VHF Spectrum Monitoring Using Meraka Cognitive Radio Platform

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Abstract. The radio frequency (RF) spectrum is a natural resource used by wireless network operators to provide radio communications and transmission systems. The scarcity of RF spectrum has led to the development of dynamic spectrum access techniques to achieve more efficient spectrum utilisation. A number of related questions arise, including: How much of the RF spectrum is currently available? How much of it can be used opportunistically and dynamically without interfering with licensed or primary users (PUs)? In this paper, we present work being conducted in South Africa on the application of software defined radio (SDR) to dynamic RF spectrum usage. Specifically, we discuss the Meraka Cognitive Radio Platform (MCRP) which is based on Universal Serial Radio Peripheral version 2 (USRP2) hardware and GNU radio software. We also discuss the implementation and operation of the spectrum monitoring sub-system in MCRP. Lastly, the results of the measurements which were conducted using the MCRP are presented.

Keywords: cognitive radio, GNU radio, spectrum management, universal software radio peripheral, graphical user interface.

1 Introduction

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

To enable opportunistic access to the RF spectrum and the efficient sharing of allocated bands, more flexible spectrum management techniques are required, such as opportunistic spectrum sharing, where secondary users (SUs) are allowed to operate

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frequency bands without the permission of primary users (PUs) provided that it does not introduce harmful interference with PUs. For this reason, cognitive radio (CR) is being intensively investigated by the research community, major industry communication regulators and standardisation bodies as 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". A cognitive radio network imposes distinctive challenges owing to the fact that there is high fluctuation in the available spectrum over time. Thus, the various CR nodes offer different available channels at different times. As a result, 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 recognize different channels and multi-hop routing; (3) spectrum decision and sharing in a distributed setting without a central coordinator; and (4) coordination among the nodes with or without the availability of a common control channel.

Most countries have regulatory agencies that regulate the radio spectrum by means of renewable licences. However, the RF spectrum monitoring systems (equipment) used by regulators are specialised and very expensive. Consequently, in order to allow the RF spectrum to be researched and studied, there is a need to develop low-cost test beds or prototypes for spectrum monitoring. These prototypes could then be used mainly by students, but also by the wireless industry to make the spectrum usage and occupancy process more efficient and ready to accommodate existing and innovative radio-communication systems.

The advancement of radio technology to SDR has made the development of radio systems easier and more affordable. SDR refers to radios in which some or all the physical layer functions are software defined [4].

In [1], Rashid et al. found that spectrum utilisation can be significantly improved by adopting SDR technology. Such radios are able to sense the spectral environment and use this information opportunistically to provide wireless links that meet the users' communications requirements optimally. These researchers investigated sensing performance implemented on a real-time testbed of GNU radio and USRP 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 the spectrum sensing problem are studied from a CR perspective and a multidimensional spectrum sensing concept is introduced. The challenges associated with spectrum sensing are discussed and enabling spectrum sensing methods are reviewed**.** The paper explains the concept of cooperative sensing and its various forms. External sensing algorithms and other alternative sensing methods are also discussed. Finally, the sensing features of some current wireless standards are given.

In this paper, active spectrum scans are used to show 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 proven to be capable of scanning spectrums. These spectrum scans were conducted in Pretoria.

The rest of this paper is organised as follows: Section 2 discusses how SDR is adopted in RF spectrum usage and Section 3 describes the platform used to collect the frequency scans and monitor them using a GUI. The results of our measurements are discussed in Section 4. Section 5 concludes the paper.

2 Overview of Software Defined Radio (SDR)

2.1 Software Defined Radio

The Wireless Innovation Forum defines SDR 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. In this case, software pieces, and not hardware components, treat the signals to extract the information.

SDR has the ability to tune into any frequency band and receive different modulations across a large frequency spectrum by means of 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 SDR is that all the modulation and demodulation is done 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 signal, you merely have to write an appropriate software program. A computer [6] can then be used to 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 and cost-effective compared to traditional radios.

2.2 Software Defined Radio Design Overview

The diagram in Figure 1 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 design with a motherboard containing ADC/DAC, an FPGA performing sampling rate conversion, a host interface, and a plug-in daughterboard containing frequency-specific RF front ends. The antenna picks up the signals from the air and feeds them into the USRP2. From the USRP2, the signals are transmitted to the personal computer (PC). For a receiving scenario, the real-time signal is fetched by the RF transceiver via the antenna; it is subsequently converted from RF to an intermediate frequency (IF). Then the signal is passed to an analogue-to-digital converter (ADC). The USRP2 contains a 14-bit ADC converter. After digitisation, 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 signal samples are decimated so that the data rate can be adapted by the performance of the transmission interface (Gigabit Ethernet) and the computers computing capability.

Finally, the FPGA transfers the processed data to the Gigabit Ethernet controller, which passes it over to the computer. For real-time monitoring, the spectrum at a certain centre frequency is displayed over a GUI window. For 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. However, post-processing is beyond the scope of this paper.

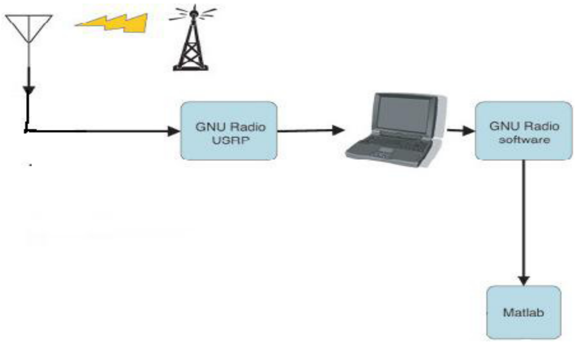

Fig. 1. SDR architecture [6]

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 a 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 2.60 GHz 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 SDR device developed by Ettus Research LLC, which allows for the creation of a CR node.

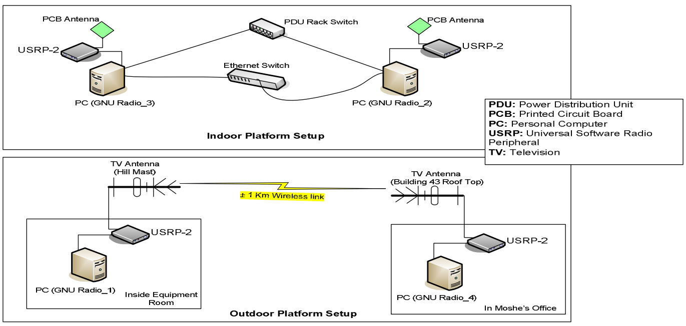

Fig. 2. The Meraka Cognitive Radio Platform [10]

3.2 Detailed Explanation of the MCRP

The USRP2 is composed of a motherboard that performs some baseband processing and of daughter-boards that carry out 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 to 2.2 GHz frequency range are used. SDR is a radio communication system in which components that would have typically been implemented with 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 an SDR that 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.

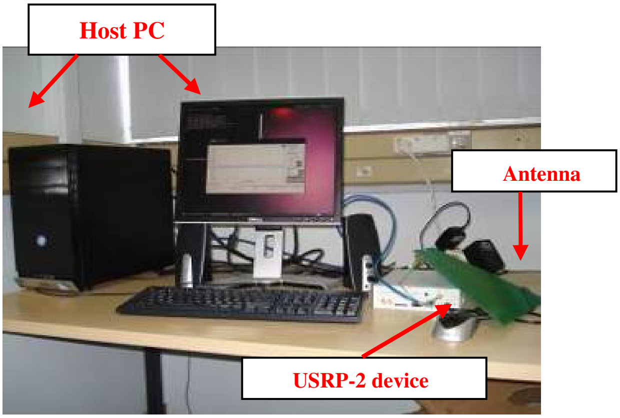

Fig. 3. GNU radio-based SDR components

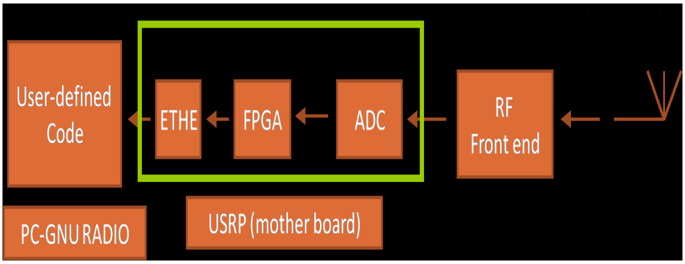

Fig. 4. Hardware block diagram [6]

4 VHF Measurements and Results

The aim of our measurement is to scan the very high frequency (VHF) spectrum band, from 30 MHz to 300 MHz. A GNU Radio program is used to collect the raw data from the USRP2 and store them in 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 approximately 700 kHz bandwidth and Fast Fourier Transform (FFT) size of 1024. The data (.dat file) is accessed by MATLAB for post-processing (see Figures 8–9).

The results of the spectrum scans were also displayed in real time over a GUI developed for convenience (see Figures 5–7). The interface takes the desired centre 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 centre frequency. The gain is set at 15 dB to amplify the signal, while the channel is unoccupied. This simply means that a specific channel in the radio frequency spectrum is available for use.

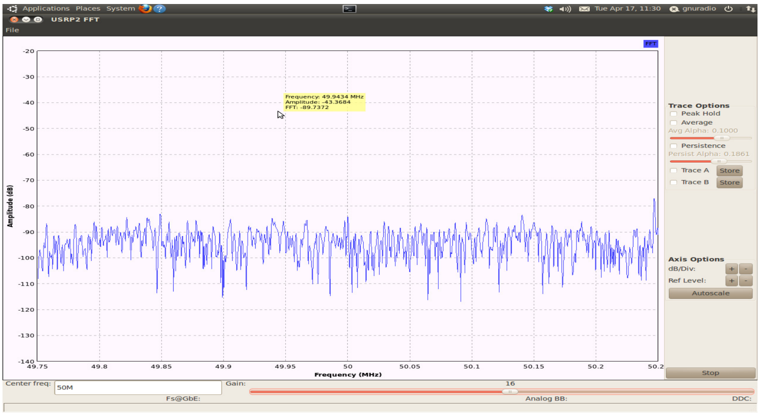

Fig. 5. Centre frequency for 50 MHz

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

Fig. 6. Centre frequency for 100 MHz

Figure 7 shows the monitored VHF at centre frequency 189.2 MHz. The gain is set at 20 dB. It can be seen that there is some activity going on; therefore, in the radio frequency spectrum this channel is not available for use. Any attempt at using the frequency or any neighbouring channels will result in interference.

Fig. 7. Centre frequency for 189.3 MHz

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 were captured at a centre frequency of 100 MHZ and plotted over 2000 samples, appended in a (.dat) file. A MATLAB program was 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 utilisation of monitored RF spectrum bands in a real-time environment.

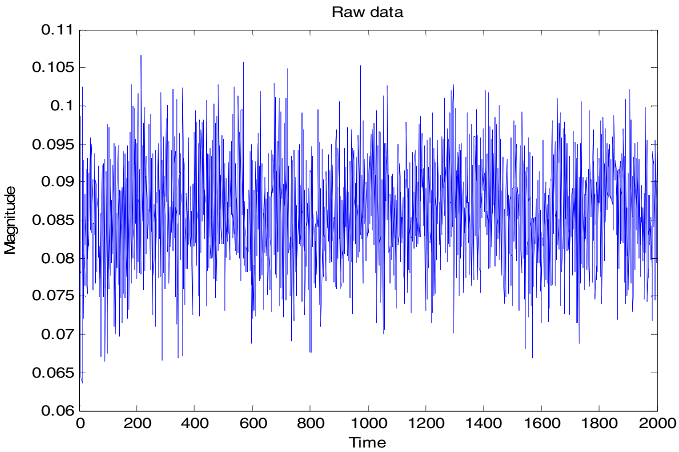

Fig. 8. Raw data captured at 100 MHz plotted over 2000 samples

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

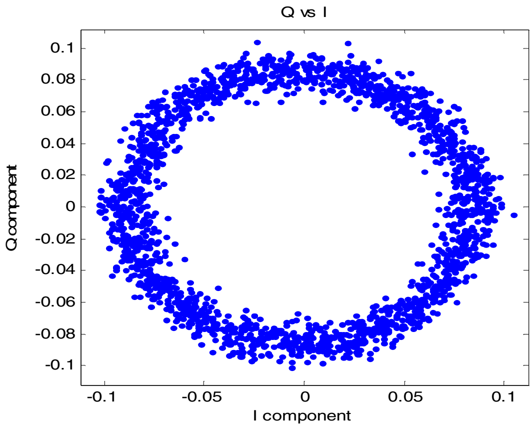

Fig. 9. Signal constellation plot

The results show that it was possible to monitor the frequency occupancy within the VHF band. It can be seen in Figure 5 that at 50 MHz, there was no ongoing activity, which means that the 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 monitoring was also conducted in real time at 189.3 MHz and 100 MHz, with the strongest signal being 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 proven that the monitoring tool proposed in this project is capable of spectrum scanning. The MATLAB post-processing, which took place in non-real time, was intended to provide information on the spectrum usage at a certain frequency for someone who was not present during the real-time monitoring.

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 an overview of SDR, its design implementation and the way the RF spectrum can be monitored via GUI using MCRP. A detailed description of the platform was given. We have also shown that, through active spectrum scans, it is possible to monitor the frequency occupancy within the VHF band. As a real-time monitoring tool, the GUI has been proven to be capable of performing spectrum scanning and can be used to avoid interference between RF users. Illegal transmissions can also be detected within the VHF band and the tool can therefore be used to support the work of ICT regulatory services. In further work, this sub-system could also be extended by improving the integration and inter-operation of its components and by incorporating security features.

References

[1] Rashid, R.A., Sarijari, M.A., Fisal, N., Yusof, S., Mahalin, N.H.: Spectrum Sensing Measurement using GNU Radio and USRP Software Radio Platform. In: Proc. of The Seventh International Conference on Wireless and Mobile Communications 2011, pp. 237–242 (2011)

[2] Mitola III, J., Maguire Jr., G.Q.: Cognitive radio: making software radios more personal. IEEE Personal Communications 6(4) (1999)

[3] Federal Communications Commission (FCC): Facilitating opportunities for flexible, efficient and reliable spectrum use employing cognitive radio technologies: Notice of proposed rulemaking and order. ET Docket 03–108 & 03-322 (2003)

[4] Wireless Innovation Forum (was SDR Forum), What is software defined radio, `http://www.wirelessinnovation.org/page/whatisSDR`

[5] Yucek, T., Arslan, H.: A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications. IEEE Communications Surveys & Tutorials 11(1), 116–130 (2009)

[6] Manicka, N.: GNU radio test bed. M.S. thesis. Dept. Computer Science and Electrical, University of Delaware (Spring 2007)

[7] Ettus Research website, USRP, http://www.ettus.com/ (accessed: April 01, 2012)
[8] GNU Radio website, http://gnuradio.org/redmine/ (accessed: April 01, 2012)
[9] Newman, T.R., Bose, T.: A cognitive radio network testbed for wireless communication and signal processing education. In: Proc. DSP Workshop and Signal Processing Education Workshop, Marco Island, FL, USA, pp. 757–761 (January 2009)
[10] Masonta, M.T., Johnson, D., Mzyece, M.: The White Space Opportunity in Southern Africa: Measurements with Meraka Cognitive Radio Platform. In: Popescu-Zeletin, R., Jonas, K., Rai, I.A., Glitho, R., Villafiorita, A. (eds.) AFRICOMM 2011, Part I. LNCST, vol. 92, pp. 64–73. Springer, Heidelberg (2012)