Co-existence of TV Broadcast and Wireless Systems for Public Safety Networks in the TV White Space

L. Kabiru[1*], N. T. Surajudeen-Bakinde[1], N. Faruk[2], A. A. Ayeni[2]

[1]Department of Electrical and Electronics Engineering, University of Ilorin, P.M.B. 1515, Nigeria.
[2]Department of Telecommunication Science, University of Ilorin, P.M.B. 1515, Nigeria.

ABSTRACT: The spectrum sharing between primary TV systems (Channels 9 and 35) and Public Safety Networks (PSNs) is presented in this article. The networks to be deployed within Television White Space (TVWS) in Ilorin metropolis of Kwara State operate on a secondary basis spatially, without causing harmful interference to incumbent TV users. In order to guarantee the protection of incumbent TV users both in VHF and UHF bands, minimum separation distances were suggested considering field strengths of 36 dBu and 41 dBu as the protected contours for the two bands respectively. The effects of varying the transmit power and the antenna height of the secondary system on the coverage area are emphasized in this work. Aggregate interference effect from the multiple secondary systems on the TV service coverage was also investigated. The performances of VHF and UHF bands were also verified when used for secondary transmission both at lower and higher transmit power scenarios. The results of this work show that the safety networks can co-exist with the TV systems without causing harmful interference with the suggested separation distances at the edge of the noise-limited service area, where the signal-to-noise ratio is 16 dB as recommended by the International Telecommunication Union-Radio sector (ITU-R).

KEYWORDS: PSN, TV systems, Signal-to-Noise Ratio, TV White Space, Service coverage.

[Received April 18 2016; Revised October 3 2016; Accepted November 27 2016]

I. Introduction

Public safety is a general term which encompasses law enforcement, response to fire, natural and artificial disasters, medical emergencies, threats to public order and a host of other life-threatening situations (Arthur, 2012). In some cases, the law enforcement agencies, volunteer efforts, medical responder cohorts are augmented with National Emergency Management Agency (NEMA) and non-governmental organizations with the intent to ensure safety. The prompt response to disasters depends on the effectiveness of communication systems and management of relevant information. For instance when a tragic disaster occurs, the emergency response strategy will be established at appropriate level depending on the nature of the disaster, while necessary resources and technical support are mobilized to take emergency response actions and to report relevant developments to the administrative body immediately (Heejoong, 2012).

The urgent need for this research work is due to the insurgency experienced throughout the nation, most especially in the northern part of Nigeria which witnessed the brutal attacks from a sect called Boko-Haram, whereby GSM base stations were destroyed to prevent communications between the people and the emergency agencies. A means of GSM-independent communication is presented in this article.

White spaces are vacant frequency bands between occupied (licensed) broadcast channels or broadcast auxiliary services like wireless microphones (Sascha and Michael, 2008). Due to high demand for spectrum as a result of rapid growth in wireless technology, efficient use of spectrum is becoming more essential requirement. Within the radio spectrum, the portion of the spectrum below 1 GHz is of particular interest because of the favourable propagation characteristics compared to those of the higher frequencies, which are currently used to provide wireless services, such as mobile internet and Wireless Fidelity (Wi-Fi) (Heejoong, 2012).

In this regard, there are challenges facing the researchers, which include how to develop channel spaces that can be utilized by the new services due to the TV transition era (The Nigerian National Broad band Plan 2013-2018). Therefore, a new concept has emerged to use unoccupied spectrum in the TV band, which is called TV White Space. According to (Hufford, 2004), the expectations from using TVWS for wireless broadband services are high, and a lot of works have been done on the commercial and technical viability of TVWS operations. The tangible secondary use of the spectrum is now the focus after a lot of research has been carried out on the general availability of whitespace spectrum (Beek, 2011).

Faruk et al. (2013) worked on reliable prediction technique to allow efficient utilization of TVWS in Nigeria. Gbenga-Ilori and Sanusi (2014) worked on maximizing the available TVWS in Nigeria through the determination of spectrum savings after the analogue-digital switch-over. The effects of TVWS on digital dividend and internet penetration in Africa were studied by Opawoye et al. (2015).

*Corresponding author's e-mail address: klateef004@gmail.com

doi: http://dx.doi.org/10.4314/njtd.v13i2.3

U.S and Korea were successful in deploying two kinds of devices i.e. TETRA base stations (BSs) and mobile stations (MSs) which operate at adjacent channel of TV as interferers. Shamsan et al. (2008), explained the role played by Microsoft in the first U.S deployment of TV white spaces in Claudville, Virginia with the intent to provide a broadband network as an alternative to the existing network. Achtzehn et al. (2012), explained how the deployment of a cellular network in the TVWS could be done. Singapore White spaces Pilot Group (SWSPG) was established in April, 2012 with support from Infocomm Development Authority (IDA) to deploy white spaces technology pilots in Singapore, which invariably accelerates the adoption of white space technologies world-wide. In the same year, Heejoong et al. (2012) studied the environmental improvement for DTV white space utilization with narrow band system, and a suggestion for a DTV White Space management scheme that will be able to enhance spectrum efficiency by considering unoccupied channel conditions according to the density of DTV transmitters and relays was given.

As a matter of fact, there is the need to establish standards to enhance the efficient utilization of spectrum. Chittabrata and Sumit (2011) provided insights and important considerations for successful development of new wireless standards. Naotaka et. al. (2012) and David et al (2008) devised techniques to protect the incumbent service by stating the requirements for communication and interaction between a White Space Device (WSD) and Geo-location data base, and this is also the major reason why FCC stated the required separation distance in addition to the protected contour based on the antenna height of the WSD as shown in Table 1 (FCC, 2008).

In this research work, the primary aim is taking the advantage of available spectrum resources in VHF and UHF TV bands (Channels 9 and 35 respectively) within Ilorin City to propose the possibility of deploying public safety networks, which would serve as means of facilitating the information dissemination among the public safety agencies.

Table 1: FCC protection areas.

Antenna Height of Unlicensed Device (m)	**Required Separation(km) From Digital or Analog TV (Full Service or Low Power) Protected Contour**	
	Co-channel (km)	Adjacent Channel (km)
< 3.0	6.0	0.1
3 - < 10.0	8.0	0.1
10 – 30.0	14.4	0.74

II. MATHEMATICAL DESCRIPTIONS OF SOME PROPAGATION PARAMETERS

A. Path Loss Model

There is no precise propagation model used for various studies on spectrum sharing, because the particular deployment of the systems requires using specific signal propagation model that conforms to the specific system. Davidson model is a derivative of the Hata model which is an empirical formulation of the graphical path loss data provided by Okumura and is valid for frequency range of 150 MHz to 1500 MHz (Faruk et. al., 2013). Davidson model provides six correction factors which make its range extend to 300 km and also gives minimum prediction errors compared to its counterpart path loss models.

Path loss equation for Davidson model is given as follows:

$$L_D = L_{HATA} + A(h_{te}, d_{km}) - S_1(d_{km}) - S_2(h_{te}, d_{km}) - S_3(f_{MHz}) - S_4(f_{MHz}, d_{km}) \quad (1)$$

where, L_D is the Davidson path loss model in dB,

$$L_{HATA} = 69.55 + 26.16 \times \log_{10}(f_c) - 13.82 \times \log_{10}(h_{te}) - a(h_{re}) + (44.9 - 6.55 \times \log_{10}(h_{te}))\log_{10}(d) \quad (2)$$

$a(h_{re})$ is the correction factor for the receiver height

For a small and medium city,

$$a(h_{re}) = (1.1 \times \log_{10}(f_c) - .07)h_{re} - (1.56 \times \log_{10}(f_c) - 0.8)$$

For large city the receiver correction's factor is:

$$a(h_{re}) = \begin{cases} (8.29(\log_{10}(1.54 \times h_{re})^2) - 1.1); & f_c \le 200\,\text{MHz} \\ 3.2 \times (\log_{10}(11.75 \times h_{re})^2) - 4.97; & f_c \ge 400\,\text{MHz} \end{cases}$$

$A(h_{te}, d_{km})$ and $S_1(d_{km})$ are distance correction factors

$$A(h_{te}, d_{km}) = \begin{cases} 0; & d < 20\,\text{km} \\ 0.62317 \times (d - 20)[0.5 + 0.15 \times \log_{10}(h_{te}/121.92)]; & 20\,\text{km} \le d < 300\,\text{km} \end{cases}$$

$$S_1(d_{km}) = \begin{cases} 0; & d < 20\,\text{km} \\ 0; & 20\,\text{km} \le d < 64.38\,\text{km} \\ 0.174 \times (d - 64.38); & 64.38\,\text{km} \le d < 300\,\text{km} \end{cases}$$

$S_2(h_{te}, d_{km})$ is the base station antenna correction factor;

$$S_2(h_{te}, d_{km}) = \{0.00784 \times |\log(9.98/d)| \times (h_{te} - 300) \quad \text{for } h_{te} > 300\text{m}$$

$S_3(f_{MHz})$ and $S_4(f_{MHz}, d_{km})$ are frequency correction factors.

$$S_3(f_{MHz}) = \frac{f_c}{250 \times \log 10(1500/f_c)}$$

$$S_4(f_{MHz}, d_{km}) = [0.112 \times \log_{10}(1500/f_c)](d - 64.38) \quad \text{for } d > 64.38\text{ km.}$$

B. Signal Field Strength

The signal field strength is obtained by deducting the signal path loss (in dBm) from the transmitted power (in dBm) for the TV systems over some kilometers away from the transmitter. Then, the signal field strength is computed in (dBu) to obtain the protected contour and the protected region for the TV systems. This can be obtained directly from the magnitudes of the path loss at various distances away from the transmitter from equation (3) (Heejoong et. al., 2012)

$$P_t(dBm) = E(dBu) - 130.8 + 20\log_{10}(615/f_{mid}) \quad (3)$$

where, P_t is the signal power in dBm, E is the electrical field strength in dBu and f_{mid} is the center frequency in MHz.

C. Signal-to-Noise Ratio

The signal-to-noise ratio can be calculated as follows (Andreas et al, 2011):

$$SNR = P_t + G_t + G_r - L_D - L - N - IM \geqslant 16 \text{ dB} \quad (4)$$

where, L_D is the path loss (in dB), L is the additional loss margin = 10 dB, N is the thermal noise which is equal to -105.2 dBm, IM is the interference margin = 3 dB, G_t is the transmitter antenna gain (in dB) and G_r is the receiver antenna gain (in dBu). Then, the simulation parameters are shown in Table 2.

Table 2: TV and PSN system parameters

Parameter	Value
Channels	9, 10, 21, 31, 35, 41, 51 & 61
Frequencies (MHz)	203.25, 235, 470, 550, 583.25,630, 710 & 790
ERP for TV system (kW)	65
Transmit Power for WSD (W)	0.04, 0.1, 0.25, 0.5, 1, 2 & 4
BS Antenna height (m	10, 30, 50, 100, 150 & 200
Receiver antenna height (m)	1.5
Transmitter antenna gain (dB)	16
Receiver antenna gain (dB)	8
FCC protection margin (dBm)	-114
D/U ratio at noise limited contour (dB)	15.5

D. Analysis of Aggregate Interference

Due to the imperfection of the TV receiver filter characteristic, the interferences from secondary users (SUs) that are simultaneously active on both co-channel and different adjacent channels would cause cumulative damaging effect on the TV reception as a result of shrinking of the coverage area. This cumulative effect of interferences from multiple channels can be modeled by the weighted summation of the interferences from different channels (Lei et. al., 2014) converging at point P as shown in Figure 1.

Assuming the transmitting power level is Ps for the SU on channel y, the interference received by a TV on channel *x* in pixel ***i*** can be written as shown in eqn (5):

$$I_s = P_s . g. G_r . L_D \quad (5)$$

where, g is the channel fading random variable in dB, G_r is TV receiver antenna gain in dB and L_D is the path loss in dB between SU and TV receiver.

Thus, the aggregate interfering power from each individual secondary transmitter is given by eqn (6):

$$I_{agg} = \sum_{k=1}^{N} I_i = \sum_{k=1}^{N} \frac{S}{N} . P_s . g . G_r . L_D \quad (6)$$

where, N is the number of secondary transmitters deployed in the white space and $\frac{S}{N}$ is minimum required signal-to-noise ratio between channels of the primary and secondary systems.

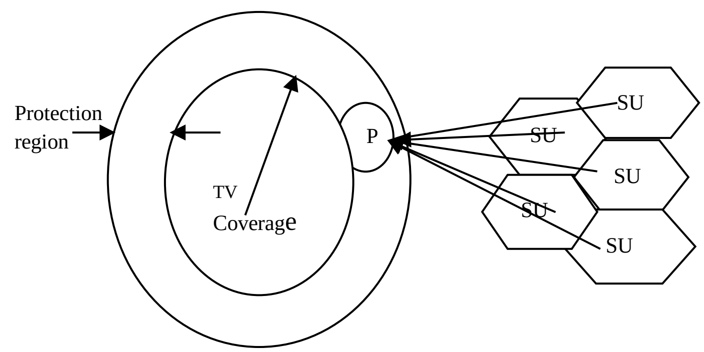

Figure 1: Multiple secondary networks deployment outside TV protection area.

III. METHODOLOGY

In this paper, the focus was on TV channels (NTA-channel 9 and KWTV-channel 35) in Ilorin City of Kwara State, Nigeria and the two TV channels serve as primary systems, while various TV channels in the TVWS were considered as the secondary systems. In this process, Grade B contour is considered for a system in which a primary transmitter communicates with primary receivers within the noise-limited region (Ayeni et. al., 2015). The SU can reuse the same frequency near the cell edge of the PU if it meets the required criterion, specified by FCC for white space. The TV service area is the geographical area within the TV noise-limited grade B contour, i.e. where the received signal strength for channels 7 through 13 and channels 14 through 69 exceeds 36 dBu and 41 dBu for VHF and UHF DTV systems respectively. In order to ensure the PU is highly protected, the SUs must be located outside the grade B contour of the PU putting into consideration the minimum protection distance as laid down by FCC in (FCC, 2008).

Figure 2 shows the spectrum sharing for single primary transmitter and single secondary user in which r_p represents the protection contour-radius, r_n is the no-talk radius and $d_n(\Delta)$ is the protection region. Thus, it can be established that no-talk width is given by:

$$r_n = r_p + d_n(\Delta) \quad (7)$$

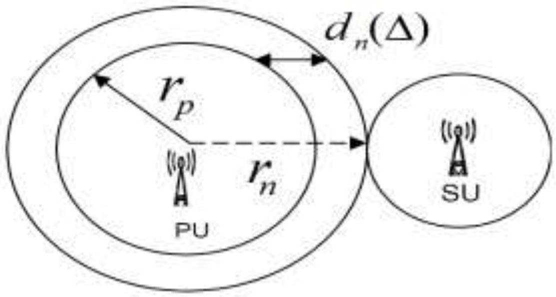

Figure 2: Spectrum sharing for single primary transmitter and single secondary user (Ayeni et. al., 2015).

Then, the points at which 36 dBu and 41 dBu were obtained are the service coverage for both VHF and UHF TV signals respectively.

The SNR was also obtained for all the channels in which channel 31 was singly chosen for the network deployment and the remaining channels would serve as back-up channels. That is, if the primary TV system which is the licensed user of the spectrum is detected in channel 31, the secondary network could be made to operate on any of the back-up channels. The separation distances were calculated by considering the noise-limited region which is the point at which SNR ⩾ 16 dB.

IV. Results and Discussion

It was observed that channels 9 and 10 (VHF) with transmit power of 4 W EIRP and fixed antenna height of 150 m have coverage reduction ratio of 90% when the transmit power is reduced to 40 mW. Invariably, for all UHF channels 21, 31, 41, 51 and 61 under the same power consideration as for the VHF, an average coverage reduction ratio of 84.6% is obtained.

Taking into account the ITU regulation of 36 dBu and 41 dBu for service contours for digital VHF and UHF TV systems respectively, the minimum received signal strength is -95.8 dBm for channel 10 transmitting at high transmit power of 4 W which when extra protection margin of 15.5 dB D/U ratio is imposed reduces to -111.3 dBm. For channel 31, the minimum received signal strengths for both portable and fixed devices are -71.2 dBm and -95.2 dBm, which reduce to -86.7 dBm and -110.7 dBm respectively in the presence of extra protection margin as shown in Figure 3. The implication of these values with respect to -114 dBm defined by FCC as the criteria of the empty spaces for TV white space (Nasir et. al., 2013) is that FCC has chosen additional sensing margins of 27.3 dB and 3.3 dB in both cases of channel 31, but the margin is 2.7 dB in the case of channel 10.

More so, Figures 4 and 5 compare the coverage reduction of the TVBD network due to the primary TV interference with

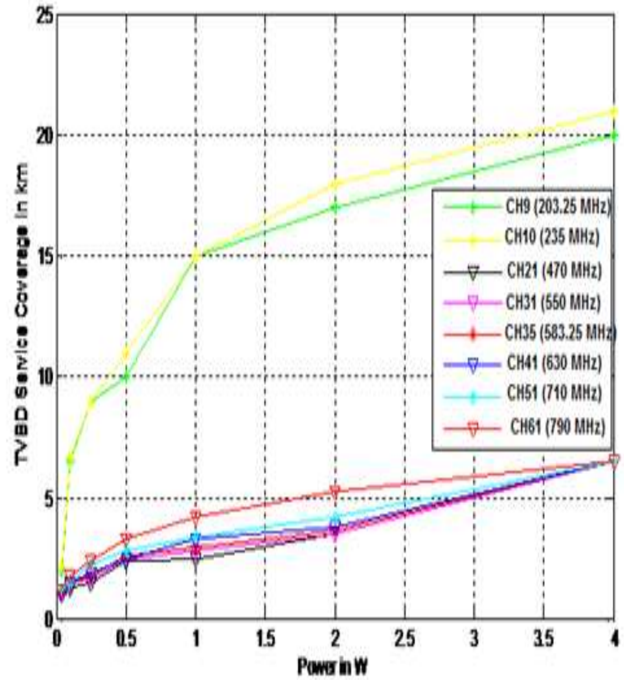

Figure 3: TVBD Service coverage versus Transmit power.

the two transmit power levels of 40 mW and 4W under variable antenna heights in which the minimum and maximum antenna heights considered are 10 m and 30 m (for fixed device) and 10 m and 150 m (for portable / mobile device) respectively. With 4 W transmit power for channel 10, the service coverage of a TVBD network in the presence of primary TV signal is reduced by 52.3% under the influence of the minimum and maximum antenna height scenarios, while for the UHF channels it is reduced by average value of 44.4% as Figure 4 depicts. For transmit power of 40 mW, the coverage reduction ratio for UHF channels is 50% on average as shown in Figure 5.

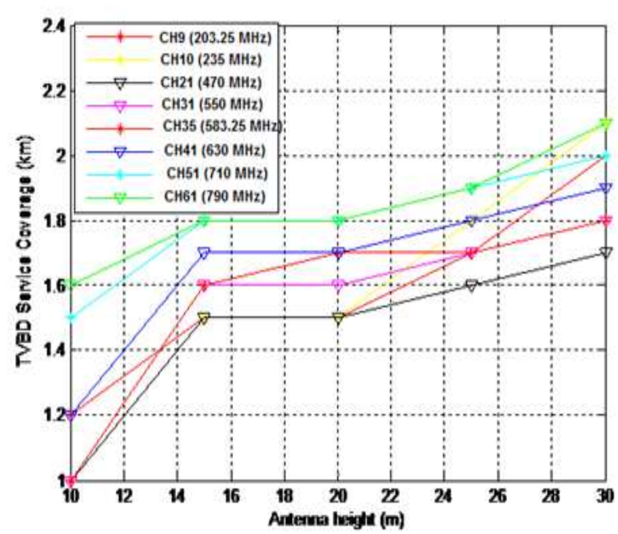

Figure 4: TVBD Service coverage versus Antenna height (for fixed device).

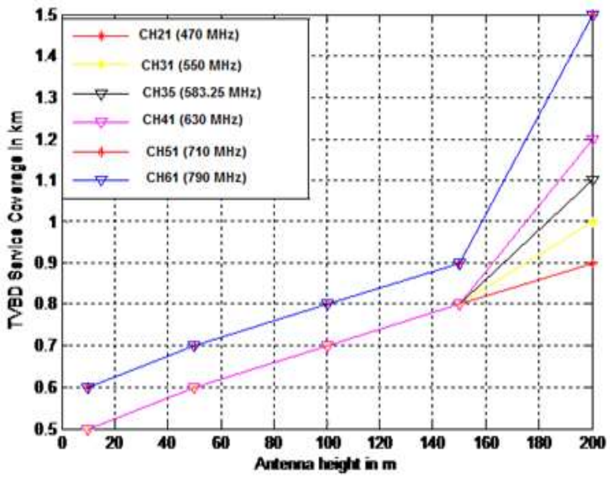

Figure 5: TVBD Service coverage versus Antenna height (for portable /mobile device)

In particular, by considering channel 10 (VHF) and channel 31 (UHF) keeping the remaining channels as back-up channels, the deployment possibilities of the secondary device in the spectrum hole can be established. Since the primary motive is to ensure the co-existence of the TV system and the secondary device without the secondary users causing harmful interference to the incumbent TV users, the percentage reduction of the service coverage is very essential in this scenario as well.

In addition, for the primary TV (channel 9) with ERP of 65 kW and antenna height of 100 m above terrain, the no-talk width for the primary TV is found to be 47 km, and for channel 35 the no-talk width is 40 km. Then, the separation distances of 5 km was obtained for the VHF and 2.2 km for UHF when the maximum transmit power is used (for fixed device), while for the minimum transmit power, the separation distance between the UHF TV and secondary device is 1.0 km for mobile device.

V. CONCLUSION

The prospects of exploiting unused spectrum capacities in the TV band white space for deployment of wireless device that could serve as public safety network have been studied in this article. The approach used in achieving the results emphasized how crucial the effects of varying the transmit power and the antenna height on the service coverage area of the TV system. We have estimated the coverage areas of the TV system and the minimum required separation distance between the TV receiver's antenna and the base station of the PSN. The coverage reduction ratio is also investigated when the PSN operates at different power.

The results of this research work affirm the co-existence possibilities between the TV systems and PSN in as much as the effective parameter selection is made for both fixed and mobile devices to avoid harmful interference to the incumbent TV users, especially for UHF in which there is still extra white space when the minimum threshold as laid down by FCC is considered. The results also showed that the fixed device with transmit power of 4 W and maximum antenna height of 30 m has interference reduction of 2.5% to operate with minimum antenna height of 10 m for VHF, and the interference is reduced by 2.3% for UHF. In the case of mobile device with transmit power of 40 mW and maximum antenna height of 150 m, the interference is reduced by 6.8% to operate with minimum antenna height of 10 m. This shows that mobile devices are more reliable in terms of ensuring protection of the incumbent TV users against harmful interference in UHF, while the fixed devices are preferable for VHF.

REFERENCES

Achtzehn, A.; Riihijärvi, J.; Martínez Vargas, G.; Petrova, M. and Mähönen, P. (2012). Improving Coverage Predition for Primary Multi-Transmitter Networks Operating in the TV Whitespaces. Proc. of IEEE SECON 2012, Seoul, Korea.

Andreas, A.; Marina, P. and Petri, M. (2011). Deployment of a cellular network in the TVWS: A case study in a challenging environment. A conference paper of CoRoNET 11, Las Vegas, Nevada, U.S.A, 1-2.

Arthur, P. T. (2012). Public Safety Networks as a Type of Complex Adaptive System. Research paper, Department of Information and Process Management, National Science Foundation Bentley University, 2-3.

Available online at: www.necsi.edu. Accessed on May 15, 2015.

Ayeni, A.A.; Faruk, N.; Surajudeen-Bakinde, N. T.; Okanlawon, R. A. and Adediran, Y. A. (2015). Spatial Spectrum Utilization Efficiency Metric for Spectrum Sharing System .International Journal of Digital Information and Wireless Communications, 44-51.

Beek, J. v. d.; Riihijarvi, J.; Achtzehn, A. and M¨ah¨onen, P. (2011). UHF white space in Europe - a quantitative study into the potential of the 470-790 MHz band. IEEE Symposium on New Frontiers in Dynamic Spectrum (DySPAN). Available online at: www.inets.rwth-aachen.de. Accessed on October 10, 2014.

Chittabrata, G. and Sumit, R. (2011). Co-existence challenges for heterogeneous cognitive wireless networks in TV white spaces. IEEE wireless communication, 18 (4): 22-31.

David, G.; Greg, B.; Larry, E.; Steve, K. and John, G. (2008). Geo-location Data base Techniques for incumbent protection in the TV white space. IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), in Chicago. Available online at: www.ieee.org. Accessed on November 10, 2015.

Faruk, N.; Adediran, Y.A. and Ayeni, A.A. (2013). Optimization of Davidson Model based on RF measurement conducted in UHF / VHF bands. ICIT 2013 6th International Conference on Information Technology, Al-Zaytoonah University of Jordan, 1-7.

Faruk N.; Ayeni A.A. and Adediran Y.A. (2013). Impact of Empirical Path loss Models on Spatial TV white space utilization. European Scientific Journal, 7: 543-547.

FCC, "Second Report and Order and Memorandum Opinion and Order", in FCC 08-260, Nov. 2008. Available online at: www1.i2r.a-star.edu.sg. Accessed on November 24, 2015.

Gbenga- Ilori, A. O. (2010). Development of VHF and UHF spectrum optimization for Digital Services in selected states of Nigeria. A PhD Dissertation submitted to the Department of Electrical Engineering, University of Ilorin, 151-152.

Gbenga-Ilori A.O. and Sanusi O.I. (2014). Maximizing TV white Space in Nigeria using an optimized SFN and k-SFN network design. International Journal of Science, Environment and Technology, 3: 1489-1501.

Harrison, K.; Mishra, S. and Sahai, A. (2010). How Much White-Space Capacity Is There? IEEE Symposium on New Frontiers in Dynamic Spectrum. Dept. of Electrical Engineering and Computer Sciences, UC Berkeley, 1 –10. Available online at: www.eecs.berkeley.edu. Accessed on May 10, 2015.

Heejoong, K.; Hideki, S. and Akira, K. (2012). Study on Environment Improvement for DTV White Space Utilization with Narrow Band System. International Journal of Networks and Communications (IJNC). Keio University Japan, 2: 38-46. http://research.microsoft.com. Accessed on September 18, 2014.

Hufford, G.A.; Longley, A.G. and Kissick, W.A. (2004). Longley-rice methodology for evaluating TV coverage and interference. FCC OET BULLETIN No. 69.

Lei, S.; Ki Won, S. and Jens Z. (2014). Controlling Aggregate Interference under Adjacent Channel Interference Constraint in TV White Space KTH Royal Institute of Technology", in 7th International Conference Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM). Stockholm, Sweden, 2-4.

Naotaka, S.; Ryo, S.; Chen, S.; Kazushi, M.; Masayuki, A.; Philippe, D.; Junfeng, X.; Yuanyuan, Z. and Martino, F. (2012). TV white spaces as part of the future spectrum landscape for wireless communications. ETSI Reconfigurable Radio Systems Workshop Cannes, France. Available online at: www.docbox .etsi.org. Accessed on May 15, 2015.

Opawoye I.; Faruk N.; Bello O.W. and Ayeni A.A. (2015). Recent trends on TV white space deployment in Africa. Nigerian Journal of Technology, 34:556-563.

Shamsan, Z.A.; Faisal, L.; Syed-Yusof, S. K. and Tharek, A. (2008). Spectrum Emission Mask for co-existence between future WiMAX and existing Fixed Wireless Access Systems. Wireless Communication Center, University of Technology, Malaysia, 7(6): 629-631.

Sascha, D.M. and Michael, C. (2008). White Space Devices and the Myths of Harmful Interference. Wireless Future Program New America Foundation, 3-4. Available online at: www.nyujlpp.org. Accessed on December 25, 2015.

The Nigerian National Broadband Plan 2013-2018. Available online at: www.fmctresource.com. Accessed on January 17, 2014.