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Development of outdoor propagation models for frequency scheduling of TVWS Broadband connectivity in rural areas using dynamic spectrum method.

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Abstract

This paper presents the development of outdoor propagation models for frequency scheduling of TVWS Broadband connectivity in rural areas using dynamic spectrum method. Measurements were then taken using an RF Explorer, to determine availability of TVWS Frequencies. Analysis of the measured Signal to Noise Ratio (SNR) proved that there is the presence of TVWS frequencies at Ugbawka in Enuug State Nigeria. A database was created using an android Application where the frequencies required can be accessed on request. An outdoor propagation model was developed for Enugu rural area of Ugbawka where the path loss exponent result gave 2.15dB. Measurements were carried out to know the extent at which Indoor broadband can be enhanced using Wi-Fi in TVWS. Setting the modulation scheme to adaptive and manual at separate times, the SNR's Downlink (DL) and Uplink (UL) values were measured. Also varying the 16 QAM, QPSK and BPSK modulation modes between the DL and UL, at ½ and ¾ convolution rates at the six locations, each exhibited some pattern subject to the modulation mix. An algorithm was developed, titled, TVWS Optimization Quadrature Amplitude Algorithm, (TOQA), which showed that throughput performed better by giving 60Mbps and 70 Mbps at SNR of 5dB while the conventional algorithm gave 30Mbps and 25 Mbps at same SNR value.

Keywords: TVWS, Dynamic Access Spectrum

1.0 Introduction

Broadband internet connection is high-speed access that allows a large volume of data to be transmitted at a data transfer speed greater than 256Kbps using an Asymmetric Digital Subscriber Line (ADSL). It differs from a dial-up connection by dividing the line into many different channels, having information travel in parallel streams down these channels. Broadband connectivity is an essential infrastructure to the 21st century. Broadband Internet enables access to business and job opportunities, facilitates social interactions, improves education, health care, and enhances public safety and security measures. It has a direct impact on any nation's ability to improve the economic well-being of its people, compete globally, and create effective implementation of remote learning in rural areas. Rural areas depend a lot on agricultural activities. The quality of crops depends on weather and broadband connection provides farmers with timely warning signs and relevant information on weather condition updates. Broadband internet enables farmers to learn farm management practices, optimize irrigation and pesticide uses, monitor their equipment remotely and set up online shops for marketing their agricultural products to consumers.

Since broadband technology has so far emerged as a promising future that opens up a limitless range of possibilities on internet use, the Nigerian mobile broadband industry needs more spectrums for broadband rollout. Hence, Ezeagwu et al (2016) proposed that it is a mandatory protocol for the Government in every country to evolve an all-embracing and thorough policies that should ensure spectrum resources are effectively utilized for the overall benefit of the nation. Broadband internet connectivity can be exploited through Television White Spaces (TVWS) using Television White Space Devices or White Space Devices (WSD). Authors like Roberts et al (2015), Raj et al (2015) and companies like Carlson Wireless through their reports and publications, extensively defined TVWS as the unused, vacant, interleaved, unoccupied, unassigned frequency spectrum, located in the Very High Frequency (VHF) (174-230 MHz) and Ultra High Frequency (UHF) (470-790 MHz) spectrum band, The Very High Frequencies and Ultra High Frequencies are spectrum bands frequently used for television broadcasting, In Nigeria, the TVWS signals ranges from 470MHz to 698MHz. By the nature of TVWS, it can be effectively deployed and utilized to provide low-cost broadband internet access in rural areas rather than left unused in the broadcasting sector. TVWS transmits in lower frequencies, consumes less power over time and can travel over 400 meters. Increasing its transmission power can yield several kilometers of Wireless technology in the primary delivery medium for broadband access to end- users in Nigeria. This is because Nigeria does not have extensive copper cable infrastructure and do not benefit from broadband over ADSL. With the deployment of Third Generation (3G) and Long-Term Evolution (LTE) coverage, over 100 million Nigerians are now connected to the broadband internet with 250,000 new subscribers logging on in the last quarter of 2020 (Nigerian Communications Commission, 2020). According to Internet World Statistics, Nigerian broadband penetration is still about 28.5 percent which is still below the global penetration average of 58.8 percent (Adepetun, 2020). Unfortunately, broadband penetration is not efficient in rural areas owing to lack of infrastructural establishments in these locations. Most telecommunication service providers do not consider the rural areas as viable ventures due to their low population density, geographical barriers and large distances that are hard to overcome with current technologies in a cost-efficient manner. The high price of the spectrum within the LTE cell coverage reduces the economic feasibility of network deployment in rural areas. Due to the non-availability of broadband internet, rural areas face challenges of attracting investment, electronic education, health care, administration services and electronic banking.

2. METHODOLOGY

2.1 Development of an Outdoor propagation model

Propagation measurement aims at accurately predict the signal propagation method that properly describes the attenuation of transmitting power, or the transmitting capacity of the transmitter as signals travel away from the Transmitter towards the test bed, the Receiver. This process is defined as the pathloss. Propagation models are critically designed to suit different kinds of environment. Their accuracy in predicting signal attenuation is largely affected as their efficiency in predicting the path loss surfers when they are used in an environment other than the one for which they have been designed. The average path loss for an arbitrary transmitter to receiver separation expressed as a function of distance is given by:

$$L_P(dB) = L_P(d_0) + 10nlog_{10}\left(\frac{d_i}{d_0}\right) \qquad (3.1)$$

Where n is the path loss exponent, d_i is the measured distance and d_0 represents reference distance, $L_P(d_0)$ represents path loss at reference distance.

The pathloss propagation model was estimated from the measurements taken over a totaled distance of 1km, with frequent stops at every 100m interval from the Enugu State Broadcasting Service (ESBS) with the transmitting power of 2kw. The distance was measured using the vehicle speedometer while the RF Explorer was connected to a laptop running a Windows PC Client RF Explorer Software that contains the Spectrum Analyzer. The Spectrum analyzer produced and recorded frequency distribution results for every 100meters travelled away from the transmitter. The measurement was carried out on 07/09/2019 at 08.32.50, under an active mode. It started from the ESBS Broadcasting house where the transmitter is located at Independence layout, Enugu. The 1000meter range expired at Umuawulu Street, before Umuoji as shown by the Google Map on Figure 3.23. The first, second, third 100m measurements took place while still at Achi Street at Independence Layout, Enugu. The fourth to tenth measurements terminated along Umuawulu Street, Independence Layout, Enugu. Please, see the movement path taken in figure 3.20. as the drive test is moves from the ESBS transmitter to Ugbawka.

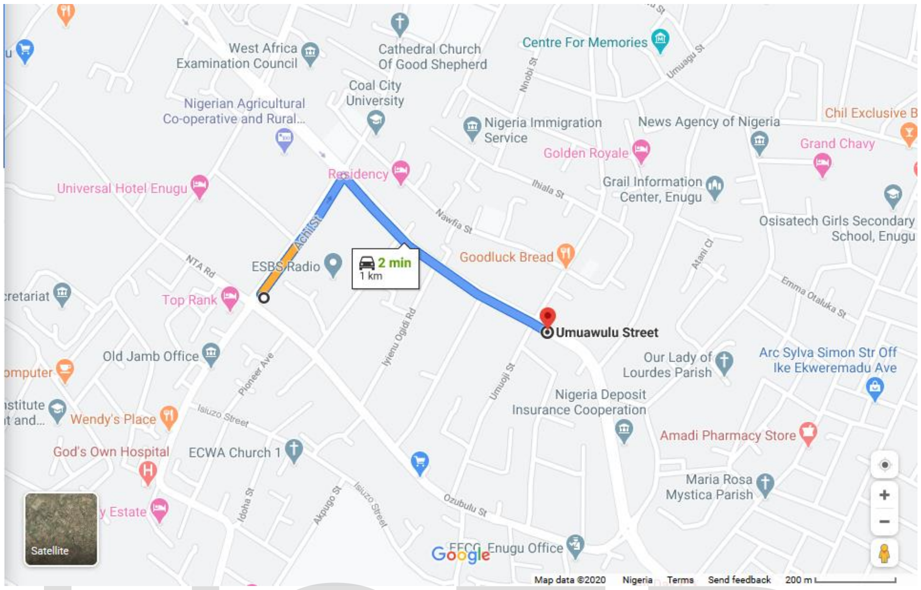

Figure 3.23: Google Map showing the travelled path from ESBS to Umuawulu Street, en route Ugbawka.

Table 3.9: Measured Path Loss (PL_M)

Distance (Meters)	***RSS (dBm)***	***Measured PL_M (d_i)***
100	*-66*	*83.99*
200	*-67*	*84.99*
300	*-70*	*87.99*
400	*-73*	*90.99*
500	*-79*	*96.99*
600	*-95*	*112.99*
700	*-83*	*100.99*
800	*-89*	*106.99*
900	*-98.5*	*116.49*
1000	*-101*	*118.99*

Note, pathloss exponent indicated the rate at which path loss increase with distance. This was calculated using the RSS data obtained from field measurements and corresponding

Transmitter Parameters, where $P_t = 2kw\ convert\ to\ dBm(63.01dBm)$ and $P_r = antilog\left({}^{RSS}/_{10}\right)$, hence obtaining $\boldsymbol{PL_M}$ for a received signal strength of -66, obtained at exactly 100m away from the transmitter. The rest of the calculations are narrated in chapter four (4).

The Other Values are generated using the same formular for all $100m \leq d_i \leq 1000m$

Path Loss exponent n, can be estimated using the data from the field measurement expressed in equation 3.3.

$$PL_M(d_i) = P_L(d_0) + 10nlog_{10}\left({}^{d_i}/_{d_0}\right)(dB) \quad \ldots\ldots\ldots\ldots.. \qquad (3.2)$$

Substituting for the known values of $PL_M(d_i)$ which is the measured path loss and d_i the distance and d_0 the reference distance which has been given to be 100m; we obtain values of the $PL(d_0)$ as a function of n. The calculation of n, the path loss exponent is shown in chapter 4

The Path loss exponent n can then be statistically evaluated through the application of linear regression analysis techniques by minimizing in a mean square sense, the difference between the measured and predicted path loss;

$$PL_M(d_i) - PL_P(d_i) = 0 \qquad (3.3)$$

The equation 3.3 is an error term with respect to n and the sum of the mean squared error is expressed as;

$$e(n) = \sum_{i=1}^{N}\left(PL_M(d_i) - PL_P(d_i)\right)^2 \qquad (3.4)$$

The path loss exponent n minimizes the Mean Square Error (MSE) and can then be obtained by taking a partial derivative of equation 3.4 and express its result to zero, then solve for the corresponding n. such that;

$$\frac{\partial e(n)}{\partial n} = 2\sum_{i=1}^{N}\left(PL_M(d_i) - PL_P(d_i)\right) = 0 \qquad (3.5)$$

From table 3.2; it has been shown that the values of $PL_P(d_i)$ are functions of n; hence substituting for the sum of both the Measured $PL_M(d_i)$ and Predicted $PL_P(d_i)$ pathlosses is;

$$2\left(PL_M(d_i) - PL_P(d_i)\right) = 0$$

$$2(141.5 - 65.58n) = 0$$

$$283 - 131.7n = 0$$

$$n = \frac{283}{131.7} = 2.15$$

The tendency for the pathloss exponent to randomly deviate from original values is inevitable in field calculations; hence, the standard deviation is calculated and to compensate for the sharing each other's difference the square root is applied to the final value. This yields a dimensionless value which is a measure of a signal's tendency to deviate from the mean. The Standard Deviation σ, about the mean value as expressed in equation 3.6 can then be determined by equation 3.8;

$$\sigma = \sqrt{\frac{1}{N}\sum (P_{LM}d_i - P_{LP}d_i)^2} \qquad (3.6)$$

Substituting the values of mean, n – Pathloss Exponent, then Squaring and solving for σ, is;

$$\sigma = \sqrt{\tfrac{1}{10}\sum(283 - 131.7(2.15))^2} \qquad (3.7)$$

$$\sigma = \sqrt{\frac{1}{10}(283 - 283.16)^2}$$

$$\sigma = \sqrt{\frac{1}{10}(-0.16)^2} = \sqrt{\frac{1}{10}(0.0256)} = \sqrt{0.00256}$$

$$\sigma = 0.051dBm$$

The result of the standard deviation from equation 3.7 indicates that there is a slight variation or adjustment from the predicted Path loss propagation and the measure for the location, it therefore becomes necessary to develop a more accurate model which will be consequently used to determine expected signal levels at required locations. The Model has been developed to satisfy the condition, $PL_0 < PL_i$. The exponent obtained from the calculations of equation 3.5 is adopted for this work. Hence the mathematical expression is obtained by adding the Standard deviation in the equation 3.3 to equation 3.6;

For this project's propagation model, known as ESUT model, the Free Space Model is adapted.

$$P_L(ESUT) = PL_M(d_0) + 10nlog_{10}\left({}^{d_i}/_{d_0}\right) + \sigma$$

Where $P_L(ESUT)$ *is the corresponding Path Loss developed by the researcher using ESBS Enugu Transmitter*

$PL_M(d_0)$ *is the Measured Path loss with respect to reference distance based at 100m*

d_i *is the distance captured under* $100m < d_i < 1000m$

d_0 *is the reference distance 100m*

Using the data provided in table 4.6, a graph was generated which showed clear comparison of the Developed ESUT Pathloss Model, corresponding Free Space Path loss Model and Hata-Davidson Pathloss Model. From the onset, it is defined that the developed model would satisfy the condition $PL_0 < PL_i$ where PL_0 is the Measured Path loss and this represents existing Path loss methods of comparison and PL is the new Enugu State University of Science and Technology (ESUT) Path loss method. The graph in figure 4.5 showed that the condition was satisfied which means that the ESUT Path loss model is best suited for the testbed as it accommodates proper attenuation for all other variables not considered by existing pathloss models – Free Space and Hata-Davidson.

Conclusion

The result showed that while obtaining latency results for iet.com and ieee.com, which are engineering research websites, they are highly not accessible most of the time. The ESUT Pathloss model was established by this project. The model, when compared with the Free Space and Hata-Davidson Model, outperformed both the Free Space Model and the Hata-Davidson Model, by the Pathloss Factor, $PL_0 < PL_i$ where the measured path loss is PL_0 and PL_i the developed Path loss model. Also, an indoor path loss model was developed which factored in all possible materials that would mitigate signal propagation. Measurement in the actual indoor environment was done

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