Chapter

Coverage Determination of Incumbent System and Available TV White Space Channels for Secondary Use in Ethiopia

Habib Mohammed, Tessema T. Terefe and Sultan Feisso

Abstract

Different path loss modelsare used to analyze the behavior of terrestrial television signals. The path loss calculated by one model differs from the other depending on different factors they consider. Frequency is one of the main factors included in each model. The frequency variation in the electromagnetic spectrum causes different response for each model. In terrestrial TV signal representation, since it is operating under VHF and UHF spectrum range, the propagation model used to model the signal must be less invariant when the transmitter is operating in VHF and UHF. If the pathloss model used is very variant it is difficult to define the coverage of the transmitters. This causes interference among transmitters and between the digital terrestrial TV transmitters and TV white space devices. Different propagation models are analyzed by their sensitivity to frequency variation from very-high and ultra-high frequency spectrums. After the best model is selected, we have used this model to find the coverage of the incumbent transmitter, which then is used to analyze free channels for secondary use. First the pathloss at VHF and then for UHF is calculated. This difference is then compared and the result indicates that ITU-R P.1546–5, which incorporate terrain data is best of others. Using this model and further analyze the coverage and free channels, we have found a minimum of 408 MHz free contiguous bandwidth, by considering a worst-case scenario, which is placing a WSD at the incumbent transmitter.

Keywords: Contour Coverage, Free Channels, Pathloss Models, Co-Channel, Adjacent Channel, Field Strength, Digital Terrestrial TV, TV White Space

1. Introduction

TV White Space is the free channel or frequency range which was already dedicated for terrestrial television transmission in one country's boundary. The channels reserved for this primary use may be found free in time and spatial variations. The availability of free channels depends on these variations. The variations on the other hand resulted from geographical difference and other parameters. These parameters are factors on which different propagation models depend. Considering different parameters, the signal of TV propagation must be represented more closely to the natural signal loss of the propagation. For this comparison, different propagation models are taken in to account which have different response for different parameters. One may be very sensitive for frequency, where the other considers mainly the terrain and the other may be more sensitive to weather. In addition to these differences in consideration of different parameters, there are some parameters to affect all the models. Frequency is one of these parameters. The propagation losses have different values of sensitivity. Different sensitivity for frequency will cause different response for differences in frequency from very-high frequency (VHF) to ultra-high frequency (UHF). The difference is also not the same for the same variation in frequency for the two frequency ranges [1]. The availability of free channels directly related to the coverage of primary digital terrestrial TV (DTT) transmission system [2–5]. The coverage of incumbent system is directly related to pathloss models which are used to represent the signal propagation of TV signals. Its area of coverage is calculated by using the minimum receivable signal by the DTT receiver which is to be modeled with precise pathloss model [6]. If the pathloss model used for this modeling is very sensitive for frequency in VHF and UHF, it shows a significant variation in coverage area which may result in difference in number of available channels. So, we must select less sensitive model. Propagation models used for modeling the DTT signal, and also for tv white space (TVWS), must be perfect in operating under VHF and UHF band. Also, they must be models which can cover long range in signal propagation, since TV signals cover long distances with small power. In this paper, related works are revised in part II. The next part focuses on coverage determination factors. In IV, system model and problem formulation are discussed. After this, results are discussed and relevant conclusion is given then.

2. Related works

Many papers are done on propagation models to represent TV signals. These papers tried to compare different models with different parameters [7–11]. In [8] Irregular Terrain Model (ITM) is compared with Irregular Terrain With Obstruction Model (ITWOM) and it suggests ITM model to be better for TV signal modeling, since ITWOM is better in shorter distances which range up to 20 km and since TV signal covers distances up to 100 km and more. This paper also compares ITM, ITU-R P.1546–5 recommendation, Hata Devidson Model, Deygout, Episton-Peterson, and Giovanelli models with real measured data and points out that ITU-R P.1546–5 recommendation shows significant errors for distances above 50 km where as Hata Devidson model gives small errors. It suggests ITM to be better in error minimization with cost of huge computation time and steps, by considering terrain of some part of Greece. R. Gorrepati et.al in [9] analyzed the performance propagation models in estimating the TV coverage and they compared Hata and ITU-R P.1546–4 recommendation. The basic parameter for comparison is consideration of terrain data and the result shows the coverage is better when terrain data is considered using ITU-R P.1546–4 model. The paper concludes, propagation models which consider terrain data have better performance in coverage estimation TV transmission. But it only considers two models. Mesele Mekonen [7], tried to select propagation model for signal representation of TV signals. He has selected ITU, Stanford University Interim, Cost231 Hata, Okumura Hata, Okumura and Free space pathloss models for comparison. His comparison was by pathloss values of different propagation models and selected Okumura Hata pathloss model to have the lowest value for rural and for urban areas, SUI model is selected for shorter distances and Okumura model for longer distances. But according to [12], COST231 Hata model is valid for frequencies 500 MHz–1500 MHz and link distances up to

20 km. So, it does not include VHF frequency and long ranges of coverage. Also, Stanford University Interim according to [13], and ITU-R P.1411 model according to [14] are not used to model TV signals in both VHF and UHF range and for transmitter antenna heights of higher value. This paper does not also consider the real terrain map of Ethiopia. The propagation models selected for comparison must be valid for both VHF and UHF frequency ranges, larger range of signal coverage and higher Tx antenna heights. Papers done before do not try to compare the propagation models according to their sensitivity to frequency variation in VHF and UHF bands. Since this will cause a significant coverage difference in incumbent system, we have tried to compare pathloss models using their sensitivity behavior to frequency by including propagation models which include Ethiopian terrain data. And using this model, we have investigated the how much capacity is available in Ethiopia.

3. Coverage determination factors

3.1 Incumbent coverage determination

The coverage of primary DTT signal is the area between the transmitter and the points at which the received signal has the minimum receivable quality. At these points the signal power is considered to be of minimum value for a primary receiver below which it cannot have a viewable quality [2]. The determination of coverage area is essential in primary system deployment in order to avoid interference [3]. It can be determined by using noise limited contour or interference limited contour. The former method formulates the coverage area to be the area under the points where the signal carrier to noise ratio is less than the difference of minimum receivable signal value and noise floor. The later method is based on similar formulation where it uses interference instead of noise floor [15].

3.2 Terrestrial TV network frequency

The cellular system for DTT planning uses different planning system [2]. The frequency assignment for each transmitter can be of single channel or multiple channels. If the transmitter broadcasts with two or more channels in its coverage range, it is multiple frequency transmission. Otherwise, it is single frequency transmission. For Ethiopian case, the responsible body, Ethiopian Broadcasting Authority, plans which form of transmission should be deployed in one place. Dominantly, multiple frequency transmission is deployed in the country. The authority is also responsible for other planning strategies for terrestrial TV. The single frequency transmission uses only one frequency and there must be sharp gap between neighboring cells in order to avoid interference. It is usual to use in digital TV transmission. Multiple frequency transmission on the other hand relies on using different channels in the licensed range of frequency for TV all over the country. Different transmitters can use different channels for broadcasting. DTT and analog terrestrial TV (ATT) can use this method. The planning body is responsible for allocation of frequency for each transmitter. The power limit and the coverage should be planned in proper way, so that the secondary use is also facilitated well [16]. There must be a reference for the planning which is derived according to ITU recommendation. Regional conference decisions have also their own contribution in planning of national terrestrial TV [17, 18]. The planning includes fixing the outdoor receivers of antenna height 10 m and indoor mobile receivers to be 1.5 m. In Ref. planning configuration, reference values for receivable field strength, location probability and maximum interference level are set [6].

3.3 DTT protection

The primary transmission system must be kept from different interference sources which can result from white space use also [3]. The protection level for which the receiver of incumbent system kept unaffected is known to be protection ratio. It is the allowed level of signal quality determined by the deference of primary signals and interfering signals. It can be given as carrier to noise ratio, carrier to interference or interference to noise ratio [6]. It is limited by the national regulatory body. For Ethiopian case, since it is in region one, means its bandwidth is 8 MHz, the protection ratio is given by the following **Table 1**. **Table 1** below, illustrates the co-channel and adjacent channel protection ratio at 8 MHz channel bandwidth.

3.4 Propagation models

The frequency for terrestrial TV is different from radio frequency range which are used for other services. Although most of the propagation models developed and being modified are for mobile technology, there are also some propagation models which can cover the frequency range of terrestrial TV broadcasting.

ITU-R P.1546–5 [2, 3, 20]: This propagation model gives a point to area prediction of signals in the frequency range from 30 MHz to 3GHz with in a distance up to 1000 km and effective antenna height up 3000 m. It is statistical model for land, sea and mixed paths. The value of field strength is given in a graphical and tabulated form for some fixed values of frequency, effective antenna height and distance from the transmitter. To find the value of field strength with factors of different values from the givens, it is advisable to use interpolation (when the required value is between given values) or extrapolation (when the required value is out of the given values in the table or graph). The field strength interpolation (formulas for different parameters are given [3] as:

For distance, d, the interpolated field strength (E_d) can be obtained as

$$E_d = E_{inf} + \frac{(E_{sup} - E_{inf}) \log \left(d/d_{inf} \right)}{\log \left(d_{sup}/d_{inf} \right)} \; dB\left(\mu \frac{V}{m}\right) \tag{1}$$

For frequency [3] f, *the interpolated field strength* (E_f) *can be obtained as*

$$E_f = E_{inf} + \frac{(E_{sup} - E_{inf}) \log \left(f/f_{inf} \right)}{\log \left(f_{sup}/f_{inf} \right)} \; dB\left(\mu \frac{V}{m}\right) \tag{2}$$

and

For antenna height (h_1), the interpolated field strength E_{h_1} can be obtained as value [2],

Protection ratio for 8 MHz [2, 19]	
Channel type to be protected	**Protection ratio (dB)**
Co-channel (ΔF = 0)	17
Adjacent channel (ΔF = $\pm$1)	−36

Table 1.
Protection ratios [2, 3].

$$E_{h_1} = E_{inf} + \frac{(E_{sup} - E_{inf})\, log\left({}^{h_1}\!/_{h_{inf}} \right)}{log\left({}^{h_{sup}}\!/_{h_{inf}} \right)}\, dB\left(\mu \frac{V}{m} \right) \tag{3}$$

Here, the subscripts *inf* and *sup* indicates the values of respective parameters given in the graph or table directly below and above the required value, respectively. In this model there are other factors like time percentage and location probability to be taken into account.

Okumura Hata Model [8]**:** Covers distance (d) up to 100 km. The operating frequency (f) ranges from 150 MHz up to 1.5GHz.

The loss for urban areas (L_{urban}) is given by:

$$L_{urban} = 69.55 + 26.16\, log\,(f) - 13.82\, log\,(h_t) - a(h_r) + (44.9 - 6.55\, log\,(h_t))\, log\,(d) \tag{4}$$

The correction factor $a(h_r)$ for middle and small cities is given by:

$$a(h_r) = (1.1\, log\,(f) - 0.7)h_r - (1.56\, log\,(f) - 0.8) \tag{5}$$

For open or rural areas (L_{rural}), it become:

$$L_{rural} = L_{urban} - 4.78(\,log\,(f))^2 + 18.33\, log\,(f) - 40.94 \tag{6}$$

Longley Rice/Irregular Terrain Model [21]**:** It is a model covers a frequency range from 20 MHz to 20GHz. The analysis uses several parameters and contains complex equations where it is simplified by a software called, Signal Propagation, Loss and Terrain Analysis Tool, SPLAT! It takes in the real terrain data and gives the output in coverage map or report in text format. Here we use point to point analysis, where the real data of the terrain is considered.

Hata Devidson Model [22]**:** The model uses frequency 30 MHz–1500 MHz, distance 1 km–300 km, Tx HAAT 20 m–2500 m and Rx antenna 1-10 m.

$$PL_{HD} = PL_{Hata} + A(h_1, d_{km}) - S_1(d_{km}) - S_2(h_1, d_{km}) - S_3(\,f_{MHz}) - S_4(\,f_{MHz}, d_{km}) \tag{7}$$

Where,

$$PL_{Hata} = 69.55 + 26.16\, log\,(f) - 13.82\, log\,(h_1) - a(h_2) + (44.9 - 6.55\, log\,(h_1))\, log\,(d) \tag{8}$$

and the correction factor for receiver antenna is the same as that for Hata model above. *A* and S_1 are factors that extend distance up to 300 km. S_2 is correction factor for HAAT to cover up to 2500 m. And S_3 and S_4 are correction factors for frequency to cover up to 1500 MHz. Hata Devidson Model terms are described in **Table 2** for different distance ranges.

Distance (km)	$A(h_1,d_{km})$	$S_1(d_{km})$
D_{km} < km	0	0
20 < d_{km} < 64.38	$0.62137(d_{km}-20)*[0.5 + 0.15log_{10}10(h_1/121.92)]$	0
64.38 < d_{km} < 300	$0.62137(d_{km}-20)*[0.5 + 0.15log_{10}10(h_1/121.92)]$	$0.174(d_{km}-64.38)$

Table 2.
Terms in the Hata Devidson model.

And for other correction factors, $S_1(h_1,d_{km}) = 0.00784/log_{10}(9.98/d_{km})/(h_1\text{–}300)$, $h_1 > 300$ *m,* $S_3(f_{MHz}) = f_{MHz}/250log_{10}(1500/f_{MHz})$ *and* $S_4(f_{MHz},d_{km}) = [0.112log(1500/f_{MHz})](d_{km}\text{-}64.38)$, $d_{km} > 64.38$ *km.*

Egli Model [10]**:** A model for UHF and VHF in frequency range of 40 MHz–900 MHz. It calculates point to point link path loss for urban and rural as well. It is developed to include irregular terrains and its loss formula is given by:

$$PL_{Egli} = \begin{cases} 20\,log\,(f) + 40\,log\,(d) - 20\,log\,(h_t) - 10\,log\,(h_r) + 76.3, h_r \leq 10m \\ 20\,log\,(f) + 40\,log\,(d) - 20\,log\,(h_t) - 10\,log\,(h_r) + 83.9, h_r > 10m \end{cases} \quad (9)$$

Where h_r is receiver antenna height AGL in meter, h_t is transmitter antenna height AGL in meter, d is the distance between transmitter and receiver in kilometers and f is the frequency in MHz.

4. System model and problem formulation

4.1 Problem formulation

For efficient utilization of free channels, keeping the interference minimum at the same time, the path loss model used by calculation engine must be efficient, where it should support both VHF and UHF. The path loss model should be less variant in different frequency ranges. If the path loss value has significant difference for frequency values in VHF and UHF, this will cause significance difference in contour coverage of the digital TV (DTV). This will on the other hand cause a variation in channels which are set free or occupied. Free channels for VHF may be occupied on UHF and vice versa. Propagation models selected for comparison must support the working frequency range of TV system. They must also be applicable for rural areas, since TV white space is assumed to be more applicable for rural areas. For our case, the TV frequency ranges from 174 MHz to 846 MHz. So, all the propagation models are defined for this frequency range. After the propagation model is selected, the coverage of the TV transmitter should be analyzed and this is used further to analyze the free channels which will be available as white space channels.

4.2 System Modeling

For the analysis purpose we have selected the above propagation models. These models are compared by their response for frequency variation. The analysis is done using Matlab software and SPLAT!. For those which can be simulated using Matlab, we have selected the transmitter to be Furi, which is located south west of Addis Ababa city and five different test points. To guarantee the reason of selection, Furi is working in frequencies under channel 7 and channel 42 [23]. The test points are selected in order to consider different points in geographical location, distance and terrain types. All the points shown in the **Figure 1** below are different in pathloss calculation parameters.

Frequencies of comparison are center frequencies for VHF and UHF frequency ranges of Ethiopian TV transmission band. The center frequency for VHF in Ethiopian case is taken by using the calculation formula:

$$f_{c(VHF)} = {(178MHz + 220MHz)}/{2} \quad (10)$$

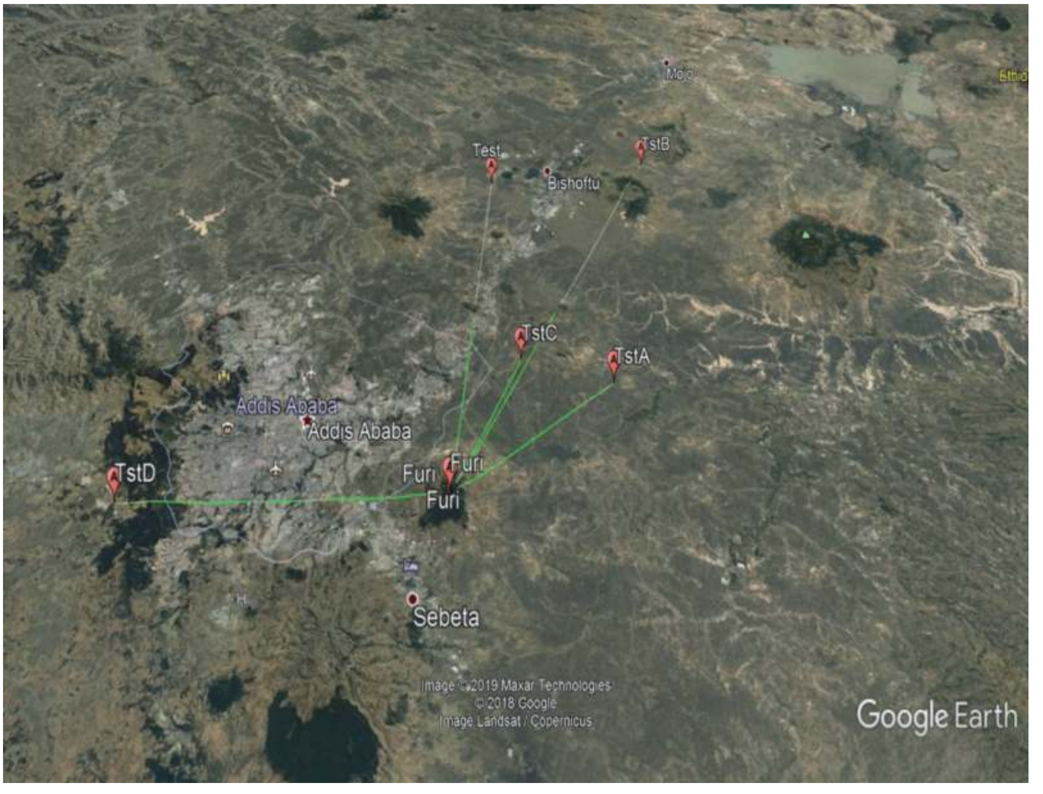

Figure 1.
Test points for pathloss analysis (adapted from Google Earth).

And its value is 199 MHz. For UHF case, the minimum frequency is 474 MHz and the maximum frequency is 786 MHz. The center frequency then is 636 MHz, with equation below.

$$f_{c(UHF)} = {}^{(474MHz+786MHz)}\!/_{2} \tag{11}$$

Other parameters taken as common for all models are:

- Transmitter height above ground level = 30 m, which results in HAAT of 639.42 m at Furi.
- Receiver antenna height = 1.5 m.
- Time and location probability for Longley Rice model are 0.95 and 0.5 respectively
- And the distance between Tx. And Rx. is 35 km (from **Figure 1**)

For the pathloss analysis of Longley rice model the real data is used for different locations. These test points (shown in **Figure 1**) are selected at random. The points selected, although they are random, are selected from different locations to include different propagation path types.

5. Discussion of results

The response of propagation models for frequency variation from VHF and UHF shows different value for various models. For the models described above, a detailed comparison is made so as identify which propagation model is best fit for quantifying the available TVWS channels in Ethiopia's TV frequency interest. When the proposed propagation model (ITU-R P.1546–5) is implemented after interpolation, the pathloss must be changed toa new loss with the following formula:

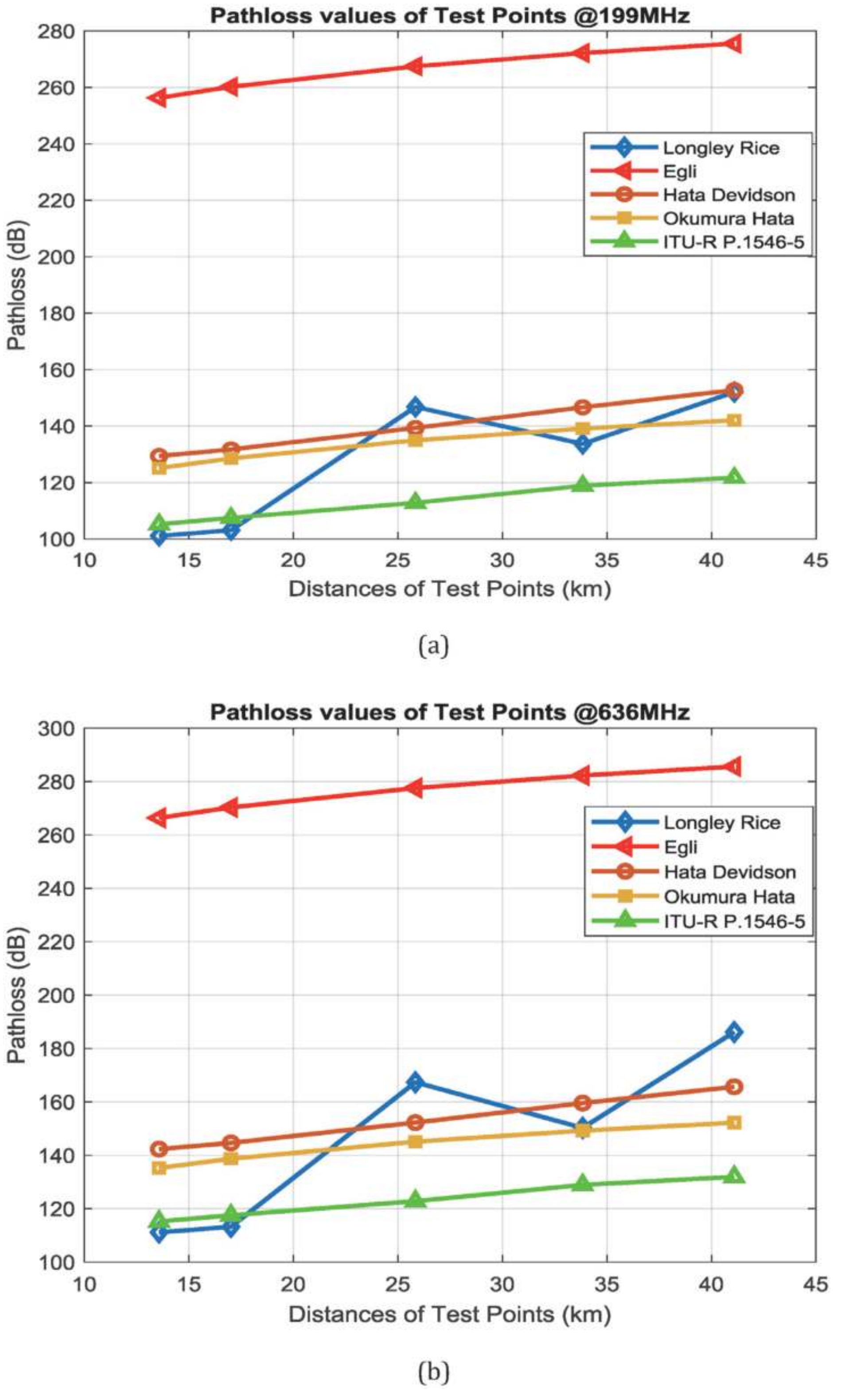

Figure 2.
Pathloss model results (a) and (b).

$$L = 139.3\text{-}E + 20log(f)\ where\ E\ is\ in\ dB\left(\mu\frac{V}{m}\right) where\ f\ in\ MHz \tag{12}$$

After this transformation is made different calculations are performed and compared with the loss difference of other models by using the scenario depicted in **Figure 1**.

As can be seen from **Figure 2**, the comparison between different pathloss models for VHF and UHF TV transmission spectrums are illustrated. The path loss is computed based on the scenario illustrated in **Figure 1**. As seen from the **Figure 1**, the proposed propagation model (ITU-R.P.1546–5) gave a much better result than others. Hence, so as to compute the available TVWS free spectrums at a certain place and location, ITU-R.P.1546–5 is the best propagation model.

Based on the results obtained in **Figure 2**, sensitivity of the propagation models comparison can be best described at different frequency ranges as depicted in **Figure 3**. As seen in **Figure 3**, the Longley Rice model is very sensitive at different frequency and distance ranges. It has also varying value of pathloss differences at different test points. So, taking the average of these values, we have a difference of *18.28.* The other values, as can be seen from the graph, are somewhat with constant value. Comparing these values, the pathloss model, ITU-R P.1546–5 shows the minimum variation for frequency variation of TV signals from VHF to UHF with a value of 9.9736. The other model with the nearest value is Okumura Hata model. But selecting ITU-R P.1546–5 model has better advantage in consideration of terrain data. So, ITU-R P.1546–5 is the best pathloss model to represent TV signal coverage and signal modeling. Using this pathloss model, the free channels found free with assumption that the WSD is placed at the center of each TV transmitter, which is the worst-case scenario for WSD placement, we have found free channels as shown in **Figure 4** below.

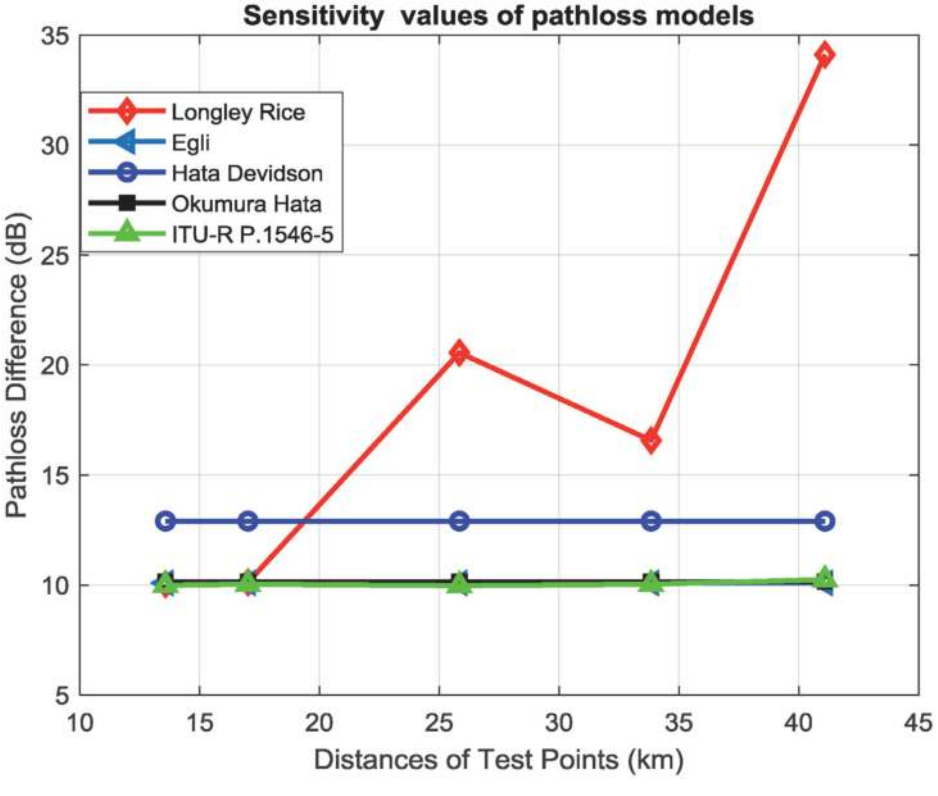

Figure 3.
Variations of Pathlosses for VHF and UHF.

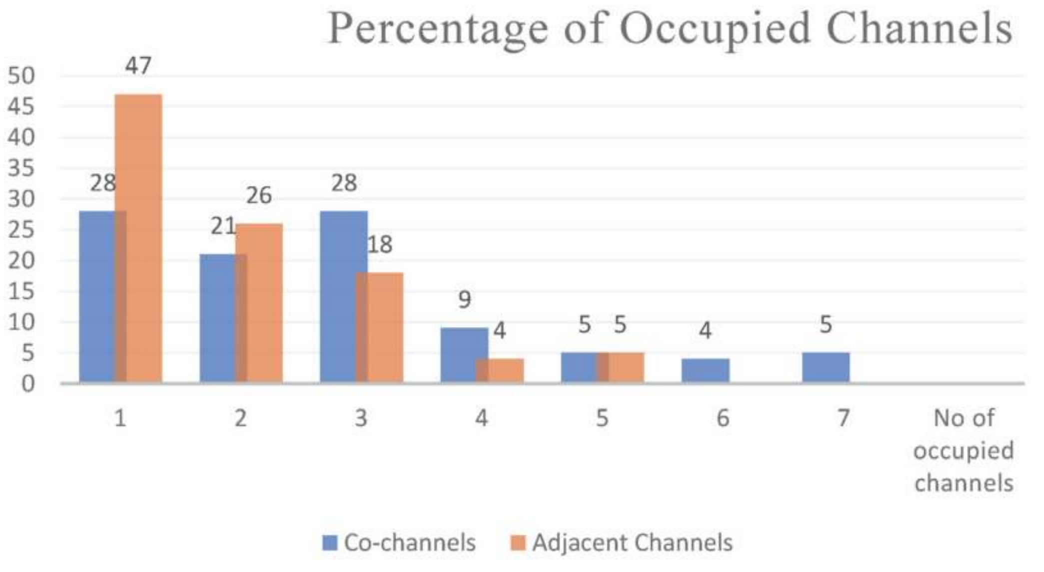

Figure 4.
Number of occupied channels and their respective percentages for Co and adjacent channels.

As can be seen from **Figure 4**, among the 58 TV transmitter channels, sites which have 1 occupied co-channel and adjacent channel is 28% and 47% respectively. Likewise, sites which have 2 occupied co-channels and adjacent channels is 21% and 26% respectively and so on up to 7 occupied co-channels and adjacent channels. These values indicated that there are 51 to 57 free unoccupied free channels in Ethiopia among the 58 TV transmitter. Exploiting such vacant TV spectrums for affordable wireless broadband, machine to machine communication, vehicle to vehicle communication vision sensors and etc. are very promising. **Figure 4** also depicts that the highest capacity for secondary use is concentrated around one up to three. This implies that the majority of free channels, which can reach 80% of free channels, have a minimum of 51 channels (contiguous bandwidth of 408 MHz) available.

6. Conclusion

From the given models, looking at the values of differences in loss at different frequencies, small variations are observed at ITU-R P.1546–5 model. Hence, we can select ITU-R P.1546–5 recommendation to be less sensitive to the variations in frequency from VHF to UHF. So, it is the best model to represent the TV signal with less variation in loss value whether the TV is operating in VHF or UHF band by incorporating the real terrain data of Ethiopia. Using this pathloss model, we have calculated free channels and found many free channels. Out of 58 TV channels, a minimum of 51 channels are free for secondary use. It indicates there is a sufficient amount of contiguous bandwidth up to 408 MHz for white space use.

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