

RealSense: Real-time Compressive Spectrum Sensing Testbed over TV White Space

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Abstract—Nowadays, wideband spectrum sensing, as one of the vital technologies of cognitive radio (CR), has the potential to find more temporarily available frequency bands to meet the growing demands of wireless services. As the vast number of samples are required to be collected and processed, traditional wideband spectrum sensing methods become inefficient and cause large energy consumption. Therefore, many theoretical work focus on applying compressive sensing (CS) into wideband spectrum sensing to alleviate this issue. In this paper, to verify the CS-based spectrum sensing scheme in real-world scenarios, a real-time compressive spectrum sensing testbed is proposed to process the real-time data collected from the TV white space (TVWS) spectrum. The proposed testbed consists of two parts: a sensor node, and a real-time signal processing platform based on National Instruments (NI) LabVIEW software to process the spectral data and control the sensor.

Index Terms—Cognitive Radio, Compressive Spectrum Sensing, TV white space.

I. INTRODUCTION

With the rapid development of wireless technologies such as machine-to-machine communications and Internet of things, the current static frequency allocation policy faces a primary challenge of spectrum scarcity [1]. On the other hand, not every channel in every portion of the spectrum has been fully utilized all the time even for the 'busy' spectrum below 6 GHz in the urban areas, as shown in Fig. 1. This has encouraged the regulatory bodies such as Federal Communications Commission (FCC) in the U.S. and Office of Communications (Ofcom) in the U.K. to release the underutilized licensed bands for temporary secondary access through the use of cognitive radio (CR). For instance, in the most locations around the world, there is certain unused TV band spectrum, named as TV white space (TVWS), which could be used for a range of wireless applications, from broadband communication, wireless offloading, to machine-to-machine communication [2]. Therefore, unlocking the TVWS spectrum implies significantly increasing the total amount of bandwidth available for users and alleviating the pressure on other spectrum bands.

To put such unused ultra high frequency (UHF) TV spectrum to good usages, the fast and accurate spectrum utilization detection is crucial to ensure that there is no harmful interference caused to the surrounding primary transmissions. One of the current operational mechanism to discover available channels is using the geo-location databases which only protects registered primary systems [3]. For the concern of the database update speed and the secondary access for the public

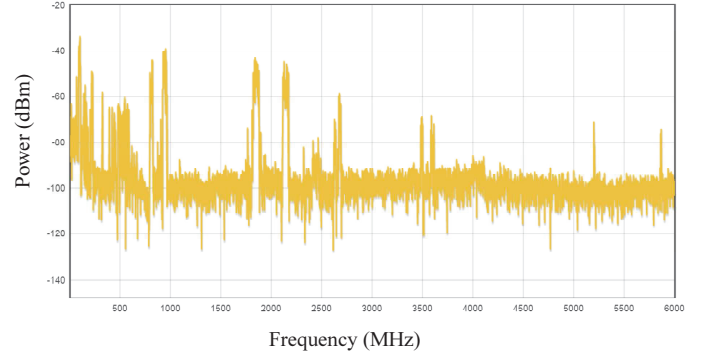


Fig. 1. The real-time spectrum occupancy recorded at Queen Mary University of London (51.523021°N 0.041592°W) in London, United Kingdom. The figure shows that the spectrum is sparsely occupied below 6 GHz [5].

use, spectrum sensing, as the vital important technology in a CR system, was proposed to efficiently use the underutilized portion of spectrum [4].

Spectrum sensing is defined as the task of finding spectrum holes over time and space domain by the secondary users (SUs) in an unsupervised manner. Nevertheless, the wideband TVWS spectrum challenges traditional spectrum sensing algorithms in terms of sampling rate and computational complexity. Therefore, compressive sensing (CS) [6] was applied to implement wideband spectrum sensing with sub-Nyquist sampling rates by exploiting the sparse nature of the underutilized wideband spectrum in practice [7], [8]. Recently, there are some theoretical work on applying CS in wideband spectrum sensing over TVWS. In [9], each SU implements wideband channel division to sense K out of L channels and then matrix completion is performed at a fusion center to reconstruct the original spectrum for decision making. In [10], a hybrid framework is proposed to incorporate the advantages of both geo-location database and CS-based spectrum sensing. In [11], an efficient cooperative spectrum sensing scheme based on subspace decomposition is developed by exploiting the common signal support shared among multiple SUs, in which the energy consumption on wideband signal acquisition, processing, and transmission is reduced with detection performance guarantee.

It is indicated in [9]–[11] that the performance of reconstruction algorithm in CS-based spectrum sensing has significant influence of the detection capability. Therefore, a platform which could test the CS-based sensing algorithms in real-world



(a). Outdoor sensor node setup at Queen Mary University of London

(b). Rfeye portable sensing node

Fig. 2. (a) Outdoor fixed sensor node deployed in Queen Mary University of London and (b) the portable sensor node for mobile spectrum surveillance.

scenarios is crucial for community research. In this paper, we demonstrate a testbed that implementing the compressive spectrum sensing algorithm with LabVIEW software and processing the spectral information collected by a sensor node. The sensor node is deployed in real-time environment. Different to the simulation or small controlled laboratory experiments, the proposed testbed offers to researchers a realistic environment for verifying the reconstruction algorithms with the practical and varying channel environment.

II. REAL-TIME COMPRESSIVE SPECTRUM SENSING TESTBED

The proposed testbed consists of a sensor node and a real-time spectral information processing platform based on National Instruments (NI) LabVIEW software [12] to process the data and control the hardware.

A. Sensor node system

The sensor node applied in the proposed real-time compressive spectrum sensing testbed is a RFeye node, which is an intelligent spectrum monitoring system. According to the working type of sensor node, the testbed has two sensing modes: fixed sensing mode and portable sensing mode. As shown in Fig. 2, the fixed outdoor RFeye node is located at Queen Mary University of London (51.523021°N 0.041592°W), and the antenna height is about 20 meters above ground. The portable sensor node is for mobile spectrum surveillance in urban/rural areas and demonstration purpose. When the fixed outdoor sensing node is applied in the proposed testbed, the collected data is transmitted through the Internet or local area network (LAN), which is encrypted as javascript object notation (JSON) message. If the portable sensing node is utilized to form the testbed, the sensor node is directly connected with PC which runs the spectral information processing platform via Ethernet cable. In order to demonstrate the proposed testbed at the conference, the portable sensing mode is adopted.

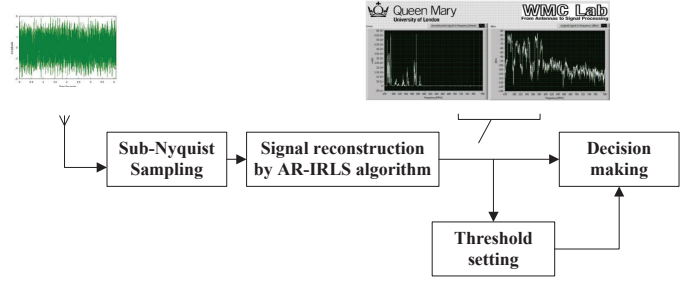


Fig. 3. The block diagram of the real-time spectral information processing platform.

B. Real-time spectral information processing platform

Based on the NI LabVIEW software, as the second part of the proposed testbed, the real-time spectral information processing platform is developed for processing the information collected by the sensor node and displaying the reconstructed results. As shown in Fig. 3, the proposed platform is mainly composed of four parts: sub-Nyquist samples collection, signal reconstruction by adaptively-regularized iterative reweighted least squares (AR-IRLS) algorithm [13], threshold setting and decision making. As the reconstruction performance of CS-based spectrum sensing scheme has significant impact on the detection capabilities [11], one targets of the propose testbed is to implement the reconstruction algorithms and verify their performance in the real-world scenario. Basically, the reconstruction algorithms of CS could be broadly categorized into two types: optimization-based algorithm and greedy algorithms. In the proposed testbed, the optimization-based AR-IRLS algorithm has been implemented as the reconstruction algorithm of this platform since AR-IRLS algorithm can produce exact reconstruction with fewer measurements and reduced computational burden than the conventional IRLS algorithm. After the signal reconstruction from collected sub-Nyquist samples, the spectrum sensing techniques shall be performed, e.g., energy detection and feature detection, on the reconstructed signal in order to make the decision of the channel occupancy status. Compared with other conventional spectrum detection technologies, the energy detection methods do not require any prior knowledge of the PUs, i.e., modulation type, with lower implementation and computational complexity [4], therefore, we adopt the energy detection method [14] in the proposed testbed.

As shown in Fig. 4, the front panel of the proposed testbed displays both original signals and reconstructed signals in order to demonstrate the reconstruction performance. The power spectrum of signals shown in the left two diagrams is in linear form and the other two diagrams show the signals in dBm form. The signals at the top are the original signals collected in real-time and the signals at the bottom are the corresponding reconstructed signals. Therefore, the differences between original signals and reconstructed signals could be visualized and easily to be identified by audiences.

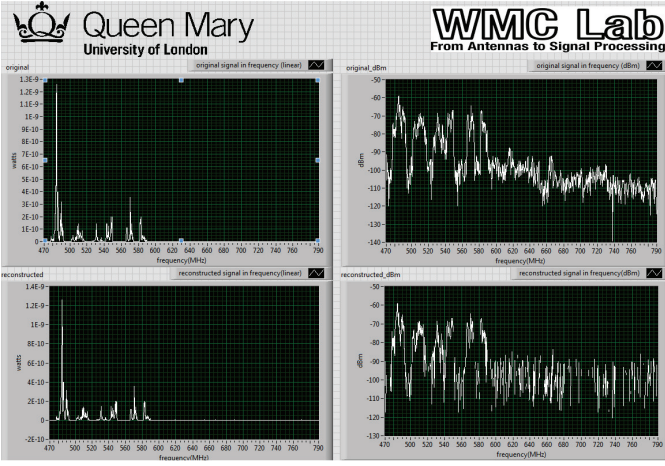


Fig. 4. The front panel of the proposed testbed.

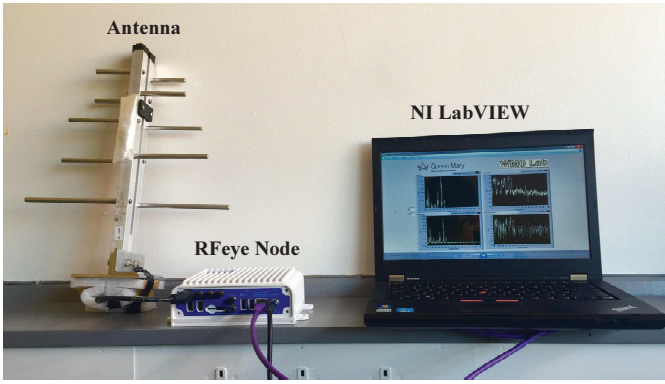


Fig. 5. The demo setup with portable sensor node.

III. DEMONSTRATION

The demonstration presented at the IEEE WoWMoM 2017 conference is a live demo of the proposed real-time compressive spectrum sensing testbed. The demo setup is relatively flexible in terms of space constraints and hardware requirements. If possible, a $2m \times 2m$ area with a desk to place the equipments would be sufficient.

As shown in Fig. 5, the proposed testbed consists of the commercial nondirectional UHF antenna, the portable sensor node, and a laptop installed our real-time spectral information processing platform. All devices includes cables would be prepared by ourselves and this demo only requires power supply for both sensor node and laptop.

Most of theoretical work about CS-based spectrum sensing scheme are based on the simulated signals. This demo will allow the audiences to observe the real-world spectrum over TVWS and compare the original signals with reconstructed signals from the front panel. During the demo, the audiences could also observe the influence on reconstruction performance caused by different compressive ratio, i.e., different number of collected samples.

IV. CONCLUSION

We present a demo of the real-time compressive spectrum sensing testbed, which exploits the effectiveness of the adaptively-regularized iterative reweighted least squares (AR-IRLS) reconstruction algorithm over TV white space (TVWS) in real-time processing and also visualises the differences between reconstructed signals and original signals in the front panel of the proposed testbed. This work also enables the verification of different CS-based spectrum sensing algorithms in real-world scenarios.

ACKNOWLEDGMENT

The authors would like to acknowledge the Engineering and Physical Sciences Research Council (EPSRC), Innovate UK for funding the work, and CRFS Ltd for providing the RFeye node.

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