FSL Based Estimation of White Space Availability in UHF TV bands in Bergvliet, South Africa

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Abstract- The paper describes the predictions made for Bergvliet, South Africa in terms of the availability of the frequency spectrum occupied by analogue TV broadcast around that area. The focus is made on the availability of under-used TV channels in the UHF TV frequency bands. The free space loss (FSL) formula, together with a line of sight condition, are applied to the information about the location and power of TV transmitters around this area. The predictions show 61% correlation between the measurements and predictions and indicate that 3 to 12 television channels are available, out of 39 tested (16 to 96 MHz out of 312 MHz measured), where the availability is defined by the strength of signal being less than or equal to -114 dBm.

Index Terms— Cognitive Radio, Frequency Spectrum, Television, TV, UHF, White Space Device, WSD, free space loss, FSL

I. Introduction

The worldwide migration of television (TV) broadcast from analogue to digital, known as digital switch-over or DSO, will result in freeing up large portions of Very High Frequency (VHF) and Ultra High Frequency (UHF) bands. The unused portions of the radio frequency (RF) spectrum in these TV bands are commonly called the *TV White Spaces (TVWSs)*. Due to their attractive propagation characteristics [1], such as long distance propagation, penetration through the walls, and some non-line-of-sight operations, TVWSs are considered excellent for wireless communications, and have attracted attention of mobile operators, researchers and regulators. Such propagation characteristics are especially critical to provide connectivity to rural, remote areas with low population density, where the present day technology is often too specialized and thus expensive, or uses too high frequencies and thus does not propagate far enough.

The demand for broadband communications continues to grow at an accelerated rate, leading to a constant need for bandwidth. With the fear of RF spectrum scarcity, regulators around the world [2], [3], together with the United Nations' International Telecommunications Union (ITU) [4] are looking at different solutions and regulatory policies that could lead to efficient utilization of the TVWS spectrum. This will be especially important after the global DSO deadline set for 2015, when the inefficient analogue broadcasting is to be stopped completely and huge amount of previously occupied spectrum is going to become available. One such approach to utilise the available spectrum is the use of cognitive radio (CR) technology and so-called the white space devices (WSDs), capable of opportunistic and/or dynamic spectrum access (DSA).

WSD is a radio device capable of using the cognitive capabilities to operate on TVWS spectrum without causing harmful interference to the licensed or protected services. Depending on the country, these protected services include terrestrial analogue and digital TV receivers, program making and special event (PMSE) systems including wireless microphones, radio astronomy services (608-614 MHz) [5] and any services deployed by certain countries within the TV frequency band. The European Communication Commission (ECC) broadly categorizes the WSDs as portable/personal devices, home/office devices and access point devices [5]. There are different use cases for WSDs, which includes rural broadband, indoor broadband (Wi-Fi like) and machine-to-machine communications. The actual killer application for WSDs will depend on the market and the country's needs. In developing regions, such as Africa, CR technology and WSDs are likely to be used for rural broadband connectivity. For instance, recent RF occupancy measurements conducted in South Africa have shown very low usage of TV spectrum in rural areas [7], [8]. To operate as secondary users, WSDs are expected to first determine vacant spectrum bands and also have the capability to detect the onset of protected or licensed users. WSD can determine TVWS spectrum using one or a combination of these techniques: spectrum sensing, geo-location database or beaconing. To enable early deployment of CR and WSDs, regulators and IEEE 802.22 standard [6] prefer the use of geo-location databases technique to determine TVWS than spectrum sensing. A geo-location database must know the location and characteristics of primary transmitters as well as the applicable spectrum regulations. It must be able to report and possibly predict the signal strength and chances of interference, so that it can perform spectrum management and respond to automated queries from a CR or WSD requesting spectrum in real or near-real time.

In order to be able to start utilizing the WSD, and in absence of commonly accepted or available geo-location database, it is important to have the information about the amount of activities in the spectral bands relevant to TVWS. The work in this paper is considers the present TV receiver requirements, location and specifications of the TV stations in an area of South Africa and applies the free space propagation loss equation and line of sight constraints to estimate the amount of spectrum available for WSD operation in that area.

The paper is structured as follows. Section II briefly overviews the analogue TV standards and requirements, applicable to South Africa. The next section reviews the propagation model used. The results of the modelling, comparison to measurements and a discussion are presented in Section IV. This is then followed by conclusions.

II. Key Aspects in Analogue TV Relevant to WSD

The DSO from analogue broadcasting to DVB-T2 is scheduled to start in December 2013, with the aim of ensuring that the ITU July 2015 deadline is met. The analogue signals do not include any redundant encoding and are sensitive to interference. Our study shall, therefore focus on the analogue TV broadcast coverage predictions. As a member of ITU Region 1, South African analogue TV broadcast standard and frequency plan are similar to those used by the European Conference of Postal and Telecommunications Administrations (CEPT) [5]. Currently, despite hectic preparations DSO, and some implementation of dual illumination, the majority of broadcasting is mainly analogue.

In planning/calculating the coverage for analogue TV transmitters, there are different parameters to be considered. Such coverage is normally calculated for each frequency using appropriate technical parameters, considering the effect of interfering transmitters and using the service contour values (e.g. the minimum field strength, as specified in Table 1 [9]). While the national frequency plan still shows the UHF frequency range from 470-854 MHz, recent developments [4] shows that this range will be reduced to 470-694 MHz. The South African government though the Department of Communications have declared the upper UHF band (790-862 MHz) as the first phase of the digital dividend [10].

South Africa uses PAL system I with 625 lines, and TV channel bandwidth 8 MHz. Some of the key specifications on the TV signal are listed in Table 1.

Table 1: Technical parameters defined by ICASA [9]

Parameters	Values
UHF band IV/V frequency range	470 to 854 MHz
Channel Bandwidth (VHF/UHF)	8 MHz
Min. field strength (UHF band IV)	65 dBμV/m
Min. field strength (UHF band V)	70 dBμV/m

The sensitivity values may be translated from dBμV/m into dBm by using the expressions from [14] for the antenna gain $G=4\pi A/\lambda$ (where A is the effective area of the antenna's aperture and λ is the wavelength) and incident power density of plane electromagnetic wave $W=E^2/376.7$ (Watts/m^2; where E is the field strength in V/m) combined to obtain the power at the receiving antenna's terminals $P=W{\cdot}A$ (Watts). Numerically, for the frequencies within this band and 0 dBi antenna gain, this leads to the need to have signal of at least -63..-65 dBm. An aerial used for outside installation on the roof of a house usually has gain of 10-20 dBi, permitting to receive even lower signal levels successfully.

Throughout this document, an ICASA dataset received directly from ICASA, and describing the position and characteristics of the TV transmitters throughout South Africa in a manner similar to [9] has been used. A sample of the distribution of the TV transmitters around South Africa based on this data is shown in Figure 1.

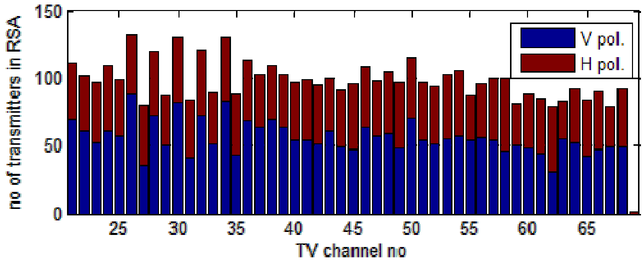

Figure 1: Distribution of TV transmitters in South Africa, per TV channel and polarization.

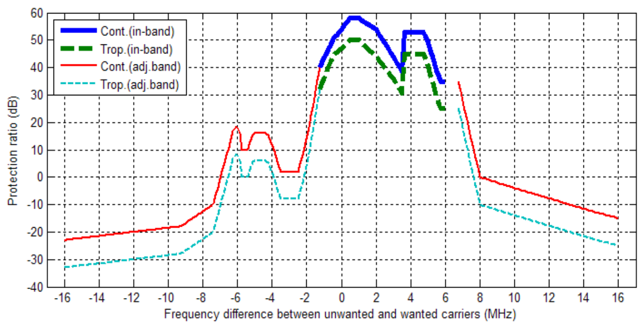

Figure 2: Protection ratio for PAL/I channels [11].

The paper uses an approximation ignoring the protection ratios. The document [11] defines the protection ratio degree of protection for the TV broadcast, required to achieve the desired level of picture quality [12, 13]. The protection ratio mask from [11] used for PAL/I is shown in Figure 2. This paper does not consider this or any other mask and focuses on a simpler discrete point approximation. An additional motivation for postponing implementation of this mask is due to the some difference in the information provided in [11] against the more recent information provided in [9], which still needs to be clarified.

III. Methodology, Propagation Model and Input Data

The paper uses the following chain of calculations to estimate the propagation of the signal from a TV transmitter to a receiver, applied to every TV transmitter individually:

1) The equivalent radiated power (ERP) value obtained from the list of TV stations is converted into the equivalent isotropic radiated power, as follows: EIRP = ERP - 2.15 (dB). The calculations in the paper are based on a recent spreadsheet with TV stations obtained from ICASA. An important assumption was made about the data available there for the ERP units to be dBW. In addition, the few erroneous values have been ignored.

2) The propagation loss is computed using the free space propagation loss formula: PowerLoss(dB) = 20lg(4piD/lambda), where D is the straight line distance between transmitter and receiver, and lambda is the wavelength.

3) Instead of frequently used simple criterion of a maximum distance, the line of sight (LOS) visibility is estimated by taking into account the heights of the transmitter and receivers and the radius of curvature of Earth. At this point, it may be noted that it was assumed that the Earth is “flat”, i.e. the Earth radius was assumed constant and no vertical profiling information was taken into account, except for the known vertical height of the transmitters, receivers and antennas. In addition, it may be noted that the assumed LOS was around 50% cross-section of the first Fresnel zone [16].

The signal strength at the point of a receiver was evaluated by applying the above-mentioned steps to all of the known TV transmitters and accumulating the signal power.

The propagation and frequency bandwidth availability were made for a specific site at Bergvliet with readily available measurement data. The site is located at the following coordinates: longitude 34° 3'21.38"S, latitude 18°27'31.55"E, altitude 12 m. The antenna is at the mast height of 12 m.

IV. Results and Discussions

All the results in this section are per the site mentioned in the end of the previous section. The normalized results of the predictions are shown in Figure 3. This figure shows the received signal strength due to all individual transmitters (referred in the figure to as “un-groupped”), as well as signal powers grouped by the frequency. The latter data is shown as all the signals, including those outside of the line of sight (referred to as “inc. NLOS”), and the signals restricted by the line-of-sight (LOS) conditions (“LOS only”). Magenta dots and circles refer to the maximum possible sum of powers (when the powers are simply added as for coherent signals). Blue symbols refer to the common RMS type of addition. The difference between two symbols of the same color and at the same frequency may for example be used in interpret the closeness of the signals from the different transmitters. The empty space between two regions with active transmitters in the figure shows the expected absence of the TV transmitters listed to transmit outside of the designated frequency bands.

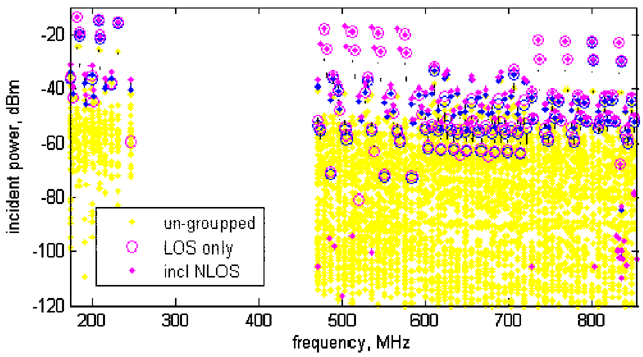

Figure 3: Predicted signal strength received at the location, due to the all transmitters

The measured data is available for the frequency range from 470 MHz to 790 MHz. A comparison of the normalized measured and predicted data is shown in Figures 4 and 5. The pictures indicate a reasonably good match between the measured and predicted estimates for the activities in the TV band.

This data was then processed to obtain a distribution indicating the maximum power present per each specific TV channel. This process was applied to both predicted and measured data to compare the results directly. The distance between the LOS predicted and measured data was found to be around 51 dB +- 20 dB.

In order to quantify the quality of the predictions, a figure of merit in the form of a correlation coefficient was introduced. The correlation coefficient for the correlation between predicted LOS and measured data is 0.61. This could be compared to 0.32, the value of the correlation between the predicted data including NLOS (no LOS filtering applied) and measured data. As it was observed from the previous plots, the data filtered by LOS criterion is much closer to the measured data.

Next, the distribution data was then also used to compute the available/unused bandwidth (white space), subject to a given maximum level of power present in the channel. The bandwidth available was computed by multiplying the number of unused channels by the width of a channel, 8 MHz. The estimations were done within the frequency band measured (the predictions could be used for a wider band) and assuming application of a 51 dB displacement to the predicted data, as established earlier.

accurate propagation model, not accounting for the actual topology/elevation profile of the Earth surface and not taking the buildings into account.

The predicting model is based on the free space loss equation and thus assumes the lowest degree of attenuation (it is unlikely that there could be any (a) sufficient size natural or man-made structures operating as a waveguide and helping the wave to propagate with an attenuation exponent better than 2, and/or (b) re-reflecting structures resulting in more than 3 dB of constructive interference).

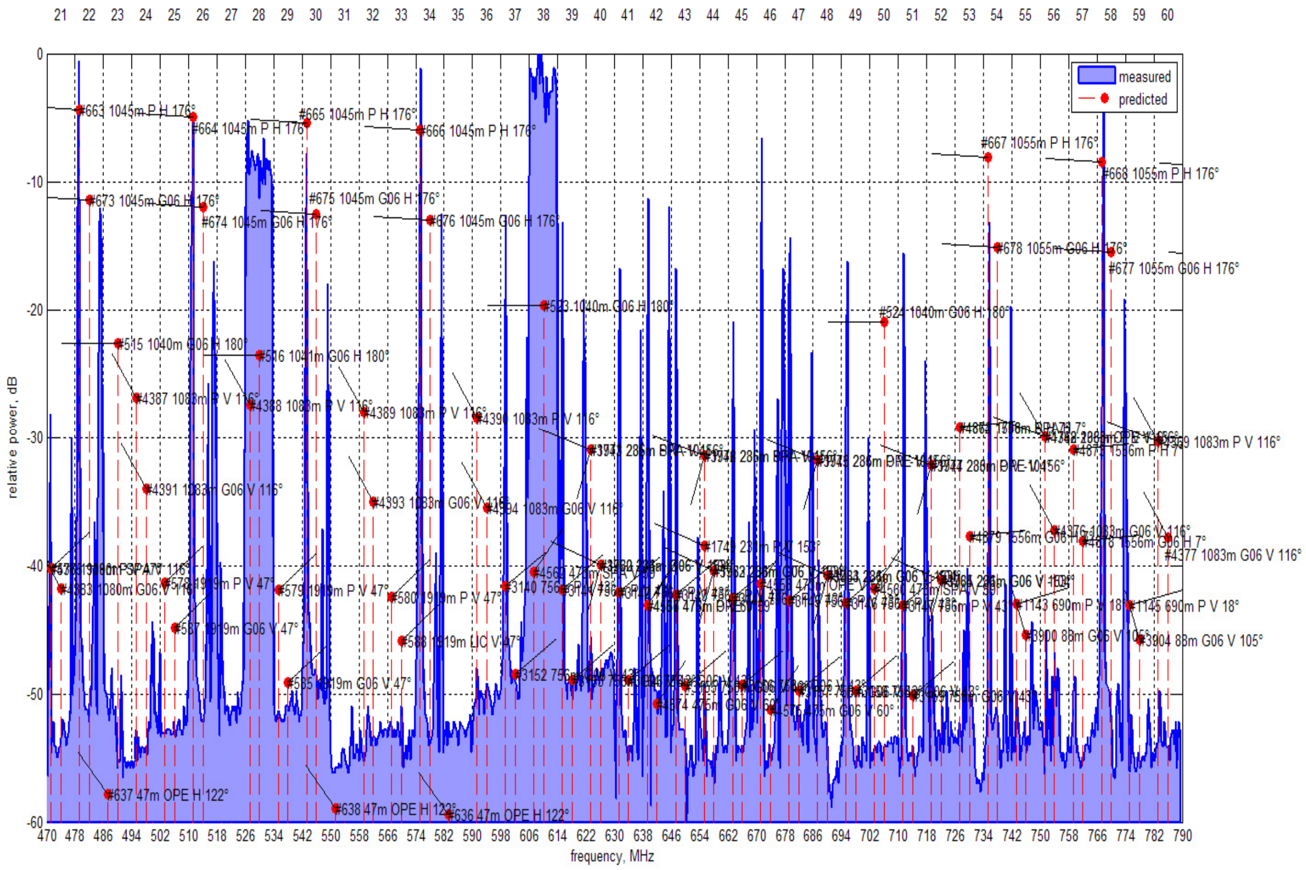

Figure 4: Normalized predicted (LOS only) vs measured values versus frequency (bottom axis) and TV channel no (upper axis); the text next to the solid red dots include the following information: number in ICASA's list of transmitters, site plus mast height (in meters), program status, and numerical value for the angle to the transmitter (in degrees)

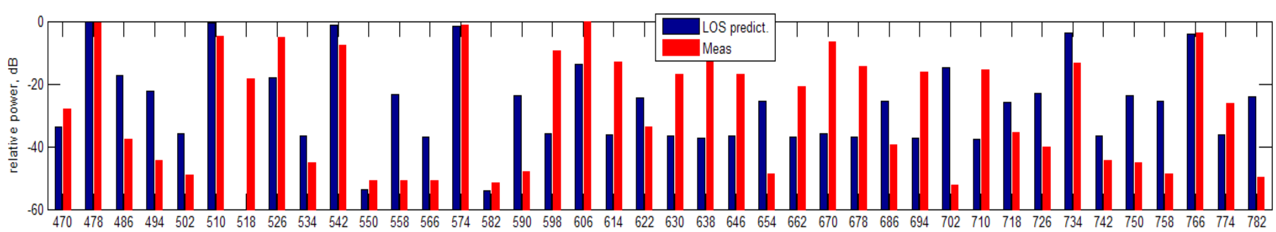

Figure 5: Max signal strength per TV channel - bar plot comparing the measured and simulated data side by side

Figure 6 shows that the estimations based on the predictions match well with the estimations based on the measured data when a higher threshold value is used. The big difference at the lower threshold values is due mainly to presence of multiple predicted peaks/TV station, not found in the actual measurements. This could possibly be due to incorrect status of those stations and/or due to insufficiently

Thus, subject to the omitting the use of the protection ratio for the adjacent channels, it should be possible to consider the prediction plot as the lower bound of the available bandwidth. In a similar manner, it is likely that the measured data represents the upper bound of the available bandwidth.

Even with the strict -114 dBm signal strength threshold used, a well-populated area like Bergvliet can offer at least 2 channels worth 16 MHz of bandwidth. The measurements indicate possibility of 96 MHz of white space bandwidth. Considering that Bergvliet and surrounding areas have population density of around 1600/km2 [15], it is likely that more remote/rural areas can offer even greater bandwidths.

V. CONCLUSION AND NEXT STEPS

The paper has discussed the steps made towards predicting the availability of TV white space spectrum in Bergvliet, South Africa. It was estimated that, in an urban area called Bergvliet, the amount of white space could, at this point of time, be between 16 to nearly 100 MHz.

The next steps shall include taking into account more accurate vertical profile of the Earth's surface, and applying the protection ratio spectrum mask.

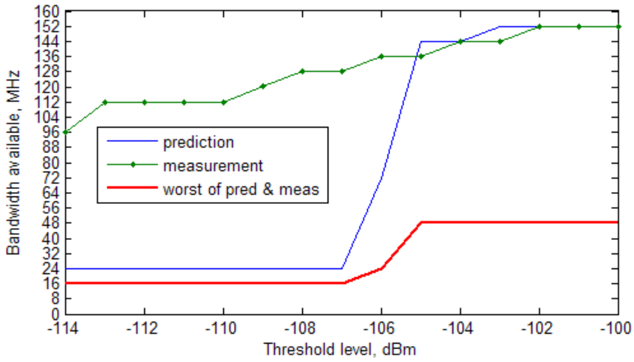

Figure 6: Spectrum availability estimated using predicted and measured data, via 8 MHz bins. The prediction and measurement curves are based on the predicted and measured data, respectively, alone. The 'worst of pred & meas' refers to selecting the lowest count of available channels between predictions and measurements.

VI. ACKNOWLEDGMENT

The assistance in preparing this work by Richard Makgotlho, Independent Communications Authority of South Africa (ICASA) is gratefully acknowledged. The measured data was kindly provided by Grintek Ewation (Pty) Ltd. (www.gewspecmon.co.za).

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