Detection of an LTE Signal Based on Constant False Alarm Rate Methods and Constant Amplitude Zero Autocorrelation Sequence

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***Abstract*: In order to detect the presence of primary user (PU) signal, spectrum sensing is a fundamental requirement to achieve the cognitive radio (CR) goals. This ensures the efficient utilization of the spectrum. There are many methods for signal detection such as cyclostationary detection, cyclic prefix detection, energy detection, and detection based on fractional Fourier transform (FrFT). The aim of this paper is to propose a novel method for detection of long term evolution (LTE) signal. In this method, Constant Amplitude Zero Autocorrelation (CAZAC) sequence, as a polyphase code, is chosen for the detection of the LTE signal because of its good periodic correlation properties. We will show constant false alarm rate (CFAR) properties that can be used for the reduction of noise power effect to determine a detection threshold. Finally, the proposed method is compared to three other methods and simulation results show that the performance is acceptable.**

I. INTRODUCTION

The demand for the radio-frequency (RF) is increasing to support the user needs in wireless communication. RF spectrum is a scarce resource and requires efficient utilization. Cognitive radio, based on software-defined radio systems, has been proposed as a means to promote the efficient use of spectrum by exploiting the existing spectrum holes. Therefore, the efficient use of spectrum is very important. For example, in an LTE communication system, the spectrum is not occupied by the transmitted signal all the time. Hence, the secondary user could use the spectrum while the LTE signal is absent. Many signal detection techniques can be used for spectrum sensing, such as matched filtering, energy detection, and PU signal feature detection based on cyclostationary properties. Each method has some advantages and disadvantages. For example, the energy detection is simple but its major limitation is the uncertainty of noise power. Reference [1] shows that it is possible to estimate the noise power by using CFAR methods. On the other hand, in low SNR conditions, cyclostationary technique performs well but it is more complex than energy detection technique. Our goal in this article is to obtain a proper detection method with low false alarm rate for LTE signal.

The rest of the paper is organized as follows: Sec.II introduces the LTE signal and its properties. A new method for LTE signal detection is proposed in Sec.III.A. One of the CFAR methods is described in Sec.III.B .A method based on FrFT is shown in Sec.III.C. In Sec.IV compares four general methods and finally, concludes the paper.

II. LTE SIGNAL

In this section, we describe LTE signal and its features briefly. LTE is the next step forward in cellular 3G services, and it is 3GPP standard that provides speed of up to 50 megabits per second (Mbps) for an uplink and a speed of up to 100 Mbps for downlink. Bandwidth will be scalable from 1.25 MHz to 20 MHz .LTE signal uses OFDMA and SC-FDMA as the multiplexing scheme in downlink and uplink, respectively.

One of the most significant properties of SC-FDMA is the reduced PAPR compared to OFDM. The LTE transmitted signal is segmented into frames, which are 10 msec in duration. Frames consist of 20 slots of 0.5 msec.

Subframes contain two slots with 1.0 msec in duration. Slots consist of either 6 or 7 OFDM symbols, depending on whether the normal or extended cyclic prefix is employed. Fig.1 shows the LTE generic frame structure [2].

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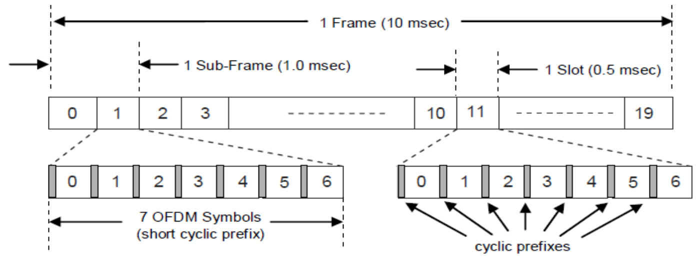


Fig.1: LTE generic frame structure

The Random Access Channel (RACH) is an uplink channel that can be used for the initial contact of mobile users to the base station and f or short data packet transportation. It is classified into two categories: non-synchronized random access and synchronized random access. In a cognitive radio, since the secondary users are not synchronized with primary users, we assume non-synchronized random access. Constant Amplitude Zero Autocorrelation (CAZAC) sequence has many applications in channel estimation and time synchronization. Fig.2 shows the uplink preamble transmits structure over RACH in 3GPP LTE, and the DFT-SOFDM technique is used here. As shown in Fig.2, in each frame the first slot contains the preamble. The preamble can occupy L consequent carriers as shown in the Fig.2.

Reference [3] introduces the CAZAC sequence as a preamble signature. An asynchronized detector based on this property is introduced in [3]. CAZAC sequence is described as in (1),[3].

$$c_k(n) = exp\left[\frac{i2\pi k}{L}\left(n + n\frac{n+1}{2}\right)\right] \quad n = 1, \dots, L \quad if\ L\ is\ odd$$

$$c_k(n) = exp\left[\frac{i2\pi k}{L}\left(n + \frac{n^2}{2}\right)\right] \quad n = 1, \dots, L \quad if\ L\ is\ even \qquad (1)$$

Where L is any positive integer bigger than one and k is a prime number. This CAZAC sequence consists of L sub carriers and to build the sequence

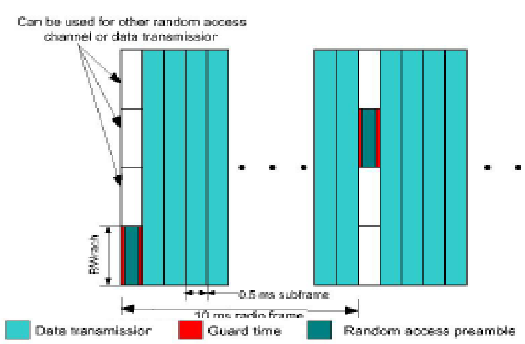


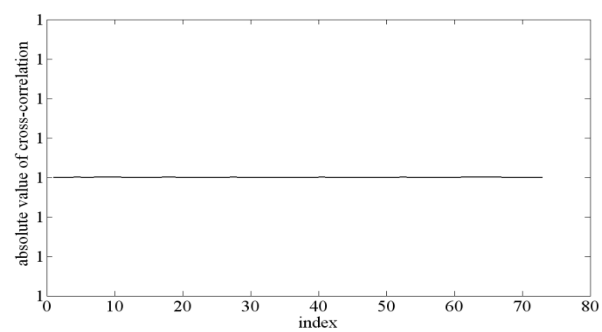
Fig.2: RACH preamble slot and frame format [3].

the value of $c_k(n)$ has to be assigned to the n^{th} carrier. The important feature of this sequence is its periodic cross-correlation function property that can be defined as follows:

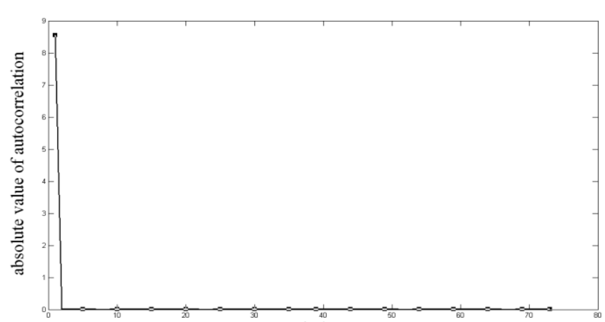
$$corr_m = \frac{1}{\sqrt{L}}\sum_{n=0}^{L-1} a_n b^*_{(n-m) mod\ L} \qquad (2)$$

Where a and b are two CAZAC sequences that have the same prime length (L) with different values for k. When a and b represent the same sequence, (2) changes to the autocorrelation function.

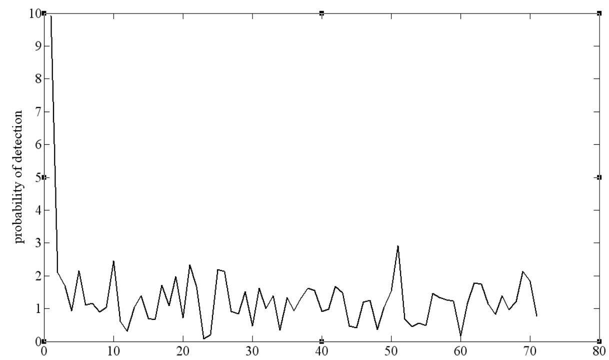
Equation (2) indicates a cyclic property, where for different values of m a correlation with a new version of the same CAZAC sequence is obtained with a circular shift of size m. In reference [3], it is shown that absolute value of $corr_m$ is 1 in cross-correlation (different values for k), if L is a prime number larger than 2; and the absolute value of $corr_m$ is zero for all values of index m except for m=0 in autocorrelation (same values for k). The results show that the single maximum of magnitude at $corr_0$ is $\sqrt{L}$ [3]. Fig.3 shows these properties. Fig.3 (a) and Fig.3 (b) show the correlation property with the length of 73 and Fig.3 (c) and Fig.3 (d) are with additive white Gaussian noise ($AWGN$) of 0 db signal-to noise ratio (SNR). We will suggest a detection method based on this property.



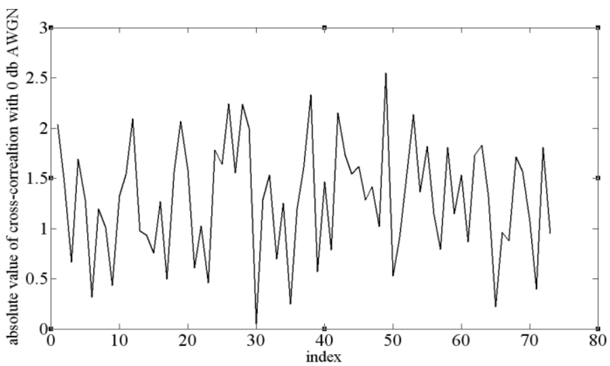
(a)



(b)



(C)



(d)

Fig.3 Correlation functions of CAZAC sequence in the presence of noise a) cross-correlation without noise. b) Autocorrelation without noise. c) Autocorrelation with AWGN channel. d) cross-correlation with AWGN channel

Low false alarm rate is one of the important features of signal detectors and CFARs are detectors with this property. The goal of CFAR methods is to reduce the effect of noise and finally to obtain the proper threshold level for detection of LTE signal. Since the threshold of our proposed method is related to the variance of noise, one would need to use CFAR methods for reduction of noise effects. In the following, we obtain the probability of detection in a constant false alarm rate for LTE signals.

III.

III. SYSTEM MODEL

A The proposed method

Based on the discussed feature, the following algorithm can be proposed for LTE signal detection. First, it is necessary to listen to the channel and take samples in an interval of one OFDM symbol length. A sampling interval should be chosen to guarantee the presence of a complete CAZAC sequence according to RACH preamble slot. Afterwards the sampled sequence can be transferred to the frequency domain, using FFT operation. Then, using a sliding window of size L the whole symbol is scanned through correlating with the expected CAZAC sequence with L. Then, the maximum value for different m is calculated. It is considered that the maximum absolute value of this function belong to CAZAC sequence. Therefore, the maximum of absolute value of test statistic is chosen and squared for different sequences. It is necessary to determine the best threshold that causes low alarm rate and good detection but the uncertainty of noise variance is one problem for determining of a proper threshold. There are some techniques for the reduction of noise effect. One of them is CFAR method. In reference [1], Lehtomaki shows that it is possible to use the CFAR methods, used only in RADAR, in energy detector and the noise power level is estimated with using CFAR methods. For example, [1] introduces the cells in energy detectors. We should also define cells in our detector. The defined cells here are time cells regarding the sampling in time. In this article, our aim is to use the CFAR methods for the reduction of noise effect. There are some techniques for implementation of CFAR such as CA-CFAR, FCME, BCME, GO-CFAR, SO-CFAR, and so on. Each of them is applicable for the particular conditions. The used method is cell averaging constant false alarm rate (CA-CFAR). The cell averaging (CA) detector is useful for maintaining a constant false alarm rate in exponentially distributed noise. First, it is necessary to determine the probability density function (PDF) of the decision variable under H_0 hypothesis. Let H_0 be the null hypothesis, i.e., it shows the existing signal is noise. In general, the form of noise is known but some parameters, such as variance are ambiguous. Also, it should use adjacent cells of a cell under test (CUT), known as a reference cell, for estimation of unknown parameters. In the next section, the CA-CFAR and its application in our proposed method is described.

B CA-CFAR and its application in this method

One of the most popular and simple detectors that is introduced with CFAR is CA-CFAR. This detector reduces the effect of noise by taking average of reference cells. In energy detector, this detector obtains threshold by estimating the power of noise and this processor is known as an optimum CFAR method for white Gaussian noise. Reference [4] shows that it is ML[2] estimation and we use this processor for setting threshold. So, first, it is necessary to get the statistic distribution of noise when only noise is present. As the method was mentioned above, the samples follow the exponential distribution with σ_n^2 as a variance, where σ_n^2 is variance of noise. When signal is present, it is assumed that $corr_m$ still follows the exponential distribution with changed parameters. The absolute of $corr_m$ has Rayleigh distribution with variance as a parameter of Rayleigh and therefore, the square power of absolute of $corr_m$ has a chi-square distribution. If the samples of reference cells are noise, the statistic of detector, known as $X_{CA} = \sum_{i=1}^{N_R} x_i$, would be a chi-square distribution with $2\times N_R$ freedom degrees, whereas N_R is cell numbers. Finally, CA-CFAR detector indicates that the target signal is present if the statistic of cell under test (X) extends T_{CA}

[1]Maximum Likelihood

where T_{CA} is the coefficient of CA-CFAR. The false alarm probability for this process is:

$$P_{FA} = P(\frac{X}{X_{CA}} > T_{CA}; H_0)$$
$$= P(\frac{(\frac{X}{2})}{(\frac{X_{CA}}{2\times N_R})} > N_R T_{CA})$$
$$= 1 - FCDF(N_R T_{CA}, 2\times 1, 2\times 1\times N_R) \quad (3)$$

We use (3) for obtaining T_{CA} that follows equation (4):

$$T_{CA} = {FCDF^{-1}(1 - P_{FA,DES}\ , 2\times 1, 2\times 1\times N_R)}/{N_R} \quad (4)$$

FCDF is Fischer cumulative distribution function. The below formula shows this function:

$$FCDF(X, V_1, V_2) = F(x|V_1, V_2) =$$
$$\int_0^x \frac{\Gamma[\frac{(v_1+v_2)}{2}]}{\Gamma(\frac{v_1}{2})\Gamma(\frac{v_2}{2})} \left(\frac{v_1}{v_2}\right)^{\frac{v_1}{2}} \left(\frac{t^{(\frac{v_1-2}{2})}}{\left[1+(\frac{v_1}{v_2})t\right]^{\frac{v_1+v_2}{2}}}\right) dt \quad (5)$$

Fig.4 shows the probability of detection for LTE signal and Gaussian noise with false alarm probability (P_{FA}) equals 0.005 and 1000 time repeats.

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C. Detection based on FrFT

A chirp function is a signal that contains all frequencies in a certain interval and sweeps through it while it progresses in time. If the frequencies of the signal sweep linearly through the frequency interval [w_0; w_1] in the time interval [t_0; t_1], then we should have $w = w_0 + ({(w_1 - w_0)}/{(t_1 - t_0)})(t - t_0)$. Thus, such a function will look like exp {i(xu+γ)u}. The parameter *x* is called the sweep rate. Regarding the properties of CAZAC sequence, it has chirp shape.

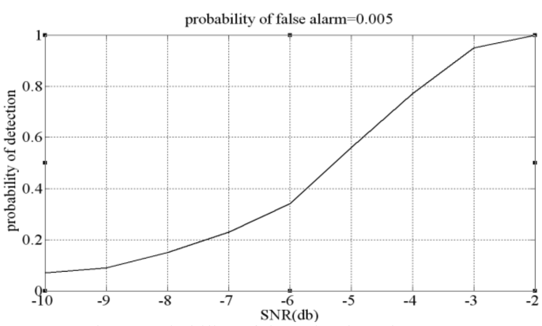

Fig.4: Probability of detection based on SNRs

Based on the chirp shape, we can use different transformers. These transformers are fractional Fourier transforms, Wigner–will, short time Fourier transforms, wavelet transform. We consider FrFT regarding the properties of CAZAC sequence and its chirp shape. If we assume $\alpha = a\frac{\pi}{2}$, then the FrFT has an integral representation:

$$(F^a f)(\xi) = \int_{-\infty}^{\infty} f(x)\ K_a(\xi, x)dx \quad (6)$$

First, it is necessary to introduce the kernel of this transform. The Kernel of FrFT has the below form [5]:

$$K_a(\xi, x) = \sum_{n=0}^{\infty} \lambda_n^a \phi_n(\xi)\phi_n(x) \quad (7)$$

Where Φ_n and $\lambda_n{}^a$ are eigen function and eigen value, respectively.

If a is not coefficient of π, the kernel of FrFT is defined as follows:

$$K_a(\xi, x) = C_\alpha exp\{-i\frac{x\xi}{sin\,\alpha} + \frac{i}{2}(x^2+\xi^2)\cot\alpha\} \quad with\ C_\alpha = \sqrt{\frac{1-i\cot\alpha}{2\pi}} \quad (8)$$

Also, we can consider the FrFT kernel as a chirp function with sweep rate $\frac{1}{2}\ cot\alpha$ where α is assumed to be $\frac{\pi}{2}$, $a\in\mathbb{R}$. Based on the expansions of chirp series, the basic functions are orthogonal, since:

$$\int_{-\infty}^{\infty} K_a(\xi, x)K_a(\xi, y)dy = \delta(x-y) \quad (9)$$

So, the fractional Fourier transform of chirp function $e^{\frac{i}{2}(xu^2+2\gamma u)}$ is:

$$\sqrt{\frac{1+i\tan\alpha}{1+x\,tan\alpha}}\, e^{i\frac{u^2(x-\tan\alpha)+2u\gamma\sec\alpha-\gamma^2\tan\alpha}{2(1+x\tan\alpha)}} \quad (10)$$

If the sweep rate of chirp signal equals $\frac{1}{2}\ cot\alpha$, the FrFT of chirp signal will be a delta function [6]. We use this feature and calculate FrFT of the samples. Similar to the method which is mentioned above, we should listen to the channel and get samples that their length equals the length of OFDM symbol. Then, each time, after getting FFT, we calculate FrFT of sequence that its length is *L* where *L* is the length of CAZAC. If the sequence is CAZAC sequence, then we obtain the maximum result relative to other sequences. By setting threshold, Fig.5 shows the logarithmic probability of detection based on different SNRs.

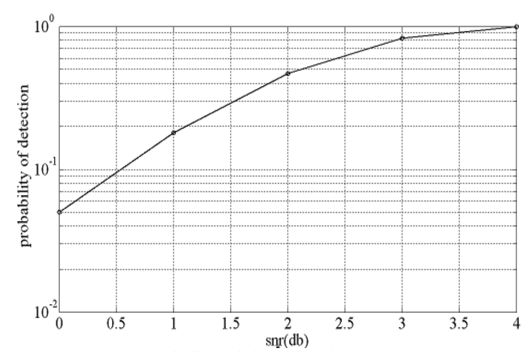

Fig.5: Probability of detection based on SNRs

IV. The comparison of four detectors

In the next figure, we will compare four methods. Two methods that are mentioned above compare with detection based on cyclic prefix of one symbol OFDM [7] and energy detection [1].

In this section, we consider individual detector based on the non-zero autocorrelation property that is based on cyclic prefix (CP) of OFDM signals. Formally, this property may be stated as follows. Assume that the length of the useful symbol data is T_d and cyclic prefix is T_c for an OFDM system, the autocorrelation coefficient for the system at $\tau = \pm T_d$ will be $\mu = \frac{T_c}{T_c + T_d}$ where the autocorrelation may be estimated as [7].

$$R(\tau) = \frac{1}{M}\sum_{t=1}^{M} x(t)x^*(t+\tau) \quad (11)$$

Where *x(t)* is the received OFDM signal and *M* is the number of samples used in autocorrelation estimation.

In the simulation, we consider 1024 as an OFDM symbol length and a non-fading additive white Gaussian noise and the detection is done in the non-cooperative condition. As Fig.6 shows, the cp detection has the best performance but shows only that the present signal has OFDM modulation and also we should know about the length of cyclic prefix and should synchronize with primary user. The advantage of cp detection is detecting in negative SNR. Our proposed method has a good performance and acts similar to the matched filter so that this detector is optimum. On the other hand, it has a lower computation complexity relative to detector based on FrFT. The detector based on FrFT is not CFAR but our proposed method is CFAR .i.e. the false alarm probability is constant.

As shown in Fig.6, energy detection has a weak performance relative to others but the implementation of this detector is simple. Consequently, for spectrum sensing of the LTE signal, every four methods has some advantages and disadvantages but regarding advantages and disadvantages, our proposed detector is better than others.

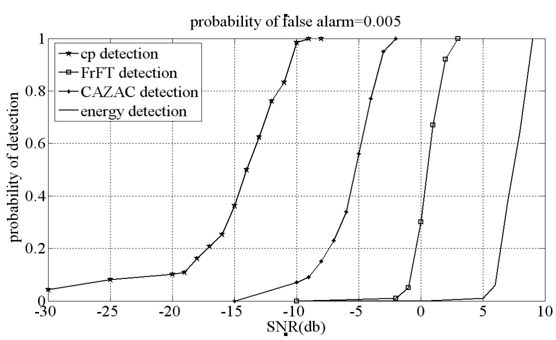

Fig.6: The probability of detection for four methods.

The proposed detector has complexity regarding the existing correlation. For solving this problem, we propose to use the sign bit instead of the real and imaginary value and use only -1 or 1 instead of values. Therefore, the complexity would be lower. Also, we need only four XOR for implementation. The major limitation of this method is the lower performance relative to the usual form of detector. Fig.7 shows the comparison of two methods mentioned above. As shown in Fig.7, the performance of the second method reduces.

V. CONCLUSION

In this article, first, we introduced LTE signal as a next 3GPP standard. Then, we described some properties of this new technology. CAZAC sequence was introduced as a preamble because of good correlation property. We proposed a new method for detection of this signal based on CAZAC sequence. Then, we introduced a method based on the chirp properties of CAZAC sequence and calculated FrFT instead of FFT. We got the CAZAC sequence as a maximum absolute value. Finally, we showed the probability of detection four methods. The results showed that the proposed method does well and is suitable for cognitive radio. Our proposed method has this advantage that if the present signal is not noise, we will understand that the present signal is LTE signal because the LTE signal has this sequence. Meanwhile, we improve implementing of proposed method by using quantization and only sign bit.

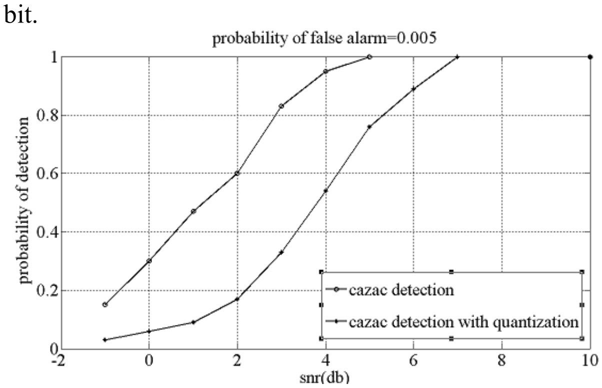

Fig.7: Probability of detection based on SNRs for detector with low complexity

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