Chapter 6

A Collaborative Approach for Compressive Spectrum Sensing

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ABSTRACT

Compressive Sensing (CS) has been proven effective to elevate some of the problems associated with spectrum sensing in wideband Cognitive Radio (CR) networks through efficient sampling and exploiting the underlying sparse structure of the measured frequency spectrum. In this chapter, the authors discuss the motivation and challenges of utilizing collaborative approaches for compressive spectrum sensing. They survey the different approaches and the key published results in this domain. The authors present in detail an approach that utilizes Kronecker sparsifying bases to exploit the two-dimensional sparse structure in the measured spectrum at different, spatially separated cognitive radios. Simulation results show that the presented scheme can substantially reduce the Mean Square Error (MSE) of the recovered power spectrum density over conventional schemes while maintaining the use of a low-rate Sub-Nyquist Analog to Information Converter. It is also shows that one can achieve dramatically lower MSE under low compression ratios using a dense measurement matrix while using Nyquist rate ADC.

INTRODUCTION: CONCEPTS AND CHALLENGES

CR technology is gaining more ground each day as a promising technology to mitigate the limited availability of radio spectrum resources. Spectrum Sensing is considered one of the most important tools in opportunistic CR systems, where the secondary user should efficiently detect the signals from PUs, so that it does not cause harmful interference to them.

In spite of the tremendous evolution that occurs in CR related technologies, spectrum sensing in wideband CR networks remains one of the most challenging issues facing the widespread of this technol-
ogy. The CRs need to sense the wide-band spectrum in order to detect the unoccupied channels available for opportunistic use. For example, digital TV signals with a power above the threshold of $-116$ dBm should be detected with a probability of at least 0.9 and with 0.1 maximum probability of a false alarm. Several issues that challenge spectrum sensing performance could be summarized as follows;

- **Hardware Requirements:** One of the hardware challenges relates to the need to sample the signal at a very high sampling rate especially in wide-band networks. As, according to Shannon theorem, the sampling rate must be at least twice the highest frequency component of the signal to avoid aliasing, which is called the Nyquist sampling rate. This requires expensive, complicated Analog to Digital Converter (ADC) with high resolution, wide dynamic range, and low power consumption. The current technology forms an obstacle to design such a high sampling rate with wide dynamic range ADC (Yucek & Arslan, 2009). Novel approaches are required to simultaneously sense wide-band multiple channels using a limited number of RF interfaces.

- **Noise Uncertainty:** Energy detection based spectrum sensing requires a precise estimation for the environmental noise statistics, which are used to obtain an accurate calculation of the threshold needed to differentiate between free and busy channels. The main problem is that such a precise estimation of noise is not always attainable. In general, energy detection performance deteriorates as noise uncertainty increases. This behavior is continued till the performance decreases significantly and the system fails at specific SNR no matter the number of measurements. This phenomenon is called SNR wall.

- **Hidden Primary User:** The Hidden Primary User problem arises when the cognitive radio device fails to detect the PU transmitted signal, causing unwanted interference at the primary user receiver. This problem occurs due to many factors, such as the relative locations of devices and severe multipath fading and shadowing. Cooperative sensing is proposed as a solution for handling this problem, where exploiting spatial diversity among several collaborating CRs had proven to be an effective method to improve the detection performance, but at the expense of cooperation overhead on the network resources. Researches try to reduce the amount of the overload data. Various Fusion techniques such as soft decision methods or hard decision methods can be used for combining information from different cognitive radios.

The enormous technological progress in digital signal processing enhanced by the engagement the wireless communications and signal processing has paved the way for mitigating some of these issues. Specifically, CS has been proposed as an effective technique to alleviate some of these problems through efficient sampling that exploits the underlying sparse structure of the measured frequency spectrum.

The hardware requirements issue for example can be mitigated through CS based spectrum sensing approaches; the signal is captured using low speed Analog to Information Converter (AIC) rather than conventional high speed Nyquist ADC. The AIC is known for its ability to capture the signal using its information rate rather than its symbol rate. A practical realization of it was given in (Kirolos, Ragheb, Laska, Duarte, Massoud, & Baraniuk, 2006) where; the analog signal is multiplied by a pseudo-random maximal length PN sequence of $\{1, -1\}$. The rate of change of this PN sequence is higher than the Nyquist rate. The signal is integrated then sampled at its information rate using low speed ADC. The only problem with this scheme is that it is subject to model mismatches and non-linearity inherent in pseudo random generator, multiplier and integrator.