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**Research Paper**

# Design and Simulation of Television White Space Technology for Rural Broadband Connectivity in Nigeria

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***ABSTRACT:*** *Due to its capacity to pass through barriers and resilience to attenuation, television white space (TVWS) is now a top communication technique for broadband connectivity, a new trend to further close the digital divide, and connectivity in rural areas. Given that most rural areas are sparsely populated, a suitable TVWS deployment that meets the desired service quality is necessary to provide the required coverage. The capacity simulation with MATLAB and the distance distribution technique were used to model the TVWS network. The results show that a network with one white space base station (WSBS) and ten CPEs (customer premises equipment) was able to achieve a channel capacity of 23 mbps with a signal quality of 10 dB. An improvement of 10mbps was achieved by Namibia trial, 12mbps was achieved by Cape town trail and 16mbps was achieved by Microsoft TVWS experiment in Kenya.*

***KEYWORDS:*** *Amplitude, Customer Premises Equipment, Shannon Capacity , Poisson Point Process, Signal.*

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## I. INTRODUCTION

The availability of a reliable access to broadband connectivity in rural communities is crucial to the rapid development of the communities and decongestion of the urban areas. Rural areas are predominantly characterized by lack of infrastructures, poor and unreliable access to virtual communities which makes these areas totally isolated from the data and communication world. Recently, there are unprecedented high traffic of rural-urban migration inspired by high standard modern developments and straightforward access to information and communication technology [4][6]. High rate of urbanization is often related to environmental pollution, unemployment, housing problems, high rate of crimes, overcrowding, poor health and widespread of diseases per se governments are seeking ways to mitigate these adverse effects by trying the concept of decentralization [2][4]. In developing country like Nigeria with high number of rural areas and few urban areas, where there are high rate of rural-urban migration as a results of search of quality life and lack of basic infrastructures like quick access to information and communication within the rural areas, the decentralization of key infrastructures from urban to rural communities is that the only strategy to establishing a balance and eliminating marginalization between these areas [3]. Rural broadband connectivity is an approach to empower the local communities in addressing their challenges associated with information and communication connectivity.

During the world pandemic era because of restricted movement and physical contact making broadband network connectivity gained prominence in urban areas because it became the key means of connecting with friends and families, trading goods and services, ending education, health, science, security and media activities, amongst others. At such disturbing times, lack of internet access in rural areas creates what's called digital divide, were by limiting economic process and restricting flow of knowledge to the society at large [2]. The establishment of efficient and sustainable broadband connectivity within rural areas will be possible with the utilization of Television white space technology (TVWST). Since the agricultural communities are posed with complex geographical landscape, density of population and remote terrains making the deployment of fixed-wire-line infrastructure challenging and capital intensive for telecommunication companies. Then, the consideration of TVWST becomes much vital to the agricultural characteristics in covering larger areas and achieving affordable broadband connectivity while eliminating the employment of complex high investment communication infrastructures technology within the rural communities [1][5].

TV white space is that Unassigned spectrum within 470 MHz to 694 MHz range of the Ultra-High Frequency (UHF) band, primarily in rural service areas, may be utilized to supply underserved and unserved areas with broadband internet connection. in the country. Spectrum bands are often organized into a defined several frequency channels, each of which has bands assigned to it for various wireless communication services. One of the main characteristics that define an electromagnetic field (EMF) is its frequency or its corresponding wavelength. Fields of different frequencies interact with the body in different ways. One can imagine electromagnetic waves as series of very regular waves that travel at an enormous speed, the speed of light. The frequency simply describes the number of oscillations or cycles per second, while the term wavelength describes the distance between one wave and the next. Hence wavelength and frequency are inseparably intertwined: the higher the frequency the shorter the wavelength. [10].

### 1.1 Guidelines on the Utilization of Television White Spaces in Nigeria

These guidelines provide an underlying model to enable unlicensed transmitters to work within the UHF band as assigned on a primary basis to the broadcast TV service on frequencies and in locations where the spectrum is either not assigned to licensed services or is not used at recognized times. In order to protect primary users from harmful interference [8].

- These license-exempt radio transmitters will assist the development of Internet of Things applications, including agriculture, and provide inexpensive broadband and Internet access in unserved and underserved areas of the nation.
- For stationary TVWS devices, the maximum conducted power must not exceed 1 W (30 dBm) inside a channel that is open and must not exceed 50 mW (17 dBm) as measured within any 100 kHz of the channel.
- The maximum conducted power for IoT TVWS devices inside any 100 kHz frequency block within an open channel shall be 50 mW (17 dBm) EIRP.
- The height above average terrain (HAAT) of the area where the transmit antenna is located cannot exceed 250 meters.
- The transmit antenna height must not exceed 100 meters above the surface of the earth.
- Fixed TVWS devices must comply with co-channel and neighboring channel separation distances in order to operate with spectral densities of up to 10 W (40 dBm) EIRP in rural regions, 4 W (36 dBm) EIRP in suburban areas, and up to.
- For TVWS devices with a maximum EIRP of 4 W, the in-block EIRP spectral density limits are 50 mW (17 dBm), and for TVWS devices with a maximum EIRP of 10 W, the in-block EIRP spectral density limits are 125 mW (21 dBm).
- For stationary TVWS devices, the maximum conducted power in an open channel is 1 W (30 dBm), and the maximum conducted power spectral density, as measured in any 100 kHz of the channel.

## II. MATERIALS AND METHOD

This research used the Poisson Point Process (PPP) distribution model of density $\lambda$ for the Customer Premise Equipment (CPEs) in a channel environment, the link capacity performance of network is analysed using Matlab. The design is made up of a single distant white space base station (WSBS) serving a group of Customer Premise Equipment (CPEs). White Space Base Station and its group of CPEs is known as a cell. The ideal separation distance between co-channel CPEs must be designed in order to maximize link capacity and maximize the penetration power of TVWS. The operational standards and regulations' rules provided the parameter values. The parameters used for analysis includes

- CPE Separation,
- Signal to Interference and Noise Ratio (SINR)
- Number of CPEs per WSBS
- CPE distance from WSBS
- WSBS Effective Isotropic Radiated Power (EIRP)
- CPE EIRP.

## 2.1 TV White Space Design Model

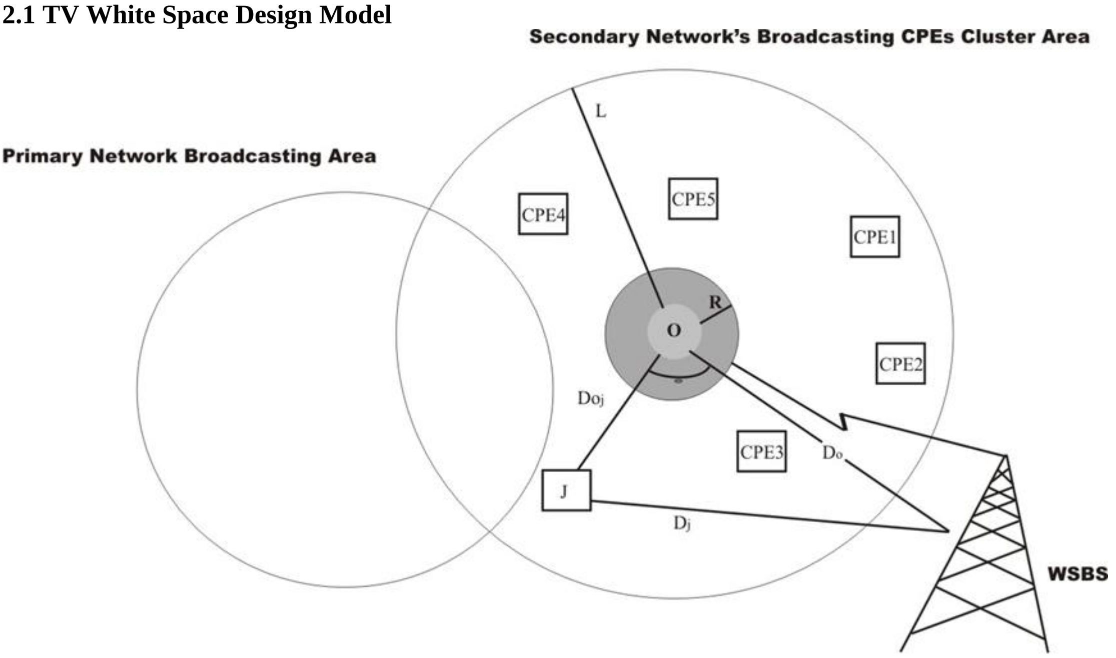


**Figure 1: Primary-secondary systems coexistence design model.**

This scenario illustrates the TVWS's user-centric deployment model, in which arbitrary deployment is probably to occur [9]. Customer premise equipment (CPE) is distributed using a Poisson Point Process (PPP) with density. In heterogeneous networks, where several small cell base stations can be placed, the base station's placement is random.

The Shannon capacity for a specific target CPE ($CPEo$) at the center of a cluster $C_o$ for a channel with bandwidth $B_O$. is stated as [7]

$$C_o = B_O log_2 (1 + SINR_o) \qquad (1)$$

Where $SINR_o$ is the ratio of the received signal power ($P_R$) to the interference ($I_{CPEo}$) and Noise ($N_o$) at the centre CPE ($CPEo$) which is given as

$$SINR_o = \frac{P_R}{N_o + I_{CPEo}} \qquad (2)$$

Let $P_{o,x}$ = interference power level of the xth CPE and

$L_{o,x}$= channel pathloss between $CPEo$ and xth CPE positioned at a distance $M_{o,x}$

Total interference at the centre CPE ($CPEo$) equals

$$I_{CPEo} = \sum_{x=1}^{N} I_{CPEx} + \tau_o \qquad (3)$$

$$I_{CPEo} = \sum_{x=1}^{N} \frac{P_{o,x}(g_{o,x})^2}{L_{o,x}} + \tau_o \qquad (4)$$

$$I_{CPEo} = \sum_{x=1}^{N} I_{CPEx} + \tau_o = \sum_{x=1}^{N} \frac{P_{o,x}(g_{o,x})^2}{L_{o,x}} + \tau_o \qquad (5)$$

Where,
$\tau_o$= self interference effect in $CPEo$
N = number of interfering CPEs in the cluster
$g_{o,x}$= gain between the CPEs

Let all the CPEs have the same configuration for every CPE cluster.
Meaning;

$$p_{o,x} = p_o \quad and \; g_{o,x} = g_{x,o} = g_o \tag{6}$$

Because the signal from the base station before getting to has gone through some form of degradation from the environment, we can have that;

$$P_R = \frac{P_w g_w g_o}{L(M_o)} \tag{7}$$

Where:
$P_w$ = power gain from the white space base station
$g_w$ = channel gain from the white space base station
$L(M_o)$ = path loss between whitespace base station $CPEo$ and which depend on the distance between them $M_o$.

If we combine equation (2), (5) and (7) to get another $SINR_o$ as:

$$SINR_O = \frac{\frac{P_w g_w g_o}{L(M_o)}}{N_o + \frac{P_{o,x}(g_{o,x})^2}{L_{o,x}}} \tag{8}$$

Replacing $g_{o,x}$ $and$ $P_{o,x}$ respective with $g_o$ $and$ $P_o$

$$SINR_O = \frac{P_w g_w g_o}{L(M_o)[N_o + \sum_{x=1}^{N} \frac{P_{o,x}(g_{o,x})^2}{L_{o,x}}]} \tag{9}$$

For a wider coverage maintaining good signal power (SINR) is required for the rural populated area to benefit from the white space network.
Because of the largely available TV white space the method applied is distance distribution method where a point and its nth in two-dimensional plane [7] is given as:

$$F_n(r) = \frac{e^{(-\lambda \pi r^2)^n}}{r\,\Gamma(n)} \tag{10}$$

Where $\lambda$ is the number of nodes per each surface area and $\Gamma(n)$ is an incomplete gamma function.
But we are to target a particular received signal power compared to the interference and noise SINR ($\gamma_T$) should be met.
The probability the signal power will drop less than the targeted value is given as:

$$P_{out} = P_r(SINR_o \leq \gamma_T) \tag{11}$$

Assuming a very small drop noise level $N_O$, using equation (9), we can input $\gamma_T$ as:

$$\gamma_T = \frac{P_w g_w g_o}{L(M_o)[\sum_{x=1}^{N} \frac{P_o(g_o)^2}{L_{o,x}}]} \tag{12}$$

Note: using equal distance interference nodes $M_{o,x}$ which is the distance between the CPEo and M CPE from equation 12 will be thus

$$P_w g_w g_o = \frac{\gamma_T\, L(M_o) N P_o (g_o)^2}{L(M_{o,x})} \tag{13}$$

$$\gamma_T\, L(M_o) N P_o (g_o)^2 = P_w g_w g_o L(M_{o,x}) \tag{14}$$

$$\gamma_T\, L(M_o) N P_o g_o = P_w g_w L(M_{o,x}) \tag{15}$$

$$M_{o,x} = M_o = \frac{\gamma_T \, L(M_o) N P_o g_o}{P_w g_w L} \qquad (16)$$

$$M_o = L^{-1} \frac{\gamma_T \, L(M_o) N P_o g_o}{P_w g_w} \qquad (17)$$

From cumulative distribution function equation 10 within a cluster of CPE the probability outage ($P_{out}$) of a link to the closest CPE is taken as:

$$P_{out} \simeq 1 - e^{(-\lambda \pi r M^2)} \sum_{k=1}^{n=1} \frac{(\lambda \pi M^2)^k}{k!} \qquad (18)$$

So from equation 11 haven a **v** number of available channels at a particular targeted area, the total capacity $C_o$of $CPEo$ is expressed as

$$C_o = \sum_{k=1}^{V} (1 - P_{out}) B_k \, log_2 (1 + \gamma_T) \qquad (19)$$

Put equation (18) and (19) our link capacity becomes

$$C_o \simeq \sum_{k=1}^{V} \sum_{q=1}^{N-1} B_k \log_2(1 + \gamma_T) \frac{(\lambda \pi M^2)^q}{q!} e^{(-\lambda \pi M^2)} \qquad (20)$$

In this research the base station has three white space radio antennas 120 degrees apart to give omnidirectional coverage to the area is used. Each antenna provides 120 degree coverage which is called a sector and the three sectors makes up a cell and a cell is a geographical area covered by on base station.

If $S_N$ is the number of sectors for a cell and $C_p$ is the cell capacity and $C_e$ is the total capacity for each sector then;

$$C_p = \sum_{l=1}^{S_N} C_e \qquad (21)$$

Say all sector have equal coverage capacity for a given channel bandwidth $B_S$. The capacity of each customer premise equipment CPE can be gotten from equation 20 to be:

$$C_N \simeq \frac{1}{S_N} \sum_{1}^{S_N} \sum_{q=1}^{N} B_s log_2(1 + \gamma_T) \frac{(\lambda \pi M^2)^q}{q!} e^{(-\lambda \pi M^2)} \qquad (22)$$

Before live implementation, testing of the developed technique is required. Most of the time, testing and evaluating the protocols or theories proposed is not practically feasible through real experiments as it would be more complex, time consuming and even costly. So, to overcome this problem, "SIMULATORS and TESTBEDS are effective tools to test and analyze the performance of protocols and algorithms proposed[11].

## III RESULTS AND DISCUSSION

The purpose of the study is to evaluate the TVWS network's channel capacity in relation to various network factors. The NCC guidelines that have been established served as the foundation for the analysis.

Table 1 below gives the parameters used for this research work. The research used $\lambda$ = 0.1 which means one CPE for a 10km square area (which gives us 1.8km radius

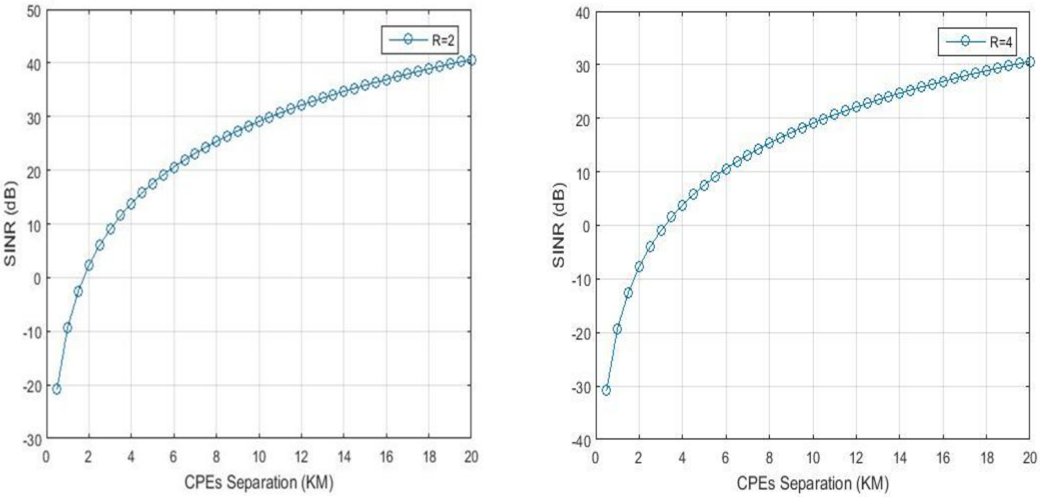
**Table -1 Parameters for simulation**

| S/N | PARAMETERS | VALUES |
|---|---|---|
| 1 | Channel bandwidth ($B_s$) | 8MHZ |
| 2 | Gain of the WSBS ($g_w$) | 11DB |
| 3 | WSBS EIRP ($P_W$) | 36 DBM |
| 4 | CPE EIRP ($g_o$) | 30DBM |
| 5 | WSBS HAAT ($H_B$) | 60M |
| 6 | CPE HAAT ($H_{re}$) | 10M |
| 7 | Noise (N) | -174 BM |
| 8 | CPE Density ($\lambda$) | 0.1 |

This section the channel capacity performance versus different network parameters is presented.

### 3.1 Signal to Interference and Noise Ratio (SINR)

The figure below shows the relationship between the SINR and the CPE separation (M) for a particular base station range (R).



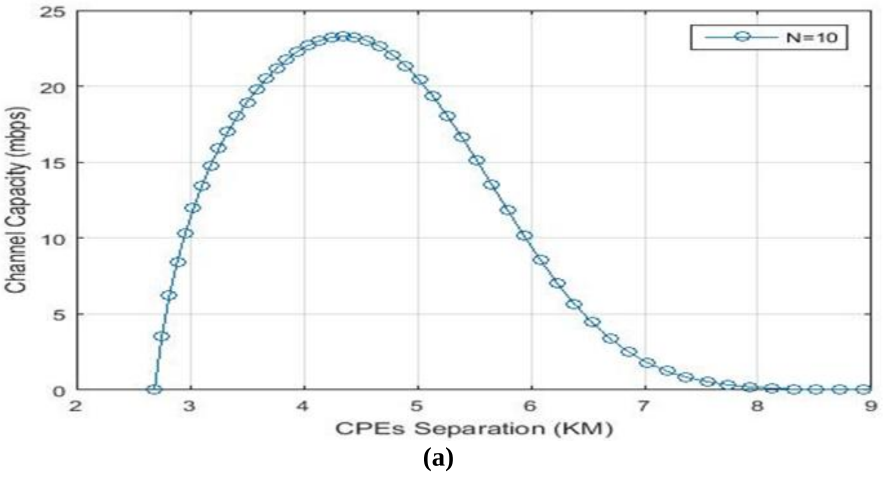
**(a)** **(b)**

**Figure 2: The SINR with the CPE Separation for WSBS range R=2&4**

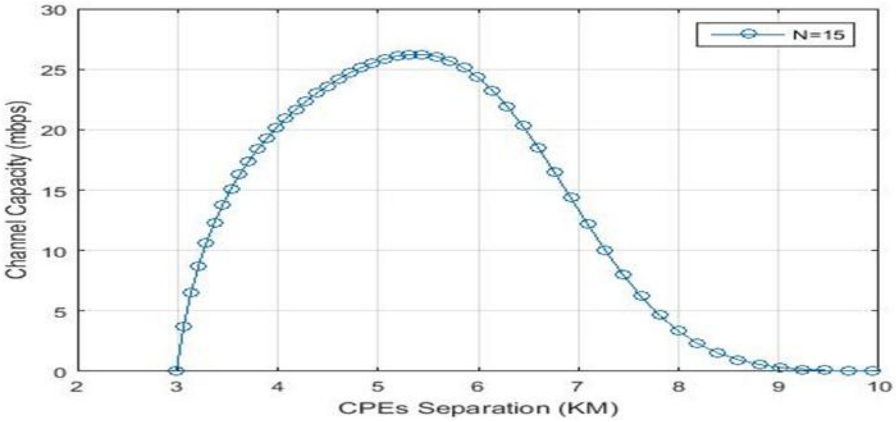
There is continuous increase in SINR with M because interference is reduced, also important to note from figure 2 (a) and (b) for a given M distance if we double R result to almost a doubled decay in SINR.
The target SINR has to be achieved for a system to deliver the needed quality of service.

### 3.2 Channel Capacity

The quality of the signal is determined by channel capacity as shown before. Meaning the signal to interference and noise ratio (SINR), the separation of CPEs (M), the number of CPEs (N) and the distance between the WSBS and the target CPE (R).



**(a)**



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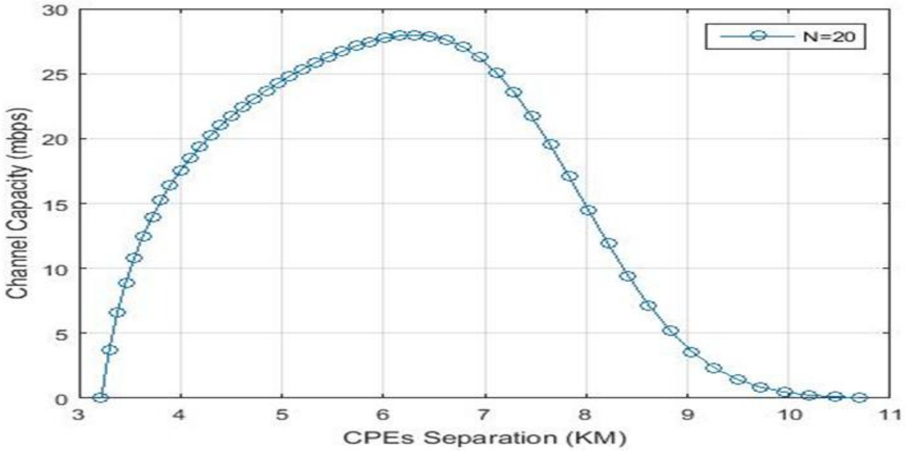


**Figure 3: Channel Capacity versus CPE Separation (M) for SINR=10Db and R=5 for Number of CPE N=10,15&20**

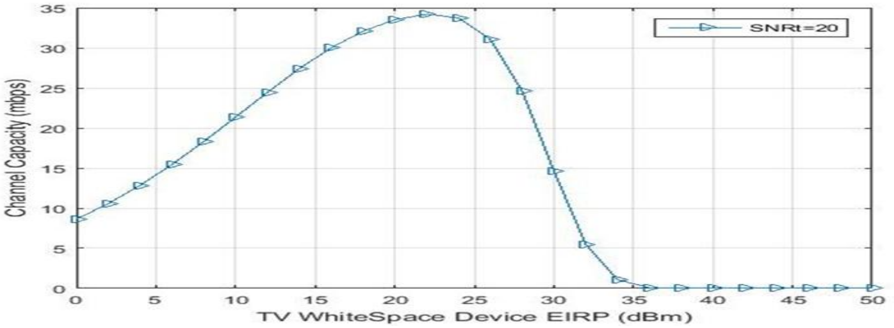
The figure 3 above displays the channel capacity versus the CPEs separation distance for a white space Base station range of 5km.

Since the distance between CPEs (M) depends on the number of CPEs used which in turn determine SINR, as the number of CPEs (N) increases M should also increase to retain the same SINR (Service Quality).

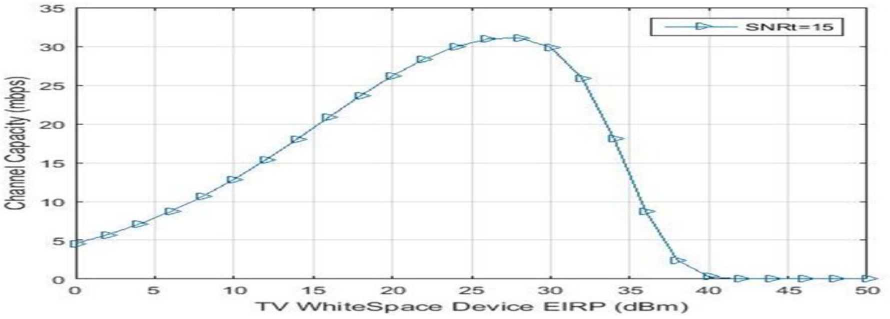
The figure above reveals that raising the number of CPEs and maintaining the same CPE separation will result to drop in channel capacity because of interference, for instance at M equals 4km for 10 CPEEs the channel capacity is 23mbps for 15 CPEs the channel capacity is 20mbps and for 20 CPEs the channel capacity is 18mbps.

We also see that to obtain a channel capacity of 23mbps at a target SINR of 10db the separation of CPE is around 4km. However as given by equation -- the channel capacity later begins to drop as M go beyond threshold value where workable SINR is unachievable.

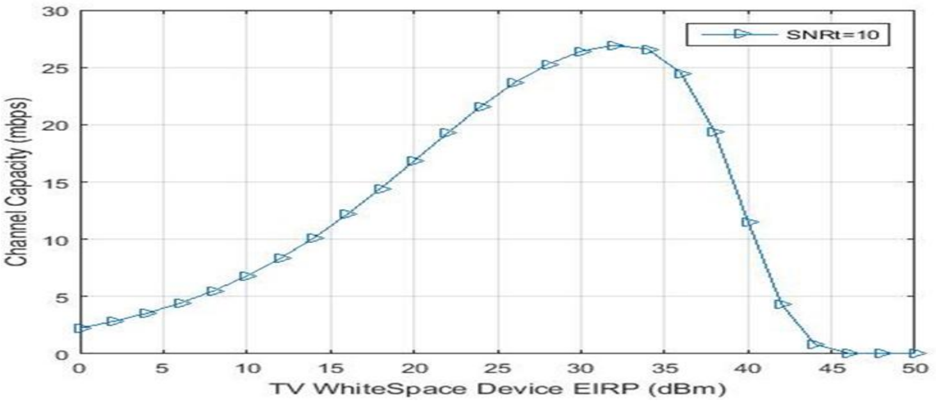
Other sources of losses arethe statistical or unpredictable nature of several of the parameters in equation 11. For example, both $\sigma$ and $S_{min}$ are statistical in nature. The equation also does not account for other statistical factors such as meterological conditions along the propagation path [5].



**(a)**



**(b)**



**(c)**

**Figure 4: Channel capacity vs TVWSD EIRP for SINR=10,15&20**

From figure 4 above the channel capacity and the TVWSD EIRP have an increasing relationship up to a point where any increase in power will bring down the capacity of the channel. From equation 17 increase in CPE separation is expected which will in turn reduce interference. On the other hand for the increase in TVWSD EIRP added to the increase in D the overall impact will cause the channel capacity to drop.

We also have from the figure that small SINR target at TVWD's power can be accepted because more interference is tolerated, for example for 5db of SINR, 30 dbm power can give a capacity of 14mbps. Table 2 shows the results of other TV White Space trial projects deployed in Africa.

**Table 2: Previous TV White Space Channel Capacity Results Achieved**

| TV White Space Trials | Link Distance/Coverage Area | Channel Capacity Achieved |
|---|---|---|
| Namibian Trial<br>M.T. Masonta *et al*. 2014 | 9,424 $km^2$ / 12 km | 10 Mbps |
| Cape Town Trial<br>Albert A. *et al*. 2014 | 6km | 12 Mbps |
| TVWS Experiments in Kenya – Microsoft<br>M.T. Masonta *et al*. 2014 | 14km | 16 Mbps |
| **Nigerian Trial ( This research work**) | 10$km^2$ | 23 Mbps |

## IV CONCLUSION

This research work proposed to analyze the performance of the TV white space network. A network following a Poisson Point Process for the distribution of the customer premise equipment CPEs in channel environment that is characterized by Hata Propagation model which help to account for path loss.The research took advantage of the distance between CPEs in rural areas to achieved high channel capacity. The research has shown channel capacity framework for TV white space network deployment that is built on the distance distribution that is suited for rural areas. A scenario where the CPEs are spaced equally and have the same device configuration were considered. The following are the recommendations made:

i. To maintain a target SINR for an increase in the number of CPE, The CPE separation should also increase appropriately to reduce interference

ii. Since in the rural areas available number of TV white space channels are very large, channel aggregation can be applied to better the capacity for the users. In this case three channels of 8MHZ to obtain 24MHZ bandwidth channels.

iii. It is recommended that further research considering different Customer Premise Equipment (CPE) configuration and performance of CPE should be conducted.

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