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A Technique for Planning Microwave and Cellular Path Profile in the Tropics and Determination of Antenna Tower Heights (A Study of Onitsha/Nnewi Axis of Anambra State, Nigeria)

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Abstract - This paper presents a technique for proper planning of outdoor microwave and cellular path profile and determination of correct antenna tower heights in order to ensure Radio Line-of-Sight (LOS) clearance of the first Fresnel Zone or Radius from intrusions and obstacles in the Radio propagation path thereby improving the Quality of Service (QoS) delivery of deployed Systems

Keywords: **Radio Spectrum, Microwave, Cellular, Path Profile, Assessment Technique, Path Loss.**

I. INTRODUCTION

Radio spectrum is the portion of electromagnetic spectrum dedicated to telecommunications. The frequencies range is from 10 kHz to 3000GHz. This natural resource is the base for wireless technologies like mobile communications, microwave, and the use of GPS [1]. Microwave is the term that collectively refers to the decimetric wave (UHF: 300MHz-3GHz) and the centimetric wave (SHF: 3GHz-30GHz), although the term is often extended to cover the whole of ultra short wave band (VHF, UHF and SHF). VHF wave, also called metric wave is in the frequency range of 30MHz-300MHz. As a result of rapid growth in wireless telecommunications, there has been an increasing need for proper network coverage predictions. This proper network coverage predictions planning requires a good understanding of the fundamental limitations caused by various environmental condition to the propagation of the signal such as interference and multipath fading [2]. When a radio frequency (R.F) power is fed into a transmitting aerial or antenna, electromagnetic energy at the same frequency will be radiated from the aerial. This energy is propagated away from the aerial in a number of directions, predicted by the radiation pattern of the aerial [3].

This paper is concerned with unguided (Space) propagation of radio waves, that is, radio relay links and wireless transmissions in the intervening medium in-between Base Transceiver Stations (BTS) antennas, using carrier frequencies, from 30MHz up to 30GHz. Where a location has been earmarked or decided upon, for citing a BTS, the exact point to site facilities is primarily determined by reception of the strongest signal field strength [4] however, in Nigeria, economic consideration and political patronage remains topmost in the choice of locations of Communications facilities without due diligence and proper feasibility studies and careful technical planning. What type of antenna and the gain to be deployed, the height of antenna to be installed, and over what kind of terrain the signal propagates, becomes a secondary issue when the different levels of Governments interferes in Management decisions, and in the quest of Network Operators to post huge profits and returns on investments (ROI)

The primary issue that must be considered in any transmission system is how to establish Channel links among users within the network in the radio wave coverage, in the environment of Wireless (microwave or cellular) communications. Each site or location should have just one antenna tower, no matter the type, or number of systems deployed, whether a First Generation (1G), second (2G), third (3G) or even the Next-Generation Networks (NGN), as Service Providers are at liberty to mount the aerials of two or more different Generation Systems, or that of other Service Providers, on the same tower and even provide facilities to other Service Providers on Co-Location arrangement. The concern here should be on how to mitigate spurious emissions and interferences from the different networks sharing space on same tower, which could be tackled by implementing antenna or space diversity

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The cellular concept seeks to make efficient use of available channels (Radio spectrum) by breaking a large coverage area into smaller areas called "cells" and within each cell, deploy a low-power transmitter, and aerial or antenna must be mounted on a tower (mast) to provide coverage, only within that cell [5]. In modern urban propagation environment, the cell coverage area is less than 2kilometers [6]. It is safe to infer that cell-splitting makes the network very expensive as a large area, hither-to, covered by only one transmitter (tower) now has several towers, one for each cell, hence, the antenna tower height calculated for any site for microwave systems is equally applicable for cellular systems. Proper planning of Microwave and Cellular Path Profile and determination of correct outdoor antenna tower heights is necessary to ensure Radio Line-of-Sight (LOS) clearance of the first Fresnel Zone or Radius from intrusions and obstacles in the Radio propagation path; thereby improving Quality of Service (QoS) delivery of deployed systems

II. LITERATURE REVIEW

In Land mobile environment (microwave and cellular), buildings and vegetation/foliage significantly influence Radio signal propagation, and for wireless subscribers in urban environment, either walking or driving along a city street, they are generally located among buildings, so that the Base Station antenna are seldom visible (Non Line-of-Sight). The radio signal therefore reaches the receiver by travelling past rows of buildings [7]. For a Microwave Radio relay link spanning close to 50kilometers (between sites or Repeaters/Amplifiers), the signal may propagate over difficult terrains, which may include buildings, foliages/vegetation, body of water (sea), sand (desert) etc.

Experimental measurements show that beyond 1kilometer, Radio signal generally decay continually with distance. This gradual decay or reduction of Signal Power as the signal propagates from Transmitter to Receiver, or from one BTS transmitting tower to another, as distance increases is called Propagation Path Loss, L_p which could be predicted, using propagation models [8].

In general, Path Loss (L_p) is expressed as: $L_p = \frac{\text{Transmitted Power}}{\text{Received Power}}$ (1)

Which in decibel (dB) is: $L_p\ [\text{dB}] = 10\text{Log}\ [\frac{Pt}{Pr}]\ \text{dB}$ (2)

The Power of the Received Signal is reduced due to some, or all of these listed factors:

- Free Space loss, A_o
- Earth's curvature (k factor, $k = \frac{4}{3}$ for tropics)
- Multi-Path effects – Reflection, Refraction, diffraction, Scattering, Absorption etc.
- Fading
- Environment – Urban, Suburban and Rural
- Nature of terrain – Flat or Hilly topology, desert, vegetation/foliage, ocean etc.
- Frequency used – In this paper, 300MHz for microwave and 800MHz for cellular Systems.
- Effective antenna heights, which we are about determining.
- The attenuation that is acceptable between the transmitter output and the receiver input.
- The required fade margin (this depends on type of system deployed).
- Distance between sites (stations).

The Free Space Loss, A_o can be calculated as a function of wavelength (λ) and distance (D) between sites, or deduced from Nomogram No. 1 (Figure 1)

L_{fs} (dB) = $-\ 10\ \text{Log}\ (\frac{\lambda}{4\pi D})$ (3)

Wavelength (λ) = $\frac{\text{Speed of Light (c)}}{\text{Frequency}} = \frac{3 \cdot 10^8\ \text{meters}}{F\ (\text{Hz})} = \frac{300\ \text{meters}}{F\ (\text{MHz})}$, where distance, D between sites or Locations is in kilometres (km), then:

$\boldsymbol{\lambda}$ (km) = $\frac{0.3\ \text{km}}{F\ (\text{MHz})}$ (4)

Substituting wavelength in kilometre (km), Equation (4), into Equation (3) yields:

$L_{fs} = -\ 10\ \text{Log}\ (\frac{0.3}{4\pi FD})^2$ (5)

Expanding Equation (5) yields:

L_{fs} (dB) = $-\ 20\ \text{Log}\ (0.3) + 20\ \text{Log}\ (4\boldsymbol{\pi}) + 20\ \text{Log}\ F\ (\text{MHz}) + 20\ \text{Log}\ D\ (\text{km})$

$= 32.44 + 20\ \text{Log}\ F\ (\text{MHz}) + 20\ \text{Log}\ D\ (\text{km})$ (6)

Equation (4) is Harald T. Friss Free Space Loss.

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III. SYSTEM ASSIGNMENT

Having predicted or calculated the Free Space Loss, A_o, the question that remains to be answered is, "will the equipment or System, when deployed work over this path?"

The first step in arriving at the answer is to calculate the Flux or Power budget by deriving the System or Transmission Path Loss (TPL=A_p). Most often, System Loss or Transmission Path Loss gives a better expression of Received Signal Strength at a distance, than just Path Loss, when all losses/attenuation are accounted for, in a link budget. The System Loss is depicted in Figure 2.0.

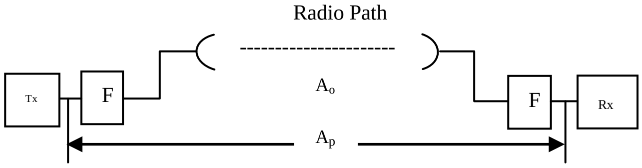

Fig 1: System Assessment

A_p = Transmission Path Loss (attenuation in dB)

$A_p = A_o + A_f + A_t + A_F + A_a - G_t - G_r$ (7)

Where;

A_o = free space loss (path loss)

A_f = filter loss

A_t = transmission line or feeder loss

A_F = multi-path fading

A_a = atmospheric absorption loss

G_t = transmitter antenna gain factor

G_r = receiver antenna gain factor

If the transmission line plus filter loss between transmitter and transmit antenna L_t and that between the receiver and receive antenna L_r are considered, Equation 3.1 becomes:

$A_p = A_o + A_f + A_t + A_F + A_a + L_t + L_r - G_t - G_r$ (8)

In most calculations for System Assessment, A_F and A_a are not considered because their effects are not noticeable at frequencies less than 6GHz (peculiar to commercial operations), and again, the use of high gain directional antenna or smart antenna and inclusion of Fade Margins into the System completely overcome their effects. Also L_t and L_r are ignored because of their very small values [9].

For System Loss therefore, Received Power is:

P_r (dBm) = P_t (dBm) – A_p (dB)

= P_t (dB) + G_t (dB) + G_r (dB) – L_p (dB) (9)

Another vital parameter for consideration is; what kind of system do we wish to deploy? Microwave or CDMA System.

For Microwave: Analogue – Frequency Division Multiplex (FDM) or Digital – Pulse Code Modulation (PCM) or Delta Modulation (ΔM) for Military equipment, the criterion of excellence of FDM system is the signal to noise ratio (SNR) that the user will experience on a communication channel.

FDM system value is derived from the expression:

$SNR = S_v - A_p$ (10)

Where SNR = Signal to Noise Ratio in the Top channel of the Radio equipment

S_v = System Value

A_p = Transmission Path Loss (TPL)

The system value derived from the parameters of the radio equipment and the multiplexer used takes into account, such factors as:

- Radio transmitter power output (P_t)
- Radio noise figure (N_R)
- Channel capacity (C)

Where $C = 2W\log_2 m$ (11)

For binary Channel m = 2, hence,

C = 2W bits/sec and W = bandwidth.

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The FDM margin is the SNR of an FDM System, referred to the standard. For instance, on all Military systems, an FDM margin of 0dB would represent a SNR of value of 35 dB [10]. Positive margin implies that the system will work, while negative margin indicates that Standards are not met, and so, System will not work.

The effect of the Transmission Path Loss (A_p) on a PCM system is to cause transmission error in the pulse stream. The starting point of Digital Communications is the sampling theorem. A typical telephone signal, within the frequency band 0.3 – 3.4 KHz can be sampled at an 8 KHz rate. This exceeds the Nyquist rate of 6.8 KHz by an adequate amount to allow suitable filters to be designed. The next step is to convert each sample value into a series of binary digits and two processes are involved – quantization by which each of the samples is represented by a discrete value chosen from a fixed number of possible levels and the second process is coding. By coding, each level is represented by a series of binary digits. The final result of sampling, quantizing and coding is to replace the Analogue signal by a series of pulses and the whole process is called Pulse Code Modulation (PCM) [11]. The maximum acceptable error rate for PCM system is laid down in the manuals of the equipment vendors or manufacturers. For Military equipment, it is quoted as 1 in 10^3[10].

Each radio/multiplexer combination has a “maximum” permissible transmission path loss ($A^{\wedge}_p$) calculated for.

The quality of a PCM system is indicated by the PCM margin which is given by:

PCM margin = ($A^{\wedge}_p$ - A_p) dB (12)

Hence, if the margin is negative, the error rate standard will not be met, resulting in noisy circuits (degradation of service offered). The basis of PCM has been to sample the input signal and to transmit coded forms of the sample values.

In the particular case of Delta Modulation (ΔM) a single binary digit is used to describe the change from one sample value to the next. The digit is derived by comparing the signal amplitude at a sampling instant with the value obtained by reconstructing the signal from the previous digits. The reconstructed signal is thus quantized. The equipment needed either at the transmitter or at the receiver is much simpler when Delta Modulation is used than in the case of Pulse Code Modulation [11].

For Cellular, as with any Communications System, the basic performance measure is the accuracy with which it can transmit information from one point to another. This involves answering two questions:

- Can the receiver properly detect the transmitted data stream, so as to accurately determine whether each transmitted bit is Logic “1” or “0”?
- Can the receiver correctly extract the information content from a properly reconstructed data stream?

The first question addresses the quality of the physical transmission and directly relates to subject of this Paper. For instance, propagation Path Loss (Attenuation) makes it difficult to reliably extract the data stream from noise floor and interference levels that are above the minimum prescribed threshold value of 18dB for CDMA Systems, for instance. The second question relates to such issues as how well the receiver can identify the start of a frame, de-multiplex the tributary signals and extract the payload. These issues are independent of whether Transmission System employs wireless (Microwave or Cellular), Optic Fiber or Copper-wire medium, and this is outside the scope of this Paper. One important transmission performance metrics for Cellular Systems is the Signal-to- Co-Channel- Interference Ratio ($\frac{S}{I}$ or SIR) or its variant, the Bit-Error-Rate (BER), which is primarily due to noisy environment. In-order to increase noise immunity, it is necessary to increase the Signal Power. However, the amount by which the Signal Power should be increased to obtain a certain level of fidelity (acceptable bit-error probability) depends on the particular type of modulation employed.

The power efficiency, η_p (energy efficiency) of a digital modulation scheme is a measure of how favorable this trade-off between fidelity and Signal Power is made, which often is expressed as the ratio of the Signal Energy per Bit to Noise Power Spectral Density ($\frac{E_b}{N_o}$), required at the receiver input for a certain probability error, say 10^{-5}.

IV. ANALYSIS OF OUTLINE OF ASSESSMENT TECHNIQUE, PLOTTING OF PATH PROFILE AND DETERMINATION OF ANTENNA TOWER HEIGHTS

The following procedures are considered in arriving at a correct and proper radio path assessment.

(i). Plot the path profile between sites (locations) from a Map (Figure 3.0), using the correct K Paper (Figure 5.0).

(ii). Draw the radio line of sight (RLOS), in this case, Onitsha and Nnewi in Anambra State of Nigeria on the Map, and note contour values.

(iii). Plot the lower half of the boundary of the first Fresnel Zone onto the profile, using the

Formula, $r = 548\sqrt{\frac{d_1 * d_2}{F * D}}$ (13)

(iv). Deduce the Free Space Loss, either mathematically, using Equation (6), that is:
$A_o = 32.44 + 20\log F*D = 32.44 + 20\log F + 20\log D$ or by use of Nomogram No. 1 Scale (Figure 4.0).

(v). Deduce the diffraction loss/losses, according to the type of path from Nomogram No. 1

(vi). Work out the Radio Path Loss (RPL).

(vii). Work out the Transmission Path Loss (TPL).

(viii). Assess system performance and fade margin.

A path profile is a scale representation of vertical section through the terrain along the line of path. It is derived from the CONTOURS of a map, and shows the relative heights of all points on the map. These heights are plotted on curved graph, using the correct k factor for the frequencies concerned, hence the name k- graph.

For such profiles to be correct, several scale relationships must be correct. These are:

(i). Vertical profile height to actual ground height.

(ii). Horizontal profile distance to actual ground distance.

(iii). Curvature of base line; related to (i) and (ii) above.

A profile and method by which the topography of the locations is produced is shown in Fig 5.0.

Onitsha is found to be 200ft = 60 meters above sea level and Nnewi 500ft = 150 meters above sea level. To determine the antenna tower heights which is to be added on the path profile, determine and plot the boundary of the first Fresnel zone and draw the radio line of sight (RLOS) to join the two antennas.

Determine 1st Fresnel zone radius, r_1, using the Nomogram No. 1 or by calculation:

(For microwave Systems, Standard Repeater distance is D = 50km, and the radius of the zone, r_1 at a point 10 km from one end of the 50km path is always calculated on the profile to identify if intrusions or obstacle are in the zone). In our case, D = 19.8km, d_1 = 4km and d_2 = 15.8km.

Apply Equation (4.1); $r = 548\sqrt{\frac{d_1 * d_2}{F * D}}$ that is, that is, $r_1 = 548\sqrt{\frac{4 * 15.8}{300 * 19.8}}$ =56.53m

This could be verified, using the Nomogram No. 1

(i). Join the 4km point on d_1 scale to the 15.8km point on the d_2 scale, thus obtaining an Intersection point on the unmarked scale. Call this point "A"

(ii). Join the 19.8km on the "D" scale (see Figure 4.0) which is shared with the d_1 scale to point "A" and extend the line onto the d_2 scale. Call this point "B" on the d_2 scale.

(iii). Join "B" to the frequency (F) scale, 300MHz and obtain the intersection on the r_1 scale, Which is 57 meters?

Compare calculated result of 56.53 meters.

For Cellular Systems, determination of the antenna tower heights using Equations 4.1 and 4.2; and substituting 800MHz frequency for 300MHz and joining "B" to the frequency (F) scale, we obtain the intersection on the r_1 scale, which is 35 meters.

Compare calculated result of 34.6meters. (Equation 4.1): $r_1 = 548\sqrt{\frac{4 * 15.8}{800 * 19.8}}$ = 34.6m

Note that the elevation of d_1 is 120 meters above sea level.

On commercial link, 0.8 of the 1st Fresnel zone clearance ($0.8r_1$) is acceptable. Other users of tactical radio relay systems such as the Military may not afford this luxury.

Hence, $0.8r_1$ = 45.22 meters for Microwave and 27.68 meters for Cellular (calculated) and this is the lower arc of the 1st Fresnel zone. Mark off this clearance on d_1, which is 165.22 meters (Microwave) and 147.68 meters (Cellular) above sea level and extend RLOS from these point backwards to cut point A (Onitsha) ordinates as shown in Figure 4.2

Point A can be deduced using the formula, h_k to compensate for Earth's bulge.

Earth's bulge, $h_k = \frac{4}{51} * \frac{(d1d2)}{K}$ (14)

With standard atmosphere and $k = \frac{4}{3}$, $h_k = \frac{d_1 * d_2}{17}$ (15)

So, h_k = 37.2 m, which approx. 40m.

Point A = h_k + Elevation of d_1 = 40 + 120 =160 meters.

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Recall that Onitsha is 60 meters above sea level. It follows therefore, that the height of the antenna tower at Onitsha is 100 meters. Extrapolate the RLOS of the antenna at Onitsha, point A, through d_1 clearance to point B (Nnewi) on Figure 4.2. The ordinate at B represents the antenna tower height which for Nnewi is determined to be 90 meters.

The planned route, Onitsha to Nnewi profile is a free space profile, since no intrusion exists in the 1st Fresnel boundary.

A visit to NITEL Office at Upper Iweka, Onitsha and Nnewi confirm actual antenna heights to be: Onitsha, 100 metres, while Nnewi is 85.7 metres.

Let us assume intrusion exists in the propagation path, the Diffraction Loss, a_s could be calculated using Nomogram No.1.

Knife-edge diffraction paths are of two types:

- Single knife-edge paths
- Multiple knife-edge paths.

The Diffraction Loss, due to knife-edge intrusions is a complex function of the height of the intrusion, h above, ($h > 0$) or below ($h < 0$) the RLOS and the 1st Fresnel Radius, r_1.

Thus, to determine Diffraction Loss, the following must be known:

(i) h (meters). This can be measured form the profile (Map), where knife-edge exists.

(ii) The value of r_1 (meters at the knife-edge), deduced as follows:

Assume now that the previous path profile (Onitsha - Nnewi) has a positive intrusion ($h > 0$) of 10 meters above the Radio Line of Sight (RLOS) at d_1 = 4 km, d_2 = 15.8 km and r_1 = 57 meters as previously deduced from Nomogram No. 1, then a_s can be found using Nomogram No. 1 as follows:

The values of h and r_1 are joined by a straight line and the value of a_s is read off on the center scale (Figure 4.0). If $h > 0$, as in the case above, the right side of the scale (headed $h > 0$) is used.

In the above illustration, the Diffraction Loss, $a_s = A_s$ = 8.2 dB.

V. SUMMARY AND CONCLUSION

The Global System for Mobile Communications (GSM) explosion that began in Nigeria in year 2001 ushered lofty prospects of changing the face of Information and Communication technology for the better in Nigeria. Unfortunately, eleven (11) years after; hopes, aspirations and expectations for improved service delivery have at best, remained a mirage for most Nigerians. Today, Nigeria is dubbed one of the fastest growing markets in the world for Mobile Communications, competing with China, yet service delivery has remained abysmally poor. Prediction simulation conducted in previous work showed that the higher the BTS or Repeater Station antenna tower heights are, the lower the Path Loss experienced on that route, with the probability that deployed Systems on the route would provide better Quality of Service (QoS), hence the need for proper planning of out-door Microwave and Cellular path profile and determination of correct antenna tower heights, so as to mitigate intrusions and obstacles in the Radio propagation path.

In practice, real circuits may differ from the hypothetical reference circuits, but these differences are permitted as long as the equipment installer or Service Provider observes certain rules, having calculated or predicted some basic parameters which this paper tried to define. It is the responsibility of the Service Provider to ensure system availability at all times, which could be guaranteed by the deployment of Dual Path – Hot Standby terminal or Frequency/Antenna/Space Diversity terminals to overcome problems of fading, ducting or chronic interference and spurious emissions of the frequency in use. Where and when Network Operators or Service Providers and indeed, planners of Communications Systems take notice of the technique proffered in this paper and carry out due diligence and proper feasibility studies before deployment of facilities in Nigeria, Consumers would then be at the threshold and era of improved Quality Service delivery. This will ultimately reduce the cost of doing Business in Nigeria (e-commerce) and automatically translate to reduced tariff, leading to improved Gross Domestic Product (GDP) in the economy.

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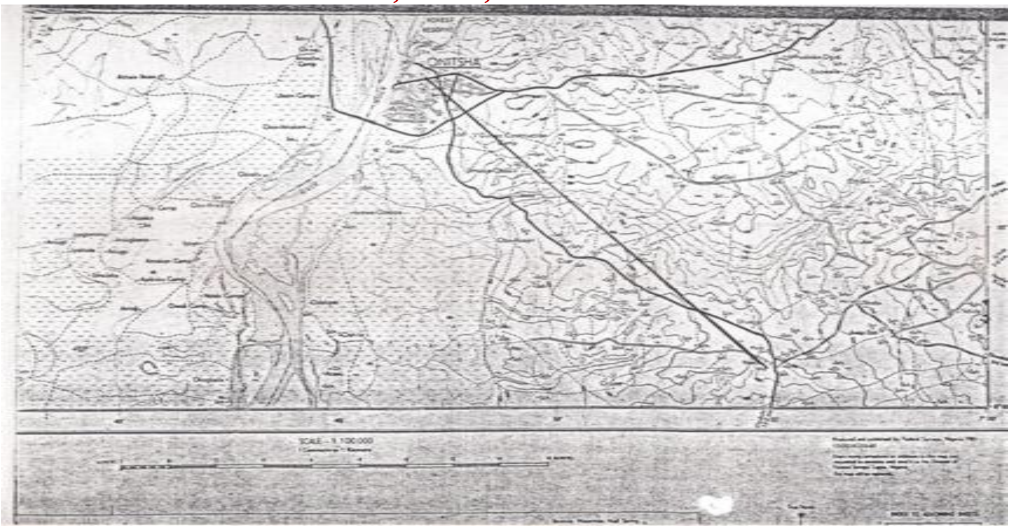

Fig 2: Location Map(Onitsha-Nnewi)

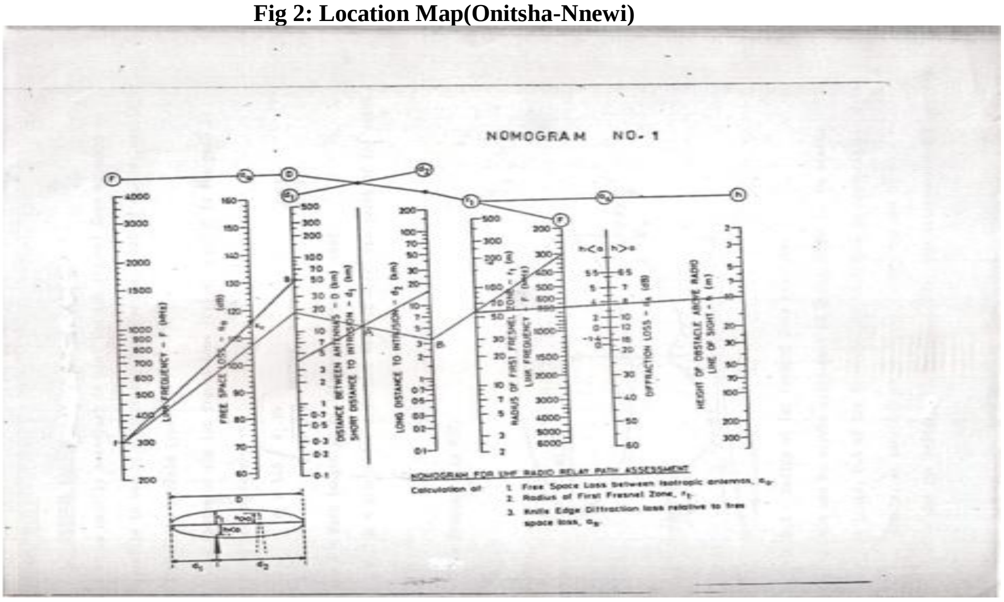

Fig 3: Nomogram No.1 scale

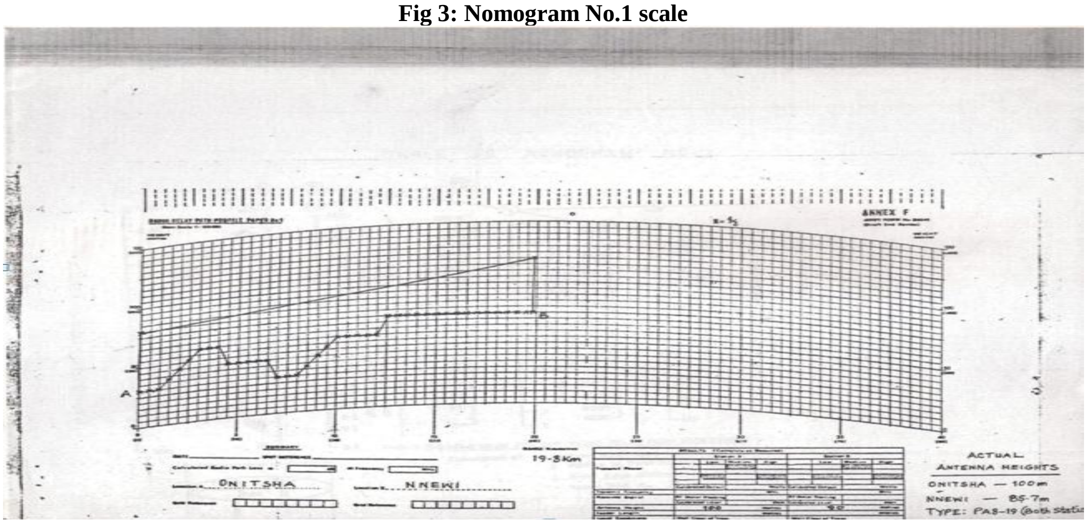

Fig 4 : Onitsha – Nnewi Path Profile on K – Graph Paper

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REFERENCES

[1]. L. C. Sanchez, "Simulation and Performance Evaluation of Co-existing GSM and UMTS Systems," Master's Thesis submitted to the Dept. of Electronic/Telecommunications University of Gavle; January, 2010.

[2]. E. A. Ubom, "Path Loss Characterization of wireless Propagation for South –South Region of Nigeria," Master's Dissertation submitted to the Dept. of Electronic/Computer Engineering, Nnamdi Azikiwe University, Awka; October, 2010.

[3]. M. Dolukhanov, "Propagation of Radio waves". Mir Publishers, Moscow, pp 21, 118-124; 1971.

[4]. G. Markov, "Antennas," Progress Publishers, Moscow, p 306, 1971.

[5]. H. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio Services", IEEE VT – 29 (3), 1980.

[6]. G. L. Stuber, "Principles of Mobile Communication", Kluwer Academic, U.S.A; 2001.

[7]. H.H.Xia, "An Analytical Model for Predicting Path Loss in Urban and Suburban Environments," IEEE Trans. On Veh. Tech; p18, 1996.

[8]. L. C. Liechty, "Path Loss Measurements and Model Analysis of 2.4 GHz wireless Network in an outdoor Environment", Georgia Institute of Technology, August 2007.

[9]. Adejumo, S. A (Lt. Col), "Problems of Signal Communications in developing Armies of Africa", the signaler, a Quarterly journal of the Nigerian, p15; 1989.

[10]. A. O. Ogbomudia (Lt. Col), "Telecommunications problems in the Armies of 3rd World Countries", the signaler, a Quarterly journal of the Nigerian, pp25 - 26; 1989.

[11]. Brown, J and Glazier, E. V. D, "Telecommunications "Chapman and Hall Ltd Publishers, London, p201; 1974.