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TV WHITE SPACE DETECTION USING USRP

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ABSTRACT

The burgeoning demand on radio spectrum owing to explosive development in wireless communication necessitates efficient use of the available frequency spectrum. But this need is at cross purposes with the present system of fixed spectrum allocation. The use of TV white space for communication is one way of circumventing this problem. In this paper a Universal Software Radio Peripheral (USRP) is employed to detect the unused spectrum in TV band. The USRP is a hardware platform for software radio.

Keywords: *Spectrum sensing, TV white space*, *Software Defined Radio (SDR), Universal Software Radio Peripheral (USRP)*

1. INTRODUCTION

In most countries, including India, the radio frequency spectrum is managed by allocating different bands of the spectrum for the use of certain specific purposes. This is called Fixed Spectrum Allocation where only the licensed/primary users can use their assigned band for transmission. It ensures interference free operation for each radio service. These include uses such as military and public safety purposes as well as commercial applications such as radio, television and broadband Internet. But in such a scenario, a major portion of the allocated spectrum remains under-utilized as the vast bulk of that spectrum is not in use round the clock. This points to the need for a different approach to spectrum allocation whereby users are assigned a band if it is currently unoccupied by the licensed or primary user (PU). This dynamic spectrum allocation requires continuous monitoring of the frequency spectrum and dynamic assignment algorithms.

Even in today's highly interconnected world via mobile and high-speed communications, two-thirds of the world's population is yet to gain access to the Internet because fixed broadband access is unaffordable. Spectrum sensing can provide opportunistic access of the sparsely available spectrum. TV White Space (TVWS) spectrum refers to the band of frequencies in the VHF and UHF television broadcast bands that are left unutilized by existing licensed users. Television networks leave buffers/gaps between channels to minimize interference. This space is similar to the 4G spectrum and hence can be used to provide widespread broadband internet.

White Space can radically change how we purchase and utilize wireless internet. Though yet to be widely adopted, the idea of deploying of TV white space to facilitate better coverage and transmission rates which cater to the huge requirement in data traffic is gaining popularity. This behooves us to explore this under-utilized resource. The ultimate goal of any opportunistic spectrum access scheme is to make use of the white space without causing any inconvenience to authorized ones. This would make more prime spectrum freely accessible and is an effective solution, particularly in rural areas where wired connections are unaffordable or unavailable and here comes the relevance of our project.

Various studies have been conducted across the world to investigate the feasibility of using white space for different communication applications. In an experimental study carried out in the sub-urban areas of New Delhi, India, day-long spectrum measurements were conducted for several days in the sub-GHz band to estimate how much of the spectrum remains unused [1]. Studies have also been conducted on technical challenges associated with Super Wi-Fi mainly based on incumbent detection and avoidance. As a part of this, an energy detector was implemented on the UHF TV

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band using USRP E110 and GNU Radio [2]. A WhiteFi prototype with a Wi-Fi card has been built by Microsoft Research in collaboration with Harvard University that provides a new adaptive spectrum assignment algorithm to handle temporal variations [3]. A labVIEW based SDR using NI USRP, capable of operating over the entire 2.4GHz ISM band was developed and implemented by the School of Electrical and Electronic Engineering, University of Manchester, UK [4]. Other research in this area include studies on the sensing performance of wireless microphone signals using three different algorithms based on Energy Detection [5].

Microsoft and Google have carried out several studies on TVWS technology. Microsoft's trial project on Redmond, Washington campus was one of the first TVWS-based trials to use an experimental license from the Federal Communications Commission in the US and encompasses the nearly 600-acre campus. Microsoft has also conducted and supported commercial pilots and trials in Singapore, the UK and the US [6].

The objective of this work is to employ a Universal Software Radio Peripheral (USRP) for spectrum sensing to detect unused spectrum in the TV band. Programmed using LabVIEW, a system-design platform for visual programming language, this spectrum analyzer is built to monitor the TV spectrum across several bands by specifying an array of frequencies to which the USRP receiver tunes successively. The TV bands may vary for different countries. In this work, the TV band from 470MHz to 490MHz which comes under UHF Band IV among the classification of TV bands in India, has been sensed. But the prototype developed can be applied to any band in the TV spectrum taking into consideration the range of tunable centre frequencies of the USRP being used. This work does not take into account the spectrum history of the band being sensed. The model works on instantaneous sensing of the desired spectrum but simultaneous sensing of different channels has been incorporated. In a Cognitive Radio setup, when a channel is being utilized by a secondary user, the same channel cannot be used for sensing simultaneously. Secondary user data transmission must be interrupted to sense that channel, which degrades the efficiency of the overall sensing system [7]. A way around this conundrum is to sense an intended channel in parallel, to implement Dynamic Frequency Hopping. This sensing of several intended channels can be realized in our design by simply changing the elements of the carrier frequency array. Thus, this design can be used as part of a larger spectrum sensing or cognitive radio system.

This paper is organized as follows: Section 2 describes the concept of spectrum sensing and its relevance. In section 3, TV white space and its potential are discussed. Section 4 describes the implementation environment. Section 5 explains the experimental setup. Section 6 summarizes the results of real time spectrum sensing. Section 7 concludes the paper with a discussion on the future scope in this area.

2. SPECTRUM SENSING

The remarkable growth in the field of wireless technology requires the efficient utilization of sparsely available spectrum, hence the relevance of spectrum sensing. Spectrum sensing, also referred to as spectral occupancy measurement, is a radio process by which the specified RF bandwidth is monitored for occupancy. This process finds wide application in dynamic spectrum access networks that are designed to maximize spectrum efficiency and capacity within the highly crowded transmission environments. Dynamic spectrum access is an access strategy which aims at transmitting data through spectral holes or white spaces. When the incumbent user is not accessing the allocated spectrum, the secondary nodes can temporarily borrow the spectrum to transmit their data. This can be carried out in various ways after analyzing channel gain and signaling. In a system consisting of many primary and secondary users, the latter need to dynamically exploit the unused spectrum of the primary users as and when it becomes available. This can be achieved by employing various spectrum sensing techniques. This can involve various trade-offs.

Spectrum sensing, which is the primary job of Cognitive Radio (CR), is carried out by adopting certain algorithms such as Matched filter detection, Cyclostationary method or Energy detection. In Classical Energy Detection principle (CED), the energy of the received signal is computed and compared to a threshold value in order to decide whether the desired signal is present or not. In this method, also known as radiometric detection, the energy received in a particular primary band during an interval is measured. It is a non-coherent detection method in which the primary signal is detected based on the sensed

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energy [8] [9]. It is the most popular sensing technique in cooperative sensing due to its simplicity and non-requirement of prior signal knowledge. As it ignores the structure of the signal, it is said to be a Blind signal detector which estimates the presence of the signal by comparing the energy of the received signal with a known threshold value derived from the statistics of the noise. The energy of the signal can be maintained in both time domain and frequency domain [10].

The cyclostationary method relies upon periodic redundancy introduced into a signal by sampling and modulation. Owing to periodicity, these cyclostationary signals exhibit the features of spectral correlation and periodic statistics, which is not found in stationary noise and interference [11]. This feature is robust to noise suspects and is more dependable than energy detection in low signal-to-noise ratio (SNR) regions. Although a priori knowledge of the signal characteristics is essential, the synchronization requirement of ED is eliminated and is capable of distinguishing the transmissions from various types of licensed signals. Yet computational complexity presents a bottleneck for its implementation and an alternate approach is the Matched filter detection.

The output SNR for a given input signal is maximized in Matched filter detection employed using a linear filter. It is applied when the secondary nodes are aware of primary user arrival and is identical to correlation where the unknown signal is convolved with filter response. This method is desirable when the CR user possess sufficient information of incumbent ones and takes less detection time to meet the constraints of probability detection [12].

One of the key considerations in designing a spectrum sensing system using any of these algorithms is the collection and storage of the obtained spectral measurements, through a spectrum sweep. A spectrum analyzer can provide an instantaneous depiction of a bandwidth via the sampling of intercepted signal pulses at some rate. Considerations when parametrizing a spectrum sweep include the sweep time and resolution, i.e., the speed and detail with which the spectrum sweeps are obtained. Higher resolution sweeps take much longer sweep times, but provide more accurate estimate of the spectrum.

3. TV WHITE SPACE

White spaces, also referred to as “spectral voids”, are the regions allocated to primary users which remain as unused broadcasting frequencies in the wireless spectrum. The voids provided by television networks between channels for buffering purposes to alleviate interference with each other result in white space. White space availability in the TV band (between 471.25 and 863.25 MHz) also arises from the digital switch-over of analog TV channels, allowing more TV data to be transmitted over the same frequency band. These frequencies can be made available for unlicensed use by secondary users at locations where the spectrum is not being occupied by licensed users. This leads to more efficient use of the existing spectrum. However the incumbent user is protected from any interference from the unauthorized ones. The secondary user must vacate the band once the primary user arrives.

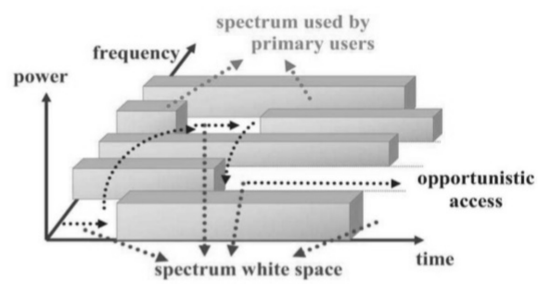

Figure 1: Illustration of White Spaces in Spectrum

The TV bands in India can be classified primarily into three categories: VHF Band-I, VHF Band-II and UHF Band-IV. The VHF Band-I extends from 54 MHz to 68MHz and comprises 2 analog TV channels, VHF Band-II extends from 174 MHz to 320 MHz and comprise of 8 channels and UHF Band- IV extends from 470 MHz to 582 MHz and comprises 14 channels. The former two bands have a bandwidth of 7 MHz and the latter has a bandwidth of 8 MHz. Frequencies from 585 MHz to 698 MHz are allotted to mobile TV broadcast services [13].

TV white space technology is a promising one in the current scenario to provide broadband connectivity to rural areas. Internet connectivity is scarce in areas with low population density due to environmental obstacles, distance from major Internet Service Providers, and lack of financial incentives. This results in expensive and complex networks leaving the rural communities with little options. While traditional Wi-Fi weakens over rugged terrain, the TV band can penetrate buildings and terrains with good signal strength. Also they provide larger coverage and greater bandwidths

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which make them suitable for providing wireless internet connectivity to rural areas where adopting wired infrastructure is not cost efficient. The Wireless Regional Area Network (WRAN) uses TV white spaces to bring broadband access to hard-to-reach as well as low population density areas [14].

TV white spaces can be used in unified broadband communication services which connects an entire office or campus. It can be used in realizing a smart home or smart city by offering a broadband signal capable of handling multiple devices reporting large amounts of data across long distances. Industrial applications include dedicated machine to machine communication between two remote devices or remote monitoring of power plants. They can also be used in healthcare for remote monitoring of patients. Other applications include remote and broad sensing network for weather, traffic or environment monitoring and disaster management systems.

4. IMPLEMENTATION ENVIRONMENT

A software defined radio was developed using USRP and LabVIEW for conducting real time spectrum sweeps in the UHF TV band. The experiment was conducted in an indoor environment. The experimental setup of NI USRP 2920 and PC is shown in figure 2. The software platform used was NI LabVIEW.

3.1 Software Defined Radio-NI USRP 2920

A Software Defined Radio (SDR) is described as “a radio in which some or all of the physical layer functions are software defined” [15]. In an SDR, some of the functions which are conventionally hardware-implemented like mixers, filters, modulators/demodulators, amplifiers, detectors, etc. are instead implemented through software by means of a personal computer or embedded system. The greatest advantage of SDR is that it ushers increased flexibility to the device since the operating parameters such as operating frequency range, bandwidth, modulation type, data encoding, network protocol and other communication parameters can be changed by simply changing the software executed in the processing resource (GPP, DSP and FPGA) without the need for hardware modifications. The key difference between traditional radio and software defined radio is that the latter senses its environment and adapts to it.

The Universal Software Radio Peripheral (USRP) is a flexible transceiver that can transmit and receive radiofrequency signals in several bands. USRP connected to PC via Ethernet connection, working in pair with NI-LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is able to perform multiple input, multiple output (MIMO) functionalities. LabVIEW is a graphical oriented programming language developed by National Instruments which has virtual instruments as building blocks. The measurements performed by the NI USRP can help realize the pattern of channel occupancy in any environment so that constantly occupied or unoccupied channels can be predicted and exploited in dynamic spectrum networks [16].

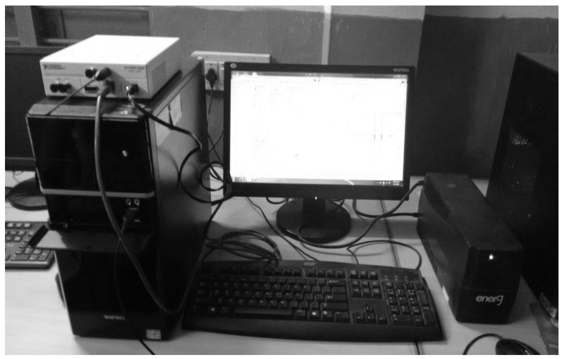

Figure 2: Experimental Setup

The NI-USRP 2920 used for real-time spectrum sensing had the following specifications:

- Tunable center frequency from 50 MHz to 2.2 GHz that covers FM radio, GPS, GSM, radar and ISM bands
- Up to 20 MHz baseband I/Q bandwidth with a streaming rate of 25 MS/s for host-based processing with NI LabVIEW
- Windows 7/Vista/XP compatibility [17]

5. EXPERIMENTAL SETUP

The LabVIEW application developed implements a basic spectrum analyzer based on NI USRP hardware with a real-time display of the spectrum. It configures the USRP to perform a visual perusal of a running spectrum over a given band. The NI USRP-2920 transceiver acquires spectral data continuously at the specified I/Q sampling rate (S/s) [18].

After initializing the software reference to the NI USRP hardware, a frame of IQ baseband signal samples are acquired. The parameters for acquisition are set in the USRP receiver

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configuration. This includes the carrier frequency which has been specified as an array of frequencies of interest (from 470MHz to 490MHz). The acquisition is carried out in two While Loops. For every iteration of the outer loop, the VI tunes the NI USRP radio transceiver to a new sub-band frequency for a fresh set of acquisitions at that frequency. The VI is thus invoked multiple times to obtain a set of acquisitions to calculate an averaged spectrum. This is done to sustain a higher IQ rate. A fast Fourier transform (FFT) power spectrum of the current frame acquired is plotted. A view of the front panel of the application when it is carrying out spectrum sensing at 485MHz central frequency is shown in figure 5.

6. RESULTS AND DISCUSSION

Spectrum sensing was carried out in an indoor setup consisting of the USRP and a PC. Spectrum sweeps were conducted in the UHF TV band from 470MHz to 490MHz with each sweep covering a bandwidth of 5MHz centered at frequencies 470MHz, 475MHz, 480MHz, 485MHz and 490MHz. To identify the occupied bands in the sensed spectrum, energy detection principle was used. The magnitude spectrum obtained for a carrier frequency of 470MHz showed several small peaks above -80dB whereas those for 475MHz and 480MHz showed strong peaks throughout the band indicating the presence of signal. The plot for 485MHz had strong peaks above -80dB only towards the higher end of the band while that centered at 490MHz was devoid of peaks above -80dB indicating the potential for usable white spaces in these bands. In order to obtain a better view of the location of peaks in the acquired data, it was exported to an Excel format. The raw data as well as the magnitude levels above a threshold of -80dB were plotted using Matlab (figures 3 and 4, respectively).

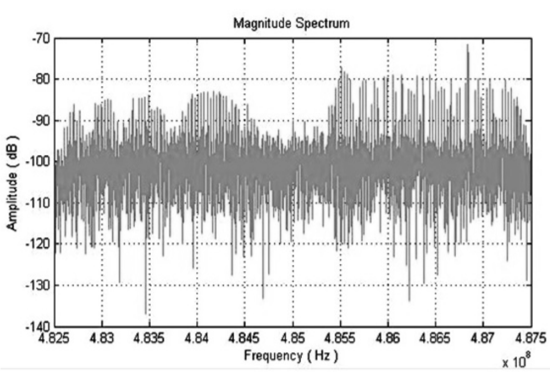

Figure 3: Sensed Spectrum at 485MHz

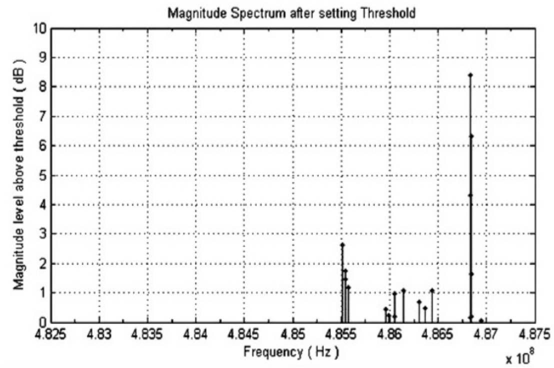

Figure 4: Spectrum (485MHz) After Setting Threshold

7. CONCLUSION

A prototype of TV white space detector that monitors multiple bands in the TV spectrum for occupancy was built using USRP. The UHF TV band from 470MHz to 490MHz was monitored with each spectrum sweep covering a 5MHz bandwidth at a time. The unoccupied bands or white spaces were identified by applying the Energy Detection principle.

Filter effects become apparent in the obtained spectral measurements when acquiring real-time data at the maximum bandwidth 20MHz that is supported by the USRP 2920. Thus to realize a higher IQ rate for spectrum sweeps, additional baseband signal processing to remove these effects is necessary, which is not included in this design. For processing a wide frequency band, a massive amount of memory and high computational capability are requisites for the host PC, the lack of which can lead to an overflow error. The host system's inability to maintain streaming at high IQ rates restricted the duration of spectrum sensing. Thus spectrum sweeps could be carried out for only very short periods of time, but at different time of the day for different days to characterize the spectrum and set a suitable threshold. Only instantaneous snapshots of the spectrum were used to identify the white spaces.

In future, a more extensive spectrum monitoring application may be built by storing the spectrum history and performing analysis, either real-time or offline. To continuously sustain a large real-time bandwidth, a host system with larger memory and faster processor need to be used. If the application does not require continuous processing or for offline spectrum analysis across a wide band, the aggregate spectrum can be built by acquiring

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the spectrum piece by piece and stitching them together over time.

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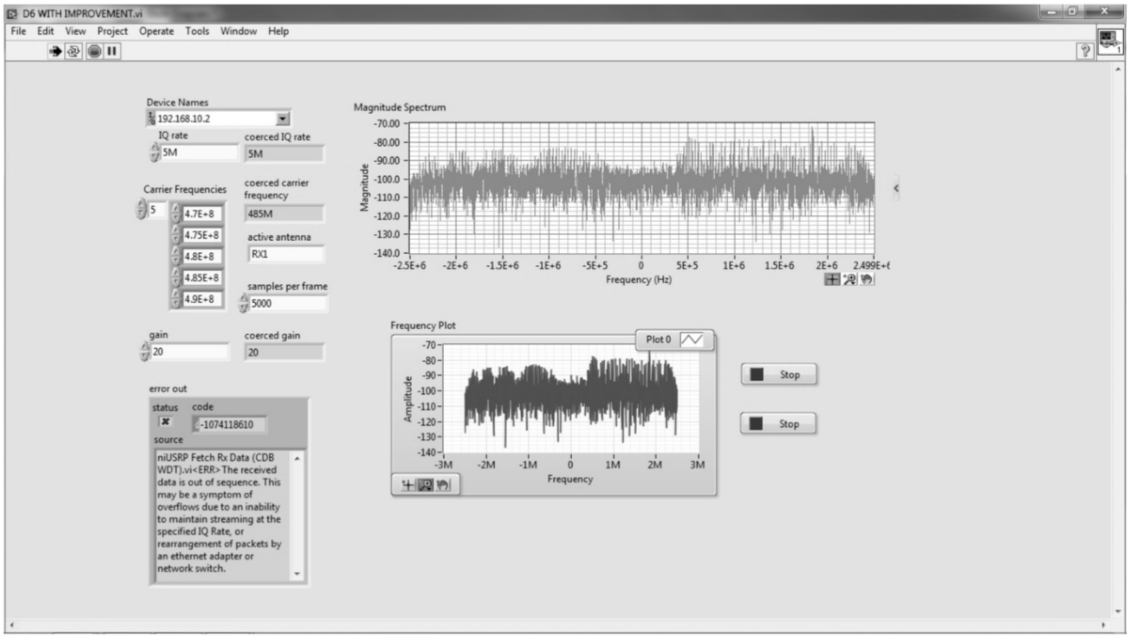

Figure 5: Front Panel View of Sensing at 485MHz