TIME SENSING FOR COGNITIVE RADIO SYSTEMS

Abdulrahman H Altalhi (King Abdulaziz University, Jeddah, Saudi Arabia; ahaltalhi@kau.edu.sa); Ahmed Barnawi (King Abdulaziz University, Jeddah, Saudi Arabia; ambarnawi@kau.edu.sa)

ABSTRACT

Sensing the radio environment is the most important and challenging role played by the cognitive radio handset in mobile next generation networks. In related work, we have introduced a novel approach for sensing the frequency using wideband chirp signal. In this paper, we utilize the inherent characteristics of the chirp signal to sense the temporal (time related) behavior of primary users. Our method shows promising results in terms of accuracy and complexity.

1. INTRODUCTION

Mobile Next Generation Network (MNGN) is characterized as heterogeneous network where variety of access technologies are meant to coexist. Cognitive radio stands out as a candidate technology to address many emerging issues in MNGN such as capacity, quality of service and spectral efficiency.

Cognitive radio networks promises improving spectral efficiency by opportunistic use of available radio frequencies. The success of this transmission strategy depends greatly upon the agility in sensing frequency, time, or space in dynamic radio environment. Thus a cognitive radio user behaves accordingly not to contribute excessive interference to primary (incumbent) users of the radio channel.

The problem of spectrum sensing is a typical tradeoff problem where the accuracy and system simplicity are inversely related. The most known sensing techniques used are match filtering, energy detection, and cyclostationary features detection [4][5]. Match filtering is the technique with optimal detection, however due to system requirements it is practically difficult to implement [5]. Though at a lower level of implementation difficulty the performance of cyclostationary features detection is near optimal, system complexity is not trivial [5]. Energy detection is the least complex and most inaccurate among the three methods [4].

Wideband chirp signal offers distinctive characteristics that can be exploited in variety of applications in communications engineering. In [6], a novel spectrum sensing technique in infrastructural cognitive radio network based on the use of the chirp signal is used. Simulation results have shown ability to sensing primary users' carriers with Signal to Noise Ratio (SNR) as low as -25 dB. This accuracy has been attributed to the virtue of chirp signal matched filter's output which impressively filters out the noise component of received signal.

Sensing duration (i.e. how long should cognitive radio switch to sensing mode) is a challenging aspect in spectrum sensing as primary users can claim their frequency at any time [2]. Thus Sensing frequency (i.e. how often cognitive radio should perform spectrum sensing) brings about a tradeoff between time of sensing and accuracy [2]. Although we don't focus on this tradeoff, we argue that our method could contribute toward this issue as it improves sensing the temporal behavior of primary user.

In this paper, we look into methods to sense time related aspects of a primary user taking advantages of chirp signal's characteristics. We rely on the chirp signal cross correlation characteristics in time domain to determine the time of the transmission. The goal is to equip cognitive radio user with capabilities to characterize the interference and hence behave accordingly.

This paper is organized as follows; in II, we briefly talk about the chirp signal and its characteristics. In III, we outline the network architecture. In IV, related work on frequency sensing is presented. In V we explain the temporal sensing methodology. In VI, we present the simulation model. In VII, the results are shown and discussed and in IX we conclude.

2. CHIRP SIGNAL

Wideband chirp signal is a result of linear frequency modulation of digital signal. The instantaneous frequency of the chirp signal increases or decreases linearly with time, Figure 1a shows a chirp signal. The bandwidth of a chirp signal, $\boldsymbol{F}$, extends from the starting frequency sweep, $\boldsymbol{f_1}$, to the final frequency sweep $\boldsymbol{f_2}$. With proper choice for processing gain i.e. $\boldsymbol{FT}$ product, where $\boldsymbol{T}$ is the bit period, the spectrum of chirp signal has a distinctive near square shape, Figure 1b.

Chirp signal has very interesting correlation characteristics that gave it multi use in different applications [7]. In our methodology we are interested in two characteristics which will be helpful for sensing both frequency and time related behavior of primary user.

As for frequency sensing, spectral resolution in the presence of white noise is sought. The spectral resolution is obtained by cross-correlating the chirp signal with locally generated copy of itself (i.e. matched filtering). The result of this is optimal reception of chirp signal where excessive noise components are removed, Figure 3b.

As for temporal (time related) sensing the resolution sought is in the time domain. This resolution is obtained by correlating the received chirp with a locally generated conjugate of itself. The result of this operation is removal of noise components and resolution in time domain, Figure 5a.

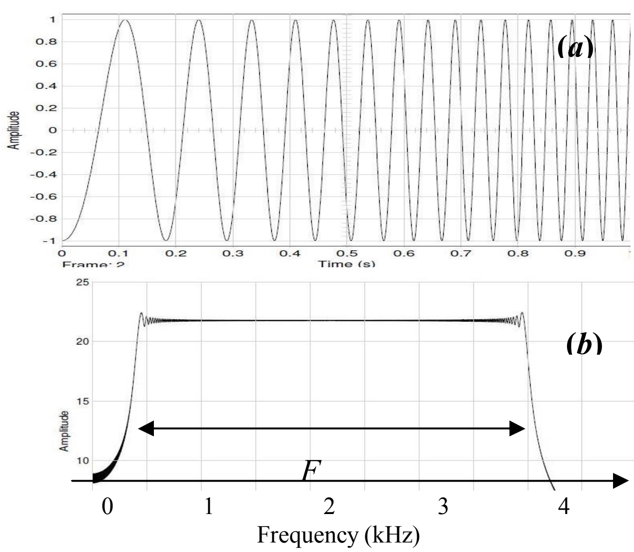


Fig. 1. (a) Chirp signal, (b) Chirp spectrum

3. COGNITIVE RADIO NETWORKS

Cognitive technology is the underlying technology behind the solutions proposed to address capacity and performance improvement in MNGN. A network that enables self organization, Dynamic Spectrum Access, handoffs between access technologies or handovers between micro/macro/femto cells will defiantly require this technology [1]. In such a system, possession of local cognition (via rigorous sensing) determines the vital decisions to be made by users in heterogeneous wireless networks.

3.1 Cognitive Network Architecture

Cognitive Radio Network can be deployed in different methods such as infrastructural and distributed architectures, to serve licensed and unlicensed applications. In this work we are concerned with infrastructural architecture. Figure 2 shows the system architecture. The system is hybrid and contains two networks; a primary radio network and a cognitive "adaptive" radio network [5]. The two networks are not physically connected however they meant to coexist.

3.1.1 Primary Radio network

Primary radio network is the essential part of the system. It consists of a primary base station serving primary "licensed" users over the primary coverage area. The primary base station performs normal functions of a cellular base station.

3.1.2 Cognitive Radio network

The cognitive radio network is the adaptive part of the system. It consists of cognitive radio base station (CR-BS) serving cognitive radio users (CR-user). The cognitive radio coverage area overlaps with primary coverage area. A CR-user is ought to behave in opportunistic manner where it only can transmit after sensing the availability of the radio resources thus guarantee no excessive interference occurs at a primary user's receiver.

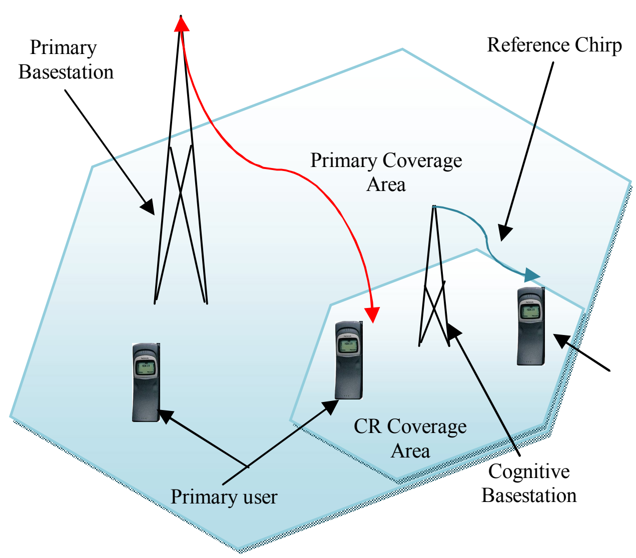


Fig. 2. System Architecture

4. WIDEBAND FREQUENCY SENSING

In [6] we have presented a novel approach for sensing frequency in cognitive radio environment. Figure 3 shows spectrum of received chirp signal. The "interesting" characteristic or received chirp signal is obvious where a near flat floor extends over the bandwidth i.e. 3600 Hz. For chirp signal period of 1 s, the processing gain is 3600. It is shown that two distinctive peaks occur at frequencies corresponding to primary users' carrier frequencies at 500 Hz and 1800 Hz. Figure 3a shows the scenario where Signal to Interference plus Noise Ratio (SINR) for the interfering (primary users) carriers is 20 dB. Figure 3b shows the scenario where SINR is -5 dB. It is obvious that as SINR decreases, noise floor rises toward the peak value.

In order to quantify the performance of the system we define ***d*** which measures the distance (in dB) between the peak of the carrier's spike and the flat floor of chirp signal spectrum. In Figure 8, we plot the carrier's SINR versus ***d***, normalized to value of ***d*** at SINR = 10 dB. The value of ***d*** = 0 dB signifies that the spike is no longer distinguishable from the noise and therefore probability of false alarm is very likely. The level of the noisy floor should determine the threshold value for the decision circuit. It is obvious that as SINR decreases d decrees. For our setup, it is shown that ***d*** = 0 at SINR= -25 dB which is extremely a low SINR value.

5. TEMPORAL (TIME RELATED) SENSING METHODOLOGY

The proposed wideband cognitive radio sensing techniques is designed for infrastructural cognitive radio networks. A reference chirp signal that is transmitted over the coverage area of cognitive radio "femto" cell is used in this process. The idea is to utilize resolution characteristics of chirp signal (in time and frequency) while removing excessive noise interference in the reception process.

Temporal sensing for primary user's time related behavior could be summarized as follows:

1) CR-BS broadcasts a low power reference chirp signal with a bandwidth covering the sensed spectrum.
2) After traveling over the radio channel and interfering with primary users' transmissions and noise, the reference chirp signal is correlated with a locally generated conjugate of the reference chirp signal. Figure 13b shows the received signal. As it is shown, the presence of the tone is sensed as soon as the flat top starts to change.
3) Finally, the output of chirp signal correlation is fed to delay estimation circuit to estimate the delay referenced to the starting moment of tone's reception.

5.1 Delay Estimation Circuit

Delay estimation circuit is simply a timer that starts counting the tone delay referenced to the starting time of the chirp signal reception. The timer is re-set as soon as the flat top of received chirp signal has begun to deform. The deformation corresponds to the moment a primary user starts to transmit. To sense this moment, received samples must be compared against a threshold value. The threshold value should be set just above the flat top of the received waveform.

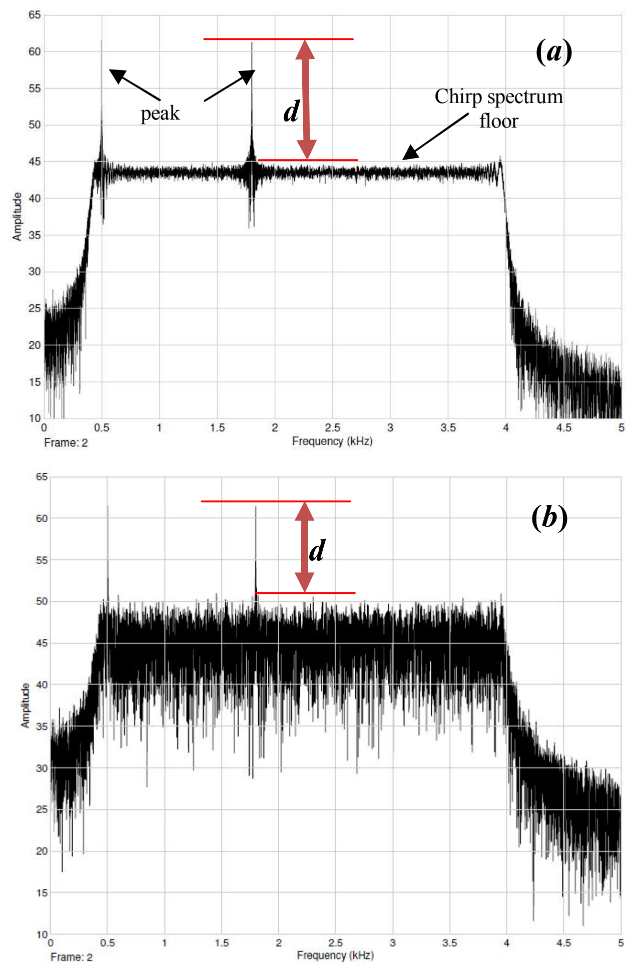


Fig.3. Received chirp spectrum (a) SINR = 20 dB, (b) SINR = -5dB

6. SIMULATION MODEL

Simulations models using Matlab are constructed to draw initial conclusions on the sensing methodology. Figure 4 shows a block diagram for the simulation model that was implemented using Matlab™. The reference chirp signal is received at the CR-receiver after interfering with primary user's signals in AWGN channel. The Chirp signal is firstly received and cross-correlated with a locally generated conjugate of the reference chirp signal. Then the output passes to a delay estimation circuit to estimate the moment when primary user's transmission took place.

characterization in heterogeneous future networks will benefit from these findings.

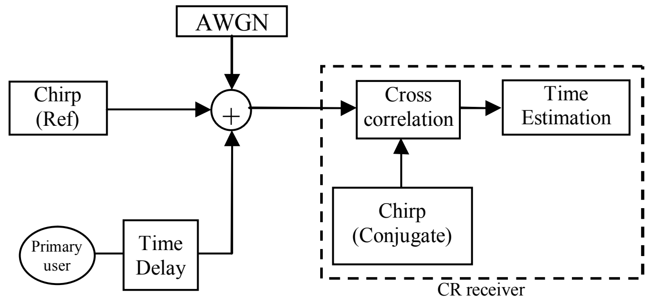


Fig. 4. Simulation model

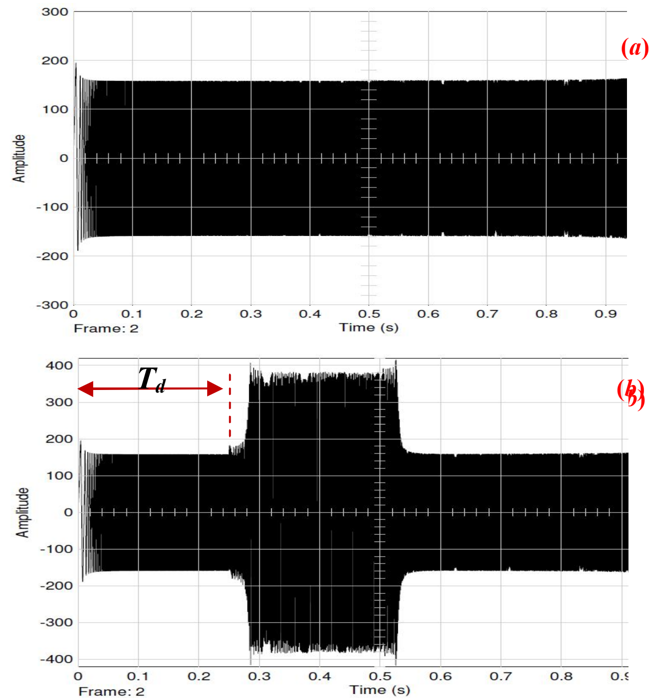


Fig. 5. Output after correlation (a) without the presence of primary tone and (b) with the presence of primary tone.

7. RESULTS AND DISCUSSIONS

Figure 5a and 5b show the output of received signal after cross-correlation with the conjugate of referenced chirp signal in time domain without and with an interfering tone respectively. As it is shown in Figure 5b, the presence of the tone is sensed as soon as the flat top of the cross-correlation's output starts to change. We denote T_d as the time at which primary user started to transmit. T_d is referenced to the beginning of chirp signal's reception.

In order to evaluate the performance, Figure 6 shows the delay estimation error probability P_d versus SNIR. It is shown that as SNIR decreases, error probability increases as the marking of the tone presence become difficult to recognize from background noise.

Further performance improvement is possible have we applied coherent "optimal" detection of the tone, Figure 6. The requirement for such improvement is a prior knowledge of the carrier frequency. This knowledge can easily be obtained from spectrum sensing based on chirp signal [6].

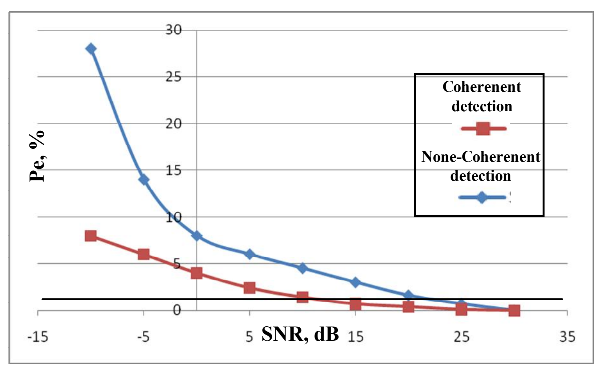
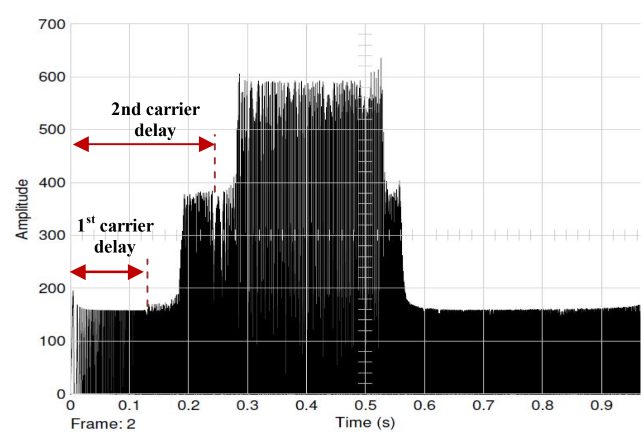


Fig. 6. SNR vs probability of error

Another aspect to be investigated is the case of multi carrier reception. An example of the superposition of carriers resulted from this scenario is shown in Figure 7. To resolve this ambiguity, interference suppression technique should be used. This technique can be accomplished using band pass filtering to filter out the tones of interest (one at a time) having had knowledge of their frequencies.



8. CONCLUSIONS

Our novel methods for sensing temporal user behavior in cognitive radio environment significantly enhances temporal sensing at moderate complexity. We have evaluated the performance against different parameters and created different related arguments. Future work aiming to design an SDR-based system for interference

Fig. 7. Superposition of two received tones

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