The White Space Opportunity in Southern Africa: Measurements with Meraka Cognitive Radio Platform

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Abstract. The global migration of television (TV) from analogue to digital broadcasting will result in more spectrum bands (known as TV white space), previously used in analogue broadcasting, becoming available and unoccupied. A question is on how much white space is available and how can it be used opportunistically and dynamically without causing harmful interference to licensed users? In this paper, we present work that is currently ongoing in our research lab with regard to the use of cognitive radio for accessing TV white spaces. We discuss the Meraka Cognitive Radio Platform (MCRP) developed using the second version of the Universal Software Radio Peripheral hardware and the GNU Radio software. We also present early results of the measurements conducted using the MCRP in rural and urban Southern Africa areas. The measurement results indicate that there are substantial white spaces available in both rural and urban areas for digital dividend.

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

1 Introduction

The demand for broadband access in the modern information society is seen as a driver for rapid growth and development of wireless communication systems. In wireless communication networks, radio frequency (RF) spectrum is the most precious and expensive wireless network resource which needs to be well regulated. Regulators manage the RF spectrum with the aim of minimizing interference between wireless devices. It is therefore crucial to implement effective spectrum management policies to ensure efficient usage and fair sharing of the RF spectrum. With the global digital switchover (DSO) of television (TV) transmission from analogue to digital broadcast, a large portion of the very high frequency (VHF) and ultra high frequency (UHF) bands will be freed and available on a geographical basis for other uses. Such spectrum bands are widely known as TV "*white spaces*" (TVWS). In order to benefit

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from the digital dividend brought about by the DSO, regulators from the developed countries (such as the United States and United Kingdom) are promoting license-exempt cognitive radio (CR) access to certain licensed TV bands. To enable secondary or opportunistic access to the TVWSs, CR [1] is being intensively investigated by the research community, industry major communication regulators and standardization bodies as a key enabling technology. Cognitive radio is defined by the Federal Communications Commission (FCC) as [2]: *an intelligent wireless communication system capable of changing its transceiver parameters based on interaction with the environment in which it operates.* It allows the implementation of dynamic or opportunistic spectrum access without causing any harmful interference to the licensed or primary users (PUs).

With the decision of the FCC to open up TVWS for unlicensed use [3]-[4], there has been a large amount of interest in producing systems that make use of this new TVWS spectrum using CR technology. Some early experiments have simply attempted to translate the IEEE 802.11 networks into the TV spectrum bands [5]. The same initiative has also been considered by the Office of Communications (Ofcom) in the United Kingdom [6]-[7]. It is believed that regulators, as well as industry and standardization bodies, from other developed countries are also working towards accessing TVWS using CR technology. In South Africa, the Independent Communications Authority of South Africa (ICASA) is also considering different options to ensure a fair and well-balanced reallocation of TVWS in order to benefit from the DSO [8]. However, it is not yet clear whether ICASA will follow the FCC and Ofcom approaches or not.

As research on CR technology develops, and more countries switch over from analogue to digital TV, big questions or challenges arise on the detection techniques to be used and how to protect incumbents. Currently two main techniques are being discussed, and regulators have to decide on the best reliable technique to access the TVWS. The first technique is based on the use of geo-location databases with prediction. And the second technique is based on spectrum sensing using CR technology [9]. Both techniques have their advantages and disadvantages. However, we believe that geo-location databases can be used for the initial set of no-go areas of the spectrum bands and spectrum sensing (with continuous measurements) to be used to avoid unknown and unpredictable sources of interference.

Using TV bands for other communications system can be achieved by understanding the current usage and availability of white spaces. Different techniques, such as spectrum audit, non-real time measurements and real-time measurements (frequency scan) can be used to determine the usage and available spectrum bands. In this paper, we present our initial measurement results showing the actual usage of TV bands transmitted using analogue transmitters in selected urban and rural areas of southern Africa. We scanned TV spectrum in Pretoria, in rural areas of the Northern Cape Province of South Africa, and in Macha, which is in a rural part of Southern Province in Zambia. Measurements were conducted using the Meraka Cognitive Radio Platform (MCRP). In Pretoria, frequency scans were done for more than a week, whereas in the rural areas the scan ran for about twenty four hours. The spectrum scans revealed medium usage of TV spectrum in Pretoria, and very low usage in rural areas.

Even before DSO, large portions of spectrum in the VHF and UHF bands remain constantly unused. We conducted similar measurements in Santa Barbara (US, where one of the authors is based). The results are not included here, due to space limitation, but they show no available bands when compared to Pretoria.

The rest of this paper is organized as follows: Section 2 discusses different cognitive spectrum access techniques for TVWS and some standardization efforts. Section 3 describes the platform used to collect the measurements or frequency scans. The results of our measurements are discussed in Section 4. Section 5 concludes the paper.

2 TV White Spaces Access

The migration of TV stations from analogue to digital or digital switchover (DSO) has already started in some developed countries. In the US, DSO was completed in June 2009 and other countries are also following. Although officially completed in June 2009, DSO in US was not a smooth process. For instance, it was reported that digital TV viewers from many cities in the US could not receive the signal, and FCC officials have held meetings to discuss a potential solution to the reception problems [10]. In some cases, broadcast stations had to increase power levels or add translators to extend the signal to more viewers [10]. Due to the complexity of DSO, several countries decided to extend their DSO completion dates, with UK expected to finish by 2012 and South Africa expected to be complete by December 2013. These countries may learn from the challenges experienced by the US when implementing DSO.

Successful operation of CR for secondary operation in TV bands depends on the successful detection of TVWS and on the ability to avoid harmful interference to the incumbents. In white spaces bands, licensed or primary users (PUs) include digital TVs and wireless microphones. Regulators in most countries are faced with a challenge of deciding the access method for ensuring that CR devises do not cause harmful interference to incumbents. Three methods were considered by the FCC and Ofcom: *geo-location databases*, *spectrum sensing* and *beacons.*

2.1 Geo-location Database Technique

With a geo-location database approach, the PU may be registered in a database and the CR user will have to first determine its location and then interrogate the databases periodically in order to find the free and available channels [9],[11]. It is very important for CR devices to know their geographical location with a prescribed accuracy [11]. Such accuracy may be determined by the regulator. Other data that a CR device is expected to provide to the database may include the device type, model and expected area of operation. In response, a database is expected to reply with the available frequencies, maximum transmission power, and whether the CR device can consult a particular national or regional database.

With this approach, there is a need for either the regulator or operators to build and maintain such databases. Another issue with geo-location databases is the need for an additional connectivity by CR devices in a different band to enable access to the database prior to any actual transmission. A typical TVWS database is shown in Fig. 1. The national regulator can decide to either own or contracts out the supply of a central database, and several secondary or regional databases may be owned by network operators. Geo-location database approach is said to provide a technically feasible and commercially viable solution when compared to the spectrum sensing approach [9].

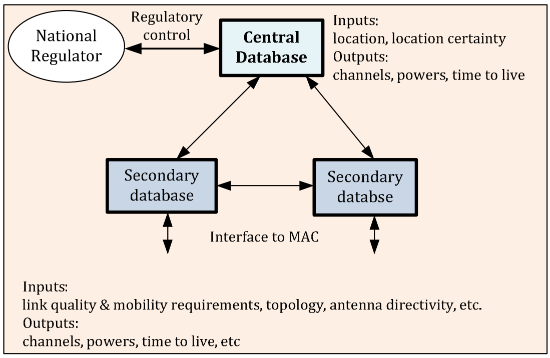


Fig. 1. A Typical White Space Database Structure [9]

2.2 Spectrum Sensing Technique

In the absence of signalling between PUs and CR users, spectrum availability for secondary access may be determined by performing direct spectrum sensing [12]. Spectrum sensing is one of the most challenging, and well explored issues in CR networks (see [12]-[15] and references therein). Two approaches are commonly used for spectrum sensing [16]. The first approach is where a high-performance detection technique is employed at individual radios and a decision on spectrum availability is taken only on one radio's results. However, this method suffers from deep channel fading and the hidden terminal problem [14]. The second approach is where the detection results of multiple radios are combined to combat multipath fading and shadowing, and to mitigate the receiver uncertainty problem [16].

The receiver uncertainty problem, which is a serious challenge for single radio spectrum sensing deployment, is due to lack of knowledge about the PU's location. Cooperation allows independently faded radios to collectively achieve robustness to severe fades while keeping individual sensitivity levels close to the nominal path loss [17]. Though not yet exhausted, research on spectrum sensing has received considerable attention.

2.3 Beacon Technique

The beacon technique allows unlicensed devices to transmit only if they receive a control signal or beacon identifying vacant channels within their service areas [11]. Such signal can be received from a TV transmitter. Without reception of a control signal, the SU will not be permitted to transmit. A challenge with this beacon approach is that it requires a dedicated beacon infrastructure to be in place. Such an infrastructure also needs to be maintained and operated by either the incumbent or a third party. As with single radio spectrum sensing (discussed above), beacon signals can be lost due to the hidden terminal problem.

All the above three techniques have their advantages and disadvantages. It is up to the regulator to decide on the best approach. However, Fitch *et al.* [9] argue that in the future, both database and spectrum sensing techniques will be used together in order to have flexibility and achieve maximum efficiency for secondary or CR users.

2.4 Standardization Efforts

Initial research and development efforts on CR technology for efficient spectrum management have been focused in the US. This was mainly driven by the desire of powerful industry players, such as Microsoft and Google, to get access to the TVWS spectrum [11]. While there are ongoing efforts to standardize the use of CR for efficient spectrum access on TVWS spectrum, the IEEE 802.22 Working Group (WG) [18] is the first wireless air interface standard at an advanced stage. The IEEE 802.22 WG is charged with the development of CR-based wireless regional area network physical and medium access control (MAC) layers for use by license-exempt devices in the TVWS spectrum [19]. A typical use case for the IEEE 802.22 standard would be in sparsely populated rural areas, because TV frequencies offer favourable propagation characteristics [19]. Other CR standardization efforts include IEEE 802.19 [20], IEEE 802.11af and the Cognitive Networking Alliance (CogNea) [21]. The IEEE 802.19 standard is aimed at enabling effective use of TVWS by the family of IEEE 802 wireless standards. IEEE 802.11af working group has been set up to define a standard to implement Wi-Fi technology within the TVWS. CogNea is an open industry association with the intention of commercialising low power personal or portable CR platforms.

3 Cognitive Radio Platform and Measurements

In this section we give a brief description of the Meraka Cognitive Radio Platform (MCRP) and then discuss the setup used for the spectrum scan carried out in both urban and rural areas in Southern Africa.

3.1 Meraka Cognitive Radio Platform (MCRP)

The MCRP is shown in Fig. 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 Fig. 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 USRP-2 package (with a single WBX daughter-board) and high gain VHF/UHF antenna (Ellies aerial VHF/UHF Combo with 15 elements). The USRP-2 is a flexible Software Defined Radio (SDR) device developed by Ettus Research LLC [22] which allows the creation of a CR node.

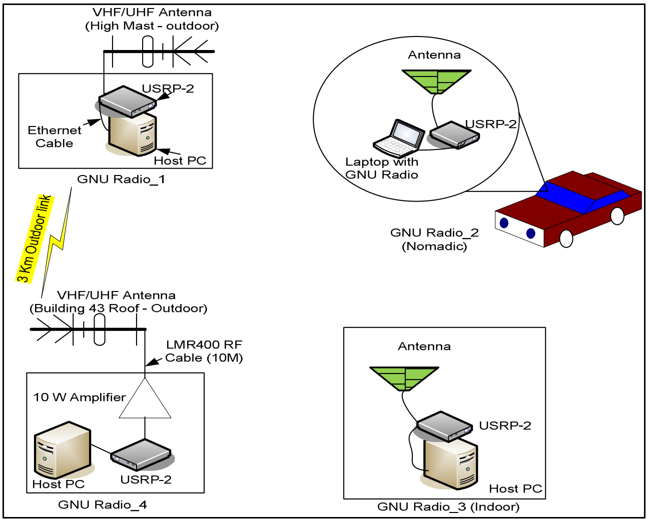


Fig. 2. The Meraka Cognitive Radio Platform

The USRP-2 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 [23] 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.

In four CR nodes, one node is nomadic, two nodes are located outside the lab, and one is within the lab and the other is located 3 km away. This 3km link allows us to capture typical interference and propagation effects that a production white space system will experience. Depending on the nature of the experiment, a 10 W amplifier can be used to boost the signal during the transmission (at unlicensed bands). An amplifier proved to be important for long distance transmission experiments since the USRP-2 are limited to 100mW output power. Each CR node is connected to the Internet for remote access. This allows remote users to run experiments on the platform from anyway in the world. For our nomadic node, we made sure that the laptop used is also connected to the Internet using the cellular network.

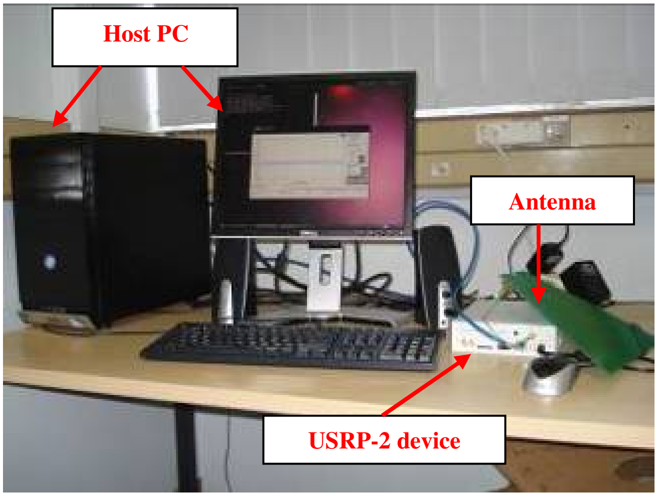


Fig. 3. GNU Radio based SDR Components

3.2 Frequency Measurements

The aim of our measurements was to scan the VHF/UHF spectrum band, from 50 MHz to 1 GHz. We conducted the frequency scan in three different places in Southern Africa. One measurement was carried out in Pretoria at the Council for Scientific and Industrial Research (CSIR) campus, which is the urban area. And the other two were carried out in the rural areas of South Africa and Zambia. In Pretoria, an outdoor CR node was used for the spectrum scan, which ran for more than a week. In the rural areas, a nomadic CR node was used for the spectrum scan, and it ran for less than 24 hours. Multiple consecutive scans were done using 800 kHz bandwidth and Fast Fourier Transform (FFT) size of 2042. The data was post-processed and FFT bins were averaged to 25 kHz buckets.

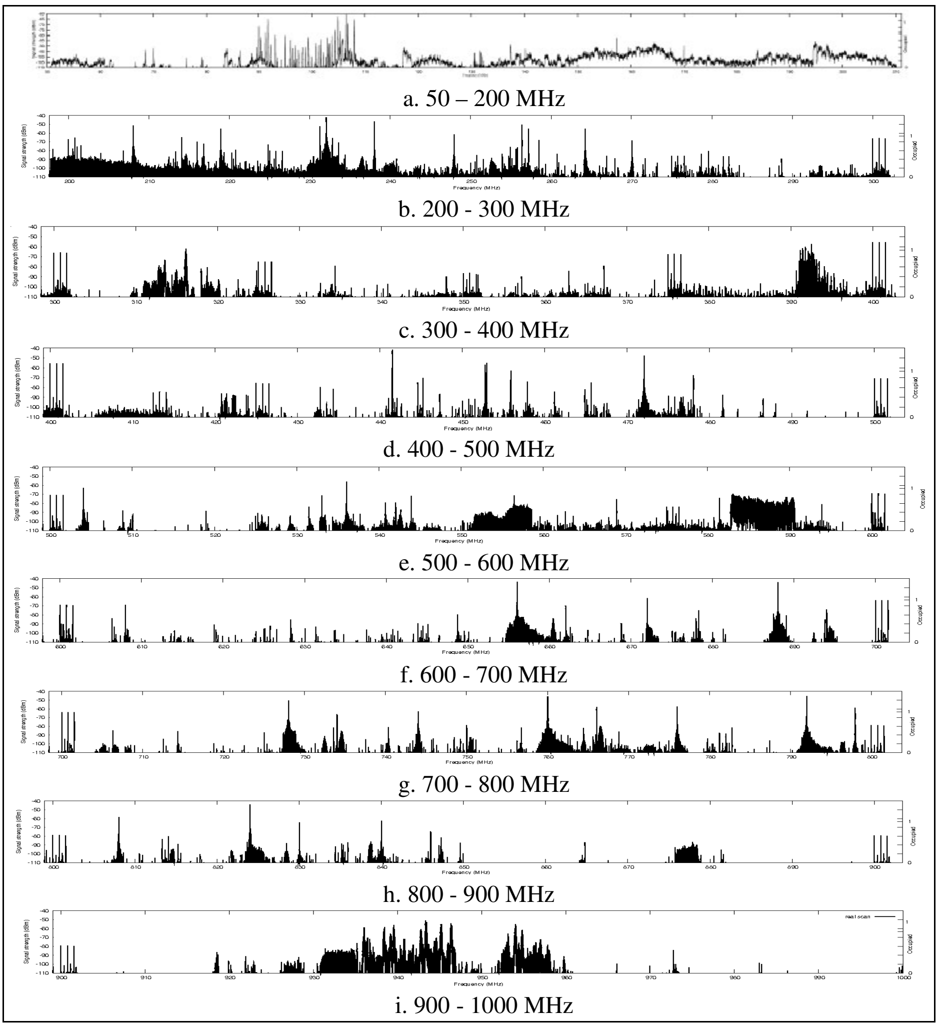
4 Results

Results of the spectrum scans were plotted from 50 MHz to 1 GHz frequency band. Figures 4-6 show results of our measurements. Fig. 4 shows results from Pretoria (which is urban South Africa). In Pretoria, the CR node antenna was mounted at the high site. Using the national broadcaster's database of TV transmitters around Pretoria, we found that there were at least four TV transmitters. From the plots, it can be seen that even before DSO, there are white spaces available in the urban areas. It is clear that once DSO is completed, there will be even more TVWS available in urban areas.

Fig. 5 shows results of the measurements in Philipstown, which is a rural village in the Northern Cape, in South Africa. As shown on the plot, the majority of the TVWS band is freely available, with some activities at a lower range of the VHF, which appear to be FM radio transmissions. There is only one TV station (SABC 2) available in the area, which appears at 300 MHz. Then other activities are at the 900 MHz, which is occupied by the cellular networks.

Similar trends can be witnessed in the rural Macha area in Zambia, as shown in Fig. 6. However, there are some activities detected between the 200-500 MHz frequency bands.

It can be seen that the spectrum usage in the urban area is much higher than the usage in the rural areas. These results simply mean that rural communities can benefit from the digital dividend using the CR technology. In order to improve broadband connectivity in rural areas, African regulators may either allow license-free operations on TVWS in rural areas or make use of CR technology to access TVWS dynamically.



a. 50 – 200 MHz
b. 200 - 300 MHz
c. 300 - 400 MHz
d. 400 - 500 MHz
e. 500 - 600 MHz
f. 600 - 700 MHz
g. 700 - 800 MHz
h. 800 - 900 MHz
i. 900 - 1000 MHz

Fig. 4. VHF-UHF Spectrum Occupation in Urban South Africa (Pretoria)

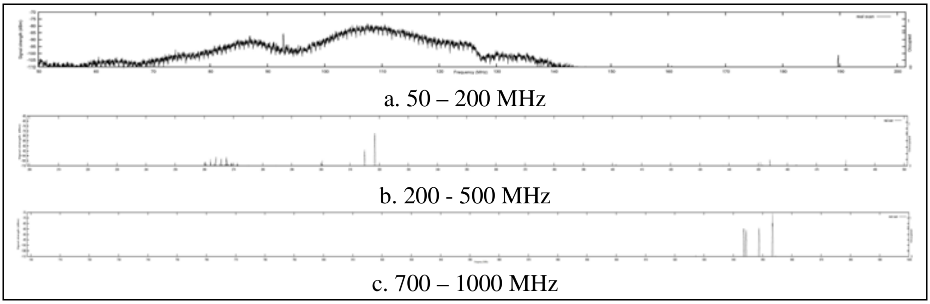


Fig. 5. VHF-UHF Spectrum Occupation in Rural South Africa (Philipstown)

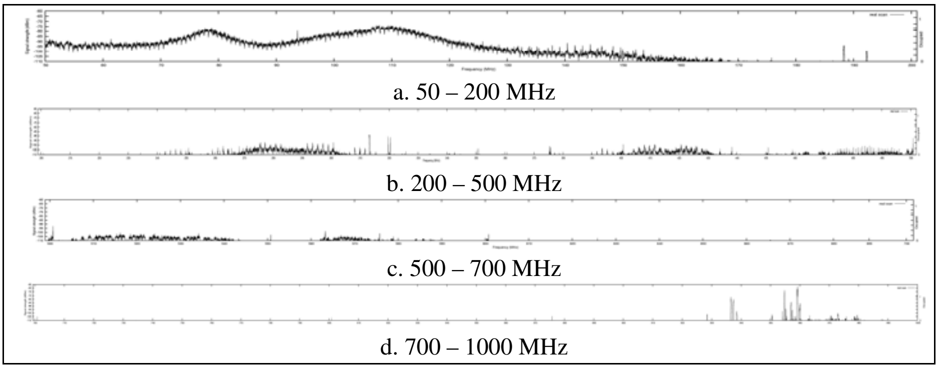


Fig. 6. VHF-UHF Spectrum Occupation in Rural Zambia (Macha rural)

5 Conclusions

The availability of TVWS presents a great opportunity for wider coverage and substantial bandwidth for broadband communications. With the global DSO, there will be even more TVWS available for wireless communications. In this paper we have shown, through active spectrum scans, that there is abundance availability of white spaces in rural areas and urban areas in Southern Africa, as opposed to the results found in Santa Barbara (USA). Our results show that both urban and rural areas will benefit from the digital dividend after the completion of the DSO. Now the question is on how African (or Southern Africa) regulators will regulate the use of TVWS. Will they follow similar approaches to those adopted by the FCC and Ofcom?

This study serves as a starting point towards the development of fully operational white space networks for rural broadband connectivity. Further work will include the development of active spectrum sensing techniques for testing on MCRP. A study on combining both spectrum sensing and geo-location databases for TVWS access will also form part of our future work.

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