Spectral occupation of TV broadcast bands: Measurement and analysis

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Abstract

The findings of a TV broadcast spectrum measurement campaign, performed at six different locations on the Hatfield campus of the University of Pretoria, are presented. Since the use of television white spaces (TVWS) could help to alleviate the impending spectrum crunch, the motivation for the study was to identify possibly unused bands for use by emerging technologies, such as cognitive radio, and also to address the hidden node problem associated with spectrum sensing (SS). This was achieved by comparing measured data to both actual TV channel allocations and a geo-location database (GLDB) for the Tshwane metropolitan area (city of Pretoria). Localised measurements indicated that a number of TVWS opportunities existed, with between 216 and 376 MHz of spectrum found to be potentially available for secondary usage. However, a comparison with TV channel allocations (256 MHz free) and the GLDB (96 MHz free) highlighted the effect of the hidden node problem.

Keywords: Cognitive radio, Detection threshold, Hidden node problem, Spectrum measurements, Spectrum occupancy

1. Introduction

Recent trends suggest an ever increasing demand for mobile broadband services that may soon outstrip available spectrum resources [1]. To meet this demand, traditional spectrum management policies need to be revised so as to ensure more efficient usage of this scarce resource. The impending switch over from analogue to digital broadcast television (TV) provides regulators with such an opportunity, since large portions of spectrum in the very high frequency (VHF) and ultra-high frequency (UHF) bands, also referred to as TV white spaces (TVWS), may be freed up as a result of this process, e.g., 75 MHz was found to have been freed up in Chicago [2].

The Independent Communications Authority of South Africa (ICASA) recently released a draft plan that would make provision for the use of digital terrestrial television (DTT) in these bands [3], thus paving the way for TVWS in South Africa after the proposed analogue switch off in 2015 [4]. To prepare for technologies that can exploit TVWS, such as cognitive radio (CR) and geo-location databases (GLDB), knowledge of the usage of these bands is needed. While techniques such as a spectrum audit may be used to quantify this, real time measurements allow for a more complete description of their actual usage.

The findings of a measurement campaign at the University of Pretoria (UP) (a good representation of a typical South African scenario) are thus presented in this article. The campaign sought to quantify the effective usage of the TV broadcast bands and was motivated by the need to identify possible portions of unused spectrum for use by secondary users. Spectral opportunities are compared using three different mechanisms: Localised spectrum measurements obtained by using a specific hardware platform [5], spectrum assignments done by the regulator [3] and a locally available static GLDB that is derived from standard wireless propagation models [6].

It is shown that a number of TVWS opportunities already exist in the South African TV broadcast bands. While similar measurements have previously been conducted [7, 8, 9, 10, 11, 12, 13, 14, 2, 15, 16, 17, 18, 19], this article provides practical insight into the challenge faced by CR networks due to SS and the hidden node problem.

The article is organised as follows: A description of the measurement system and locations is provided in Section 2, the channel occupancy decision metrics are discussed in Section 3, measurement results are presented and discussed in Section 4 and conclusions are drawn in Section 6.

2. Measurement sites and description

A wideband measurement system, described in [5], was used to measure the power spectrum of the broadcast TV bands at six different locations, labelled A to F, on the Hatfield campus of the UP, South Africa. Both the VHF (174-254 MHz) and UHF bands (470-854 MHz) were considered. Measurements were taken at a frequency resolution of 500 kHz, consisted of 500 consecutive time samples each and were repeated every minute over a period of an hour.

Photographs of the measurement sites, as well as a map of there locations, are shown in part (a) of Fig. 1. The measurement site locations were chosen to be fairly close together, with the furthest distance between any location being approximately 380 m between locations C and E. The reason for this was to demonstrate the effect of shadowing and the hidden node problem associated with SS in CR networks. Location A was situated on the roof of the Engineering 1 building (12 stories above

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(a)

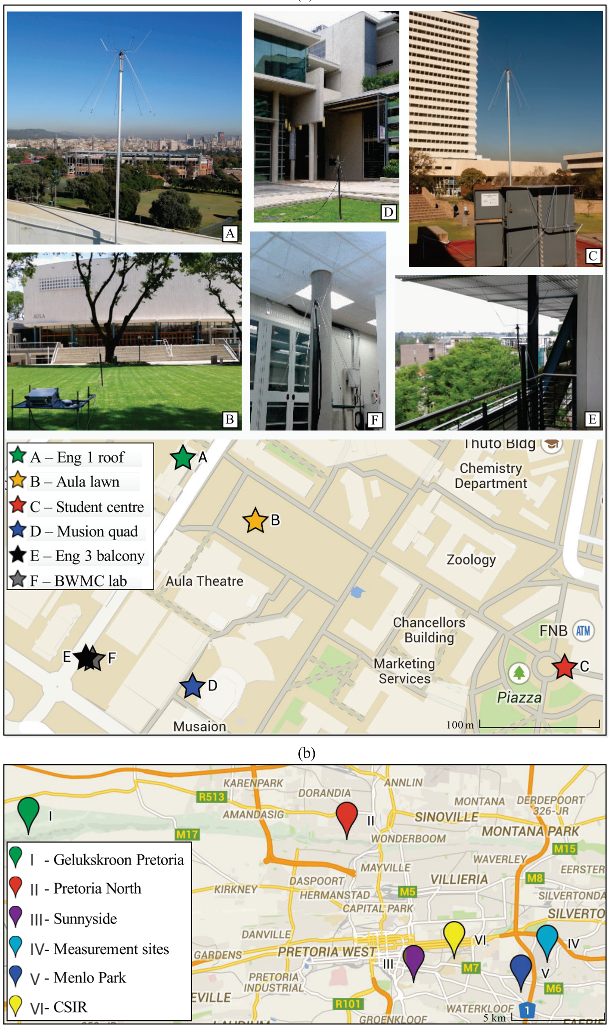

Figure 1: (a) Receiver locations on the Hatfield campus of the University of Pretoria and (b) broadcast transmitter locations for the City of Tshwane.

ground level). Location B was situated at ground level with possible shadowing due to the surrounding structures. Location C was situated one floor above ground level on the roof of the student centre, also with possible shadowing. Location D was situated at ground level in a heavily shadowed quadrangle between the Engineering 3 building, the Musaion and the Amphitheatre. Locations E and F were both situated on the 7th floor (this is the top floor) of the Engineering 3 building, with location E on the outer western balcony overlooking the central business district of the city and location F in a laboratory 20 m away. Location F was an indoor measurement site, while all of the others locations were situated outdoors.

The power measured at these locations can be attributed to five separate TV broadcast sites located within the Tshwane metropolitan area (city of Pretoria). However some measurement sites were able to detect signals from two broadcast sites situated much further away. A map showing the locations of the Tshwane broadcast sites, in relation to the UP measurement sites, is provided in part (b) of Fig. 1.

Since different levels of effective radiated power (ERP) are used for each technology, a distinction has been made between the broadcast sites for analogue television (AT), DTT and digital mobile television (DMT). The broadcast sites are listed in Table 1 together with the associated ERP broadcast for each technology (all powers are in kW) [3]. The Tshwane broadcast sites are: Gelukskroon Pretoria (GPT), Pretoria North (PN), Sunnyside (SD), Menlo Park (MP) and the council for scientific and industrial research (CSIR). The other two sites, with ERPs in excess of 100 kW, are the Sentech tower (ST) in Johannesburg (approximately 54 km away from the UP) and the Welverdiend tower (WDT) situated near Carletonville (approximately 125 km away). With the exception of the CSIR, which is only used for DMT broadcasts, all sites are currently used for AT, DTT and DMT broadcasting.

Table 1: Broadcast locations and associated ERPs (kW).

Site	Lat.	Long.	AT	DTT	DMT
GPT	$S25.6892$	$E27.9839$	100.000	70.00	100.00
PN	$S25.6914$	$E28.1672$	0.125	0.02	2.50
SD	$S25.7661$	$E28.2058$	1.000	1.00	2.50
MP	$S25.7712$	$E28.2686$	0.040	0.04	0.25
CSIR	$S25.7554$	$E28.2829$	-	-	13.00

3. Spectral occupancy and availability

To calculate occupancy, it is necessary to distinguish between what constitutes a TV broadcast signal and what is considered as noise. One approach to doing this is to select a particular threshold value λ and make the assumption that only signal components that are measured above this value are legitimate and that all others constitute noise. In this article two approaches to selecting λ were considered. In the first approach, λ was calculated from the minimum usable field strength used to calculate TV broadcast coverage, as suggested by ICASA [4]. The thresholds were thus chosen as $\lambda = -90$ dBm (55 dBμV/m) and $\lambda = -80$ dBm (65 dBμV/m) for the VHF and UHF bands respectively. The second approach was based on the maximum normal fit (MNF) algorithm, proposed in our previous work [5]. In this approach the noise distribution is separated from the signal distribution of a measured set of channels and λ is calculated as the point at which they intersect.

The first approach was followed for calculating channel occupancy (CO) and the second approach for calculating spectral occupancy (SO). For CO, if the luminance carrier of a TV channel was measured to be above λ, then that channel was considered to be occupied (8 MHz of spectrum). For SO, however, any measured signal component found to be above the chosen threshold was considered to be occupied spectrum (spectrum resolution of 0.5 MHz). These occupancies, denoted by ζ, were calculated as a percentage of either the total number of TV channels or the total number of spectrum samples that the measured band was made up of (denoted as ψ),

$$\zeta = 100\frac{\sum_{n=1}^{\psi}\rho\left(n,k\right)}{\psi}, \tag{1}$$

where,

$$\rho(n,k) = \begin{cases} 1, & r(n,k) > \lambda \\ 0, & r(n,k) \leq \lambda \end{cases} \quad (2)$$

and $r(t,k)$ is the signal power at time t and channel k.

Once occupancy has been calculated, the spectral availability (SA) of the bands can also be calculated. SA is defined as the amount of spectrum that is deemed to be unused and thus potentially available for unlicensed usage.

4. Measurement results

In this section, the measured PSD for each location is presented for both the VHF and UHF bands. Spectrum sensing accuracy and spectral availability are also discussed.

4.1. VHF results

For each measurement location, plots of the measured PSD for the VHF band (channels 4-13) are provided in Fig. 2. The measurement location has been included as a legend in the top right hand corner of each sub-plot, while the value of λ used to calculate CO is illustrated by a horizontal dashed line. From Fig. 2 it can be seen that only three channels in the VHF bands (channels 4, 8, 11) are clearly distinguishable. However, weak signals from some other channels are evident at some of the locations.

A very weak signal was detected at 239.25 MHz for location A. Since no assignment has been made for that channel, it is assumed to either be noise or an illegal transmission.

4.2. UHF results

Similar to the VHF band, plots of the measured PSD for the UHF band (channels 21-68) are provided in Fig. 3. Of particular interest were four anomalous signals that were not AT transmissions. Three of these signals occurred in channels 35,

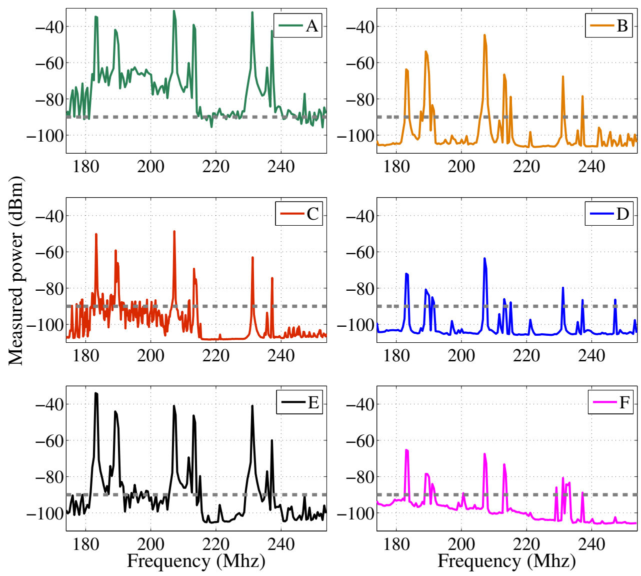

Figure 2: Measured power spectral density of the VHF bands.

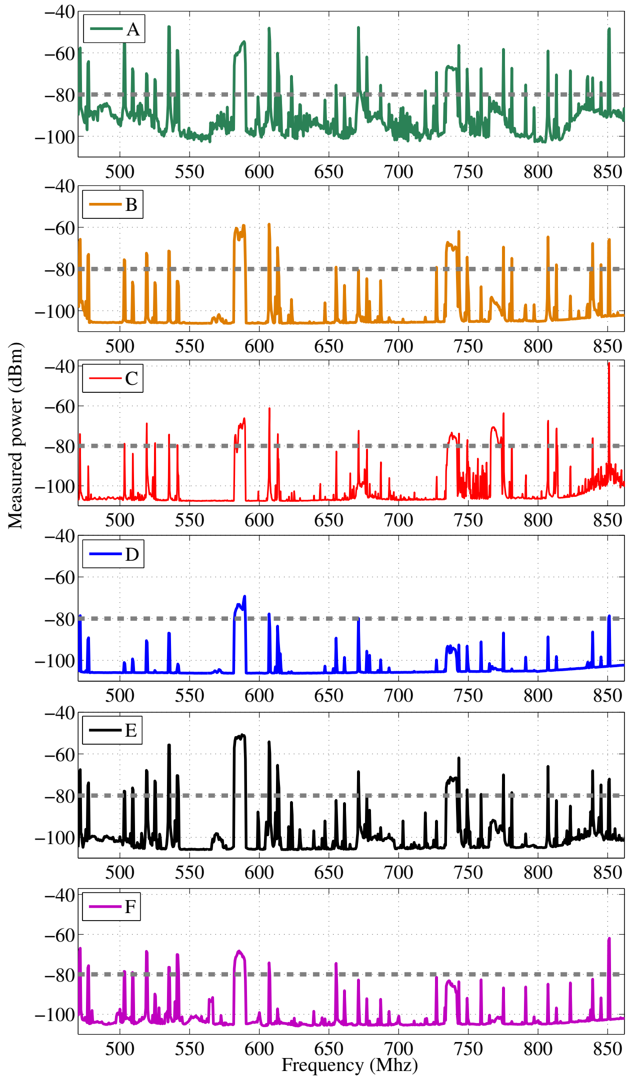

Figure 3: Measured power spectral density of the UHF bands.

54 and 58 and occupied the same amount of spectrum as a standard TV channel (8 MHz). These signals represent DMT and DTT transmissions. Channel 35 is being used for a DMT transmission that uses the digital video broadcasting hand-held (DVB-H) format and channels 54 and 58 have DTT trials running on them using the digital video broadcasting second generation (DVB-T2) format. There is a signal present at 851.25 MHz (1 MHz bandwidth) that does not seem to correspond to either DVB-T2 or AT. This signal is very strong at locations C and A, while weaker versions were detected at all of the other measurement sites. It is assumed that this signal is either a studio transmitter link (STL) for the campus radio station or an illegal transmission. Another such signal was detected at location A at 835.25 MHz.

4.3. Spectrum sensing accuracy

Illustrated in Fig. 4, a channel availability comparison has been made, for each measurement location, between (a) the measured CO, (b) the actual TV channel assignment for the

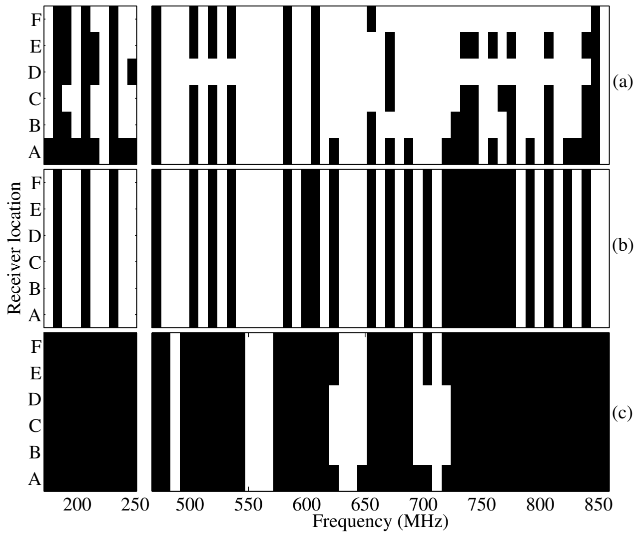

Figure 4: Comparison between TVWS opportunities for (a) measured CO, (b) actual TV channel assignment [3] and (c) the CSIR TVWS GLDB [6]. The VHF and UHF bands are respectively denoted by the blocks aligned with the left and right hand margins of the figure.

Tswhane metropolitan area (listed together with each broadcast site in Table A.5 [3]) and (c) the CSIR TV white space GLDB, based on the ITU-R P.1546-4 (B) propagation model [6]. The bands shaded in black represent occupied spectrum.

The effect of the hidden node problem is clearly evident when comparing parts (a), (b) and (c) of Fig. 4. SS accuracy fluctuated across the measurement locations and failed to detect the presence of a TV signal on a number of channels. Since the transmissions in the VHF band were very strong, SS was accurate at all locations (even weak signals from the ST and WDT transmitters were detected on some channels). However, this was not always the case for the UHF band. For both bands the difference in channel detection capability, ϵ, (as calculated against part (b) and part (c) of Fig. 4) is summarised as a percentage in Table 2. This was calculated as, $\epsilon = 100\frac{|CO-CO_x|}{N}$, where CO_x is the CO according to either parts (b) or (c) of Fig. 4 and N is the total number of channels for each band. Detected signals originating from the ST and WDT sites (e.g. channels 4, 6, 7, 9, 12 and 13 for the VHF band at location A) were not counted as they were considered false positives for the Tshwane metropolitan area.

Table 2: Percentage channel detection capability difference ϵ, for each measurement location, compared to TV band allocations and the CSIR GLDB.

Band	A	B	C	D	E	F
TV stations						
VHF	0.00	0.00	0.00	0.00	0.00	0.00
UHF	8.16	22.45	22.45	40.82	22.45	34.69
CSIR GLDB						
VHF	10.00	60.00	70.00	40.00	50.00	60.00
UHF	40.82	46.94	46.94	65.31	53.06	65.31

Table 3: Measured spectral opportunities for the TV broadcast bands.

Band	CO (%)	SA (MHz)	SO (%)	SA (MHz)
Location A				
VHF	90.00	8.00	46.25	43.00
UHF	45.83	208.00	37.56	239.77
Location B				
VHF	40.00	48.00	23.13	61.50
UHF	29.17	272.00	15.98	322.64
Location C				
VHF	30.00	56.00	45.25	43.80
UHF	29.17	272.00	17.93	315.15
Location D				
VHF	60.00	32.00	16.88	66.50
UHF	10.42	344.00	9.88	346.06
Location E				
VHF	50.00	40.00	25.00	60.00
UHF	29.17	272.00	13.90	330.62
Location F				
VHF	40.00	48.00	25.63	59.50
UHF	16.67	320.00	13.29	332.97

For part (b) in the UHF band, the largest difference was observed at location D (ϵ = 40.82 %.), while the smallest difference was observed at location A (ϵ = 8.16 %). The CSIR GLDB seems to be a more conservative approach and appeared to include transmissions from further afield, e.g. the ST site. For the VHF band at location C, the difference in CO between SS and the GLDB was as much as 70 %. Under certain scenarios this should mean better protection for the primary user, however, technologies that rely on short range communication may benefit from a less conservative approach.

4.4. Spectral availability

Calculated values for CO, SO and SA are listed in Table 3 for each measurement location. It is evident that SA, due to SS, varied according to location specific differences in SS accuracy. For example, at location D, CO was calculated to be 60 % (SA of 32 MHz) and 10.42 % (SA of 344 MHz), but at location A, this was 90 % (SA of 8 MHz) and 45.83 % (SA of 208 MHz) for the VHF and UHF bands respectively. Hence, total SAs of 376 MHz and 216 MHz were observed at location D and location A respectively. Based on CO, these locations represent the upper and lower bounds for SA at the six measurement locations.

However, according to actual TV channel assignments for the region, CO should be 30% and 48.98 % (SA = 56 MHz + 200 MHz = 256 MHZ) and according to the CSIR GLDB, a minimum of 100% and 75.51 % (SA = 0 MHz + 96 MHz = 96 MHz) for the VHF and UHF bands respectively.

For the same locations SO was calculated to be 16.88 % (SA of 66.5 MHz) and 9.88 % (SA of 346.06 MHz) at location D, and 46.25 % (SA of 43 MHz) and 37.56 % (SA of 239.77 MHz) at location A, for the VHF and UHF bands respectively. The

Table 4: Comparison of spectral utilisation at various international locations.

New York	Chicago	Barcelona	Dublin	Manama
35.93	52.40	82.08	36.36	21.30

difference between CO and SO can largely be attributed to inefficient use of spectrum by AT channels.

5. International occupancy comparison

A number of measurement campaigns have been performed around the world by both universities and organisations such as the Shared Spectrum Company. Amongst others, campaigns were carried out in New York City, NY [7], Chicago, IL [8, 2], Auckland, New Zealand [9], Barcelona, Spain [13], Aachen, Germany [11, 14], Maastricht, The Netherlands [12, 14], Dublin, Ireland [10], Manama, Bahrain, [18], Bogota, Colombia [19] and Cape Town, South Africa [15]. Selected results obtained from these campaigns are summarised in Table 4. The values presented represent the average occupancy of the bandwidth allocated for broadcast television at each location.

From Table 4 it can be seen that the broadcast TV bands were generally found to be underutilised, except for Barcelona, Spain. These values show some correlation with those provided in Table 3. It must be noted that it is difficult to obtain an exact comparison of occupancy, since there are both differences in the regulatory policy and the number of TV stations operating at each location. Also, the thresholds used to detect band usage were not always clearly defined in the literature.

6. Conclusion

Identifying TVWS opportunities may allow for more efficient usage of TV broadcast spectrum by secondary users. Spectrum measurements were thus taken at six different locations at the UP. The primary objective of the study was to identify current opportunities in these bands (particularly for this region of South Africa). The secondary objective was to compare SS accuracy to a local GLDB, in light of the hidden node problem often associated with SS in CR networks.

Location specific measurements indicated that a number of opportunities were available, with between 216 MHz and 376 MHz of free spectrum detected. However, a comparison with the actual TV channel allocations (256 MHz free for the Tshwane metropolitan area) and the CSIR GLDB (96 MHz free) highlighted the effect of the hidden node problem.

Selected results from other TV broadcast band spectrum measurement campaigns, from around the world, were also compared. These campaigns showed a fair degree of correlation with the spectral utilisation reported in this article.

Future work may include an investigation into the possible benefits to be gained through a combination of GLDBs and SS to identify localised TVWS opportunities and also include measurements covering a larger geographical region.

7. Acknowledgement

This study was supported by the Sentech Chair in Broadband Wireless Multimedia Communications at the University of Pretoria, the National Research Foundation (NRF) and the Independent Communications Authority of South Africa (ICASA).

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Appendix A.

TV channels assigned to the Tshwane metropolitan area are listed in Table A.5, together with the broadcast site from which transmissions are made for each channel [3].

Table A.5: TV channel assignment for the Tshwane metropolitan area.

Channel	Frequency	Site	Station
VHF			
5	183.25	GPT	SABC2
8	207.25	GPT	SABC1
11	231.25	GPT	SABC3
UHF			
21	471.25	GPT	MNET
25	503.25	GPT	CSN
27	519.25	SD	TSHW
29	535.25	GPT	ETV
33	567.25	GPT, PN, SD, MP	DVB-T2
35	583.25	GPT, PN, SD, MP, CSIR	DVB-H
37	599.25	PN	ETV
38	607.25	SD	ETV
40	623.25	PN	SABC2
44	655.25	MP	CSN
46	671.25	SD	CSN
48	687.25	MP	ETV
50	703.25	PN	MNET
52	719.25	PN	SABC1
53	727.25	MP	SABC2
54	735.25	GPT, PN, SD, MP	DVB-T2
55	743.25	SD	SABC2
56	751.25	PN	CSN
57	759.25	MP	SABC1
58	767.25	GPT, PN, SD, MP	DVB-T2
59	775.25	SD	SABC3
61	791.25	MP	MNET
63	807.25	SD	SABC1
65	823.25	MP	SABC3
67	839.25	SD	MNET