Practical Implementation of Geo-location TVWS Database for Ethiopia

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Abstract. The opening of Television White Spaces for cognitive access is one of the first tangible steps towards solving the spectrum scarcity as well as rural connectivity problems. Because this part of the spectrum band offers better bandwidth, good propagation characteristics such as building penetration and large coverage. In this paper, we have discussed a practical implementation of geo-location-based TVWS assignment modelling approach that solves the spectrum underutilisation problem. The model is based on the CSIR Geo-location Spectrum Database Calculation Engine that is used to intelligently, identify White Spaces in the radio frequency band of interest in Ethiopia. More broadly, we have looked on the necessary input parameters including radio propagation models fit for the Ethiopian terrain environment and calculation steps for quantifying TV White Space availability. The models used by the Calculation Engine used are able to predict the incumbent TV transmitter contour coverage distances, adjacent and co-channel protection distances, list of occupied channels on the co-channel and adjacent channel basis. Moreover, using the proposed implementation for the Ethiopia use case; considerable amount (87.9% - 98.23%) of broadcast TV channels are found to be unoccupied geographically, such channels can be used for secondary provisioning of affordable wireless broadband networks.

Keywords: Calculation Engine, Cognitive Radio, Geolocation database, HAAT, Propagation Model, Secondary User, TV White Space.

1 Introduction

The spectrum deficiency has become a restrictive factor to the wireless communication systems to alter more users and incorporate more services. Allocating new spectrum for the extra services and increasing the capacity is very expensive since the available spectrum is a depleting resource and has already been assigned to various wireless systems. These systems named as the authorized users who have an exclusive use of the spectrum. On the contrary, as it has been investigated in [1] the actual spectral burden shows that there are large idle spectral bands called White Spaces (WS). Although white spaces can be found within any allocated spectrum band, the current focus is on the broadcast television (TV) band. The availability of WS in the broadcast TV band (also referred to as Television White Spaces (TVWS) may increase due to the digital dividend resulting from the ongoing migration from the analogue to the digital broadcasting technologies or commonly known as the digital switch over (DSO). As of [2] an intensively researched technology that can offer a secondary use for TVWS application is Cognitive Radio (CR). CR allows communication of unlicensed devices, as secondary users, to access the spectrum that is temporarily unused or underutilised by incumbents. The development and use of the CR was demonstrated by the digital switchover happened in the UK [17, 31], Japan [18], US [3, 34], South Africa [6, 7, 37], Ghana [38], Tanzania [36], etc., leaving useable spectrum in the TV band to CR use. In 2008, the United States Federal Communications Commission (FCC) adopted rules to allow unlicensed radio transmitters, to operate in the broadcast television spectrum on a sharing basis with incumbents [3]. In 2013, the European Electronic Communications Committee (ECC) report 186 [4] was issued by the European Conference of Postal and Telecommunications Administrations (CEPT), in which technical and operational requirements for the operation of White Space Devices (WSDs) under geo-location approach were proposed[4]. DSO in Ethiopia is expected to be completed in 2020 [5]; thereafter, some of the TV channels will be announced as digital dividend. TVWS channels are supposed to be used by low power WSDs in such a way not causing harmful interference to the primary system. Despite the large amount of TVWS, to enable secondary operation of Cognitive radio, the WSDs should implement methods for TVWS detection and incumbent services protection. The regulatory bodies around the world, i.e., US, in Europe and in some African countries such as South Africa, Malawi, Botswana, Mozambique and Ghana have largely proposed two dominant techniques for possible operation in the TVWS. These are (1) Geo-location White Spectrum Databases (GLSDs) (2) Spectrum sensing. However, the most desirable technique for enabling spectrum sharing between primary and secondary users in a given location is through GLSDs [6, 7]. The following three applications of GLSDs make it the desirable techniques in many TVWS implementations [6, 7]. These are:

- It interprets the protective WS spectrum usage regulations provided by the national spectrum regulatory authorities.

- It assigns the locally available spectrum channels by protecting the primary user networks from harmful interference.
- It offers technical mechanisms for enabling WSDs to access locally available WS spectrum channels.

When the WSD requests for channels, the database should respond in a way to utilize free channels with priority for incumbent users. For the request to be made, the WSD device need to have dataset parameters like location, height of antenna, maximum Effective Radiated Power (max ERP), site name, channel, frequency and other relevant information which are needed by the Calculation Engine whether to avail or prohibit the requested channel. The GLSD Calculation Engine accommodates information about the primary users/incumbents and can calculate which channels and power levels are available at a given location. The Calculation Engine will do this calculation for the specific location and technical parameters offered by the device. After the calculation has made it will provide the available channels and powers to the device then the device will start transmitting [8]. The rest of the paper is organized as follows: Section II provides related work; Section III provides white space calculation Engine parameters; how the white space calculation engine works is presented in Section IV; and finally, the experimental results and conclusion are provided in Section V and VI respectively.

2 Related Work

The United States FCC was the first regulatory body to propose the GLSD dynamic white spaces access [9]. Murty et al. [10] indicated the GLSD assisted white spaces networking can provide mobile users with more convenient and stable dynamic access. Gao et al. [11] proposed the Geo-location database-driven opportunistic spectrum access approach to support the mobile users, which is designed for the vehicle-to-vehicle communication scenario. Chen and Huang [12] proposed the single-channel white spaces networking deployment with the support of Geo-location database. Madhavan et al. [13] introduced the utilization approach of low-power TVWS channels for small-coverage-range cellular networks. In addition, Ameigeiras et al. [14] investigated how to dynamically deploy the small cells in TV white spaces. It has been well demonstrated in [15], in the United States, only 5 channels per person are available on average in the UHF band. In Europe, around 18% of the UHF band is available per person [16]. Studies have also been explored in the United Kingdom [17], Japan [18] and some African countries such as South Africa [6, 7, 37], Tanzania [36] and Ghana [38]. The scenario is hugely surprising in developing countries like Ethiopia where there is very poor spectrum utilization of the TV band. There is only one terrestrial TV broadcaster in Ethiopia i.e. Ethiopian Broadcasting Authority (EBA). EBA transmits only two channels at any location in the country, each channel occupying a bandwidth of 8 MHz in VHF and UHF band. After digital switchover in Ethiopia which is expected in 2020 [5], there will be abundant amount of unused bands which may prove to be very effective in connecting the rural and remote parts of the country as it has been investigated in [19].

3 White Space Calculation Engine Parameters

3.1 Terrestrial Television Planning Models

Understanding the planning strategy of Ethiopia is the primary step since our plan is to use the Ethiopian terrestrial television as a source of TVWS. The power limit for transmitters, frequency allocation and severe cases to which the TV receiver can be functional are included in Terrestrial television Planning [6, 7]. The quality of received signal can be ensured by evaluating the signal field strength [20] or some calculations made based on collected data [21]. The planning of national terrestrial TV has valuable effect on the database design to which it puts some configurations as a reference to be utilized in different cases. These references come from the ITU recommendations for radio regulation [22]. Regional conferences for radio communication, country specific conferences and ITU multilateral agreements have also their own effect on it [23, 24]. The configurations are for transmitter-receiver pairs. Their geometrical set up includes fixed outdoor receiver with 10m antenna, mobile indoor and outdoor receiver with 1.5m antenna. Technologically terrestrial TV transmitter and receiver pairs can be classified as analogue or digital. Digital technology, since it is recent and advanced, can be used for both outdoor and indoor fixed and mobile Transmitter-receiver pair whereas analogue is used only for fixed outdoor receivers. Generally, reference-planning configurations also put reference values for field strength at the receiver, interference level and location probability for a given specific frequency [6, 7].

3.2 Terrestrial TV Network Frequency

It is very important to understand the frequency used for the network in order to have information on how a database can operate to avail free channels for secondary use. Sometimes one main transmitter with high power of transmission may be surrounded by very small power re-transmitters in order to provide full coverage to the areas which are uncovered by the main transmitters. These low power repeaters inserted in the coverage area of high-power transmitters can be owned by the national TV planning body or certain village may deploy to have good coverage within the intended area. Terrestrial TV networks based on the frequency used in one transmitter are typed as single frequency or multiple frequencies [6, 7].

Single Frequency Transmitters: these transmitters use one frequency or channel for broadcasting. The use of one channel may also be extended to the national level where only one frequency is used to transmit the TV content. During this transmission there must be sufficient gap to avoid any type of interference. The channel reuse must be applied in order to support many transmitters to cover the whole country. The separation is special gap since one frequency is used. These transmitters are usually used in DTT [6, 7].

Multiple Frequency Transmitters: At one transmitter, many signals at more than one frequency are broadcasted. Transmission of different contents can be used to allow regional broadcast of different contents. There must be good control mechanism for prevention of adjacent and co-channel interferences which are being used at one transmitter. Reuse is also allowed in multiple frequency transmitters and there is better channel utilization than single frequency transmission. Here usually analogue and mixed ATT and DTT transmissions are used [6, 7].

3.3 Terrestrian Television Coverage Determination Approaches

The area which a terrestrial TV covers is determined based on the value of power or field strength at the receiver. When we go far away from the transmitter it is obvious that the signal quality, due to power degradation, decreases and reaches to some value below which there will be no signal received. This minimum value of signal field strength is called minimum median field strength and its value is set by the planning authority. Then the area in between the transmitter and the points on which the transmitted signal gets the value equal to minimum median field strength is called coverage area. The determination of this coverage area follows two main approaches [6, 7].

Noise limited contour: in this approach the coverage is determined to be an area with in which the condition which concludes that the difference of minimum receivable signal power and noise floor of the receiver must exceed the threshold of carrier to noise ratio. Incumbent receivers must be protected from other Digital Terrestrial TV (DTT) transmitters and devices which operate with similar frequency [6, 7].

Interference limited contour: In this approach multiple frequency TV transmitters are assumed to exist. Multiple frequencies will cause interference at the receiver unless they are separated by sufficient separation distance. The coverage with this approach is formulated like noise limited contour except that noise floor of a receiver is replaced by interfering signal power [6, 7].

For analogue TV, the carrier to noise ratio is approximately 8.05 dB greater than signal to noise ratio [21].

3.4 Protection for Terrestrial TV

The incumbent transmission has to have protection from other interference sources. The protection ratio is the allowed level of received signal to give a protection for incumbent receivers to have sufficient quality of TV signal. The protection ratio may have of different forms, which can be given as carrier to noise ratio, carrier to interference ratio, noise to interference ratio, signal-to-noise ratio [6, 7, 25, and 26].

3.5 Path Loss Models for Terrestrial TV

In spite of the fact that most of the propagation models developed are for mobile technology, there are also some propagation models, which can cover the frequency range of terrestrial TV broadcasting. These models can be categorized into empirical, deterministic and mixed, where these groups can also include models of other frequency ranges [6, 7].

Empirical Models: For such models, data is collected from different locations of signal propagation path and then this value is used to model the signal. In this modeling, since the data is taken from the location of signal path, there would be less dependence of modeling on the terrain and other signal loss factors [6, 7].

Deterministic Models: As its name indicates, this path loss model uses equations already established to predict signal characteristics at a point on the path. Power and field strength are predicted at a distance from the transmitter, usually the transmitter location taken to be the center of radiating antenna. These models are developed in such a way to consider losses.

There are also models which use both methods. These are categorized as mixed models.

Table 1: Selected propagation models [6, 7, 27]

Model	Frequency Range	Distance	Category	Typical Application
Extended Hata	0.03 GHz – 3 GHz	Up to 40 km	Empirical	Point-to-point short -to- medium range planning of terrestrial broadcast station with short-to-medium height antennas. Uses measured terrain data in the form of curves.
Longley-Rice [28]	0.02 GHz – 40 GHz	1km – 2000 km	Mixed: Empirical/ Deterministic	Point-to-averaged-radial and point-to-multipoint planning and generic coordination- planning of terrestrial broadcast stations. Uses terrain profile elevation and measured data.
ITU-R P.1546-5 [33]	0.03 GHz– 3 GHz	1 km – 1000 km	Mixed: Empirical/ Deterministic	Point-to-multipoint generic coordination –planning of Terrestrial broadcast stations. Uses measured terrain data in the form of curves and terrain profile elevation 3 – 15 km from the transmitter.
TM-91-1 [29]	0.04 GHz – 1 GHz	Less than 16 km	Empirical	Point-to-point planning for short distances.

ITWOM [30]	0.02 GHz – 20 GHz	1 km – 2000 km	Mixed: Empirical/ Deterministic	Point-to-point and point-to-multipoint planning of terrestrial broadcast stations. Uses terrain profile elevation and measured data.

In the database design, we must include parameters which affect the incumbent transmission and also the function of WSD. Including significant parameters determine the quality of the database in terms of protecting the primary user and the efficient utilization of the free spectrum.

Protection Ratio: For the successful provision of desired signal quality and to make sure that, the incumbents are protected from harmful interference the terrestrial TV needs to have a minimum signal threshold level called Protection ratio. For protecting incumbents from harmful interference that might be generated by WSDs, Regulators have derived protection ratios for co-channel and adjacent channels; protection is regulated by the national body, which is responsible of allowing secondary usage of spectrum used for terrestrial TV broadcasting. Protection ratio has different values for different ITU regions. Since Ethiopia is located in region 1 (it uses 8MHz bandwidth for terrestrial TV) as it has been depicted in Table 2 below.

Table 2: Protection Ratios [31]

Regulatory body: Ofcom, UK (Class 1 WSD)	
Channel bandwidth	8 MHz
Channel type to be protected	Protection ratio (dB)
Co-channel ($\Delta F = 0$)	17
Adjacent channel ($\Delta F = \pm 1$)	-36

WSD Emission Mask: This is controlled by the regulatory body, which is used to determine the out of band emission limits of the WSD for their operation. The emission power and the operating frequency are necessary to determine the emission mask [6, 7].

4 How White Space Calculation Engine Works

As it has been described in Figure 1 below, the Ethiopia GLSD Front-End is connected with CSIR Calculation Engine (CSIR_CE) through Internet using the Application programming Interface (API) services which are based on JSON RPC 2 [6, 7, 35] for providing available spectrums, available free channels and calculated intermediate values such as contour coverage distance, adjacent and co-channel separation distance, occupied adjacent and co-channels.

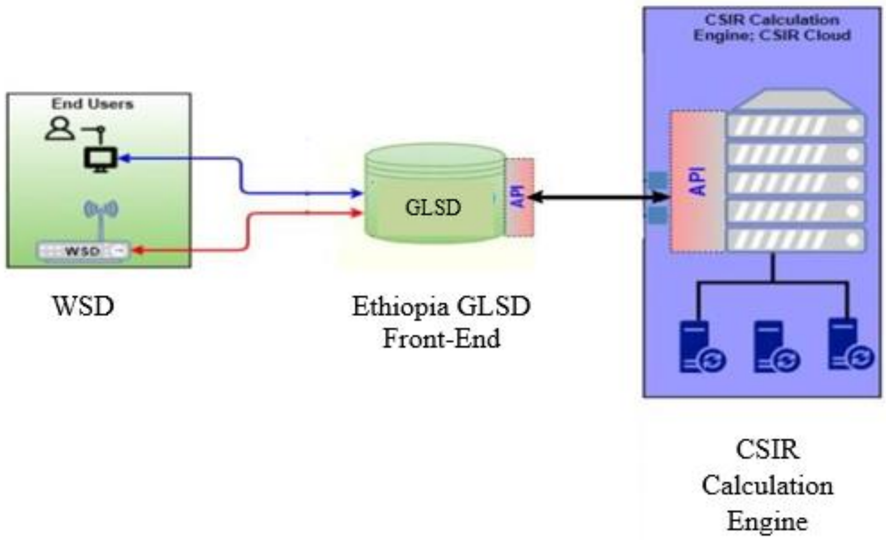

Figure 1: Communication Architecture between Ethiopia GLSD Front-End and CSIR_CE [6, 7, 35]

The first step in practical implementation of the Geo-location White Spectrum Database is identification of TV stations of interest. The transmitter data and location are obtained from EBA. First, the data obtained from the EBA is processed to give it a desired format. To do the computations, the area in the immediate vicinity and of the WSD is considered. The Calculation Engine must have the following information of the WSD for the purpose of verification. There must be an authentication whether the WSD is in the allowed list of devices. If the WSD is verified for service, then the Geo-location White Spectrum Database (GLSD) Calculation Engine accepts the location coordinates in terms of latitude and longitude coordinates. Also, the GLSD Calculation Engine must accept the antenna height of the WSD above the ground level and then check whether it is below 30m or not. If the height is in a given range, the value is recorded for further calculation [6, 7, 33, and 35]. The calculations made by the GLSD to make free channels available for the WSD may include multiple steps:

- After authentication, the database must calculate the Antenna Height Above Average Terrain (HAAT)/or the effective antenna height of the WSD.
- If HAAT is below 10 m [6, 7, 34]; use the TM-91-1 propagation model [6, 7, 29] to calculate the separation distance of the incumbent protected contour and WSD.
- For longer HAAT above 10 m, use the ITU-R 1546-5 propagation model [33] by applying interpolation for a given value of E_{WSD}. This value of separation distance is used by the database to avail the free channels (co-channels or adjacent channels) by checking whether the WSD is inside or outside the minimum distance [33].

4.1 Determination of HAAT/Effective Antenna Height

First, the geographical location of the antenna is taken as input. Then, radials at 10 degree (angular intervals can be used in accordance with the level of accuracy we need) starting from true north will be set to calculate the average terrain**.** For the determination of HAAT; the surrounding terrain of the transmitter is measured from 3.2 km to 16 km away from the transmit antenna in a desired equal step sizes. Alternatively, for the determination of Effective antenna height; the surrounding terrain of the transmitter is measured from 3 km to 15 km away from the transmit antenna in a desired equal step sizes [32]. The terrain of distance less than 3 km from the transmitter antenna does not influence the coverage, so that it is ignored during calculation. Then the average value for each radial is again averaged for all radials and this height will be given as HAAT. Allowable HAAT is defined not to be more than 250m [34].

4.2 Maximum Allowable WSD field strength (EWSD) Calculation

The maximum allowable field strength for the white space device is calculated from incumbents protected contour median field strength (dBμV/m), protection ratio (dB) and receivers' front-to-back ratio (dB).

$$E_{WSD} = E_{med} - R_p + R_{FP} \quad (1)$$

Where: E_{WSD} is maximum allowable WSD field strength, E_{med} is minimum median field strength R_p is protection ratio of incumbent receiver, R_{FB} is receiver's front to back ratio.

Using TM-91-1 propagation model [29], we can have:

$$E_{WSD} = 1.414 + 20\log(h_1 h_2) - 40\log D_{sep} + 10\log P_{WSD} \quad (2)$$

Where: h_1 and h_2 are antenna heights above mean sea level, D_{sep} is separation distance between WSD and incumbent protected contour and, P_{WSD} is ERP of a WSD in Watt.
From this equation, we can derive that the separation distance is given by:

$$\mathrm{D_{sep}} = \frac{1.085 * \sqrt{h_1 h_2} * \sqrt[4]{P_{WSD}}}{10\exp\left(\frac{E_{WSD}}{40}\right)} \quad (3)$$

The WSD must be at least this much D_{sep} away from the protected contour of incumbent transmitter for free channels to be available. If HAAT of the WSD is above 10 m, the database must use ITU-R 1546-5 propagation model at 50% of location and 1% of time [6, 7, 34] to calculate the minimum separation distance. This model takes protection ratio and HAAT as an input. By taking into consideration of pathloss which is attributable to the distance the WSD and the TV receiver; the WSD field strength E_{WSD} is therefore determined as follows:

$$E_{WSD} = 106.9 - 20\log D \tag{4}$$

Where: E_{WSD} is free space field strength for 1kW ERP, D is the distance in km [16].
From this, we can derive the distance value and for each frequency of operation of a WSD and HAAT, we have to interpolate or extrapolate to calculate the separation distance.

4.3 Contour Distance for Incumbent Transmitter

It is calculated as a function of field strength. The field strength is found with the following steps: Take the normalized field strength value of an antenna to be 0.707 at Half Power Beam width (HPBW) or use alternative method which uses depression angle and calculate it. Then, Square this normalized field strength value and multiply it with maximum ERP of the incumbent transmitter. This gives a radial ERP. Reference with 1kW ERP and change it into dB form to obtain radial power. Subtracting this radial power from minimum median field strength value of its respective frequency, will give radial field strength (E_r) [6]. Use this radial field strength value and ITU-R 1546-5 propagation model at 95% location and 50% time to calculate the contour coverage distance. Since the value may not be those given in graphs [34], it is better to interpolate the distance with the formula given below.

$$D_c = D_{inf}\left(\frac{D_{sup}}{D_{inf}}\right)^{\left(\frac{E_r - E_{inf}}{E_{sup} - E_{inf}}\right)} \tag{5}$$

where ,D_c is contour coverage distance, D_{sup} is the distance for E_{sup}, D_{inf} is the distance for E_{inf}, E_r is radial field strength, E_{sup} is the nearest field strength above E_r, E_{inf} is the nearest field strength below E_r.
The database should first have the following information saved in it. The location and contour coverage of each incumbent transmitter are basic [6, 7]. When the WSD is found in the area and it requests for free channels, the database performs some calculations using the CSIR Calculation Engine and replies for the request [6, 7]. First, the WSD sends its location, Height Above Ground Level (HAGL), ERP and channel request. The Geo-location White Spectrum Database Calculation Engine then identifies the WSD whether it is registered or not [6, 7]. Let us assume the WSD is a certified device. It then calculates HAAT by taking HAGL and WSD location as an input. Then it takes front to back ratio, protection ratio (it is different for adjacent and co channels) and minimum median field strength to calculate maximum allowed field strength of WSD. This value is used then to calculate separation distance of WSD from the contour coverage of the given incumbent

transmitter. These transmitters should be first identified as transmitters in the area where WSD causes interference. It is given to be the area with in the radius of 150km. After the separation distance is calculated, it is then added to contour coverage of the incumbent transmitter. This value is then subtracted from the distance between WSD and incumbent transmitter. Again, this difference will be used for further calculation and decision. Let's assume it is x: if x≥ 0, then the channels in the incumbent transmitter can be used, otherwise since there will be interference, no channels will be available.

4.4 Haversine Function Formula

We have used Haversine formula with the following equations to identify the sites to be affected by the WSD. Haversine formula is also used to calculate the distance of the WSD. Haversine formula takes inputs of latitude and longitude coordinates of the two locations, for which the separation distance between them is to be calculated [6, 7].

$$D=2R\arcsin\sqrt{haversine(\varphi2-\varphi1)+\cos(\varphi1)\cos(\varphi2)\,\mathrm{haversine}(\lambda2-\lambda1)} \quad (6)$$

$$\mathrm{Haversine}\ (\theta)=\sin^2(\theta/2) \quad (7)$$

Where, $\phi1$ and $\phi2$ are latitude of point 1 and latitude of point 2 respectively where, $\lambda1$ And, $\lambda2$ are longitude of point 1 and longitude of point 2 respectively and R is the radius of Earth.

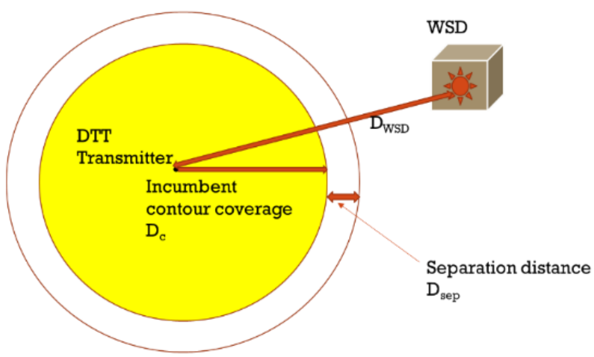

Figure 2: Illustration of WSD and DTT Transmitter location

With representation of parameters as shown in the above Figure 2, the database will be designed to function as shown in the flowchart in Figure 3.

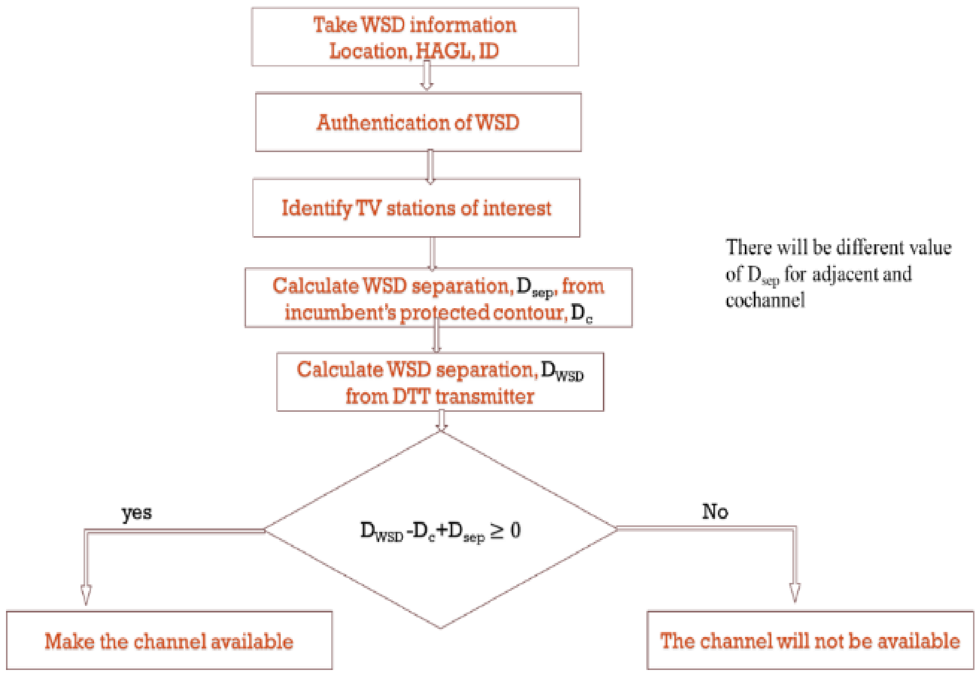

Figure 3: Flow Chart for the Calculation Engine

5 Experimental Results

We have taken the WSD to be located at a plateau near Tulu Dimtu (Addis Ababa) condominium site with transmitter HAGL to be 30m. For DTT transmitters, we have also assumed to be 30m HAGL. However, when we identified the transmitters which could be affected by the WSD, there was only Furi site (Addis Ababa) identified as depicted in Figure 4. As it can be seen from Table 3 Using GLSD Calculation Engine, we have able to determine the coverage contour distance of the given free channels and the separation distance of the adjacent and the co-channel transmitters from the contour for protecting the incumbents from harmful interference. For instance for Furi Transmitter site, the adjacent and co-channel separation distance between the WSD and the incumbent coverage contour is 1.027 km and 58.48 km respectively. To be specific, the WSD must be 1.027 km away from the protected contour of adjacent incumbent transmitter and 58.48km away from the protected contour of co-channel incumbent transmitter for TVWS free channels to be available. From the Table 4 we can see that, by using the Geo-location White Spectrum Calculation Engine, we can have a minimum of 51 free channels and maximum of 57 free channels among the total number of 58 TV transmitters' channels in Ethiopia. For example, When Calculation Engine has made a calculation for Furi transmitter site coordinates, there are about 3 occupied TV Transmitter channels and 55 free TVWS channels. In other words, the TVWS availability around Furi Area (Test Place) is around 94.8%. In general, the range of TVWS availability in Ethiopia is from 87.9%-98.23%.

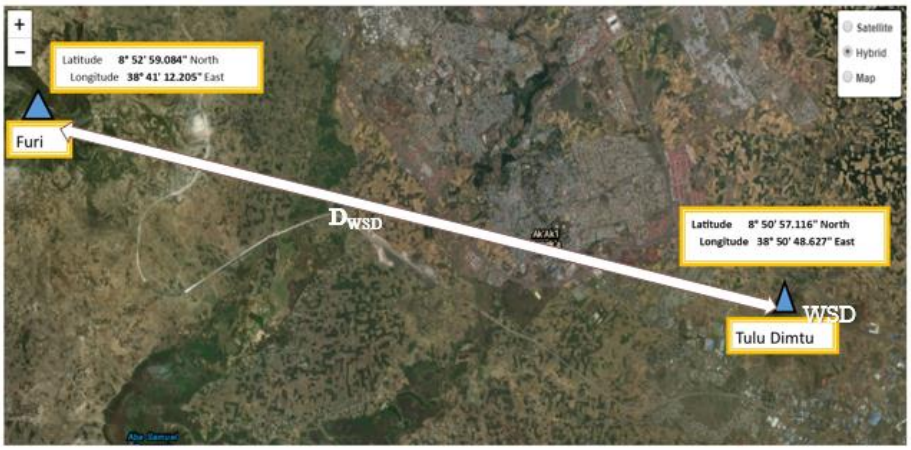

Fig 4: Testing the Calculation Engine at Addis Ababa

Table 3: Coverage contour distance, adjacent and co-channel contour distances using the proposed Calculation Engine.

Site Name	Channel	Coverage contour distances(km)	Adjacent Separation Distance (km)	Co-channel Separation Distance (km)
Furi	5	88.267	1.0207	58.48
Furi	7	88.267	1.0207	58.48
Harar	7	83.382	1.0207	58.48
Dire Dawa	5	84.495	1.0872	60.418
Jijiga	11	82.404	1.0207	58.48
Nazireth	11	85.423	1.0872	60.418
Dessie	9	79.91	0.9094	55.157
Jimma	5	79.302	0.9094	55.157
Nekemte	9	80.96	0.9625	56.737
Shashemene	5	81.552	0.9625	56.737
Dila	11	84.811	1.0872	60.418
Gondar	7	84.811	1.0872	60.418
Bahirdar	5	82.648	1.0207	58.48
Mekele	7	84.382	1.0528	59.423

Axum	9	81.552	0.9625	56.737
Assosa	11	79.91	0.9094	55.157
Gode	9	81.552	0.9625	56.737
Adi Remest	35	60.891	0.3885	35.087
Ankober	34	61.146	0.3932	35.325
Assosa	60	55.51	0.2977	30.793
Debark	57	56.061	0.3063	31.207
Dessie	48	57.864	0.3355	32.587
Dila	29	62.51	0.4191	36.59
Kebridahar	24	57.651	0.3316	32.422
Fiche	50	57.442	0.3285	32.261
Furi	42	59.216	0.3578	33.642
Gore	50	57.442	0.3285	32.261
Jijiga	43	58.981	0.3531	33.457
Jimma	45	58.524	0.3469	33.099
Jinka	46	58.3	0.3427	32.925
Kuni	35	62.224	0.4138	36.326
Maichew	54	56.635	0.3158	31.643
NefasMewca	21	65.061	0.4684	38.927
Shebel	28	62.802	0.4246	36.86
Tendaho	43	58.981	0.3531	33.457
Weldia	25	63.723	0.4424	37.705
Nekemte	38	60.174	0.3744	34.418
Gode	28	62.802	0.4246	36.86
Mekele	54	56.635	0.3158	31.643
Axum	51	57.236	0.3241	32.102
Dire Dawa	42	59.216	0.3578	33.642
Mega	53	56.832	0.3182	31.794
ChokeTeraa	32	61.673	0.4033	35.815
Abiy Adi	24	64.046	0.4486	38
Amentila	40	59.698	0.3667	34.022
Derba	34	61.146	0.3932	35.325
Warder	47	57.014	0.3382	32.754
Filtu	41	56.759	0.3618	33.83
Adigrat	51	57.236	0.3241	32.102
Ginir	45	58.524	0.3469	33.099
Dellomena	40	58.6	0.3667	34.022
Fik	51	56.186	0.3241	32.102
Maji	36	59.605	0.3838	34.85
Guba	23	64.377	0.4555	38.302
Yabello	50	55.353	0.3285	32.261
Samre	47	58.081	0.3382	32.754
Bella/Ghimi	24	57.651	0.3316	32.422

Table 4: Identification of occupied adjacent and co-channels TV spectrums for each TV transmitter sites in Ethiopia for interference protection.

Site Name	Channel	Occupied Adjacent	Occupied Co-channel
Furi	5	11 ,38 and 42	11, 38 and 42
Furi	7	11, 38 and 42	11, 38 and 42
Harar	7	5, 11 and 42	5, 11, 42 and 43
Dire Dawa	5	5 and 42	5, 11 and 42
Jijiga	11	11 and 43	5, 11 and 43
Nazireth	11	11	11, 38 and 42
Dessie	9	9 and 48	9, 48 and 25
Jimma	5	5 and 45	5 and 45
Nekemte	9	9	9
Shashemene	5	5 and 11	5, 11 and 29
Dila	11	5, 11 and 29	5, 11, 29 and 34
Gondar	7	7	5, 7 and 57
Bahirdar	5	5	5 and 7
Mekele	7	7, 54, 24, 40 and 47	7, 9, 54, 24, 40, 51 and 47
Axum	9	9, 51 and 24	7, 9, 51, 24 and 51
Assosa	11	11 and 60	11 and 60
Gode	9	9 and 28	9 and 28
Adi Remest	35	35	7 and 35
Ankober	34	34	11 and 34
Assosa	60	11 and 60	11 and 60
Debark	57	7 and 57	7, 9, 35 and 57
Dessie	48	9 and 48	9, 48 and 25
Dila	29	5,11 and 29	5, 11, 29 and 34
Kebridahar	24	24	24
Fiche	50	50	50 and 38
Furi	42	11, 42 and 38	11, 42 and 38
Gore	50	50	50
Jijiga	43	11 and 43	5, 11 and 43
Jimma	45	5 and 45	5 and 45
Jinka	46	46	46
Kuni	35	35	5 and 35
Maichew	54	7, 54 and 47	7, 54, 40 and 47
Nefas Mewcha	21	21	7, 5 and 21
Shebel	28	28	28
Tendaho	43	43	43
Weldia	25	25	9, 48 and 25
Nekemte	38	38 and 42	11, 38, 42 and 50
Gode	28	9 and 28	9 and 28
Mekele	54	7, 54, 24, 40 and 47	7, 9, 54, 24, 40, 51 and 47
Axum	51	9, 51 and 24	7, 9, 51, 24 and 51
Dire Dawa	42	5 and 42	5, 11 and 42
Mega	53	53	53
Choke Terara	32	32	5 and 32
Abiy Adi	24	7, 9, 24 and 47	7, 9 , 24, 40, 47, 51 and 54
Amentila	40	7, 40, 47 and 54	7, 9, 24, 40, 47 and 54
Derba	34	34	11, 29 and 34
Warder	47	47	47

Filtu	41	41	41
Adigrat	51	7, 9 and 51	7, 9, 24, 51 and 54
Ginir	45	45	45
Dellomena	40	40	40
Fik	51	51	51
Maji	36	36	36
Guba	23	23	23
Yabello	50	50	50
Samre	47	7, 24, 40, 47 and 54	7, 9, 24, 40, 47 and 54
Bella/Ghimbi	24	24	24

6 Conclusıon

This paper focused on the practical implementation of the GLSD modelling approaches based on the CSIR calculation engine for predicting the amount of TVWS in the Ethiopia use case. The experimental results have indicated that most of Ethiopian TV spectrums are underutilised or unused. We can observe from the results output that the implemented model is good at estimating the amount of white spaces as well as for coexistence of primary and secondary devices. Therefore, rural areas in Ethiopia have a bright future in light of using these free channels for rural broadband as well as for solving spectrum scarcity in urban areas.

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References

[1] G. Staple and K. Werbach, "The end of spectrum scarcity," IEEE Spectrum, vol. 41, no. 3, pp. 48–52, Mar. 2004.

[2] M. Fitch, M. Nekovee, S. Kawade, K. Briggs, and R. MacKenzie, "Wireless service provision in TV white space with cognitive radio technology: A telecom operator's perspective and experience," Communications Magazine, IEEE, vol. 49, pp. 64-73, 2011.

[3] FCC, "Second report and order and memorandum opinion and order," no. FCC 08-260, Nov. 2008.

[4] ECC Report 186, Technical and Operational Requirements for White Space Devices under Geo-location Approach, Jan. 2013

[5] Inview to provide middleware for Ethiopian Digital Switchover, September 18, 2017. Available

online: https://www.telecompaper.com/news/inview-to-provide-middleware-for-ethiopian-digital-switchover--1212244. (Access date: February 18, 2019).

[6] L. Mfupe, F. Mekuria And M. Mzyece, Geo-Location White Space Spectrum Databases: Models And Design Of South Africa's First Dynamic Spectrum Access Coexistence Manager, Ksii Transactions On Internet And Information Systems Vol. 8, No. 11, Nov. 2014

[7] Mfupe, L., Mekuria, F., Mofolo, M. " CSIR Geo-location Spectrum Database: Calculation Engine Application Programming Interface", [Online Available], https://glsdceapis.meraka.csir.co.za:8443/

[8] Marija Denkovska, Pero Latkoski, Liljana Gavrilovska," Geolocation Database Approach for Secondary Spectrum Usage of TVWS", 19th Telecommunications forum TELFOR 2011 Serbia, Belgrade, November 22-24, 2011.

[9] A. B. Flores, R. E. Guerra, E. W. Knightly, P. Ecclesine, and S. Pandey, "IEEE 802.11af: A standard for TV white space spectrum sharing," IEEE Commun. Mag., vol. 51, no. 10, pp. 92–100, Oct. 2013.

[10] R. Murty, R. Chandra, T. Moscibroda, and P. Bahl, "SenseLess: A database-driven white spaces network," IEEE Trans. Mobile Comput., vol. 11, no. 2, pp. 189–203, Feb. 2012.

[11] B. Gao, J.-M. Park, and Y. Yang, "Supporting mobile users in databasedriven opportunistic spectrum access," in Proc. ACM MobiHoc, 2014, pp. 215–224.

[12] X. Chen and J. Huang, "Database-assisted distributed spectrum sharing," IEEE J. Sel. Areas Commun., vol. 31, no. 11, pp. 2349–2361, Nov. 2013. ZHOU et al.: WhiteFi INFOSTATION: ENGINEERING VEHICULAR MEDIA STREAMING 2273

[13] M. Madhavan, H. Ganapathy, M. Chetlur, and S. Kalyanaraman, "Adapting cellular networks to whitespaces spectrum," IEEE/ACM Trans. Netw., vol. 23, no. 2, pp. 383–397, Apr. 2014.

[14] P. Ameigeiras, D. M. Gutierrez-Estevez, and J. Navarro-Ortiz, "Dynamic deployment of small cells in TV white spaces," IEEE Trans. Veh. Technol., vol. 64, no. 9, pp. 4063–4073, Sep. 2014.

[15] S. Mishra, A. Sahai, How Much White Space Is There?, Tech. Report UCB/EECS-2009-3, EECS Department, UC Berkeley, January 2009, http://www.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-3.html.

[16] J. van de Beek, J. Riihijarvi, A. Achtzehn, P. Mahonen, TV white space in Europe, IEEE Transactions on Mobile Computing 11 (2) (Feb. 2012) 178–188.

[17] M. Nekovee, Quantifying the availability of TV white spaces for cognitive radio operation in the UK, in: Proc. of IEEE International Conference on Communications, Jun. 2009, pp. 1–5, Workshops.

[18] T. Shimomura, T. Oyama, H. Seki, Analysis of TV white space availability in Japan, in: Proc.of IEEE Vehicular Technology Conference, Sep. 2012.

[19] H. Mohammed, K. Katzis, L. Mfupe, E. Teshale," how much TV white spaces is available in Ethiopia using geolocation spectrum white space database?,ICT4DA2019,Bahirdar, May 8-10,2019 (accepted).

[20] J. Damelin, W. Daniel, H. Fine, and G. Weldon, "Development of VHF and UHF Propagation," Report R-6602, FCC, Office of Chief Engineer, Research Division, September 07, 1966..

[21] P. G. Brown, K. Tsioumparakis, M. Jordan, and A. Chong, "UK Planning Model for Digital Terrestrial Television Coverage," R&D White Paper, WHP 048, BBC, September 22, 2002.

[22] GE-06: Final Acts of the Regional Radiocommunication Conference for planning of the digital, Vols. ITU, RRC-06.

[23] Final Acts of Europe VHF/UHF Broadcasting Conference, ITU 1961.

[24] The Chester 1997 Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the Introduction of Terrestrial Digital Video Broadcasting (DVB-T), CEPT, July 25, 1997, Chester.

[25] Recommendation ITU-R BS.707-4 "Transmission of multisound in terrestrial television systems PAL B, D1, G, H and I, and SECAM D, K, K1 and L,, 1998.

[26] Recommendation ITU-R BT.1895, "Protection criteria for terrestrial broadcasting systems," 2011.

[27] Recommendation ITU-R p.1144-6 , "Guide to the application of propagation methods of Radiocommunication," 2012.

[28] A. G. Longley and P. L. Rice, "Prediction of Tropospheric Radio Transmission Loss over Irregular Terrain, A Computer Method-1968," ESSA Technical Report ERL 79-ITS 67, NTIA-ITS, July 1968.

[29] W. Daniel and H. Wong, "Propagation in Suburban Areas at Distances less than Ten Miles," FCC/OET TM-91-1, January 25, 1991.

[30] S. Shumate, "Longley-Rice and ITU-R P.1546 Combined: A new International Terrain-specific propagation model," Proc. of 72ND Vehicular Technology Conference, IEEE, pp. 1-5, 6-9, Sept 2015.
[31] Ofcom, UK, "TV white spaces: Approach to co-existence," Technical report, September 4, 2013.
[32] Industry Canada, Spectrum Management and Telecommunications Database Requirements: White Space Database Specifications, DBS-01, Issue 1, February 2015.
[33] ITU-R, Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 300 MHz, International Telecommunication Union, Geneva, Recommendation P. 1546-5, September 2013.
[34] Federal Communications Commission, DSA / White Space Interoperability Work Group Geographic Contour Request for Comment WINNF-11-RFI-0016-V1.0.0, November 6, 2011.
[35] The JavaScript Object Notation (JSON) Data Interchange Format" RFC7159, JSON RPC 2.0, http://www.jsonrpc.org/specification.
[36] Lance Harris, Microsoft launches next TV white space pilot in Tanzania, [Online Available]: http://www.zdnet.com/article/microsoft-launches-next-tv-white-space-pilotin-tanzania/, 2013, May 13, [Accessed 27, March. 2019]
[37] Steven Song, Studies on the Use of Television White Spaces in South Africa: Recommendations and Learnings from the Cape Town Television White Spaces Trial, [Online Available]: http://www.tenet.ac.za/tvws/recommendations-and-learningsfrom-the-cape-town-tv-white-spaces-trial
[38] Microsoft 4Afrika, Spectra Wireless and Microsoft 4Afrika Launched Africa’s First Commercial Service Network Utilising TV White Spaces in Ghana (Jan. 26, 2015), [Online Available]: https://www.microsoft.com/africa/4afrika/Ghana_TVWS-PR.aspx