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Planning and Simulation of TVWS Network for Broadband Connectivity in Sparsely Populated Environment

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Abstract
Following the switchover from analogue to digital platforms, Television White Space (TVWS) affords a fertile opportunity to supplement existing licensed spectrum to ease the spectrum scarcity. Rural areas in the developing countries are predominantly unconnected as it is not viable for operators to provide broadband access in these areas. This paper designed the frame work and feasibility study for deploying broadband internet services using TVWS technology in Nnobi, a rural community in Anambra State, Nigeria. In this work field trials were carried out to identify antenna locations, an empirical propagation model was developed for the selected rural area, frequency occupancy measurement was done using 110dBm as the threshold value and capacity planning was carried out to determine the number of required sites and equipment, and finally, the network was designed and evaluated using a Radio link level software. From the results obtained such as the pathloss, antenna gain, clearance, elevation angle and distance of the CPEs from the TVWS Base station, helped in determining sites with good propagation conditions (line of site) and sites with bad propagation conditions were relocated. Equally, a comparative study of the cost of connecting such rural community using TVWS and LTE was also carried out. The results obtained showed that the cost of connecting such rural community with TVWS is about $33,809, while the cost of connecting the same community using LTE is about $239,757. The financial analysis has shown that delivering broadband for rural area using currently available technology is more expensive than using TVWS, therefore TVWS is recommended for such scenario.

Keywords: Client Premise Equipment, Dynamic Spectrum Sharing, Geo-location, Television White Space

1. Introduction

Rural broadband connectivity continues to be a challenge even as technology continues to improve networking related products and services. The driving factor is population density, which relates directly to the recovery of infrastructure costs. In areas of low population density there are not enough customers to cover the necessary infrastructure that can enable cost-effective infrastructure investment. The challenges of developing rural broadband are similar to the challenges many developing nations including Nigeria faced when rural electrification was an issue. Delivering broadband networking to sparsely populated regions is a continuing challenge. Terrestrial broadband, using fiber or copper networking, requires the same investment in rural areas as in sub-urban and urban areas. However, in rural areas there are many fewer customers to share the cost of the infrastructure which makes the cost per customer of the infrastructure unattractive to commercial providers (Flores et al. 2013). This has left many rural residents with few options for internet access; often only two alternatives exist; satellite internet or cellular broadband. For example, from the information obtained from Airtel Nigeria Limited (Airtel Nig 2019), Nnewi an urban city close to Nnobi has 5 base station whereas there is only one base station alone covering the entire community of Nnobi. This has resulted to low speed and inefficient broadband connectivity within the community.Clearly, there is a need for a more cost-effective and scalable model to deliver the required broadband capacity that will be demanded in the near future. This will require better spectrum utilization as well as more cost effective and rapid deployment of infrastructure.

The introduction of digital terrestrial broadcasting, which is underway in many parts of the world, provides many benefits, among which is the professed digital dividend. It refers to the spectrum which is released in the process of digital television transition (Brew et al. 2011). When television broadcasters switch from analog platforms to digital only platforms, part of the electromagnetic spectrum that has been used for broadcasting will be freed up because digital television needs fewer spectrums than analog television. The reason is that new digital compression technology can transmit about five digital TV channels by using the same amount of spectrum used to transmit one analogue TV channel. Digital terrestrial television (DTT) delivers an increasing number of quality television programs within the same amount of spectrum that is used by an analogue channel and uses spectrum more efficiently. Another interesting opportunity concerning spectrum exploitation, apart from the UHF band reallocation, is white spaces phenomena. The term white space is referring to the frequencies licensed for a broadcasting service but not used on designated geographical area. Therefore, many initiatives emerged recently to reallocate those parts of the spectrum as unlicensed and made it accessible to the unlicensed devices under the guaranty that they will not interfere with existing or future broadcasting services (Bayhan et al. 2016). The size of white spaces depends of geographic areas.

In Nigeria and Africa as a whole, Band III (174–230 MHz) and Band IV/V (470–862 MHz) is allocated mainly to broadcast services (NBC 2016). The use of these bands is regulated by the GE-06 agreement. This agreement for broadcast services contains frequency plans for both analogue television and digital television services. The analogue television plan will cease to exist after full transition to digital television. Generally, TV white spaces will be made more available through the transition from analogue television to digital television because digital technology allows more information to be aired using less spectrum space. The radio signals in TV spectrum travel farther and penetrate obstacles more effectively than that in typical cellular and Wi-Fi ISM bands owing to the lower frequency of TV bands (COGEU 2010). Therefore, to utilize the TVWS is of great potential for satisfying the increasing demand for wireless spectrum and providing better services. The regulator requires that the unlicensed devices must not interfere with the incumbent users and should query a geo-location database to obtain the white space availability. The major goal of this research is to improve on the performance of a cellular mobile network through opportunistic utilization of TV white space spectrum. The research focused on the planning and simulation of TVWS network for broadband connectivity in a sparsely populated environment.

1.1 Literature Survey

There is a growing recognition that dynamic spectrum sharing, especially on TVWS, has a potential to increase the availability and ubiquity of broadband access, in this way addressing the digital divide in developing regions. As a result, a number of TVWS trials have been conducted around the world with the aim of demonstrating the feasibility of dynamic spectrum sharing on the TV spectrum bands. Results from most of these trials contributed significantly towards the formulation of regulatory rules governing the use of TVWS in some countries.

Microsoft recently announced a commercial pilot in collaboration with Spectra Link Wireless, providing low cost and affordable wireless connectivity to students and faculty at universities in Koforidua, Ghana and a linked joint research initiative with Facebook (Microsoft 2014). Spectra Link Wireless will be deploying high speed wireless networks that will cover all Nations University College and Koforidua Polytechnic. The network will use TVWS frequency enabled radios and other wireless technologies to connect campus buildings ensuring they have access to fast broadband internet access. No fewer than ten schools have been connected to broadband internet service at browsing internet speeds of 4 Mbps using dormant UHF spectrum located between 480 MHz and 690 MHz meant for TV broadcasting service (Microsoft 4Afrika 2015). These schools are part of the first pilot trial in South Africa to study the effects of connecting underserviced regions to the internet using TVWS, which comprises the currently vacant frequencies meant for television broadcasting. It was also announced that the second trial could demonstrate the use of TVWS to connect rural regions in Limpopo.

Cape Town TVWS trial project was conducted to study feasibility of TVWS for broad band internet connection. The trial project was conducted for six months and launched in March 2013 in Cape Town. The pilot was a joint effort between Carlson Wireless, the Council for Scientific and Industrial Research (CSIR), e-Schools' Network, Google

Inc., Tertiary Education and Research Network of South Africa, and the Wireless Access Provider's Association of South Africa (Dynamic 2016). Technical results obtained from Cape Town TVWS trial project can be summarized as follows (Steven 2017).

- ✓ The trial offered reliable and fast broadband services
- ✓ It produced bit rates of up to 12 Mbps at distances as far as 6.5 km.
- ✓ The trial partners were also able to operate co-channel with broadcasters without causing harmful interference.
- ✓ Finally, the trial partners also observed that even in Cape Town, which was selected as the trial site because it has the highest broadcast spectrum use in South Africa and the highest potential for interference – there is significant vacant spectrum for TVWS devices to use.

Furthermore, an envisaged third trial will involve machine-to-machine (M2M) communication using TVWS frequencies in a time-division multiplexing, where different signals are sent at different times or the study of the functionality and use of TVWS Channels with regard to machines only send signals periodically. The cost of broadband remains an obstacle to internet access in rural South Africa, but by reducing the cost of broadband access millions of South Africans could get online. This creates new opportunities for education, health care, commerce and the delivery of government services across the country.

Rural Broadband Trials Laikipia County Kenya, (Dynamic 2016) shows trial TV white space (TVWS) network deployed in remote area of Kenya. This trial focuses particularly on the commercial feasibility of TVWS technology in delivering low- cost broadband in rural communities currently lacking access to both broadband and reliable electricity. In 2013, Microsoft, in collaboration with the government of Kenya's Ministry of Information and Communications, and Mawingu Networks, launched a pilot TVWS project called Mawingu (Cloud in Swahili) for delivering low-cost wireless broadband access to previously unserved locations near Nanyuki, Kenya. This trial focuses particularly on the commercial feasibility of TVWS technology in delivering low- cost broadband in rural communities currently lacking access to both broadband and reliable electricity (Sauli 2012). A trial network in Kenya uses TVWS technology and solar powered BSs to deliver broadband access and create new opportunities for commerce, education, healthcare and delivery of government services. Technical Results of Mawingu project can be summarized as follows (Dynamic 2016).

The Mawingu project has successfully demonstrated the technical viability of this model of delivery, with interference free point to multi-point coverage of up to 14 kilometres from TVWS BSs operating at only 2.5 Watts power (EIRP measurement); In total this provides approximately 235 km2 of TVWS coverage using multiple 90 degree BS sector antennas;

- ✓ The maximum achieved speed was 16 Mbps on a single 8 MHz TV channel at distances of up to 14 kilometres;
- ✓ There have been no reports of interference from any concerned parties;
- ✓ The trial project have demonstrated that the technology can support various media protocols such as streaming videos, emails, FTP, Skype voice and video conferencing, and high speed VPN services

The Microsoft 4Afrika initiative continued its pilot trial by setting out another deployment of TV white space in partnership with the Tanzania Commission for Science and Technology (COSTECH) and their local ISP UhuruOne, to provide internet access to university students in Dares Salaam, Tanzania (Microsoft 2013). The project is expected to boost the internet facilities of the university by ensuring flexibility and ease of use of internet services with the aim of connecting students both in and off campus.

The University of Malawi, in partnership with the regulator, MACRA, and the International Centre for Theoretical Physics in Trieste, launched a white-spaces pilot project in the city of Zomba, in southern Malawi. The pilot, which got underway in September 2013, has connected a number of different institutions including a school, a hospital, an airport and a research facility (Dynamic 2016). The trial uses Carlson Wireless's Rural Connect TVWS radios. Technical results obtained from Malawi TVWS trial project can be summarized as follows (Mikeka et al. 2014).

Despite the growing evidence that TVWS networks (TVWSNs) can coexist with licensed broadcast services (primary users), there are still no regulations allowing the use of TVWS in Nigeria and many African countries. There are a lot of demands for internet in the rural region of Nigeria but setting up the infrastructure in the rural area is very difficult.For effective utilization of the spatial TV white space, and coexistence between the primary and secondary users, a reliable prediction technique is required to accurately estimate the service contours of the primary users

Hence, this current work would be a case study addressing the feasibility of deploying TV white space for broadband internet access in rural areas. It quantified the available TV white space in the sparsely populated environment based on field measurement and Geo-location database prediction/creation. The work x-rayed the economic and financial viability of the technology in relation to other existing technology in Nigeria scenario using Nnobi community in Idemili North Local Government Area of Anambra State, South East as case study. This work shows which propagation model is suitable for the selected rural area by evaluating environmental factors that affect the system.The work also carried out the planning and performance prediction for the provision of broadband internet services using the TV white space technology in comparison with other existing technologies used for broadband internet services.

2.0 Material and methods

This section presents research instruments and the procedures used for the planning of the network, designing the network and simulation of TV white space network for broadband internet access. The planning phase involved determination of the target area and application and requirements for the network. The next phase was the frequency planning, using spectrum occupancy measurement. The field Radio Frequency (RF) spectrum occupancy measurements were taken at various points of the TV white Space testbed with the aim of improving the accuracy of identifying TV channel occupancy around the area. The next phase involved coverage and capacity design of the network that helped to determine quantity, location, configuration and orientation of TVWS base station and the customer premise equipment (CPEs) based on characteristic features of the testbed region. Finally, the simulation of the designed TVWS network was carried out using the specified performance metrics.

2.1 Description of the Experimental Testbed

The sparsely populated environment selected as the experimental testbed for this research work is the rural community of Nnobi in Idemili North Local Government Area of Anambra State, South East Nigeria. Nnobi is located at Latitude 6.075826 and Longitude 6.938004 as shown in figure1. Nnobi has an estimated population of about 100,000 people and mostly peasant farmers and petty traders; it has Nnewi, Nkpor, Onitsha and Awka as its closest urban cities (NPC 2006). The infrastructures/buildings and social amenities in the community which were considered in the network design include the Community Town Hall, comprehensive secondary School and Primary School, Nnobi Market, and residential houses.

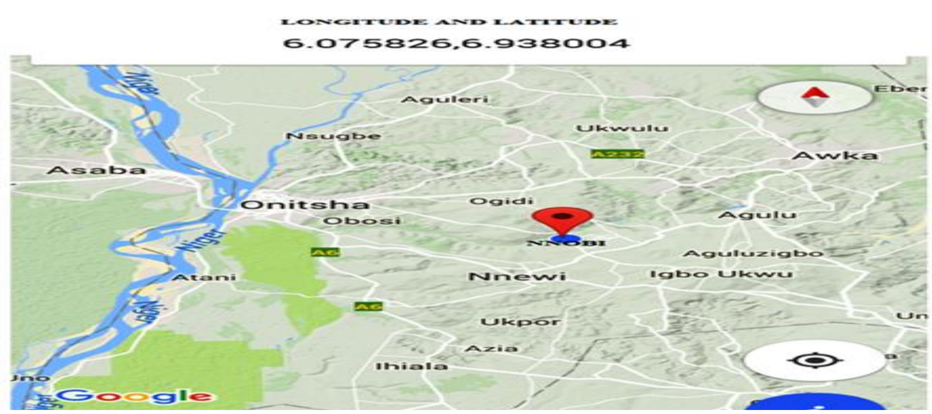

Figure 1: Map of the Experimental Testbed.

2.2 Frequency Planning

Frequency planning is the most important phase in the white space network. It determines whether the intended white space service is even possible in the wanted area. The intended service type, coverage and capacity have a great impact on usable frequencies because of the needed antenna height and transmission power. The rural broadband case uses the highest base station and CPE antenna height and power compared to other planned white space services at the moment. For this reason Field RF spectrum measurements were done within the testbed. The objective of conducting RF field spectrum measurements was to understand the RF occupancy (to determine the number of available usable TVWS channels) and channel usage within the TV ultra-high frequency (UHF) band as well as the behaviour of the WSDs. The issue of defining channel availability on the TV band is one of the most complicated one and it depends on the regulator. Each regulator can set its own minimum requirements to be fulfilled before a TV channel can be deemed available.The following equipment was used for the field measurement as shown in the setup in figure 2.

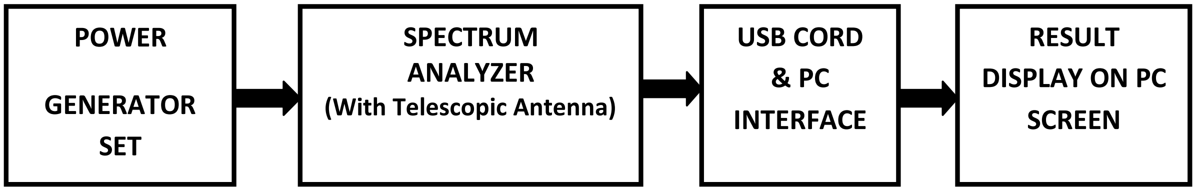

Figure 2: Block Diagram for Measurement Setup

2.3 Geographic Survey

The geographic survey was done to select and determine the precise location of all settlements in the rural community. This survey was of great importance as it helped to select areas based on the population density and location within the community that could be used for the installation of the TVWS base station and location of the CPE for maximum coverage and impact. Figure 3 shows the Google earth image of Nnobi community that was used in the survey. From the survey five (5) sites with their coordinates were selected as the best possible locations of the CPE for maximum delivery of the broadband access to majority of the dwellers of the community. The coordinates are shown in Table 1.

Figure 3: Google Earth Map of Nnobi.

Table 1: Selected Sites and Coordinates.

Site	Latitude	Longitude
AN0043	6.060728N	6.970411E
TVWS_BS(site1)	6.047207N	6.945029E
CPE1	6.034137N	6.93959E
CPE2	6.04956N	6.94908E
CPE3	6.04999N	6.955689E
CPE4	6.045404N	6.930979E
CPE5	6.035789N	6.920086E

2.4 Architectural Design of the Proposed TVWSN

In general, network architecture for a given system depends on different parameters, such as the type of the intended service, type of the communication media will be used, location where the service will be provided and service provider; can determine the network architecture. In this work TV white space would be used to provide broadband internet service for rural community of Nnobi. The network architecture is as shown in figure 4. From the physical survey carried out within the community, it was estimated that the proposed network would have about 200-to-1000 active subscribers clustered in 5 main sectors of the community; hence the proposed TVWS network topology would assume a star configuration. It would have a single base station and five client stations where each station is estimated to have about 200 active subscribers per time with more room for expansion in the future.

Each station comprises client premise equipment (CPE) and a Yagi-Uda type of antenna mounted outdoors (see figure 5) and powered by a UTP cable that terminates into an indoor Power-over-Ethernet (PoE) adapter. Additionally, the stations would have LAN switch with an interface configured with static IP address, and being able to provide dynamic IP addresses in the range of 192.168.0.0/24 to 240 to hosts on the client side using dynamic host configuration protocol (DHCP).

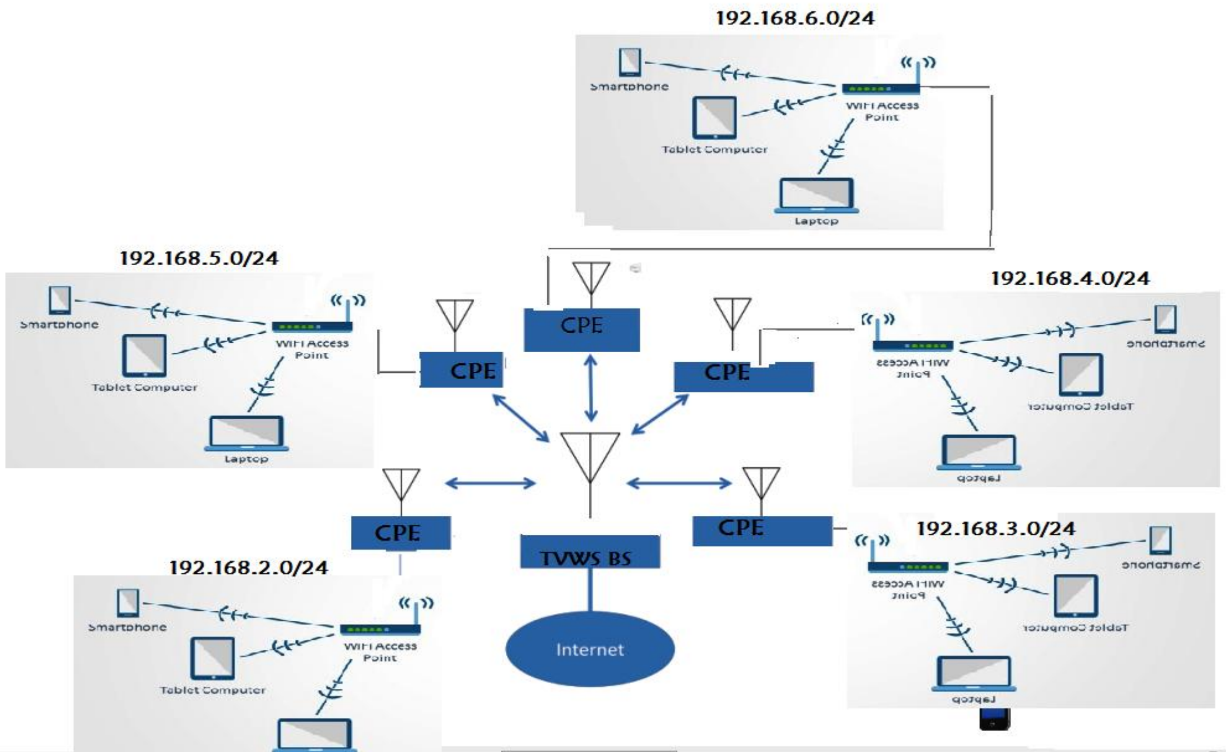

Figure 4: Network Architecture of the designed TVWS Network

The TVWS base station is an indoor device, and has ultra-low power consumption compared with cellular base stations. It transmits using a huge monopole antenna (case of Carlson radios) mounted outdoors at a height based on rigorous computations or simulation per design coverage and link quality of the star topology. Internet supply in the proposed TVWS network would be provisioned through a dedicated wireless backhaul from a transmission mast belonging to Airtel Nigeria with site ID AN0043 located around Nnobi/Nnukwa road.TVWS base station asks an online database for a list of all the available channels at its location. The database reports a list of vacant channels that would not cause interference for the TVWS base station to link connect to (a web-based Geolocation database developed by (Nwokoye 2018) is suggested for use in the experimental testbed). The TVWS base station sends a signal back to the client radio via the CPE confirming the connection, once connected the TVWS network can cover an area about 100 times the diameter of a regular Wi-Fi router. End users are customers who access internet service by using any kind of devices from TVWS CPE. The accessing method is either as Wi-Fi or using Ethernet cable. The interface between TVWS BS and TVWS CPE is air.

Figure 5: Sample of CPE with Carlson Radio.

3.0 Results and Discussions

3.1 Result of Spectrum Occupancy Measurement

There are few assumptions made in the course of carrying RF spectrum occupancy measurement within the experimental testbed. Firstly, Microphones and other wireless devices using TV band are ignored for this computation due to lack of available information. Secondly, only UHF band (470-789 MHz) was considered in this paper. Thirdly, -110dBm was used as the noise threshold for RF Spectrum measurement which is in accordance with established standards, this implied that channels with signal levels greater than -110dBm are assumed to be occupied while those with signal levels less than threshold of -110dBm are assumed free for secondary White Space Devices to transmit over. This threshold value was selected after a preliminary measurement while tuning the RF explorer to a channel with known operational characteristics. NTA Onitsha that operates at the frequency of 583.25MHz which normally ends transmission at 12am was used.

It was discovered that the ambient noise the level recorded was in the range of -111dBm to -117dBm without any transmission from the station. The ambient noise level recorded when the transmission was on is -91dBm and to accommodate low power transmissions, -110dBm was selected as the noise threshold.Since spectrum availability varies by population density and terrain features, spectrum measurements were taken in six different sites within the experimental testbed for a period of one week. According to the spectrum occupancy distribution shown in figure 6, the measurement results showed that 75 % of the spectrum was unoccupied, 10% was not fully occupied while 15% was fully occupied indicating lots of spectrum utilization opportunity. The empirical characterization of the environment showed that it is an excellent environment for deployment of CRT for optimal RF utilization for the provision of broadband internet services to the rural community.

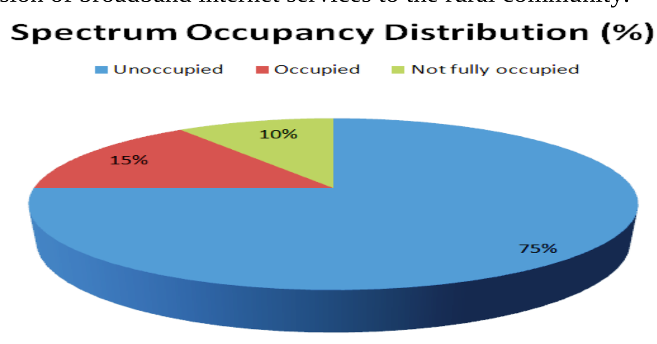

Figure 6: Spectrum Occupancy Distribution of the Testbed

3.2 Performance Analysis

Using the coordinates given in table 1, the proposed network was designed and simulated in Radio Mobile simulator to find out the best sites for the CPEs and TVWSBS as shown in figure 7. The height of the TVWS base station was assumed to be 75m and that of the CPEs was assumed to be 15m.

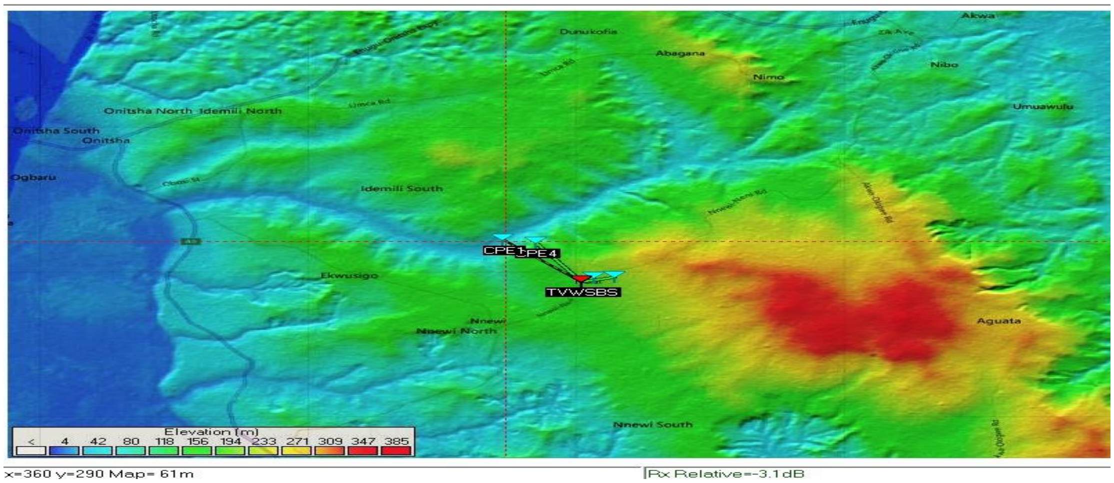

Figure 7: Designed TVWS Network for Nnobi Community

The following visual tools, coverage maps and path loss plots were used in the Radio Mobile simulator to help in the planning and location of the various transmitting and receiving antennas in the network. From the results obtained such as the path loss, antenna gain, clearance, elevation angle and distance of the CPEs from the TVWS Base station, helped in determining sites with good propagation conditions (line of site) and sites with bad propagation conditions were relocated. Figures 8, 9, 10, 11, and 12 showed the propagation characteristics between the TVWS base station and the various CPEs in the proposed network to test and confirm the best site for the location of those devices.

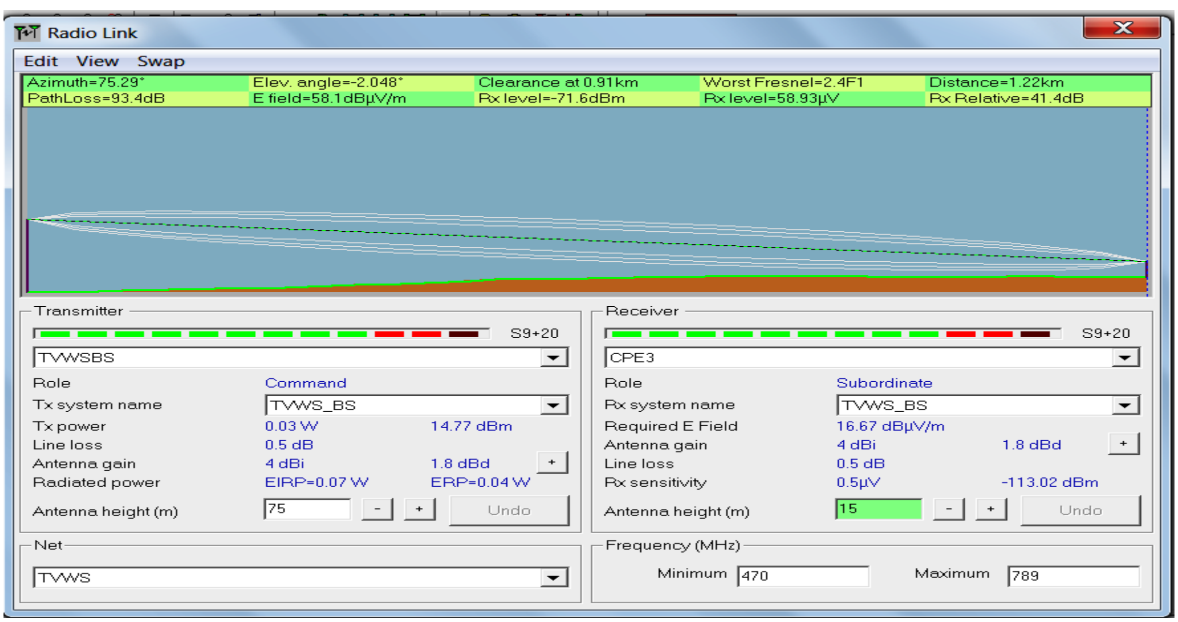

Figure 8: Radio Link performance between TVWSBS and CPE3

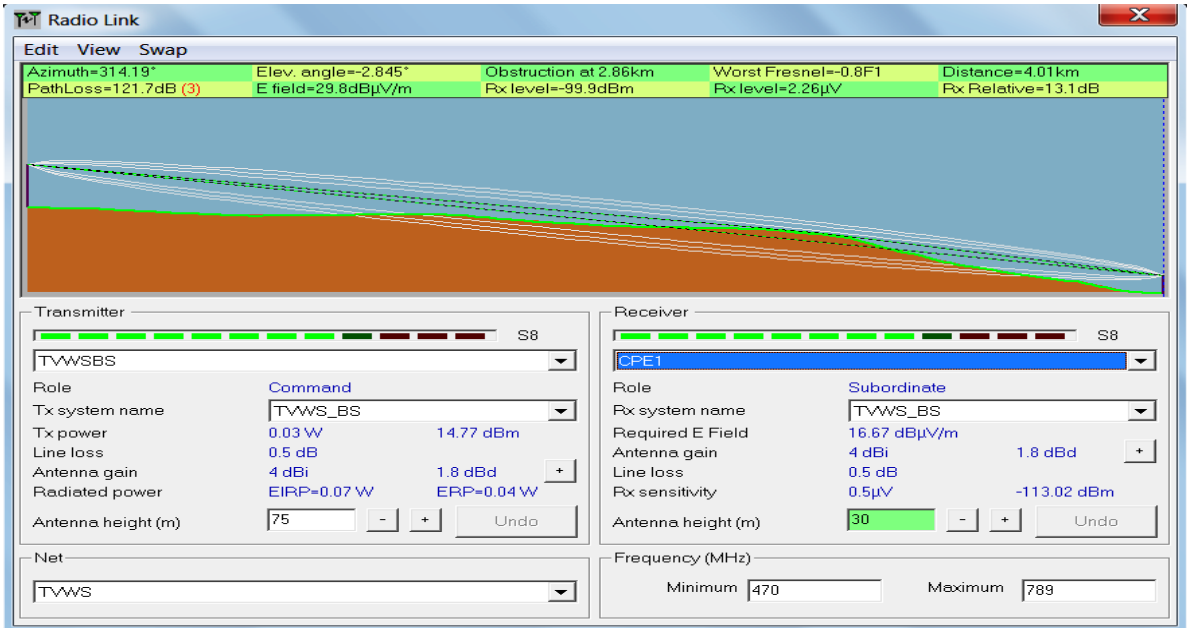

Figure 9: Radio Link performance between TVWSBS and CPE1

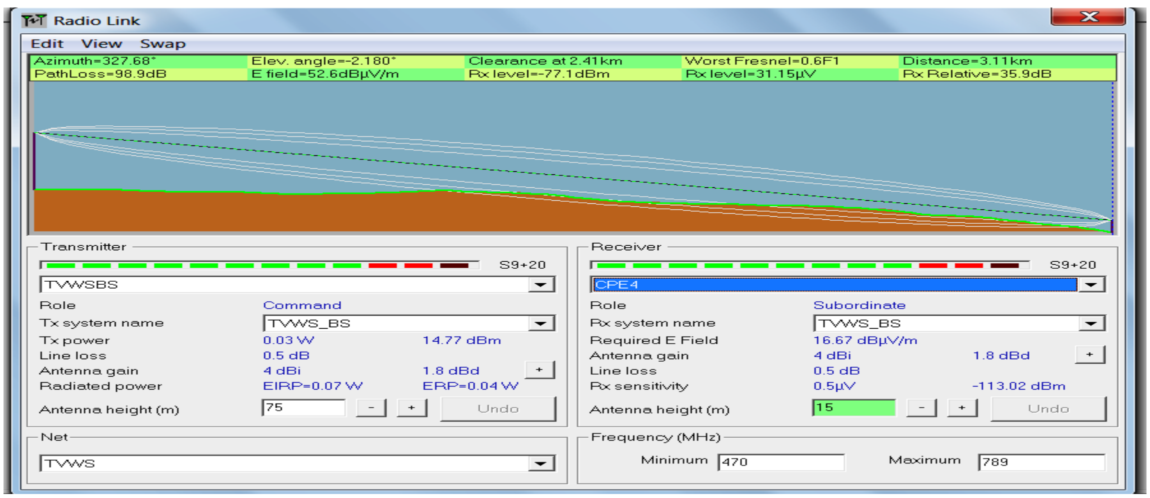

Figure 10: Radio Link performance between TVWSBS and CPE4

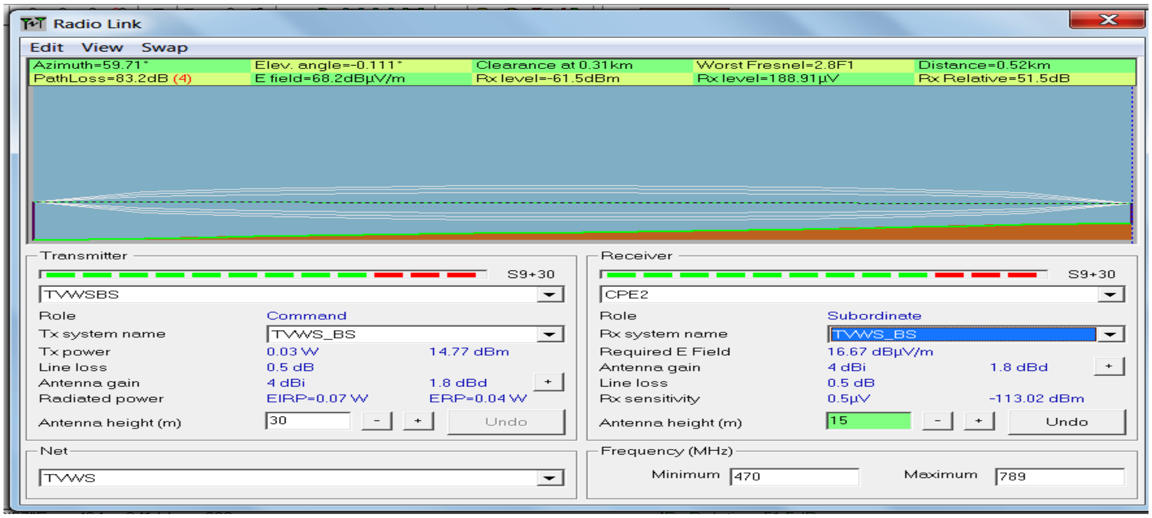

Figure 11: Radio Link performance between TVWSBS and CPE2

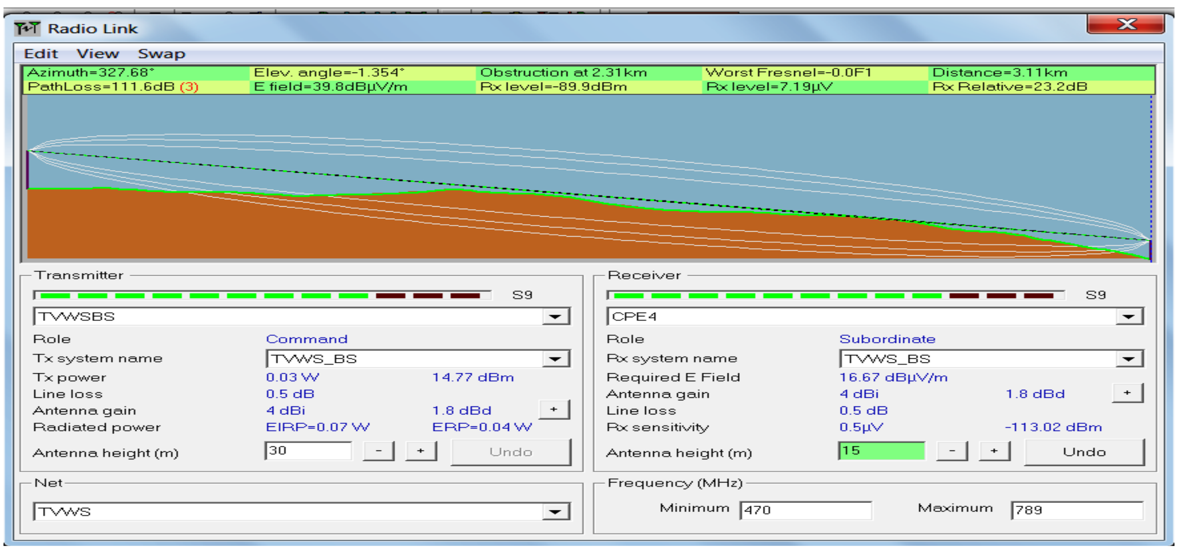

Figure 12: Radio Link performance of TVWSBS(site2) and CPE4

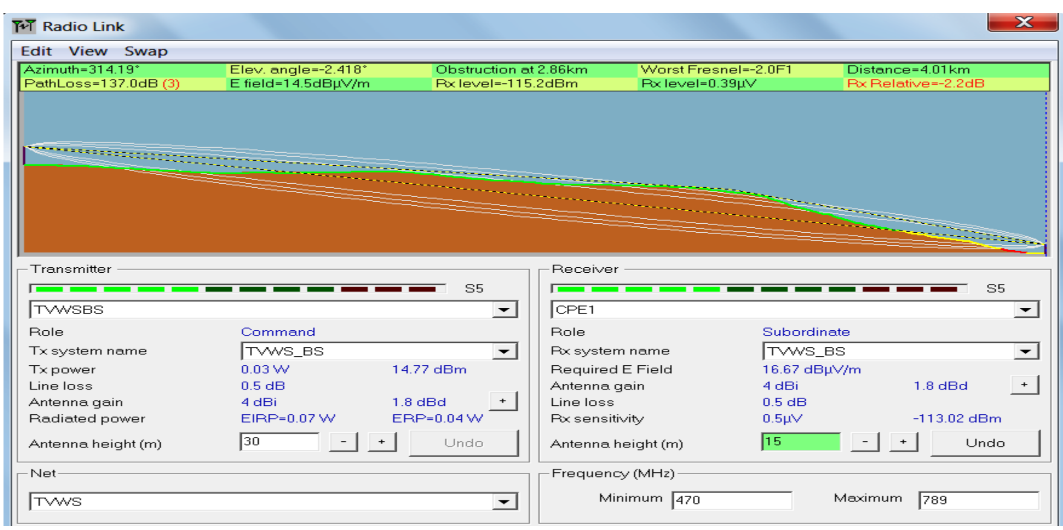

Figure 13: Radio Link performance between TVWSBS (site2) and CPE1

Simulation results showed the pathloss, antenna gain, clearance, elevation angle and distance between the TVWS base station and the proposed locations of the CPEs. Figure 9 showed that there is a very poor propagation condition between the TVWS base station and the CPE1 and hence the location of the CPE1 should be varied for maximum delivery of the broadband services to the people connected in that area. Figures 12 and 13 showed the radio link performance between the CPEs and the new location (site2) of the TVWS base station.
Preliminary tests showed that some sites were more attractive than others, mainly due to the absence of interfering signal sources in the area. The results showed that site 1 has the best signal propagation conditions between the TVWS base station and the CPEs as compared with the results from site 2. Hence site 1 was selected as the best site for the installation of the TVWS base station, which would be a Carlson radio with Omni-directional antenna. This can be installed on the already existing tower owned by Alpha Radio and Television Nnobi located at the site 1.

3.3 Economic and Financial Analysis

This section covers the cost estimates of deployment of TVWS model in a rural setting. The costs for setting the actual network, which includes design costs, deployment costs, maintenance costs, and infrastructure costs for base stations, client stations, and access points, have been calculated in US Dollars and Naira. Equally, a simple cost comparison for deployment of TVWS and LTE technologies is carried out, comparing CapEx, OpEx, for TVWS and LTE networks. Making the assumption of current generation TVWS equipment and comparing that to current generation, multi-band / multi-mode LTE. Table 2 shows the total capital expenditure for the deployment of TVWS network, while table 3 shows the operational cost of running the TVWS network. This includes Site Leasing, Backhaul Leasing, and Maintenance etc. Similarly, Tables 4 and 5 show the capital and operational cost of deploying LTE network respectively.

Table 2: Capital Expenditure for Deploying the proposed TVWS Network.

S/N	Item(s)	Cost in (₦)	Cost in ($)
1	RF to LAN per CPE (Yagi Uda)	60,590	166
2	Yagi Uda (CPE) Antenna (5)@$1000	1,825,000	5000
3	TVWS Radio (Carlson RuralConnect)	5,475,000	15,000
4	TVWS base station Antenna	292,000	800
5	Cabling	30,295	83
6	Structure	73000	200
7	Labour	73000	200
8	Switch	18,250	50
9	Lightning Shielding	12,045	33
10	Backup Batteries	320000	877
Total		**8,179,180**	**22,409**

Table 3: Operational Cost Estimate for Deploying TVWS Network.

S/N	Item(s)	Cost in (₦)	Cost in ($)
1	Electricity per year	1,496,500	4100
2	Maintenance + Engineering	109,500	300
3	Backhaul Leasing	730,000	2000
Total		**2,336,000**	**6400**

The total cost estimate for deploying a TVWS network is given as;

$$TCO = CapEx + OpEx$$

$$TCO = ₦8{,}179{,}180 + ₦2{,}336{,}000 = ₦10{,}515{,}180$$

$$TCO = \$22{,}409 + \$6400 = \$28{,}809$$

Table 4: Capital Expenditure for Deploying LTE Network.

S/N	Item(s)	Cost in (₦)	Cost in (₦)
1	2HP Air Conditioner (2)	300,000	821.92
2	Rectifier	1,800,000	4,931.51
3	Shelter	3,800,000	10,410.96
4	20KVA Generator (2)	6,400,000	17,534.25
5	Backup Batteries (16)	1,280,000	3,506.84
6	Palisade Fence	510,000	1,397.26
7	70m Tower	11,000,000	30,136.99
8	Antennas and active Equipment	45,000,000	123,287.67
9	Cost of Installation	10,000,000	27,397.26
Total		**80,090,000**	**219,424.66**

Table 4: Operational Expenditure for Deploying LTE Network.

S/N	Item(s)	Cost in (₦)	Cost in ($)
1	Electricity per year	3,041,545	8,333
2	Maintenance + Engineering	4,380,000	12,000
Total		**7,421,545**	**20,333**

Similarly, the total cost of deploying LTE network for broadband internet services in the experimental testbed is given as;

$$TCO = CapEx + OpEx$$
$$TCO = ₦80{,}090{,}000 + ₦7{,}421{,}545 = ₦87{,}511{,}545$$
$$TCO = \$219{,}424.66 + \$20{,}333 = \$239{,}757.66$$

The financial analysis has shown that delivering broadband for rural area using currently available technology is more expensive than using TVWS, therefore TVWS is recommended for such scenario. Therefore, TV white space is financially feasible for rural Nigeria compared with currently prevailing technologies. A key assumption in determining financial feasibility is the leasing available backhaul network and masts (rather than construction of new backhaul and masts) of space on existing backhaul and masts for transmission of whitespace services from the major service providers. Another assumption made was if there is no available backhaul network, TVWS can be used as backhaul.

4.0 Conclusion

The network architecture for proposed system was modeled from taking the reality of available communication infrastructure. In proposing network architecture, it is assumed that the service will be provided by any of the existing major service providers. This decreases the cost for constructing new masts and backhaul network.

A spectrum occupancy measurement within the range of 470 -789 MHz was carried out to determine the spectral status of the licensed bands of various TV stations in the experimental testbed (Nnobi Community, Idemili North LGA) and its environments in Anambra State, Nigeria.The measurement results showed that 75 % of the spectrum was unoccupied, 10% was not fully occupied while 15% was fully occupied indicating about 240MHz span of spectrum utilization opportunity. Finally, economic and financial feasibility of TV white space in rural area in Nigeria was carried out. Financial feasibility is compared with currently available broadband providing method (LTE technology). From the financial analysis it was shown that the cost of deploying TVWS network is far below (about 1/10th) of the cost of deploying LTE network, hence, TV white space is financial feasible to provide broadband internet for rural Nigeria.

5.0 Recommendation

Further studies can analyse the benefits to come to local mobile operators and small rural ISPs from opportunities through TVWS. Types of services that are expected to be offered by TVWS service providers after the pilot projects and the regulation upon them thereafter.

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