Exploring TV White Spaces for Use in Campus Networks

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Abstract. University campuses are busy places for wireless client traffic coming from Wi-Fi connections and other wireless devices that contend for the 2.4 GHz frequencies space that most campus Wi-Fi networks use currently. This is making the 2.4 GHz frequency unsuitable for Wi-Fi connection due to too much interference from other devices as well as from Wi-Fi connections themselves. TV white space could provide a suitable alternative to campus Wi-Fi networks because of its better signal propagation characteristics as compared to 5 GHz frequencies, which is currently being used as an alternative. As a first step towards white space management to prepare Africa's university campuses networks for the migration from analog to digital TV, this paper presents the results of an investigation that was conducted to look at the spatial distribution of white spaces frequencies around two university campuses in Cape Town-South Africa to assess if they are useful enough to be used for university campuses to complement White-Fi networks.

Key words: campus Wi-Fi; White-Fi; loose spectrum identification; coarse spectrum identification

1 Introduction

Without doubt, the 2.4 GHz radio frequencies contributed to the success of Wi-Fi. The success can be associated with the fact that the development and distribution of 2.4 GHz-based Wi-Fi products across nations is easier [1] as the 2.4 GHz radio frequencies are allowed for unlicensed use in almost all the regions of the world. But Wi-Fi devices are not the only ones operating in the 2.4 GHz band. Bluetooth devices, Zigbee, microwave ovens, cordless phones, wireless cameras, and many more devices also operate in the 2.4 GHz band. As a result, the band is congested in most places [2][3] making it more and more unsuitable for Wi-Fi connection due to interference from these devices. University campuses are such places where the 2.4 GHz band can be crowded or congested due to high demand for the 2.4 GHz frequency use. University campuses are busy places for wireless client traffic coming from Wi-Fi and other devices such as devices using Bluetooth (keyboards, mice, trackpads, headsets, trackballs, speakers, docks), cordless phones, microwaves, wireless cameras and many more. Wi-Fi and these other devices contend for the same channel-constrained 2.4 GHz frequency spaces making it more crowded and unsuitable for Wi-Fi use due to too much interference from other devices and the Wi-Fi connections themselves.

With the advent of 5 GHz band as an alternative solution to the over-crowding problem in 2.4 GHz band for Wi-Fi networks, some universities are rebuilding campus Wi-Fi networks that now are designed for 5 GHz frequency band [4]. Much as the 5 GHz band provides some advantages like reduced interference, as there are no Bluetooth devices and other wireless peripherals operating in the band, its poor signal propagation characteristics may not be suitable for some Wi-Fi applications [5]. Lower frequencies with better propagation characteristics are better suited for creating cost-effective, robust wireless broadband in rural areas, and self-forming mesh networks in cities capable of routing traffic at broadband speeds [5]. In addition, adopting the 5 GHz band means more associated cost due to the requirement to purchase more access points because the signals in 5 GHz band do not have better in-building penetration properties than in 2.4 GHz band. Lower frequency with better signal propagation characteristics than 2.4 GHz could be a suitable alternative. As revealed by *Fig. 1*,

Fig. 1. White spaces: spatial characteristics

ultra-high frequency (UHF) TV broadcasting band is a lower frequency with such characteristics and white spaces found in the band could be ideal choice for university campus Wi-Fi networks. As shown by *Fig.2*, when looking at their temporal characteristics, TV white spaces are unused frequency bands, which are availed by the primary users (the incumbents) to be used temporarily by secondary users subject to the protection of the incumbents' operation in the white space band. Therefore, this paper presents the results of an investigation that was conducted to look at the spatial distribution of white spaces frequencies around two university campuses to assess if they are contiguous enough to be useful for use in university campuses to complement Wi-Fi networks.

The rest of the paper is structured as follows: Section 2 discusses the methodology of how the experiments were conducted and how the results were analysed; Section 3 discusses the experimental results and Section 4 concludes the paper.

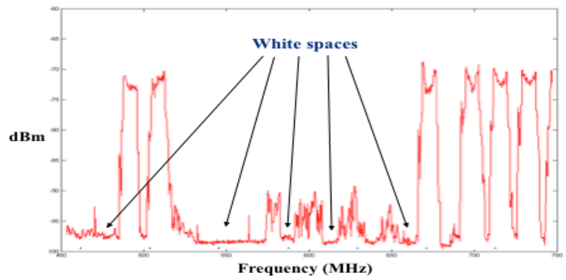

Fig. 2. White spaces: temporal characteristics

2 Methodology

This section gives a detailed discussion of how the experiments were conducted. It also discussed how the results were analysed.

2.1 Measurement Campaign

We conducted long-time indoors spectrum-sensing experiments at two sites; higher campus of the University of Cape Town (UCT) located at the foot of Table Mountain and the Bellville campus of the University of the Western Cape (UWC). At UWC, the measurement location was a postgraduate computer laboratory on the ground floor of the Computer Science Department at latitude 33°56′04.2″S and longitude 18°37′47.4″E, and at UCT, it was Intelligent Systems and Advanced Telecommunications (ISAT) laboratory on the second floor of the Computer Science Department building at latitude 33°57′24.4″S and longitude 18°27′39.4″E. The choice of the experimental sites was dependent on the fact that they are located in an area of high demand for TV service. If chunks of white spaces can be found in university campuses located in areas of high demand for TV services, then universities located in area of low demand for TV services should have plenty of white spaces, which can be utilised for campus Wi-Fi networks.

The RF Explorer model WSUB1G was used in the measurement process. The model was fitted with a Nagoya NA-773 wideband telescopic antenna with vertical polarization and has wide band measurement capability of *240 MHz* to *960 MHz*. Its complete technical specifications can be found in [6]. The Windows PC Client tool was installed on a desktop computer before connecting the RF explorer to the computer to have additional functionality. The measurement configuration is shown in *Fig. 3*.

The main aim of the experiment was to look at the geographic distribution of white spaces frequencies in this band and eventually assess whether they are contiguous enough to be used for university campus Wi-Fi networks. Our objective was to **1)** discover the spectrum occupancy in order to draw a spatial frequency map of white space bands in line with TV frequency assignments as

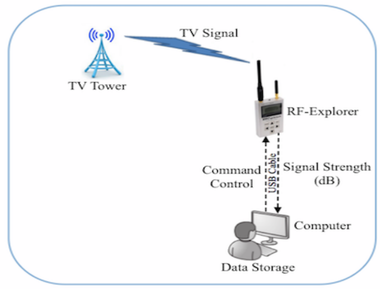

Fig. 3. Measurement configuration

allocated by ICASA and **2)** find the channels occupancy patterns in order to find how correlated they are between the two sites.

2.2 Choice of the Detection Threshold

Deciding on the threshold to be used in spectrum sensing is a challenging issue that has been at the heart of debates concerning absolute value to be used; a higher threshold value might lead to a loose spectrum identification with many false negative resulting into interference to the primary users while a lower threshold value can cause a coarse spectrum identification leading to many false positives that results into spectrum wastage. Taking into account this fact that the signal detection threshold is a critical parameter, an adequate criterion had to be used to select the decision threshold to ensure maximum protection of primary users. Therefore, we looked at the Draft Terrestrial Broadcasting Plan 2013 document from ICASA [7] to see how the UHF TV channels are arranged in the band to come up with the signal detection threshold. According to ICASA [7], UHF TV frequency band *(470 MHz and 854 MHz)* contains 48 channels of each *8 MHz* bandwidth. The 48 channels are arranged into 12 groups of 4 channels each, which means that 4 channels are available for assignments at any transmitting site on a national basis. In areas of great demand, 7 to 11 channels are assigned to a particular area by either combining lattice node points or using both VHF and UHF channels [7]. The measurement sites are typical urban areas, and as such, we considered them as areas of great demand. This was confirmed when we examined the Tygerberg transmitting site in [7], which is the closest transmitting site to UWC. There are 6 UHF channels being used by different TV broadcasting station at the site. A close examination of how these channels are allocated in the band shows that each allocated channel is spaced by at least 4 channels before the next allocated channel, with channel 22 *(478 MHz to 486 MHz)* being the first allocated channel. We believe this allocation scheme was done to reduce interference coming from other transmitters at the same transmitting site. Based on this allocation scheme, we concluded that at least the first 24 channels on the frequency band could not be detected as white spaces at our measurement sites, i.e. the signal detection threshold was lower than any of the recorded signal values in these channels. The minimum signal strength value detected in the first 24 channels was *-106 dBm*. By trying *-106.5 dBm* as the detection threshold, we managed to get that protection level. Therefore, we decided to use *-107 dBm* as the final detection threshold to add an extra level of protection to the primary users.

2.3 Performance Parameters

Two main experiments metrics were used in the analysis of data obtained:

1. The relative spectrum occupancy $O_{RS}(i)$ of channel i, defined by the three equations below.
$$O_{RS}(i) = 100 * O(i,T)/M(i,T) \tag{1}$$
$$O(i,T) = SS(i) - T \tag{2}$$
$$M(i,T) = max(O(i,T)) \tag{3}$$
where *SS(i)* is the absolute signal strength collected in channel i, T is the absolute spectrum sensing threshold below which a channel is considered unused, *O(i,T)* is the frequency occupancy of channel i and *M(i,T)* is the maximum frequency occupancy on the frequency band.

2. The channels' statistics defined by averages, variances, and correlations.

3 Experimental Results

The spectrum measurements were taken continuously for a period of 5 days and periodically saved during that period. The data recorded for each channel were averaged and the mean value was taken as the absolute received signal strength *SS(i)* for that channel. At each location, we calculated the frequency occupancy *O(i,T)* for each channel and eventually calculated the relative spectrum occupancy $O_{RS}(i)$ for each channel using the equations in the previous section. The *M(i,T)* that was greater out of the two *M(i,T)s* from the two sites was used in the calculation of relative spectrum occupancy $O_{RT}(i)$ for each channel at both locations. *Fig. 4* shows relative spectrum occupancy for all the 48 channels in the band at the two sites.

3.1 Discussion

White spaces have been detected towards the end of the band at both locations. A total of 64 MHz spectra (8 channels) have been identified as white spaces at UCT white at UWC, 112 MHZ spectra (14 channels) have been identified. It is worthy to note that the white space spectrum identified is fragmented, .e. it comprises of several non-contiguous TV channels of 8 MHz each, and as such, not

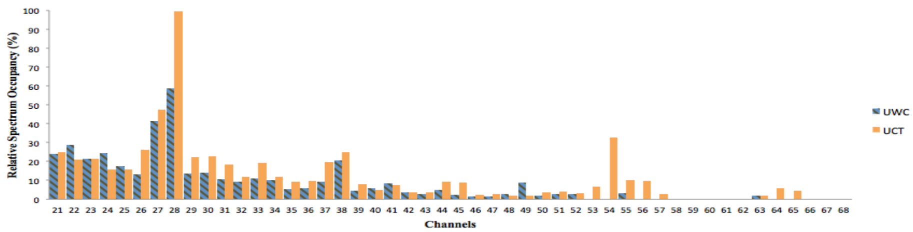

Fig. 4. Relative spectrum occupancy using detection threshold of -107 dBm

all of it may be used for secondary usage. The use of a particular frequency spectrum by wireless devices is affected by how contiguous it is [2]. Although there are emerging technologies capable of exploiting such fragmented spectrum as a whole using carrier aggregation technology [8][9][10], currently widespread technologies such as Wi-Fi and WiMAX, which could be theoretically directly applicable for white space networking through adjustment in their radio frequency front-end in order to work in the TV frequency bands require a considerable amount of contiguous spectrum [3] For example, an IEEE 802.11g network, which utilise a channel bandwidth of 20 MHz, will require three consecutive 8-MHz white space channels to operate. Based on our results, only consecutive white space channels from 58 to 62 and from 66 to 68 can be utilized for secondary usage by an IEEE 802.11g network.

The signal strengths are stronger in almost all the channels at UCT than at UWC and there are more white spaces at UWC than at UCT. This can be attributed to the difference in the floor levels where the measurements were conducted at the two sites. As discussed in *Section 2 Subsection 2.1*, the measurements were conducted on the 2nd floor while at UWC the measurements were taken on the ground floor. In general, signals arriving at lower floors encounter more diffraction, reflection, and scattering than signals arriving at higher floors [11] due to the number of obstacles blocking the signals from the surrounding environment; they are many at lower floors than at higher floors. Consequently, the received signal strength increases with increase in floor height [12]. The difference in the received signal strengths at the two sites can also be associated with the difference in signal penetration properties of the building materials of the walls of the two buildings where the measurements were conducted. Naturally some building materials allow better penetration of radio signals than others. Applying this in our scenario, it meant that the walls of the Computer Science building at UCT allow radio signals to penetrate through them easily than the walls of the Computer Science building at UWC. The strongest signal was recorded in channel 28 both at UWC and UCT. The signal strength at UCT was stronger than at UWC on this channel. Therefore, the signal strength at UCT was used as the maximum frequency occupancy $M(i,T)$, which was used in the calculation of relative spectrum occupancy $O_{RS}(i)$ for each channel at both sites. From the sites, the closest analog television transmitter broadcasting in channel 28 is Hermanus, at latitude $34°24'48''$S and longitude $19°13'18''$E.

It is about *116 Km* from UCT and about *108 Km* from UWC. Using Radio Mobile Network Planning tool [13], the shape of the Fresnel zones on the two radio links between Hermanus and UWC and Hermanus and UCT are depicted in *Fig. 5* and *Fig. 6* respectively. They reveal that there is no line-of-sight between the transmitters and the receivers and that they are totally blocked from each other to have the radio links possible. Therefore, a conclusion was drawn that the signal recorded in channel 28 at both campuses was not caused by analog TV broadcasting. A closer look at the Draft Terrestrial Broadcasting Frequency Plan 2013 document [7] shows that channel 28 is mostly used for digital mobile television broadcasting. It indicates that there is a digital mobile TV transmitter broadcasting from channel 28 at UCT, which is at latitude 33°57′21″S and longitude 18°27′38″E, about *100 Meters* away from the measurement room. The document also shows that the closest digital mobile TV transmitter from UWC is at latitude 33°52′31″S and longitude 18°35′44″E, about *7.3 Km* away from the measurement room. Looking at how close the respective digital mobile TV transmitters are from their corresponding measurements sites, it is expected to have clear light-of-sights between them and their corresponding receivers. Therefore, a conclusion was made that the signal recorded in channel 28 at both sites is due to digital mobile television broadcasting and not analog television broadcasting.

Besides the results depicted by *Fig. 4* where the signal detection threshold was chosen to ensure maximum protection of primary users, we conducted two other experiments to analyse spectrum occupancy under loose and coarse spectrum identification.

3.2 Loose Spectrum Identification

Loose spectrum identification means white space identification that results into false negatives where some channels are detected as white spaces but primary users are actually using them. In our case, choosing any signal strength value

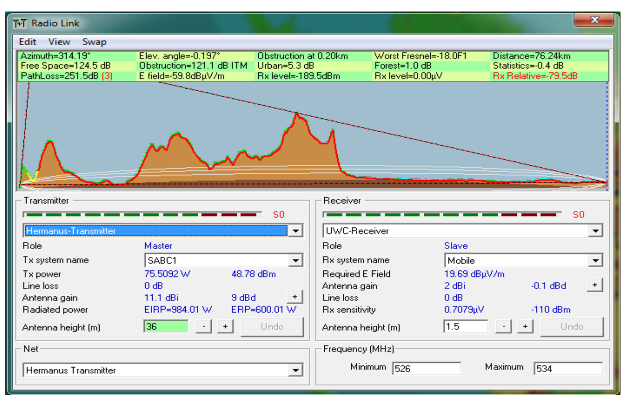

Fig. 5. Fresnel zone picture between Hermanus and UWC

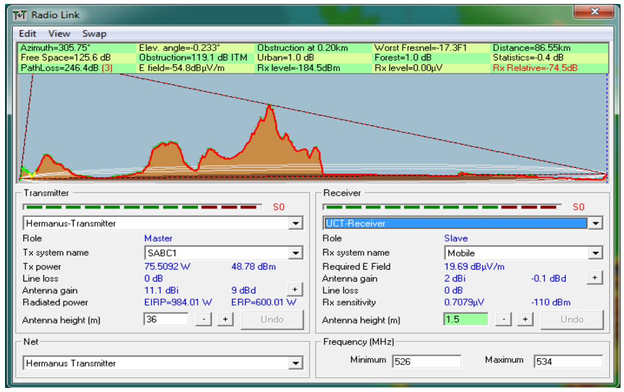

Fig. 6. Fresnel Zone picture between Hermanus and UCT

recorded in the first 24 channels results into loose spectrum identification (*refer to Section 2 and Subsection 2.2*). Therefore, the signal strength value of *-103 dBm* was selected randomly and taken as the detection threshold for loose spectrum identification out of the signal strength values recorded in the first 24 channels. *Fig. 7* shows the results of white space identification when *-103 dBm* is used as the detection threshold. As it can be seen from the figure, many of

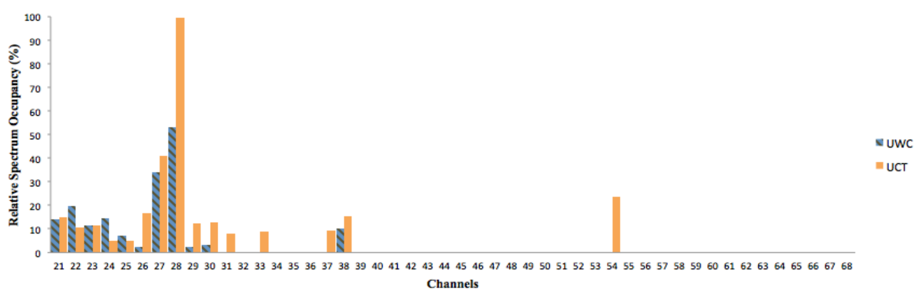

Fig. 7. Loose WS spectrum identification using -103 dBm as detection threshold

the first 24 channels have been identified as white spaces but in reality they are not. For example, channel 31 has been identified as white space at UWC but using the analog television frequency assignment 2013 database from the Draft Terrestrial Broadcasting Frequency Plan 2013 document [7], channel 31 is being used by SABC3 with its closest transmitter from UWC at Aurora, latitude 33°49′39″S and longitude 18°38′29″S. Using the transmitter parameters provided in the database and the RF-Explorer technical parameters, the radio link between the transmitter at Aurora and a receiver at UWC shows that the radio link is possible as shown in *Fig. 8* rendered using Radio Mobile Network Planning too [13]. If channel 31 is used for secondary usage at UWC as has been

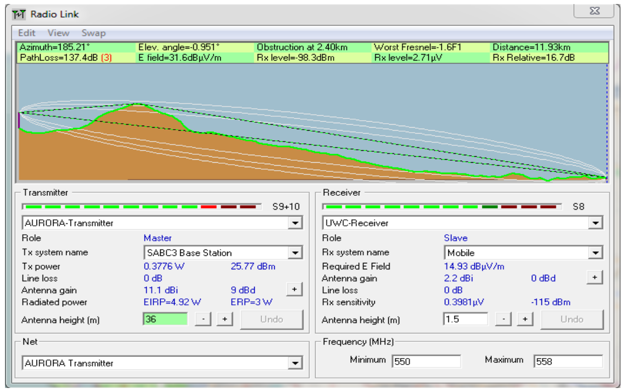

Fig. 8. Fresnel zone picture between Aurora transmitter and UWC

detected as white space under loose spectrum identification, it will results into interference of the TV broadcasting services of the SABC3 TV station.

3.3 Coarse Spectrum Identification

The FCC recommended white space detection threshold of *-114 dBm* was used. The *-114 dBm* was within its signal measurement range since WSUB1G RF-Explorer has a displayed average noise level (DANL) of *-115 dBm* [6]. The *-114 dBm* is considered conservative in the literature [14][15][16][17]. Using this detection threshold, there is no white space identified, i.e. all the channels are identified as occupied as shown in *Fig. 9*. Closest transmitters to the measure-

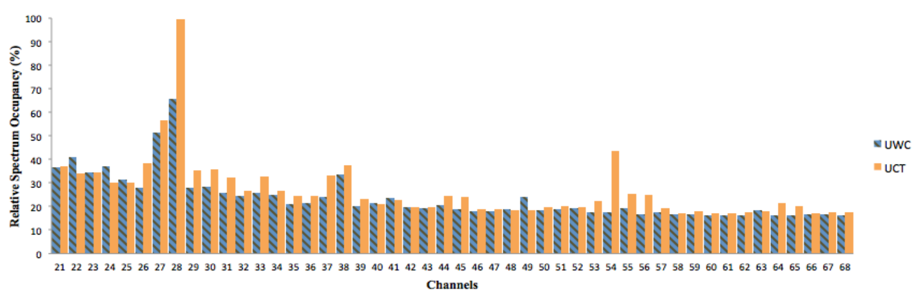

Fig. 9. Coarse WS spectrum identification using -114 dBm as detection threshold

ments sites for television station broadcasting at some of these channels are very far away from the measurements sites such that the broadcasting is not picked at the measurement sites. The channels that these far-way TV transmitters are using are supposed to be white spaces at the measurement sites.

3.4 Translating Frequency Occupancy into Bandwidth Availability

Translation of frequency occupancy into secondary bandwidth availability is dependent on several factors as discussed in [3][18][19]. Some factors may be general while others may be specific to a country. In general, some factors that would affect translation of frequency occupancy into bandwidth availability are as follows: country or region's rules for protection of primary TV transmitters such as protection regions, adjacent TV channels that limit secondary operation; TV transmitter parameters such as transmit power, signal masks, modulation/coding used and interference sensitivity; secondary user transmitting parameters such as transmit power, signal masks, modulation/coding. A detailed exploration and mathematical analysis of the translation of frequency occupancy into secondary bandwidth availability is given in [18].

4 Conclusion and Future Work

In this paper, we investigated spatial distribution of TV white spaces around two university campuses to assess their suitability for use in university campus Wi-Fi networks. Indoor spectrum measurements were conducted at the upper campus of University of Cape Town and the Bellville campus of University of the Western Cape in South Africa. The results show that some white space bands exist towards the end of the frequency band, which can be useful enough to be used for university campus Wi-Fi networks.

Spectrum sensing is a first step towards efficient campus networks management by using white spaces to complement Wi-Fi frequencies. The management of networks to accurately share the available white spaces is another important process that may require redesigning existent network management techniques to manage white spaces. Multipath routing techniques such as presented in [20][21] will be redefined to use more paths upon secondary usage when white spaces are availed by the primary users. Cost-based traffic engineering techniques such as proposed in [22][23] will also be redesigned to include parameters that account for the white space availability under secondary usage. The design of market pricing mechanisms to protect primary users while managing white spaces to meet QoS agreements between the offered traffic and the available spectrum is another issue for future research. Assessing the impact of white space management on long distance sensor deployment as raised in [24][25] is another key issue that needs to be addressed as future research work.

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