A Correlation Between RSSI and Height in UHF Band and Comparison of Geolocation Spectrum Database View of TVWS with Ground Truth

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Abstract. An investigation into the Received Signal Strength Indicator (RSSI) dependency on receiver antenna height in UHF band is conducted. The results show a high correlation between RSSI and height on channels with high signal strength. There is approximately 2.5 dBm RSSI gain per 1 m increase in height above ground up to 8.5 m. From 8.5 m to 12 m, there is no consistent observable increase in RSSI. Furthermore, the geolocation spectrum database's (GLSD) view of white space in the television band is compared with the ground truth. Results show signal presence on some of the channels indicated free by the spectrum database. These findings imply that an increase in transmission range of UHF links can be achieved by increasing receiver height. White space devices using A GLSD should additionally require spectrum scanning to determine clear channels.

Keywords: UHF television white space · RSSI vs. antenna Height · Geolocation spectrum database · Received signal

1 Introduction

The 470–890 MHz frequency range has historically been used for television broadcast. Traditionally protection of primary transmitters has been achieved through strict frequency assignment. However due to the increase in wireless applications, the spectrum assignment paradigm is shifting towards the adoption of technologies such as smart antennas, cognitive radios, adaptive coding, etc. that allow efficient utilisation and reuse of spectrum [1]. While these ideas have been around for quite some time, the technical details of dynamically allocating and sharing spectrum without interference among users are yet to be fully addressed.

This study is motivated by the ever increasing relevance of wireless communication and the particular interest in *television white space* (TVWS) based communication. The implementation of TVWS based communication might vary from application to application but, the general requirement is for the device to know the free channels in the area and determine safe transmission power

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levels to use. There are two general approaches to meeting this requirement: the device can either (i) scan its spectral environment to determine free channels or (ii) query a geolocation spectrum database (GLSD) that responds with a list of free channels based on the device's location and parameters such as antenna height, power, etc.

Each of these approaches for protection of primary transmitters and coexistence with secondary users raises several questions. Firstly, at what height should the scanning be done? Secondly, when the GLSD provides a list of free channels, are the channels really free?

To answer these questions, which are essential for purposes of TVWS device deployment, this paper firstly looks at Received Signal Strength Indicator (RSSI) dependency on receiver height over the ultra-high frequencies (UHF). Using results of RSSI dependency on height, the prospect of influencing the transmission range by varying the receiver antenna height is considered. Next, the GLSD's view of TVWS is compared with measurements to assess the availability of channels provided by the GLSD.

The paper is organised as follows: Sect. 2 gives the related work; Sect. 3 describes the method used in data collection; Sect. 4 discusses the results; and Sect. 5 concludes the paper and outlines follow on work.

2 Related Work

Studies have been done to characterise UHF wave for point-to-multi-point propagation in outdoor and indoor environments e.g. [2,6]. Substantial work has been done in the area of propagation models used to predict path loss for purposes such as estimating transmission range, inter-system interference analysis and so forth. Propagation models use known parameters such as operating frequency, distance, transmit power, antenna and terrain characteristics, etc. to predict path loss.

Results from studies [3,4], conducted to evaluate performance of propagation models show that the accuracy of path loss variability prediction is dependent on environmental characteristics in and around the area in which the model is applied. A propagation model is considered accurate if it obtains a root mean square error (RMSE) that is below a set margin for urban and rural areas. Empirical propagation models derived from measurements in one area often have to be modified to increase the accuracy when applied in a different area.

Other studies have been done to establish dependency of propagation distance on operating frequency [5], effect of distance and transmitter antenna height on path loss [6]. Previous work [7] covering dependency of received power on receiver height reported no significant dependency for height 1–3 m however, this was study was carried out in 225–450 MHz frequency range. From the literature surveyed, the RSSI dependency on receiver antenna height for the UHF television band is a less well explored issue.

3 Methodology

The study was done experimentally. The objective of the experiment was to establish the relationship between RSSI and receiver antenna height in the UHF band. In absence of additional equipment and to avoid the need for a spectrum license, the local television broadcasting was used as a source of the reference signals. The receiving hardware setup included a R&S FSH4 spectrum analyser, a 2.1 dBi gain R&S omnidirectional antenna and short cables, all mounted on a boom lifter. The spectrum analyser was controlled over a WiFi network from within a vehicle. The setup is shown in Fig. 1.

Fig. 1. Setup used to perform measurements. Visible are the boom lifter and antenna mounted on it (covered with a low permittivity radome). The spectrum analyser is mounted under the antenna (not visible).

The measurement procedure was to lift the arms of the boom lifter (with the measurement setup), measure the actual height using a laser range finder, and perform a frequency scan (the scan was set and triggered remotely, over the wireless network.). The results of a scan would be saved into a data file. This was repeated several times for each value of height.

Each frequency scan was done from 451.25 MHz until 1,081.25 MHz with resolution bandwidth of 1 MHz and video bandwidth of 3 MHz. The choice of frequency and resolution bandwidth was dictated by two factors: (i) the need to capture the video carriers of analogue TV transmissions (which are located around 1.25 MHz from the left edge of a TV band), and by the limitations on the number of points in a single sweep which can be used by the spectrum analyser used, i.e. fixed to 631 points.

The measured values, in dBm, recorded in the data files reflect the power entering the input of the spectrum analyser. These can be translated into the power incident onto the antenna by taking into account the losses in the cables and connectors (L_c, about 1 dB) and applying the antenna gain ($G_A = 2.1$ dBi) for the selected antenna. Thus, the power incident onto the antenna, P_{inc}, may be estimated via the power entering the spectrum analyser, P_{sa}, as

$$P_{inc} = P_{sa} + L_c - G_A = P_{sa} - 1.1, (dB). \quad (1)$$

3.1 First Set of Spectrum Scan Measurements

The first round of measurements was conducted at the location with GPS coordinates: 18.423980, −34.1398. This location had one floor houses and a large number of very tall trees around the area. From the presence of tall trees, one may expect that the dependence of the signal strength on the height may be weakened as compared to more empty space. The measurements were performed at the following antenna heights: 2 m, 3.25 m, 4.57 m, 6.04 m, 7.87 m, 9.27 m, 11.57 m, over the above-mentioned frequency range. Only one frequency scan was collected at this location at each of the antenna heights.

3.2 Second Set of Spectrum Scan Measurements

This location was a residential area with one floor houses and only short trees. From this, one may expect the dependence on height to be composed of two different types of dependencies: one for the heights below the average height of houses, and another for greater heights. Measurements were conducted at antenna heights 2 m, 2.1 m, 2.66 m, 3.2 m, 3.75 m, 4.3 m, 4.9 m, 5.46 m, 6.3 m, 7 m, 7.7 m, 8.3 m, 8.8 m, 9.3 m, 10.7 m, 11.9 m. Multiple samples were collected at each height.

3.3 Data Preparation

The frequency scans were conducted from 451.25 MHz to 1081.25 MHz and the results presented focus on television channels 21 to 69 (470–862 MHz).

In order to reduce the influence of random noise, the frequency points in each frequency scan have been grouped into channels 8 MHz wide, corresponding to TV channels, i.e. a channel N starting at $470 + 8(N - 21)$[MHz] and ending at $478 + 8(N21)$[MHz]. Each channel is represented by an average of all the values which belong to this channel as well as by associated statistics. In order to reduce the effects of the noise further, the values from each channel were averaged over a number of different frequency scans at the same height. Most of the results presented in this paper are based on averages from 31 frequency scans at each level.

4 Discussion of Results

4.1 RSSI Dependency on Height

In order to provide the overview of the spectrum scan, we consider the average of samples at the main height. The results are shown in Fig. 2(a). Figure 2(b) shows the Standard deviation of the samples collected, which was computed using Eq. 2:

$$\text{Standard deviation} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \quad (2)$$

where N is the sample size, x_i are the values and μ is the mean.

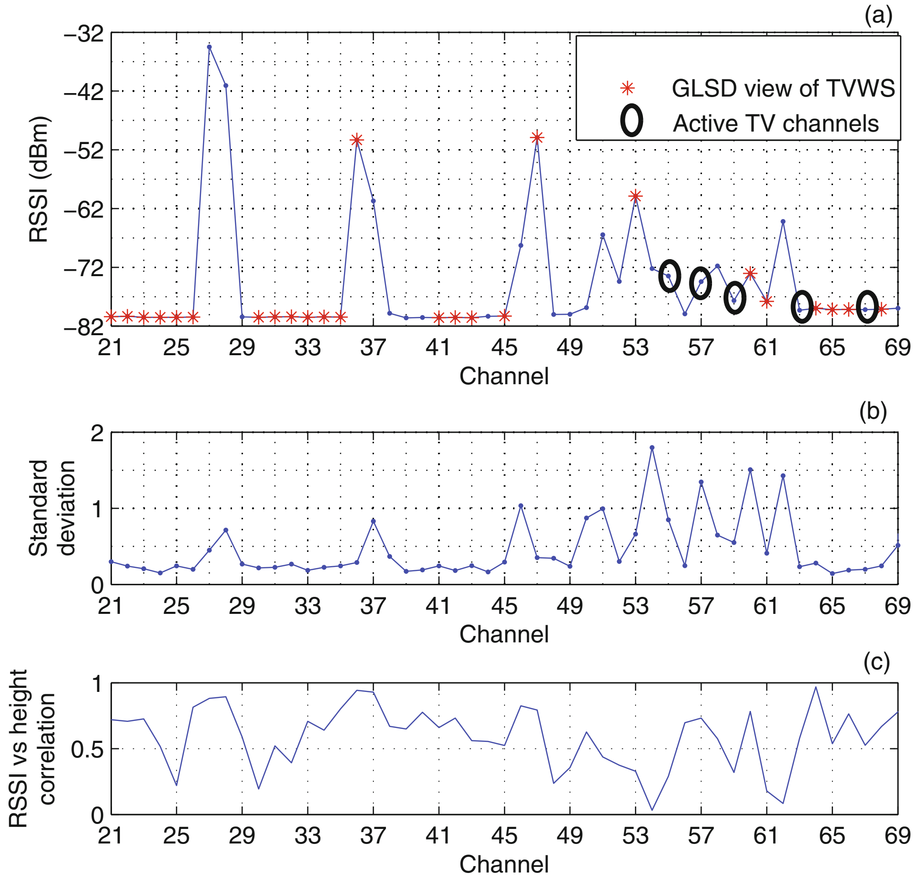

Fig. 2. Overview of the spectrum scan.

There are fluctuations in the observed standard deviation especially from channel 46 to channel 63. This could be due to changes in the spectral environment or occurrence of temporal obstructions caused by objects such as vehicles parked in the far distance thereby affecting signal propagation during the time of measurement. Spearman's Rank correlation was computed using Eq. 3 to determine statistical dependency between height and RSSI over channels 21–69.

$$\text{Rank correlation coefficient} = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n^3 - n} \sum \tag{3}$$

where d_i is the difference between the ranks for $RSSI_i$, $height_i$ pairs and n is the number of pairs observed [8].

The degree of correlation in RSSI dependency on height across channels 21–69 is shown in Fig. 2(c). Figure 3 shows the degree of correlation in RSSI dependency on height plotted against RSSI. The results show that correlation is most significant on channels with strongest signal. Therefore, to determine the RSSI dependency on height the peak channels are considered.

In Fig. 2(c) correlation of 0.96907, 0.94334, 0.92862, 0.8933, 0.88153, 0.82561 is observed on channels 64, 36, 37, 28, 27 and 46 respectively. The plot of RSSSI vs. height for these channels with the highest correlation is shown in Fig. 4.

There is approximately 2.5 dBm RSSI gain per 1 m increase in receiver height from 2 m to 8.5 m across the observed channels. The dependency of RSSI on height implies that the transmission range of UHF-based wireless links can be extended by increasing the receiver antenna height. After increasing the receiver antenna height beyond 8.5 m the observed gain in RSSI plateaus and becomes less consistent.

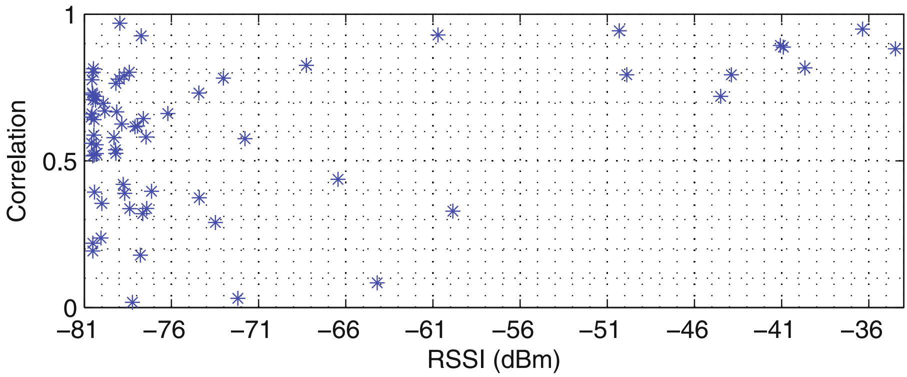

Fig. 3. Correlation vs. RSSI.

4.2 Comparing GLSD with Ground Truth

The results of the geolocation spectrum database (GLSD) query are indicated by (*) marks in Fig. 2(a). The CSIR GLSD [9] service was used to get a list of available channels or TVWS for a white space device (WSD). The GLSD's criteria for determining TVWS is based on the ITWOM+ITU-R P.1546-4(grade-B) propagation model [10] for WSD 3–10 m high and 4 W power. Details of registered television channels indicated by circular marks in Fig. 2(a) is based on information

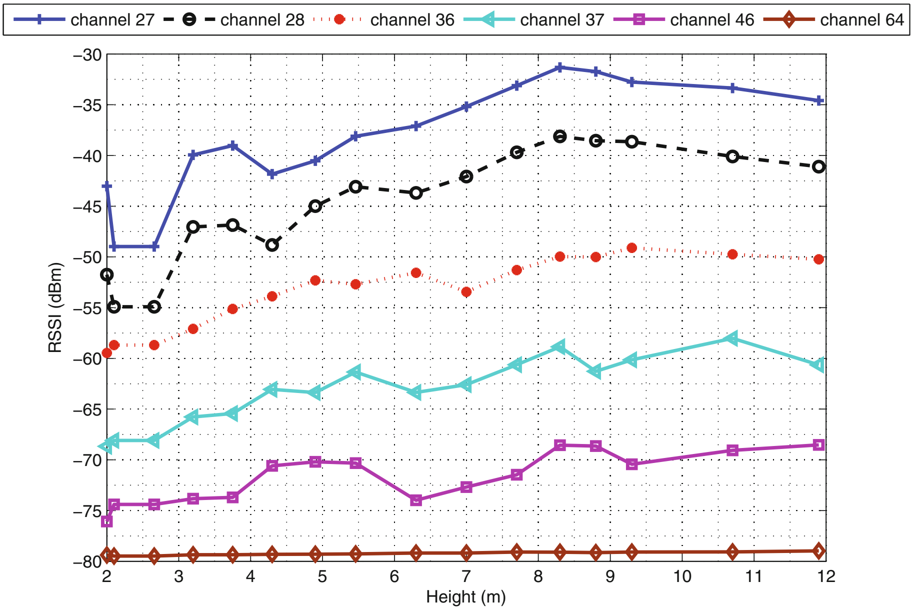

Fig. 4. RSSI dependency on receiver height at selected channels.

provided by SENTECH [11], the national licensed broadcast signal distributor in South Africa.

According to the GLSD, the following channels are free: 21, 22, 23, 24, 25, 26, 30, 31, 32, 33, 34, 35, 36, 41, 42, 43, 45, 47, 53, 60, 61, 64, 65, 66, 68. Considering the spectrum scan shown in Fig. 2(a), there is a −50.27 dBm, −49.85 dBm, −59.83 dBm, and −72.95 dBm signal present at channels 36, 47, 53 and 60 respectively, which are among the list of "free" channels provided by the GLSD.

Model-driven GLSDs use information about registered primary transmitters and compute white space at a given location based on propagation models such as ITU-R P.1546 [12]. The GLSD is required to have up-to-date information about primary transmitters but, the spectrum scan shows that some of the free channels as determined by the GLSD are in fact not free. They are tainted by unregistered sources to which a model-driven GLSD is agnostic. Furthermore, from the spectrum scan, we find (at the time) other free channels not provided by the GLSD. These findings expose the pitfalls of deploying *"sense-less"* white space devises (WSD) i.e. white space Devices with no inbuilt spectrum scanning capability. We recommend that WSDs using the GLSD for white space detection and incumbent protection supplement the query results with localised real-time spectrum scans for increased spectrum reuse and determining white space with a "finer grain".

5 Conclusion and Future Work

The correlation of RSSI dependency on antenna height is most significant over channels with strongest signal. RSSI increases as the height increases up to 8.5 m, similar to model prediction.

The differences observed in the GLSD's view of TVWS and the ground truth highlights the complex dynamics of the wireless communication medium and the limitations of propagation models. Considering the noise levels in some of the channels provided by the GLSD, the suitability of these channels will depend on the application specifics. However, it is evident that the spectrum database alone is inadequate in determining perfectly clear white space to use. Although this observation was made with TVWS GLSD, similar results can be expected with model-driven GLSD for other spectrum bands.

One limitation of this study is that measurements at different antenna heights were done one height level at a time. The observed variation in RSSI could be due to changes in the height or changes in the spectral environment over the measurement period. With this observation, future work will include a setup where measurements at different heights may be taken simultaneously.

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