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Estimation and Application of TV Whitespaces for Rural Broad Band Connectivity (Internet Access)

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ABSTRACT: *The frequencies that are suitable for radio communication are a scarce resource while some of the licensed frequency bands are considered to be underexploited. TV whitespace refers to TV channels that are not used by any licensed services at a particular location and at a particular time. Ultra high frequency (UHF) band spectrum has very good wireless radio propagation characteristics. 'White space' in the UHF bands that have conventionally been used for television broadcasting, but the opening of TV white space (TVWS) bands for cognitive access is one of the first touchable steps to solve the spectrum scarcity problem in current wireless networks. In this paper, TV whitespace technologies, the global scenario for the application of TVWS, the relevant standards, regulatory framework are discussed. The results of comprehensive spectrum measurement at different locations in Mgbakwu area of south-East Nigeria using an inexpensive handheld spectrum analyzer for quantitative estimation of TVWS in the 470-870MHz band are presented. Also presented is the feasibility study and economic viability of a TV whitespace network for internet access in a rural South-East Nigeria community. The result of the measurement carried out shows that of a total number of the TV channel allocated to the TV station only 22% is occupied while 78% was not occupied.*

KEYWORDS: *Spectrum, TV White Space (TVWS), Frequency, Rural Broadband, Internet.*

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I. INTRODUCTION

Television White Spaces (TVWS) refers to unused portions of spectrum in the television (TV) bands, such as guard bands between broadcasting channels and channels freed up by the transition from analogue to digital TV broadcasting (Maheshwari et al., 2012).

TV white space technology is a talented one in the current scenario to provide broadband connectivity to rural areas. Internet connectivity is scarce in areas with low population density due to environmental obstacles, distance from major Internet Service Providers (ISP), and lack of financial incentives. This results in expensive and complex networks leaving the rural communities with little options. While traditional Wi-Fi weakens over rugged terrain, the TV band can penetrate buildings and terrains with good signal strength. Also they provide larger coverage and greater bandwidths which allow these channels to be used for delivering broadband internet access in areas that aren't easily accessible by cable at much lower costs than optical fiber or conventional wireless networks. These frequencies can be made accessible for unlicensed use by secondary users at locations where the spectrum is not being occupied by primary users. This leads to more resourceful use of the existing spectrum. However the primary user is protected from any interference from the unauthorized ones. The secondary user must quit the band once the primary (incumbent) user arrives. The TV White space devices have the flexibility to sense, operate and log on to unused TV White Space channels. This is achievable with the use of a database that houses unused channels called geo-location database technology.

The systems operating in the TV bands are analogue TV with sensitivity value of -94 dBm, digital TV with sensitivity of -116dBm and wireless microphone with -107 dBm (Faruk et al., 2013). In this regard, Federal Communications Commission (FCC) in the United States of America (USA) announced a threshold of -114 dBm as the criteria for TVWS (FCC, 2008). The logic behind this is to make use of the unused spectrum of the incumbent systems for secondary access so that white space devices with low power can utilize this spectrum without causing interference with the incumbent systems. The unused Broadcast TV channels vary sparingly from one location to another.

This paper is aimed to investigate, assess and propose TV white space implementation architecture in Mgbakwu to provide internet connectivity in rural areas, also the relevant standards to the TVWS system, the regulatory framework and other relevant points are also discussed.

II. LITERATURE REVIEW

2.1 TV White Space Trials around in the World

There has been increasing interest in telecommunications use of “TV white spaces” in the UHF bands that have commonly been used for television broadcasting. In more and more countries, this interest is fueled by the now inexorable move towards digital terrestrial television broadcasting, the consequential and looming end of analogue terrestrial television broadcasting, continuing growth in internet usage and increasing demand for wireless broadband access. USA already has a number of certified database administrators and is the front runner in the deployment of TVWS based networks. United Kingdom (UK) and Singapore are also hastening in the deployment process. United Kingdom (UK) has had a number of pilot deployments pertaining to the use cases of Smart City, Rural Broadband, Wi-Fi Hotspot coverage, machine to machine communications (M2M), sensor networks etc. Singapore has deployed many smart grid solutions based on TVWS and is undertaking many pilot deployments for a number of use case scenarios (Manjurul and Barman 2018). In this paper the pilot deployment of Accra and Malawi are herein after considered.

2.1.1 Malawi Trial

In the Malawi trial, TVWS was used to provide internet connectivity from a base station at ZA TVWS Base station to users at Malawi Defence Force Air Wing, St. Mary Girl’s Sec School, Pirimiti and Thondwe hospital and GPS (Seismology Dept). The deployment was carried out by the University of Malawi in conjunction with the Malawi Communications Regulatory Authority (MACRA) and the International Centre for Theoretical Physics (ICTP). The technical partner was Carlson Wireless. A mobile monitoring of the spectrum was also carried out using Spectrum analyser at Pirimiti and Thondwe hospital to confirm the possibility of TVWS pilot deployment at the hospital. (Atimati et al., 2015)

2.1.2 Accra TVWS pilot network

In March 2014, SpectraLink Wireless, under authorization from the Government of Ghana’s National Communications Authority (NCA), and in collaboration with the Meltwater Entrepreneurial School of Technology (MEST) deployed a pilot network to offer free wireless broadband access for its community of Entrepreneurs in Training. (Atimati et al., 2015)

The purpose of the pilot with MEST has been to test the efficiency of using TV white spaces for Internet radio networks, in an urban environment that presents multiple sources of interference. The network has been successfully tested on channels adjacent to active television channels, over a 10 km link, with no interference observed.

2.2 TVWS Applications

The radio spectrum is extensively used, literally by everybody, in applications in our personal environment including remote keys, remote controls, microphones, burglar alarms and cordless headphones. Most users might not be aware that these are considered as radio applications. Interference is of particular concern when affecting security services using radio such as police, ambulance, air traffic control and armed forces. There are many radio applications which might be developed by using TVWS technology such as ‘‘super Wi-Fi’’ which can extend wireless hot spots to many kilometers depending on the location and extended wireless back-haul which can be established over white space to connect regular Wi-Fi access points to provide service to unserved areas. Also, there are many other application still under investigation for using TV license spectrum without harmful interference (Abognah, 2014). In addition, TVWS can be used for network offloading, serving as a backhaul, rapidly growing internet of things (IOT), machine to machine communication between two remote devices or remote monitoring of power plants, and to cheaply provide wireless fidelity (Wi-Fi) access in university campuses and public spaces.

TVWS can also be used in healthcare for remote monitoring of patients. Other applications include remote and broad sensing network for weather, traffic or environment monitoring and disaster management systems. TV bands are harmonized worldwide, and this raises the expectation that TVWS will be available globally.

2.3 TV White Space Standards

Several TV White Space standards have been developed such as IEEE 802.22, IEEE 802.11af, IEEE802.19.1, IEEE 802.15.4m, IEEE 1900.7 and ECMA 392 (Manjurul and Barman 2018). Of all these standards, the two most relevant standards in providing rural connectivity are IEEE 802.22 and IEEE 802.11af. IEEE 802.19.1 is relevant in terms of coexistence of IEEE 802 family operating in TV White Space.

2.3.1. IEEE 802.22(WRAN): IEEE 802.22 was the first standard based on Cognitive techniques that has been developed to access the TV White Spaces (Stevenson et al., 2009). The most important application of this standard is to provide wireless broadband access in rural and remote areas. The standard specifies that a large range of 33 km can be achieved with only 4 W of effective Isotopically Radiated Power (EIRP). The standard uses both geo-location database and sensing based techniques to access the TV White Spaces. This standard is capable of working in any regulatory regime (e.g. US, Japan, UK, Canada, etc.). The operational range of this band is 54-862 MHz and can work with various TV channel bandwidths i.e. 6, 7 and 8 MHz IEEE 802.22 follows a Point to Multi-Point (PMP) topology with a Base Station (BS) and its associated Customer Premise Equipment‘s (CPEs). To protect the incumbents, it follows a strict master-slave relation where BS is a master and the CPEs are its slaves. No CPE can transmit before receiving an authorization from the BS.

2.3.2 IEEE 802.11af: IEEE 802.11af standard or the White-Fi was formulated to adapt the existing IEEE 802.11 for TV band operation (Flores, 2013). IEEE 802.11af systems operate on frequencies below 1 GHz and uses geo-location database to access the TV band. This standard was designed due to the congestion in unlicensed band i.e. 2.4 GHz and 5 GHz spectrum. There are two operating scenarios of IEEE 802.11af viz. indoor and outdoor. The indoor scenario has a range of up to 100m similar to Wi-Fi. The outdoor scenario has a range of about few kilometers and is more suited for the rural setting. As TV channels may have varying bandwidths of 6, 7 or 8 MHz, it is required to aggregate the bandwidth. This standard works with the bandwidth of 5, 10, 20 and 40 MHz and hence depending on the availability of the channel, this bandwidth can be adapted.

2.4 Design of Rural Broadband using TV white space in Mgbakwu Area

In Figure 8, the proposed design of how a TVWS based communication network can be deployed in the rural areas. Two main types of deployment options have been shown here. One depicts the master-slave kind of communication between the White space devices (WSD), mainly a point to multipoint type of deployment scenario. The slave White space devices (WSD) may then emulate Wi-Fi or any other communication technology compatible with the User Equipment. If the user equipment supports, TVWS communication standards like 802.11af then that can also be supported by the slave TV White space devices (WSD). The other scenario in the figure depicts the TV band being used to provide middle mile connectivity to the Base stations and repeaters to reach the far fringe rural areas which are then served by Wi-Fi in the last mile. There can be other deployment scenarios pertinent to the rural areas depending upon the requirement. The blue clouds represent a village which is under coverage by the TV white space base station. The intermediate base stations act as relays. All the relays terminate at a base station with Fiber connectivity. For example, 543.25 MHz frequency band can be used as a frequency band for transmitting and receiving at 31 m and 5.5 m heights to provide internet connectivity in rural areas. In this case Quadrature phase shift keying (QPSK) and Quadrature amplitude modulation (QAM) modulation techniques will be used here. Point to point Topology, IEEE 802.22 standard, link budget calculation and Hata model were consider to achieve coverage distance result in rural broadband.

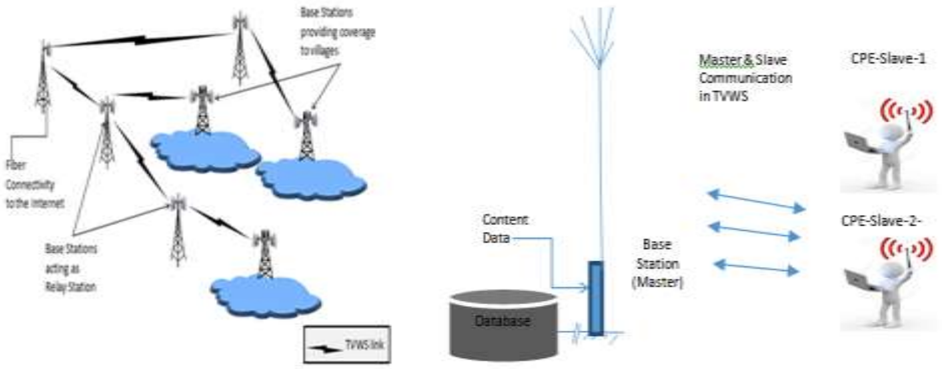

Figure 9: Proposed design of Rural Broadband using TV white space (Manjurul and Barman 2018)

III. METERIALS AND METHODS

3.1 Measurement Environment Considered

Measurements were carried out in a Rural area- Mgbakwu in Anambra State. Figure 1 shows the Google map location of the measurement site. Table 1 shows the coordinate of the measured locations.

Figure 1: Google Map of Mgbakwu

Table 1: Coordinate of the Measured Locations

Site Name	Latitude	Longitude
Mgbakwu (Rural Area)	6.2724082	7.0574914

3.1.1 Measuring Instruments/Equipment

1. Spectrum Analyzer **(**Rf explorer 3G combo model)
2. A laptop equipped with touchstone RF spectrum Analyzer software.
3. Mini USB cable.
4. A global positioning system (GPS) receiver set.

3.1.2 NBC Licensed Stations in Anambra State

The Table 2 shows the licensed TV station signal, their channels and frequency of operation that can be received within the study area.

Table 2: TV Stations parameters in Anambra State

S/No	Stations	Channel	Frequency
1.	NTA Onitsha	35	583.25MHz
2.	Anambra Broadcasting service (ASBC)	27	519.25MHz
3.	Silverbird television	30	543.25MHz
4.	MBI Anambra	41	631.10MHz

3.1.3 Measurements and Data Collection

The RF Explorer 3G combo model was used for the measurement. The RF Explorer was connected to window PC through the USB port for better visibility and other functionalities such as high resolution view, save screen shot image, print data and export to comma-seperated values (CSV) for use in 3rd party tools such as excel (RF Explorer spectrum Analyzer user manual, 2018).

Readings were taken using the spectrum analyzer to measure the received signal strength for all the 50 UHF channels (21 through 70) corresponding to 470 – 870 MHz with an Omni-directional antenna, a laptop and a GPS device for over 60 sweeps. The RF explorer antenna height is 3m above the ground, a span of 100MHz was used to enhance the visibility of the spectrum measured and the resolution bandwidth in the experiments was set to 178.57 KHz on the Rf Explorer window client.

Measurements using RF explorer revealed that the ambient noise level in the absence of any transmission channel occupied by a primary user is -108 to -115dbm. This was confirmed through repeated measurements in a known vacant channel at 24:00hrs when the station considered normally ends transmission. i.e Silver bird that transmit on 543.25MHz . Keeping sufficient cushion for low power transmission -110dbm was chosen as the noise threshold for the measurement.

IV. RESULTS AND DISCUSSION

Measurement was carried out in Mgbakwu area and environs in Anambra state, and the results are shown in Fig. 2 and table 3.
Results for spectra coverage carried out for 470-570MHz is shown in Fig. 2

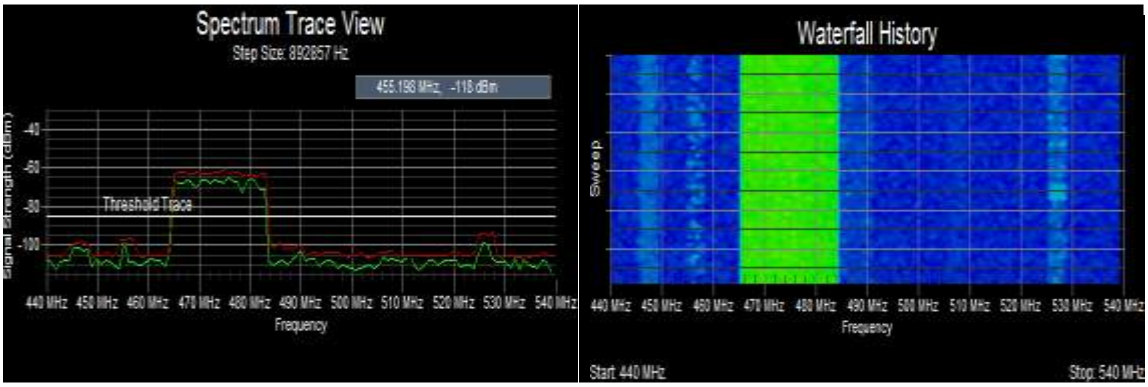

Figure 2: Spectral analysis plot for frequency span (470-570MHz)

TABLE 3: Summary of 470-570MHz Spectrum Occupancy in Mgbakwu

Frequency span	Channel no	Description	Status
470-478	21	TV broadcasting station	Occupied
478-486	22	Unoccupied	Free
486-494	23	TV broadcasting station	Occupied
494-502	24	Unoccupied	Free
502-510	25	TV broadcasting station	Occupied
510-518	26	Unoccupied	Free
518-526	27	Unoccupied	Free
526-534	28	TV broadcasting station	Occupied
534-542	29	Unoccupied	Free
542-550	30	Unoccupied	Free
550-558	31	Unoccupied	Free
558-566	32	Unoccupied	Free

Total number of channels within 470-570MHz is 12; total number of occupied channels = 4; Total number of unoccupied (whitespace) channels = 8; this shows that in this area 33% are occupied while 67% are free to be used by white space device.
Results for spectra coverage carried out for 570 to 670MHz in Mgbakwu is shown in Fig. 3

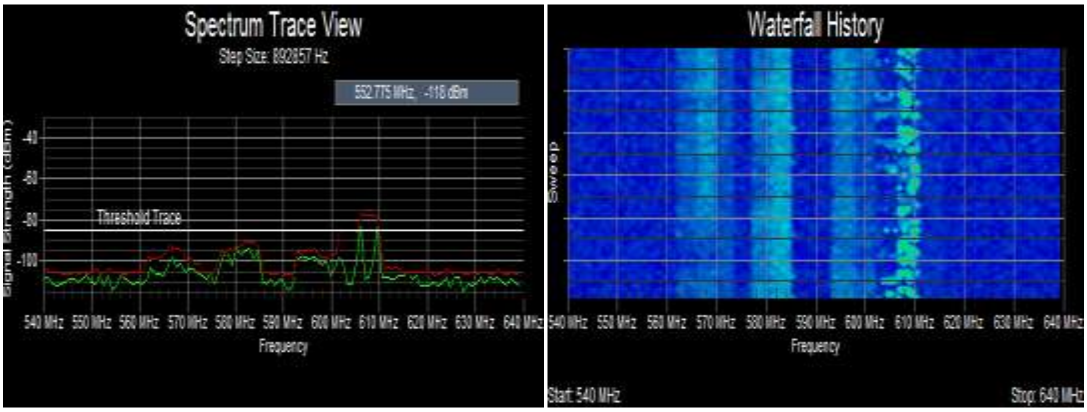

Figure 3: Spectral plot and waterfall history for frequency range 540-640MHz

TABLE 4: Summary of 570-670MHz Spectrum Occupancy in Mgbakwu

Frequency span	Channel no	Description	Usage
566-574	33	TV broadcasting station	Occupied
574-582	34	Unoccupied	Free
582-590	35	Unoccupied	Free
590-598	36	Unoccupied	Free
598-606	37	Unoccupied	Free
606-614	38	TV broadcasting station	Occupied
614-622	39	Unoccupied	Free
622-630	40	Unoccupied	Free
630-638	41	Unoccupied	Free
638-646	42	Unoccupied	Free
646-654	43	Unoccupied	Free
654-662	44	Unoccupied	Free
662-670	45	Unoccupied	Free

Table 4 shows that the total number of channels investigated in the range was 13; total number of occupied channels = 2; Total number of unoccupied (whitespace) channels = 11: This shows that in this area, 15% are occupied while 85% are free to be used by white space device.

The frequency occupancy for 670 to 770MHz range occupied by some TV stations is as shown in Fig. 4

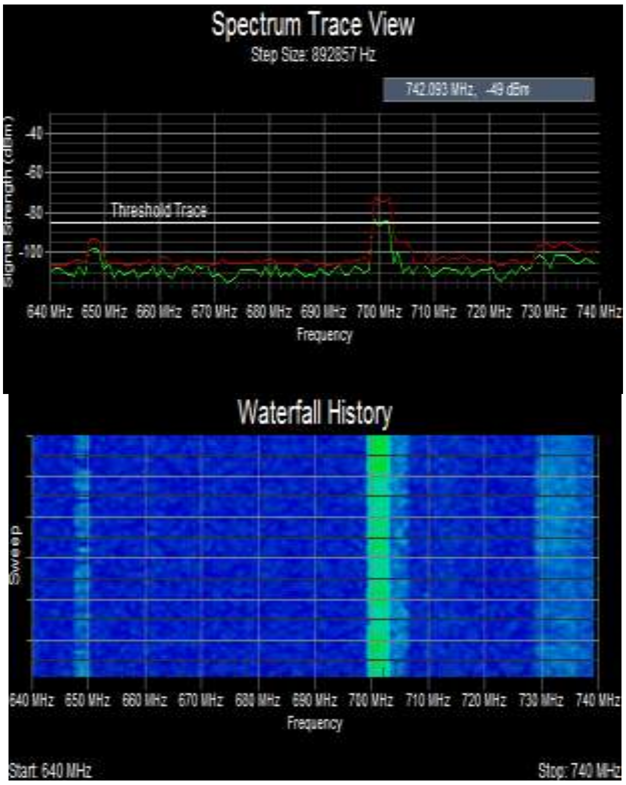

Figure 4: Spectral plot and waterfall history for frequency span (640-740MHz)

TABLE 5: 670 -770MHz Spectrum Occupancy Description of Mgbakwu

Frequency span	Channel no	Description	Usage
670-678	46	Unoccupied	Free
678-686	47	Unoccupied	Free
686-694	48	Unoccupied	Free
694-702	49	Unoccupied	Free
702-710	50	Unoccupied	Free
710-718	51	Unoccupied	Free
718-726	52	Unoccupied	Free
726-734	53	TV broadcasting station	Occupied
734-742	54	TV broadcasting station	Occupied
742-750	55	TV broadcasting station	Occupied
750-758	56	TV broadcasting station	Occupied
758-766	57	TV broadcasting station	Occupied

Table 5 shows that the total number of channels investigated in the range was 12; total number of occupied channels = 5; Total number of unoccupied (whitespace) channels = 7; This shows that in this area 42% are occupied while 58% are free to be used by white space device.

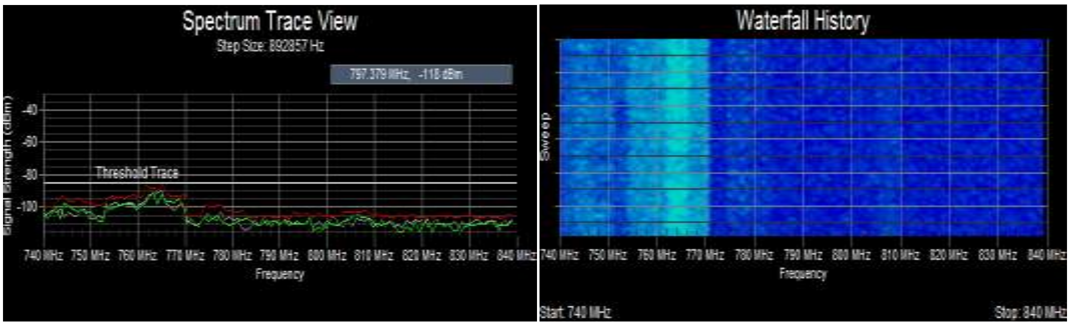

Figure 5: Spectral plot for frequency span (740-840MHz)

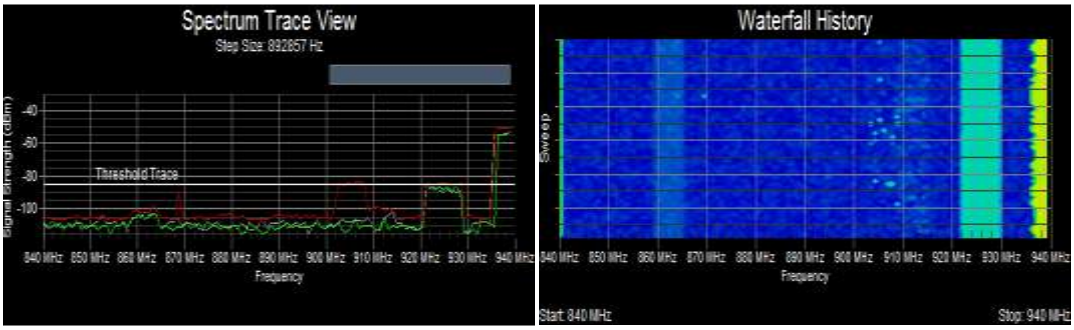

Figure 6: Spectral plot for frequency span (840-870 MHz)

TABLE 6: 770-870 MHz Spectrum Occupancy Description

frequency span	channel no	Description	Usage
766-774	58	Unoccupied	Free
774-782	59	Unoccupied	Free
782-790	60	Unoccupied	Free
790-798	61	Unoccupied	Free
798-806	62	Unoccupied	Free
806-814	63	Unoccupied	Free
814-822	64	Unoccupied	Free
822-830	65	Unoccupied	Free
830-838	66	Unoccupied	Free
838-846	67	Unoccupied	Free
846-854	68	Unoccupied	Free
854-862	69	Unoccupied	Free
862-870	70	Unoccupied	Free

Table 6 shows that the total number of channels investigated in the range of 770-870MHz was 13; total number of occupied channels = 0; Total number of unoccupied (whitespace) channels = 13; This shows that in this area 0% are occupied while 100% are free to be used by white space. Majority of the free spectral space are in this range. Fig. 7 shows the bar chart depicting spectral occupancy for Mgbakwu area of Anambra state.

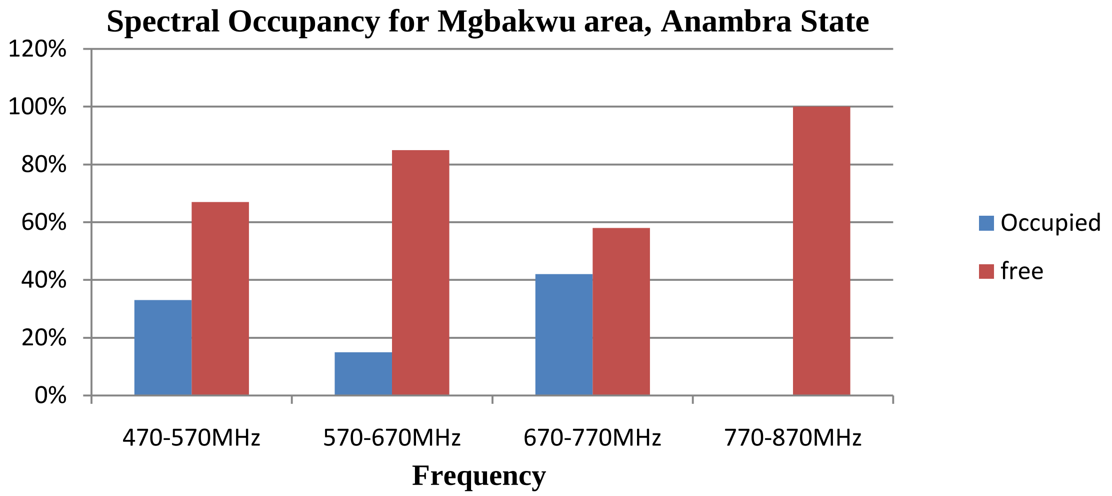

Figure 7: Spectrum occupancy in Mgbakwu Area, Anambra state.

The following is a summary of the analysis of the plots obtained from the readings. The summary is shown in Table 7.

TABLE 7: Summary of observation from spectral analysis for Mgbakwu rural area of Anambra state.

Description	Number
Total number of channel analyzed	50
Total number of occupied channel	11
Number of unoccupied (white space) channel	39
Percentage of occupied channel	22%
Percentage of unoccupied (white space) channel	78%
Total free spectrum(whitespace)	312MHz

The analysis shows that an abundance of free spectrum is available which can be utilized for rural broadband connectivity at Mgbakwu area of Anambra State, Nigeria.

V. PROPOSED REGULARITY FRAMEWORK IN TVWS USAGE IN RURAL AREA

Proposed Regularity Framework in TVWS usage in Rural Area is as shown in figure 10.

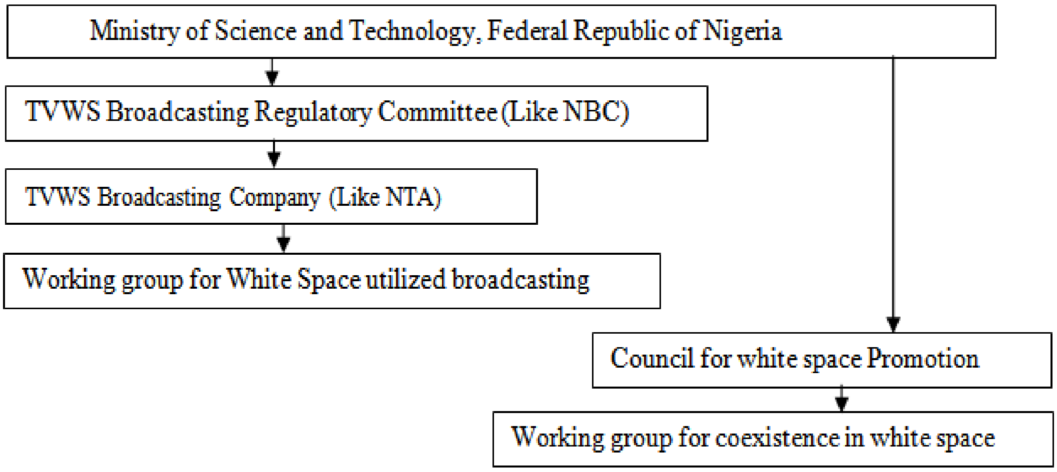

Figure 10: Flow diagram of Regularity Framework in TVWS usage in Rural Area. (Manjurul and Barman 2018)

5.1 Cost of Deployment of One Consumer Premise Equipment (CPE)

TV white space is used to provide last mile access to the users, using a base station and CPEs. One base station serves 235 CPEs and one CPE in turn serves 10 point of presence (POPs). The economic analysis is based on providing a speed of 512 kbps per point of presence (POP).

Table 8 shows the total cost of deployment for one CPE which consists of 10 access points (POPs).

Table 8: Cost of deployment of One CPE

Cost -client side for 1 CPE (10 POPs)	Cost (in Naira)	Cost (in USD)
RF to LAN per CPE (Yagi Uda)	59,760	166
Yagi Uda (CPE)	360,000	1000
Access point (Cisco linksys) * 10	180,000	500
Cabling	29,880	83
Structure	5,760	16
Labor	5,760	16
Switch	18,000	50
Lightening shielding	11,880	33

Thus, the total cost of deployment for one CPE (client side) is USD 1,864 (#671,040). According to the analysis carried out, one base station is capable of serving 2,350 POPs with the worst-case data-rate of 512 Kbps. Thus, 235 CPEs is required, whose total cost of deployment is USD 438,040 (#157,694,400).

Table 9: The total cost of deployment per site

Cost per site: Base Station	#18,000,000	$50,000
Cost -client side for 235 CPEs (2350 POPs)	#157,694,400	$438,040
Total Capital Expenditure	#175,694,400	$488,040

5.2 Proposed Financial Cost Analysis for TVWS in Mgbakwu

The Proposed financial estimations for one TVWS base-station deployment facilities in a given terrain and one-year operation cost in Mgbakwu are given in Table 10 below.

Table 10: Cost of deployment of one base station in Mgbakwu

Development Equipment item	Cost in naira(#)	Cost (in USD)
Base station total cost	18,000,000	50,000
Labour per site	1,800,000	5,000
Backup power	180,000	500
Civil engineering studies	2999,880	8,333
Cost of the tower	9,000,000	25,000
Transportation cost	599,760	1,666
Lightening shielding	299,880	833
Telecom equipment	599,760	1,666
Monitoring system	599,760	1,666
Miscellaneous	1,919,880	5,333

5.2.1 Operational Cost

Analysis for the operational cost has been summarized in Table 11. Which include cost for maintenance and providing a backhaul fiber to the base station from the internet service provider (ISP).

Table 11: Operational Cost

Cost- Operational	Cost (Naira)	Cost (In USD)
Electricity per year	2,999,880	8,333
Maintenance + Engineering base station	1,199,880	3,333
Maintenance + Engineering CPE	3,600,000	10,000
Backhaul fiber	20,999,880	58,333

5.3 Cost Comparison of Rural Broadband Connectivity

Cost Comparison of Rural Broadband Connectivity compared with Other Wireless &Wired (Fiber optic) Connectivity is as given in Table 12 Also the Comparison of TVWS with other wireless Technologies are given in Table 13.

Table 12: Cost Comparison of Rural Broadband Connectivity

Parameters	TVWS broadband wireless connectivity cost for throughput 22Mbps & 44km coverage distance (approx.)		Other wireless & wired(fiber optic)connectivity cost for throughput 10bps & 11km coverage distance(approx.)	
	Naira (#)	USD	Naira (#)	USD
Monthly maintenance cost	176,400	$490	1584000	$4400
Installation per site	306,000	$850	1476000	$4100
External wiring	1440,000	$4000, per site	15840,000	$44000
Equipment cost, per site	1980,000	$5500	1800,000	$5000

Table 13: Comparison of TVWS with other wireless Technologies. (Manjurul and Barman 2018).

Parameter	TVWS Connectivity	Wi-Fi or Other Wireless Connectivity
Distance Coverage	Can travel up to 50 km over various terrains	Can cover distance up to 4-6 km
Smooth Connecting of Coverage Area	Cover nearly 3,000 km^2 with single base station	Hop for one hotspot to another
Internet Handoff	Universal internet Coverage.	loss of internet connectivity between hotspots
Number of supportable user	In TVWS can support 40-48user per Customer Premise Equipment (CPE) in a rural Configuration.	In Wi-Fi or Other Wireless connectivity can support 2-3user per CPE in a rural Configuration.

VI. CONCLUSION

TV White Spaces that emerged as a result of digitization of analog TV transmission which have become a center of immense research to unlock the potential of unused wireless spectrum. This paper was able to analyze and quantify the available TVWS in a rural area of Anambra State Nigeria, and a wireless broadband network based on TV whitespaces was proposed along with a sustainable economic model which cannot only provide connectivity but also enable successful operation of the network at the rural areas, as an alternative way to meet the growing demands of wireless devices. This study serves as a starting point towards the development of fully operational white space networks for rural broadband connectivity and better utilization of white spaces in rural areas. A study on combining both spectrum sensing and geo-location databases for TVWS access will be the major topic for our future work.

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