VHF Spectrum Monitoring Using Meraka Cognitive Radio Platform

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Abstract. Radio Frequency (RF) spectrum is a natural resource widely used by wireless network operators to provide radio communications or transmission systems (e.g. telephone operators and TV broadcast stations). Scarcity of RF spectrums has led to the enhancement of new techniques for better utilization of the RF spectrums. The questions asked are how much RF spectrum is available and can be used opportunistically and dynamically without interfering with licensed or primary users (PUs)? More so, how will the frequency at which the PU is operating are protected against its usage by the unlicensed or secondary user (SU)? In this paper, we present work that is currently going on with regard to the use of Software Defined Radio (SDR) to utilize RF spectrum usage. We discuss the Meraka Cognitive Radio Platform (MCRP) developed using the second version of the Universal Serial Radio Peripheral (USRP2) hardware and the GNU Radio software. We also discussed how the spectrum monitoring system is being implemented on the MCRP. Lastly, the result of the measurements which were conducted using the MCRP is also presented. These measurements were conducted in South Africa.

Keywords: cognitive radio, GNU radio, spectrum management, universal software radio peripheral, television, white spaces

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1 Introduction

Wireless communications has become the effective standard for our growing and diverse demands. For communication purposes, many wireless technologies make use of RF spectrum. Hence, RF spectrum is regarded as the most valuable and highly-priced resource that needs to be controlled wisely and in the most efficient way in order to have a room for future innovations. RF spectrum refers to the range of frequencies from 3 KHz – 300GHz. A new communication paradigm to exploit the existing wireless spectrum opportunistically is necessary to overcome limited available spectrum and inefficiency in spectrum utilization [1].

To enable opportunistic access to RF spectrum and efficient sharing of allocated bands, more flexible spectrum management techniques are required such as Opportunistic Spectrum Sharing(OSS),where secondary users (SUs) are allowed to operate frequency bands without permission of the Primary Users(PUs) provided that it does not introduce harmful interference with PUs. Cognitive Radio (CR) is being intensively investigated by the research community, industry major communication regulators and standardization bodies as a key enabling technology [2]. CR [3] is defined by the Federal Communications Commission (FCC) as**:** *an intelligent wireless communication system capable of changing its transceiver parameters based on interaction with the environment in which it operates.* Cognitive Radio Network imposes distinctive challenges due to the fact that there is high fluctuation in the available spectrum in time. Different available channels are seen at different time by the different CR nodes. Due to this fact, some challenges are introduced such as: (1) spectrum sensing which needs to be done correctly and frequently. (2) The availability of routes between nodes that see different channels and multi-hop routing. (3) Spectrum decision and sharing in a distributed setting without a central coordinator. (4) Coordination among the nodes with or without the availability of a common control channel.

Most countries have regulatory agencies to regulate radio spectrum by means of renewable licenses. However, the RF spectrum monitoring systems (equipment) used by regulators are specialized and very expensive. In order to allow research and study on RF spectrum, there is a need to develop low-cost test beds or prototypes for spectrum monitoring. The prototype can be used by students' mainly and also wireless industry to make the spectrum usage and occupancy process more efficient and ready to accommodate innovative radio-communication systems or existing ones.

The advancement of radio technology to Software Defined Radio (SDR) has made the development of radio systems easy and affordable. SDR is a radio in which some or all the physical layer functions are software defined [4].

In [1] Rashid, Sarijari, Fisal, Yusof and Mahalin investigate that spectrum utilization can be significantly improved by adopting SDR technology. Such radios are able to sense the spectral environment and use this information to opportunistically provide wireless links that meet the user communications requirements optimally. They investigate sensing performance implemented on real-time testbed of GNU Radio and USRP Software Defined Radio (SDR) communication platform operating at 2.48 GHz with a bandwidth of 4 MHz.

In [5] Yucek and Arslan present a survey of spectrum sensing methodologies. Various aspects of spectrum sensing problem are studied from a cognitive radio perspective and multi-dimensional spectrum sensing concept is introduced. Challenges associated with spectrum sensing are given and enabling spectrum sensing methods are reviewed**.** The paper explains the cooperative sensing concept and its various forms. External sensing algorithms and other alternative sensing methods are also discussed. Finally, sensing features of some current wireless standards are given.

In this paper, it can be seen through active spectrum scans, that it is possible to monitor the frequency occupancy within the VHF band. As a real-time monitoring tool, the Graphical User Interface (GUI) has been proved to be indeed capable of scanning spectrums. These spectrum scans were conducted in Pretoria.

The rest of this paper is organized as follows: Section II discusses how the software defined radio (SDR) is being used to utilize RF spectrum usage. Section III describes the platform used to collect the frequency scans and being monitored using a Graphical User Interface (GUI). The results of our measurements are discussed in Section IV. Section V brings us to the conclusion of the paper.

2. Overview of Software Defined Radio (SDR)

2.1 Software Defined Radio

According to the Wireless Innovation Forum, SDR is defined as a radio in which some or all the physical layer functions are software defined [4]. At the baseline, software radios can do pretty much anything a traditional radio can do. Software pieces and not hardware components treat the signals to extract the information.

SDR have the ability to tune to any frequency band and receive different modulations across a large frequency spectrum by means of a programmable hardware which is controlled by software. A typical SDR is expected to perform significant amounts of signal processing in a general purpose computer. The principle behind software- defined radio is to do all the modulation and demodulation with software instead of using hardware circuitry.

The benefit of SDR is that instead of having to build extra hardware to handle different types of radio signals, you can just write an appropriate software program. Your computer [6] can then switch from an Amplitude Modulation (AM) radio to a High Definition Television (HDTV) or FM radio depending on the software loaded. The advantage of this approach is that the equipment is more versatile compared to traditional radios and cost-effective.

2.2 SDR Design Overview

The diagram in Figure 1 below shows how the signal flows through the system. The SDR used for this project is made of GNU radio [7] and USRP2 [8]. GNU Radio and the USRP2 are the software and hardware parts, respectively, of a complete low-cost SDR platform that has gained widespread use [9]. The USRP is a product developed by Ettus Research [8], and follows a basic concept with a motherboard containing ADC/DAC, an FPGA performing sampling rate conversion, host interface, and plug-in daughterboard containing frequency-specific RF front-ends. The antenna picks the signals from the air and feeds them into the USRP2. From the USRP2, the signals are transmitted to the Personal Computer (PC).For receiving scenario, the real time signal is fetched by the RF transceiver via the antenna; it is subsequently converted from Radio Frequency (RF) to an Intermediate Frequency (IF). Then the signal is passed to an analog-to-digital converter (ADC). The USRP2 contains a 14-bit ADC converter. After digitization, the ADC passes the resultant data to the Field Programmable Gate Array (FPGA). In the FPGA, the signal is converted from IF to baseband and the decimation of the signal samples so that the data rate can be adapted by the performance of the transmission interface (Gigabit Ethernet) and the computers computing capability.

Finally, FPGA transfers the processed data to the Gigabit Ethernet controller which passes it over to the computer. For the real time monitoring the spectrum at a certain center frequency is displayed over a Graphic User Interface (GUI) window. For a non real time monitoring the code in GNU radio processes the captured data and outputs to a file readable by MATLAB if post processing is needed. Post processing is beyond the scoop of this paper.

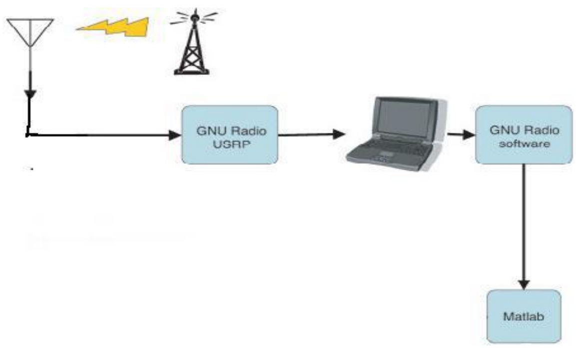

Figure 1: SDR Architecture [6]

3. Cognitive Radio Platform and Measurement

In this section we give a brief description of the Meraka Cognitive Radio Platform (MCRP) and then discuss the setup used for spectrum scanning in real time environment which was carried out in Meraka Innovation Laboratory.

3.1 Meraka Cognitive Radio Platform (MCRP)

The MCRP [10] is shown in Figure 2. The platform consists of four CR nodes, and each node is connected to the Internet using the Ethernet cable. A single node is built up of three major hardware components, as shown in Figure 3: a high speed computer (powered by 2.60GHz Dual Core Intel Pentium Processor, 2 GB memory and 500 GB hard-drive), version two of the Universal Software Radio Peripheral or USRP2 package (with a single WBX daughter-board) and high gain VHF/UHF antenna (Ellies aerial VHF/UHF Combo with 15 elements). The USRP2 is a flexible Software

Defined Radio (SDR) device developed by Ettus Research LLC which allows the creation of a CR node.

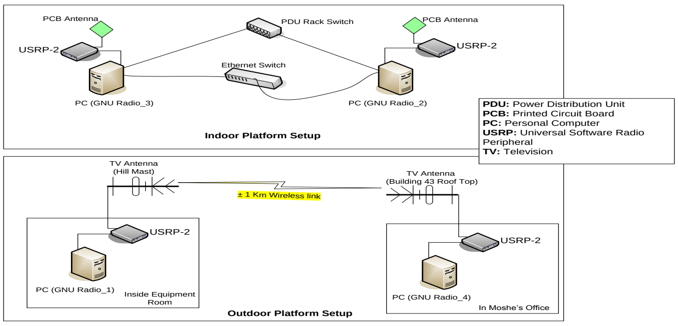

Figure 2: The Meraka Cognitive Radio Platform [10]

3.2 MCRP Detailed Explanation

The USRP2 is composed of a motherboard that performs some baseband processing and of daughter-boards that do the RF front-end part of the radio. Various plug-on daughter-boards allow the USRP to be used on different RF bands. In our lab, WBX daughter-boards with the transceiver of 50 MHz – 2.2 GHz frequency range are used. SDR is a radio communication system where components that would have typically been implemented in hardware are implemented using software.

While traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention, SDR can receive and transmit widely different radio protocols based solely on the software updates. The CR can be viewed as a SDR which is intelligent and aware of its external operating environment. Each computer hosts the GNU Radio software. GNU Radio is a free software development tool-kit that provides the signal processing runtime and processing blocks to implement software radios using external RF hardware (such as USRP) and commodity processors. GNU Radio has a large and steadily growing worldwide community of developers and users that have contributed to a substantial code base.

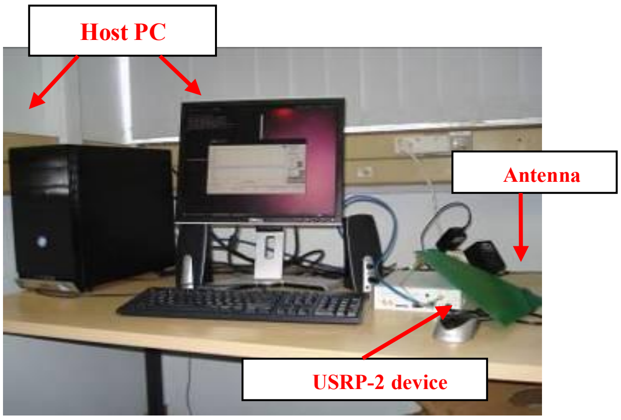

Figure 3: GNU Radio based SDR Components

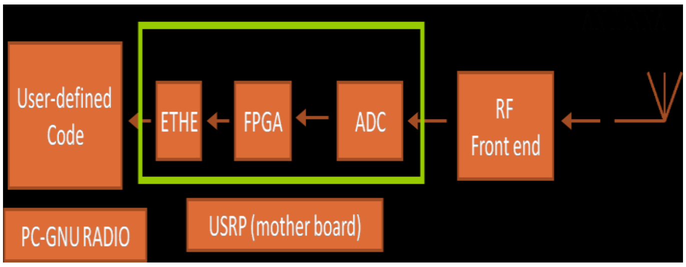

Figure 4: Hardware Block Diagram [6]

4. VHF Measurements and Results

The aim of our measurement is to scan very high frequency (VHF) spectrum band, from 30MHz to 300MHz. A GNU Radio program is used to collect the raw data from the USRP2 and stores them into a data file (.dat).The frequency scans were conducted in the innovation laboratory in real-time at the Council for Scientific and Industrial Research (CSIR). Multiple consecutive VHF scans were done using 700 kHz approximately bandwidth and Fast Fourier Transform (FFT) size of 1024 .The data (.dat file) is accessed by MATLAB for post-processing (see Figure 9-10).

The results of the spectrum scans were also displayed in real time over a Graphical User Interface (GUI) developed for convenience (see Figure 5-8). The interface takes the desired center frequency and other parameters and gives the command to the USRP2 through GNU Radio.

From the plots, it can be seen that some of the channels appear to be busy while some are not. For instance Figure 5 is the result of the frequency scans at 50 MHz center frequency. The gain is set at 15dB to amplify the signal. The channel is unoccupied. It simply means that specific channel in the radio frequency spectrum is available for use.

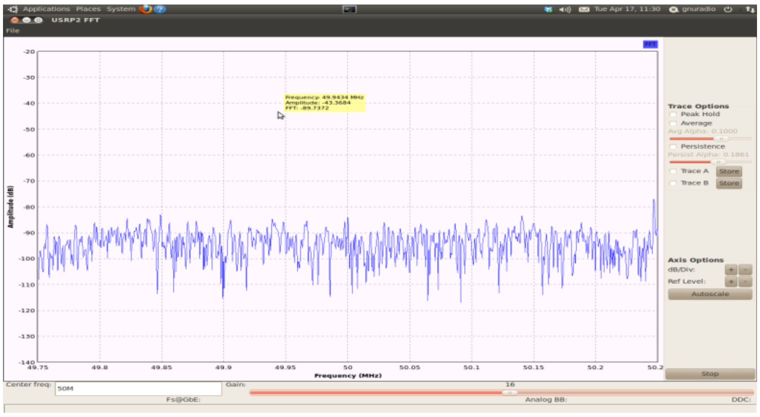

Figure 5: Center frequency for 50MHz

Figure 6 shows the result of the monitored very high frequency (VHF) at 100MHz centered frequency. It can be seen that there is a huge activity going on in the spectrum band. The gain is also set to 15dB for signal amplification. This result simply mean that special channel in the radio frequency spectrum is not available for use. Any attempt of using that frequency for any transmission purposes will result into interference.

Figure 6: Center frequency for 100MHz

Figure 7 shows the monitored VHF at center frequency 189.2MHz.The gain is set to be 20dB. It can be seen that there is some activity going on. Therefore, this channel in the radio frequency spectrum is not available for use. Any attempt of using the frequency or any very close neighboring channels will result into interference.

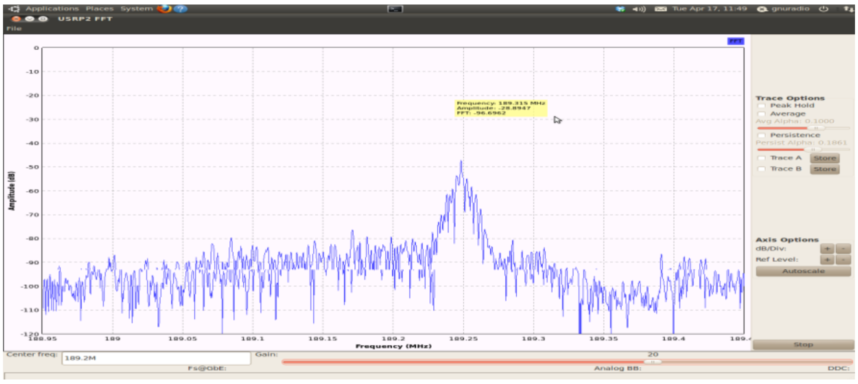

Figure 7: Center frequency for 189.3MHz

Figure 8 below shows the MATLAB plot of the RF spectrum which was captured in a non-real time environment and post-processed using the MCRP. The raw data was captured at a center frequency of 100 MHZ and plotted over 2000 samples, appended in a (.dat) file .A MATLAB program is used to access and plot the raw data file.
Thus, the magnitude, in decibels (dB) was plotted against time (in seconds).This graph helps to verify the utilization of monitored RF spectrum bands in real-time environment.

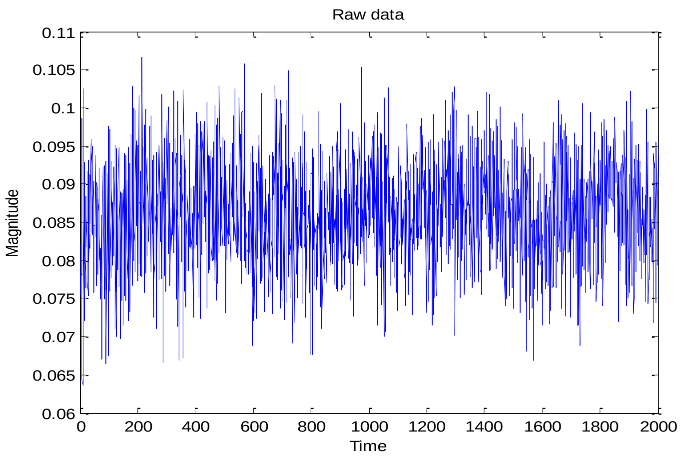

Figure 8: Raw data captured at 100 MHZ plotted over 2000 samples

Figure 9 below shows the scattered plot of the same data captured at 100MHz using a spectrum analyzer. We obtain the constellation diagram by sampling both I and Q channels at the same instant and then plotting I component against Q component of the signal on x-y diagram. The x-axis represents the in-phase carrier and the y-axis represents the quadrature carrier. There is such a high offset from the received signal due to the noise effect.

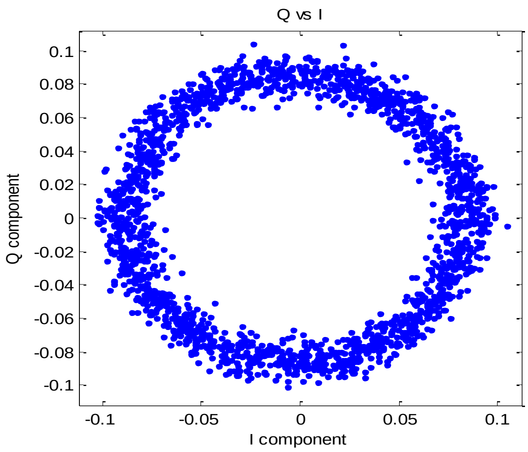

Figure 9: Signal constellation plot

The results show that it was possible to monitor the frequency occupancy within the VHF band. It could be seen in Figure 5 that at 50 MHz, there was no activity ongoing which means that specific channel is available for use and attempts to use it for transmission or any other radio usage, will not result in interference. The monitoring was also conducted in real time at 189.3 MHz and 100 MHz. The strongest signal was noticed at 100 MHz. Thus we post processed the data captured at 100 MHz in non real time. The GUI was the real time monitoring part of the project and it has been proved that the monitoring tool proposed in this project is indeed capable of scanning spectrum. The MATLAB post processing part which is in non real time is there for someone who was not present during the real time monitoring to also have some information about the spectrum usage at a certain frequency.

With these results, the monitoring tool proposed in this project can well be used to avoid interference in the VHF part of the spectrum between RF users.

5. Conclusions

In this paper, we presented the overview of the software defined radio (SDR), its design implementation and how the RF spectrum is being monitored over the GUI using MCRP. Detailed description of the platform was given. We have also shown, through active spectrum scans, that it is possible to monitor the frequency occupancy within the VHF band. As a real-time monitoring tool, the GUI has been proved to be indeed capable of scanning spectrums. It can as well be used to avoid interference between RF users. Illegal activities can thus be detected within VHF band. Therefore the tool can be used to support regulatory agencies mission. These results could be improved by repeating the experiments for spectrum decision process introducing security in order to guarantee that the service of the licensed users will not be significantly disrupted. This would help to get a better understanding of the area of research.

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