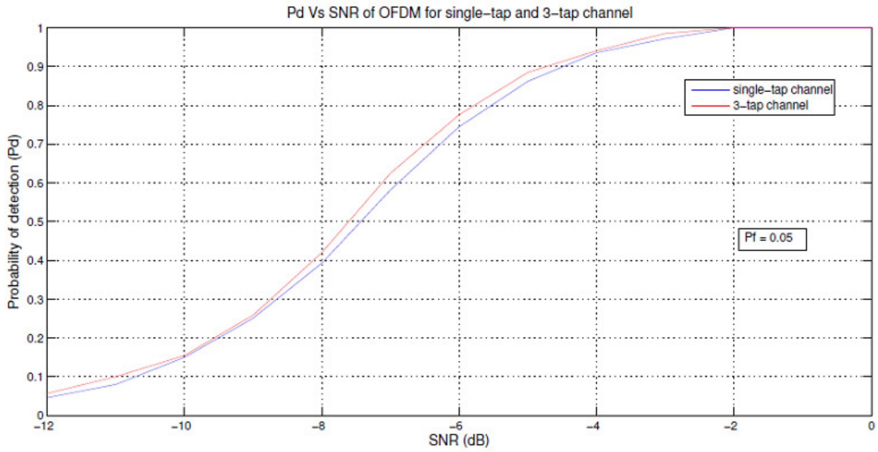

Figure 4.8: Cyclostationary detector performance under multipath.

4.3.3 Signal Identification Using CAF

The cyclic spectrum of OFDM signal can also be used to detect the FFT length used in OFDM. The position of first peak occurs at a cycle frequency of $\frac{f_s}{N_{fft}+L_{cp}}$ where f_s is the sampling frequency, N_FFT is the FFT length taken for OFDM modulation and LCP is the length of CP. An OFDM signal is taken with N subcarriers and cyclic prefix of length N=4 and is sampled at 20 MHz. The simulated result is presented for N = 128, and 128-point IFFT is applied at the transmitter end. We can observe the first peak at $\frac{f_s}{160}$ which is 12500Hz . Fig 4.9 demonstrate the same .

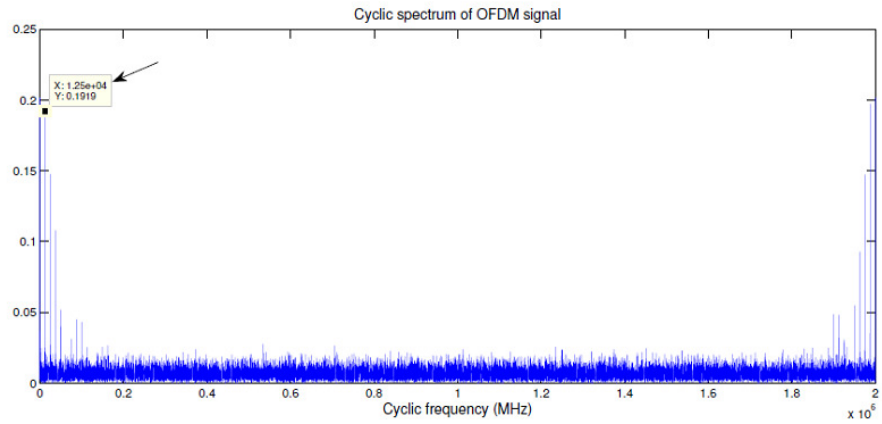

Figure 4.9: FFT length detection through cyclic spectrum of OFDM.

CHAPTER 5

Performance Analysis Of Autocorrelation And Cyclostationary Detector

As discussed previously autocorrelation detector has a performance edge over cyclostationary detector under the circumstance of completely know primary signal parameters such as Frame length ,cyclic prefix size,pilot signal position etc .But in real time environment, most of the time primary information is not known to the secondary user .Under this condition performance of cyclostationary detector is better than autocorrelation .this chapter will cover the impact of two important parameter of LTE Signal structure on Detection performance of cyclostationary detector and autocorrelation detector .This two parameter is Cyclic Prefix and frame length .

5.1 Performance Of Detectors Under Known/unknown CP

For the detectors we are considering the two cases where initially we know the CP size of LTE frame structure ,and second case CP is considered to be unknown .Here CP size is L/4 ,where L lte frame length or fft size and it's value over here is 128 .Poor and Koivunen (2009)

Fig. 5.1 indicate the performance of cyclostationary and autocorrelation detector under the known and unknown cyclic prefix size .

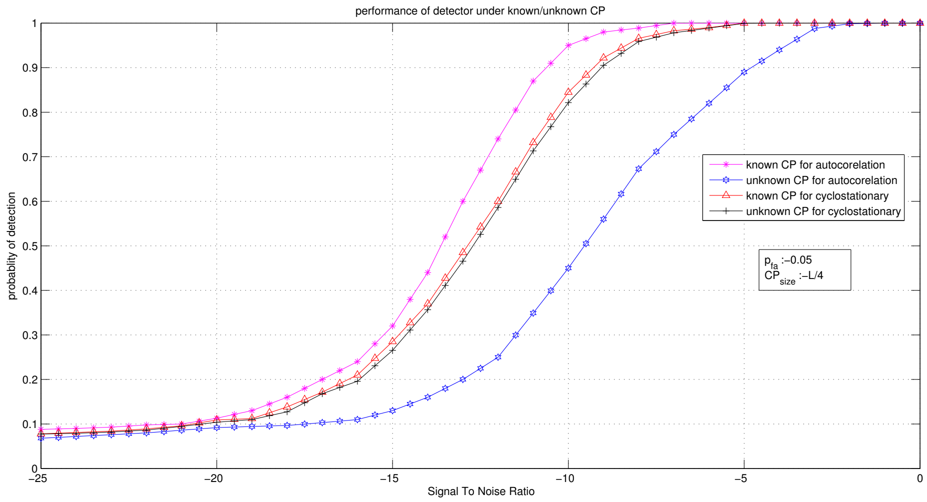

Figure 5.1: Performance of detector under known/unknown CP

As it evident from the graph that that performance of autocorrelation detector alter drastically when the CP size is unknown as compared to known cp size detection performance while for cyclostationary detector performance is almost unaltered in both the cases .

As in case of cyclostationary detector ,it observes the presence of periodic pattern in received signal and in general it checks for the presence of all the cyclic frequencies which is related to size of CP and frame length .Hence regardless the size of CP is known to cyclostationary detector ,it is able to detect the presence of periodicity in signal hence it's performance is unaltered in two cases .But in cases of autocorrelation detector to know about T_d which gives perfect autocorrelation ,CP_{size} must be known .otherwise performance of detector will not be consistent .

5.2 Detector Performance Under Varying Frame Length For Fixed Sensing Time

LTE OFDM frame structure support FFT_{length} or frame length from 128 to 2048 depending on the allotted bandwidth .Over a period of time any of the FFT_{length} is allotted to primary user . In this case we are fixing the sensing time i.e. we are fixing the sample size (M) of received signal and frame length is varied and detector performance is evaluated .

5.2.1 Autocorrelation Detector Performance

performance of autocorrelation detector under varying frame length for fixed sensing time is simulated ,Fig. 5.2 indicate the performance of detector under varying FFT_{length}.

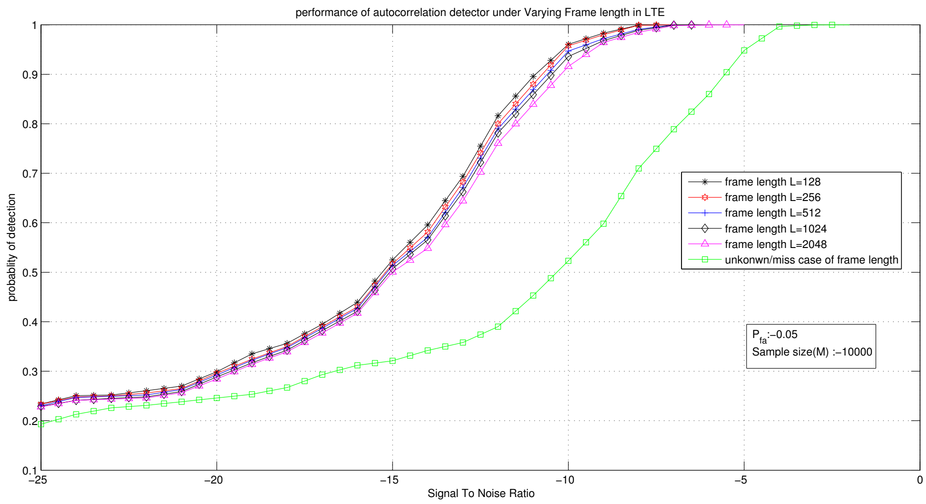

Figure 5.2: Performance of autocorrelation under varying frame length in LTE

As seen figure 5.2 as frame length(FFT_{length}) increases for a fixed sample size , the performance of autocorrelation detector deteriorates .It so happens because for a given fixed received sample size number of frame reduces as frame length increases ,for example consider a sample size M=10240 and hence for L=1024 ,number of frame will be 10 while for L=2048 ,number of frame will reduce to 5 .So more number of frames implies more correlated values ,which eventually reflects on the performance of detector.In subsequent section we will consider the case where number of frame will be made fix .

5.2.2 Cyclostationary Detector Performance

Performance of cyclostationary detector under varying frame length for fixed sensing time is simulated , Fig. 5.3 indicate the performance of detector under varying FFT_{length}.

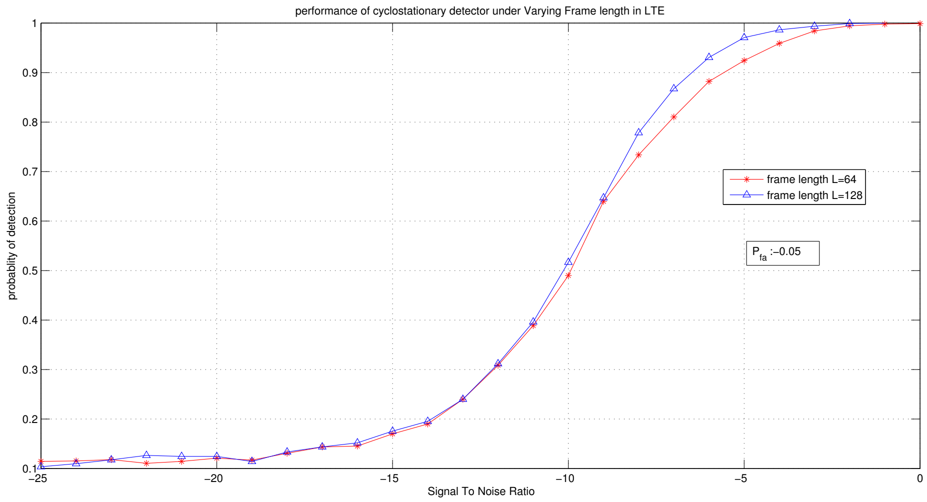

Figure 5.3: Performance of cyclostationary detector under varying frame length in lte

As seen in figure 5.3 as frame length(FFT_{length}) increases for a fixed sample size ,the performance of cyclostationary detector improves as opposite to that of autocorrelation detector . This is because fundamental cyclic frequency α is inversely related to frame length .So if frame length L is large ,cyclic frequency α will be small which implies that it's harmonic components will be closer ,so more number of peaks will be there in CAF or SCD. so detection will be better .

5.3 Autocorrelation Detector Under Varying Frame Length For Dynamic Sensing Time

As discussed in section 5.2.1 as frame length increases for fixed sample size ,performance of autocorrelation detector deteriorates .Now considering the case where sample size varies with frame length .In other way fixing number of frames used for detection at a time .

fig. 5.4 gives an performance comparison for two different frame length case with dynamic varying sensing time .

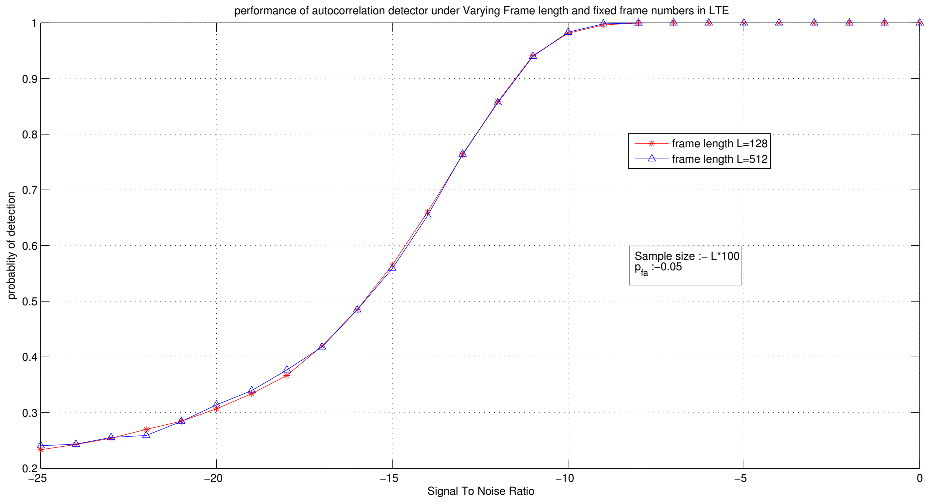

Figure 5.4: Performance of autocorrelation under varying frame length and fixed frame number

As seen IN figure 5.4 for two different frame length (FFT_{length}) by fixing the number of frame received at secondary receiver ,we get similar or unaltered performance .

CHAPTER 6

Conclusion And Future Work

6.1 Conclusion

This thesis discussed the comparative performance of energy ,autocorrelation ,ACAE and cyclostationary detector .Which conclude that energy detector has worst performance .Also under the known primary signal condition ,autocorrelation detector has better performance than cyclostationary detector.but as primary signal information is not present ,which is the most real time case , cyclostationary has robust performance as compared to autocorrelation detector .thesis also discussed regarding domain analysis of cyclostationary detector in which for cp based periodicity ,time domain detection is preferred while for pilot based periodicity frequency domain detection is preferred .performance of autocorrelation detector will change drastically under two condition of known and unknown CP while cyclostationary detector have no change in it's performance .we also consider the case of varying frame length for fixed sensing time for both the detector and concluded that in case of autocorrelation ,performance degrade as length increases while for cyclostationary detector it improves with increasing frame length.

6.2 Future Work

All the detector is implemented for only noisy channel ,fading is not considered ,similar approach can be extended to fading environment channel to compute the performance of detectors. also Autocorrelation based advance energy sensing (ACAE) detector is discussed briefly. A detail analysis of ACAE detector can be done similar to that of autocorrelation and cyclostationary detector .

APPENDIX A

Derivation Of Test Statistic For Cyclostationary Detector

let x be a received signal having cyclostationary property

R_{xx^*} =>cyclic autocorrelation function (CAF)

$R_{xx^*}(\alpha_i, \tau_{i,j})$:- caf at α_i(cyclic frequency) and $\tau_{i,j}$ is time delay .

now consider ,

$r_{xx^*} = [real(R_{xx^*}(\alpha_1, \tau_{1,1})), real(R_{xx^*}(\alpha_2, \tau_{1,2}))....real(R_{xx^*}(\alpha_n, \tau_{1,n}))....$

$imag(R_{xx^*}(\alpha_1, \tau_{1,1})), imag(R_{xx^*}(\alpha_2, \tau_{1,2})), ...imag(R_{xx^*}(\alpha_n, \tau_{1,n}))]_{1x2N}$

wher N is

$N = \sum_{n=1}^{P} N_p$ for set $\alpha_n | n = 1, 2....P$

for detecting the presence of signal consider 2 hypothesis

$H_0 : r_{xx^*} = \varepsilon_{xx^*}$

$H_1 : r_{xx^*} = s_{xx^*} + \varepsilon_{xx^*}$

also $R_{xx^*}(\alpha, \tau)$ is given as

$R_{xx^*}(\alpha, \tau) = \frac{1}{M} \sum_{t=1}^{M} x(t)x^*(t + \tau)e^{-j2\pi\alpha t}$

in the above hypothesis ε_{xx^*} is a error(or noise) in the absence of signal and for large M has Gaussian distribution .

$\lim_{M\to\infty} \sqrt{M}\varepsilon_{xx^*} = N(0, \Sigma_{xx^*})$

where Σ_{xx^*} is a covariance matrix of r_{xx^*}

Σ_{xx^*} can be found for every possible pair of (α, β) cyclic frequency

$\Sigma_{xx^*}(\alpha, \beta)$ represents one block in Σ_{xx^*} and it is determined as follows,

$$\Sigma_{xx^*}(\alpha,\beta) = \begin{bmatrix} Re(\frac{Q+P}{2}) & Im(\frac{Q-P}{2}) \\ Im(\frac{Q+P}{2}) & Re(\frac{P-Q}{2}) \end{bmatrix}$$

where $Q_{\alpha,\beta}(m,n) = S_{f_m f_n}(\alpha+\beta,\beta)$

$P_{\alpha,\beta}(m,n) = S^*_{f_m f_n}(\alpha-\beta,-\beta)$

$S_{f_m f_n}(\alpha+\beta,\beta) = \frac{1}{MT}\sum_{s=-(T-1)/2}^{(T-1)/2} w(s)F_{\tau(n)}(\alpha - \frac{2\pi s}{M})F_{\tau(m)}(\beta + \frac{2\pi s}{M})$

$S^*_{f_m f_n}(\alpha-\beta,-\beta) = \frac{1}{MT}\sum_{s=-(T-1)/2}^{(T-1)/2} w(s)F^*_{\tau(n)}(\alpha + \frac{2\pi s}{M})F_{\tau(m)}(\beta + \frac{2\pi s}{M})$

where

$F_{t(w)} = \sum_{t=1}^{M} x(t)x^*(t+\tau)e^{-jwt}$

and $w(s)$ => normalised spectral window

Generalized likely hood ratio test :-

$\Delta = \frac{p(r_{xx^*}|H_1)}{p(r_{xx^*}|H_0)} > \gamma$

$= \frac{e^{\frac{-1}{2}(r_{xx^*}-s_{xx^*})\Sigma^{-1}_{xx^*}(r_{xx^*}-s_{xx^*})^T}}{e^{\frac{-1}{2}r_{xx^*}\Sigma^{-1}_{xx^*}r^T_{xx^*}}}$

for glrt $r_{xx^*} = s_{xx^*} = r$

finally solving the above equation ,we will obtain

$e^{\frac{1}{2}r\Sigma^{-1}r^T} > \gamma$

=> $r\Sigma^{-1}r^T > \gamma'$ for H_1

hence test statistic for cyclostationary process is given as follows

$T.S. = r\Sigma^{-1}r^T$

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