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Radio Propagation Path-loss Analysis for an Operative GSM Network

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ABSTRACT

Radio propagation is one of the most fundamental parameters in mobile communications engineering. For land-based mobile communications, the received signal variation is primarily the result of multipath fading caused by obstacles such as buildings (or clutter) or terrain irregularities; the distance between link end points; externally generated noise, and interference among multiple transmissions. This inevitable signal variation is the cause of call dropping, one of the most significant quality of service measure in operative cellular (or GSM) networks. For this reason, various techniques and schemes are employed in the planning, design and optimization of cellular networks to combat these propagation effects. This normally covers the network physical configuration which include all aspects of network infrastructure deployment such as locations of base stations; heights of antennas; sector azimuth orientations; antenna selection and tilting, etc. A typical example of these schemes and techniques is the use of radio propagation models for signal prediction based on measured data. In this paper, based on the data collected from Globacom Nigeria, the Stanford University Interim (SUI) Model is selected to analyze the propagation characteristics for the Makurdi network area of the GSM Company. The results of the study gives interesting revelations about the performance of the network based on practical and ideal situations.

Keywords: *Cellular Network, Propagation Characteristics, Radio Propagation, Radio Propagation Model, SUI Model*

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I. INTRODUCTION

An understanding of the radio wave propagation characteristics of an environment is a necessary condition for effective radio network planning and optimization. This becomes very important today with the ever-increasing demand for radio channels following explosion in demand for wireless services. Wireless networks involve radio and wire-line links as well as switching hardware and software, and database operations, but service quality is mainly determined by the performance of the radio network [1], [2], [3]. The radio network is made up of a number of radio cells each served by a fixed transmitter/receiver, known as a cell site or Base Transceiver Station (BTS) or simply Base Station (BS). These cells are used to cover different areas in order to provide coverage over a wider area than the area of one cell. Cellular networks are inherently asymmetric with a set of fixed main transceivers each serving a set of distributed mobile transceivers or Mobile Stations (MS) which provides services to the network's users.

Global System for Mobile Communications (GSM) is the most widely used wireless cellular technology. Other established cellular technologies existing in the telecom industry include code division multiple access (CDMA). Its family of technologies include General Packet Radio Service (GPRS), Enhanced Data for GSM Evolution (EDGE), Universal Mobile Telecommunication System (UMTS), High Speed Packet Access (HSPA), and more recently Long Term Evolution (LTE) network [2], [4], [5].

As the radio network is connected to the mobile user, it assumes considerable importance. The BS should be capable of communicating with the MS within a certain coverage area, and of maintaining call quality standards. The radio network should be able to offer sufficient capacity and coverage. A practical network will have cells with some areas not having the required signal for various reasons depending on the propagation characteristics of the area. Propagation characteristics are defined in terms of the distance between link end points; externally generated noise; interference among multiple transmissions; varied terrain including building structures, hills, street canyons, vehicles, vegetation, etc [6]. These propagation conditions are often the causes of Radio Frequency (RF) interference and signal attenuation, which are the two major factors responsible for call dropping in operative cellular (or GSM) networks. Radio propagation varies from region to region and should be studied carefully, before predictions for both coverage and capacity are made. For this reason, various techniques and schemes are employed in the planning, design and optimization of cellular networks to combat these propagation effects. This normally covers the network physical configuration which include all aspects of network infrastructure deployment such as locations of base stations; heights of antennas; sector azimuth orientations; antenna selection and tilting, etc [1]. A typical example of these schemes and techniques is the use of radio propagation models for signal prediction based on measured data. In this paper, based on data collected from Globacom Nigeria, the Stanford University Interim (SUI) Model is appropriately selected and used to analyze the propagation characteristics for the Makurdi network area. The results of the study gives interesting revelations about the performance of the network based on practical and ideal situations.

The rest of the paper is organized as follows: Section 2 discusses cellular networks. This is followed by a discussion in section 3 on mobile signal propagation. The subject radio network planning and optimization is presented in section 4. In section 5, the types of propagation model are presented; while section 6 discuses experimental data collection and analysis. Lastly in section 7 is the conclusion.

II. THE GSM NETWORK

A GSM network is a radio network comprising of cells which are interconnected usually over a large area spanning several kilometres. These cells contain base transceiver stations (BTS) which enables the transmission and reception of radio signals to and from mobile user equipment usually referred to as mobile station (MS) such as mobile phones. These cells together provide radio coverage over a given geographical area.

The architecture for mobile cellular network is mainly divided into three subsystems: the MS, Base Station Subsystem (BSS), and Network and Switching Subsystem (NSS). Each subsystem performs its separate functions which are linked together by logical and physical channels to enable full operational capability of the system [2], [3], [4].

The MS otherwise called mobile phone or 'handset' is the part of mobile cellular network that the subscriber uses to communicate. It consists mainly of the hardware and subscriber identity module (SIM). The hardware comprises of all the electronics needed to generate, transmit, receive and process signals between the MS and BTS. The SIM provides the information that identifies the user to the network using the international mobile subscriber identity (IMSI) system.

The base station subsystem (BSS) consists of the base transceiver station (BTS) and base station controller (BSC). The BTS uses antennas, and is made up of transmitters and receivers for direct communication with the MS through the radio interface. The BSC manages the radio resources and controls a group of BTSs and also manages handovers and the allocation of channels in a network.

The network subsystem provides overall control and interfacing of the whole mobile network. It comprises mainly of the Mobile Switching Centre (MSC) which acts like a normal switching node in a telephone exchange. It also performs other tasks for a mobile phone like registration, authentication, call location and routing using the Visitor Location Register (VLR), Home Location Register (HLR), Equipment Identity Register (EIR) and Authentication Centre (AUC). Fig. 1 shows a diagrammatic view of a GSM network architecture.

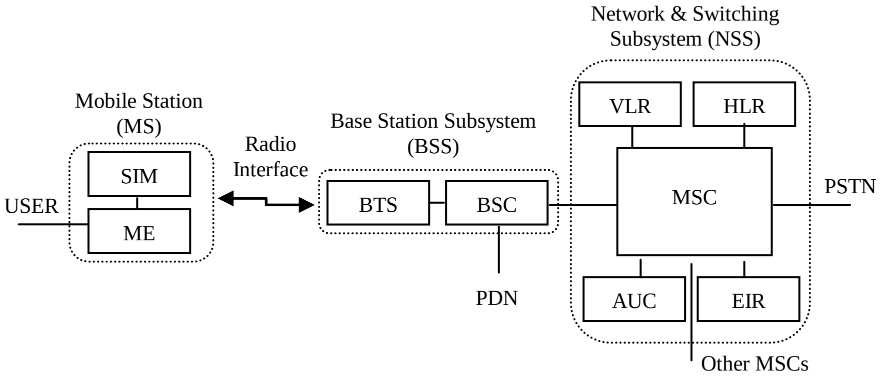


Figure 1: GSM network architecture

III. THE MOBILE SIGNAL PROPAGATION

The signal that is transmitted from the transmitting antenna (BTS/MS) and received by the receiving antenna (MS/BTS) travels a small and complex path. This signal is exposed to a variety of man-made structures, passes through different types of terrain, and is affected by the combination of propagation environments. All these factors contribute to variation in the signal level, so varying the signal coverage and quality in the network. Moreover, any signal that is transmitted by antenna will suffer attenuation during its journey in free space. The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal. The received signal by an MS could be considered as consisting of three components, namely a free space path loss component, a slow fading component due to shadowing, and a fast fading component due to vehicle velocity [7]. However, when determining handover necessities, the received signal is averaged, and over the normal averaging periods, the fast fading component of the signal is averaged out [7]. The shadowing component of the signal is a function of the cell propagation environment, and is a random variable that conforms to lognormal distribution. Therefore, the propagation characteristics of the cell environment could be represented by the statistics of the lognormal distribution. The free space path loss component that gives rise to the mean value, μ_L of the received signal can approximately be described by the empirical formula given by Hata [4]. With σ_L as the variance of the shadowing component, the composite received signal that determines handover would then be a random variant X with pdf,

$$f_x = 1/x\,\sigma_L\sqrt{2\pi}\,e^{(\ln x-\mu_L)^2/2\sigma_L^2}, x > 0. \qquad (1)$$

The propagation of the radio wave in free space depends heavily on the frequency of the signal and obstacles in its path. There are some major effects on the signal behavior as briefly described below [5].

3.1 Fading of the Signal

As the signal travels from the transmitting antenna to the receiving antenna, it looses strength. This may be due to the phenomenon of path loss or it may be due to the Rayleigh effect. Rayleigh effect is due to the fast variation of the signal level both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line of sight. Rayleigh fading can be divided into two kinds: multipath fading and frequency-selective fading.

Arrival of the signal from different paths at different times and its combination at the receiver causes the signal to fade. This phenomenon is multipath fading and is a direct result of multipath propagation. Multipath fading can cause fast fluctuations in the signal level. This kind of fading is independent of the downlink or uplink if the bandwidths used are different from each other in both directions.

Frequency-selective fading takes place owing to variation in atmospheric conditions. Atmospheric conditions may cause the signal of a particular frequency to fade. When the mobile station moves from one location to another, the phase relationship between the various components arriving at the mobile antenna changes, thus changing the resultant signal level. Doppler shift in frequency takes place owing to the movement of the mobile station with respect to the receiving frequencies.

3.2 Diffraction and Shadowing

Diffraction is a phenomenon that takes place when the radio wave strikes a surface and changes its direction of propagation owing to the inability of the surface to absorb it. The loss due to diffraction depends upon the kind of obstruction in the path. In practice, the mobile antenna is at a much lower height than the base station antenna, and there may be high buildings or hills in the area. Thus the signal undergoes diffraction in reaching the antenna. This phenomenon is also known as ‘shadowing’ because the mobile receiver is in the shadow of these structures.

3.3 Building and Vehicle Penetration

When the signal strikes the surface of a building, it may be diffracted or absorbed. If it is to some extent absorbed, the signal strength is reduced. The amount of absorption is dependent on the type of building and its environment; the amount of solid structure and glass on the outside surface; the propagation characteristics near the building; orientation of the building with respect to the antenna orientation; etc. This is an important consideration in the coverage planning of a radio network. Vehicle penetration is similar, except that the object in this case is a vehicle rather than a building.

3.4 Propagation of Signal over Water

Propagation over water is a big concern for radio planners. The reason is that the radio signal might create interference with the frequencies of other cells. Moreover, as the water surface is a very good reflector of radio waves, there is a possibility of the signal causing interference to the antenna radiation patterns of other cells.

3.5 Propagation of Signal over Vegetation (Foliage Loss)

Foliage loss is caused by propagation of the signal over vegetation, principally forests. The variation in signal strength depends upon many factors such as the type of threes, trunks, leaves, branches, their densities, and their heights relative to the antenna heights. Foliage loss depends on the signal frequency and varies according to the season. This loss can be as high as 20dB in GSM 800 systems.

3.6 Interference

The signal at the receiving antenna can be weak by virtue of interference from other signals. These signals may be from the same network or may be due to man-made objects. However, the major cause of interference in a cellular network is the radio resources in the network. There are many radio channels in use in a network that use common shared bandwidth. The solution to the problem is accurate frequency planning.

The mobile station may experience a slow or rapid fluctuation in the signal level in a radio network. This may be due to one or more of the factors discussed above. These factors form the basis of cell coverage criteria.

IV. RADIO NETWORK PLANNING AND OPTIMIZATION

Since the early days of GSM development, GSM network planning has undergone extensive modification so as to fulfill the ever increasing demand from operations and mobile users with issues related to capacity and coverage. Radio network planning is perhaps the most important part of the whole design process owing to its proximity to mobile users.

The main aim of radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The radio network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage [8]. To achieve maximum capacity while maintaining an acceptable grade of service and good speech quality is the main focus in radio network planning. Planning for a network with a limited number of subscribers is not the major problem. The difficulty is to plan for a network that allows future growth and expansion. The objectives of radio network planning [9] can be summarized as:

- To obtain sufficient coverage over the entire service area and to ensure that high quality voice services and data services with low error rates can be offered to the subscribers.
- To offer the subscriber traffic network capacity with sufficiently low blocking and call dropping rate.
- To enable an economical network implementation when the service is established and a controlled network expansion during the life cycle of the network.

As earlier stated, an understanding of the radio propagation characteristics of an environment is a necessary condition for effective radio network planning. The conventional planning approach which is widely used is called the analytical approach to cellular network planning. This approach is focused on the determination of the transmitter parameters like transmitter location, antenna type, or transmitter power. It obeys the RF objective but neglects the capacity and the network design objective during the engineering process [10]. In principle, the analytical approach consists of four phases: Radio Network Definition, Propagation Analysis, Frequency Allocation, and Radio Network Analysis [10]. Fig. 2 shows the conventional approach for cellular planning [10].

During the Radio Network Definition phase, a human expert chooses the cell sites. In order to obtain a regular structure, usually the popular concept of distributing the transmitters on a hexagonal grid is used in this step. Using these transmitter configurations, the Propagation Analysis of the area evaluates the radio coverage by field strength prediction methods. Here stochastic channel models as well as more sophisticated approaches like ray tracing techniques are applied. Usually, several field strength prediction methods are implemented but the tools offer little, if any, support in choosing the appropriate propagation model. If the planning expert decides that the coverage is not sufficient enough, new transmitter positions have to be chosen and the propagation has to be analyzed once again.

The radio network capacity issues are addressed in the next phase, the Frequency Allocation. At first, the tele-traffic distribution within the planning region is derived based on rough estimates on the land use and the demographic structure of the area. The distribution is then stored in a traffic matrix. In the next step, a hexagonal grid representing the cells is superimposed on the entire planning region. If, for a given frequency reuse pattern and for given interference distance constraints, all the cells of the area can be supplied with the required number of channels, the algorithm proceeds to Radio Network Analysis. Otherwise the algorithm starts all over again.

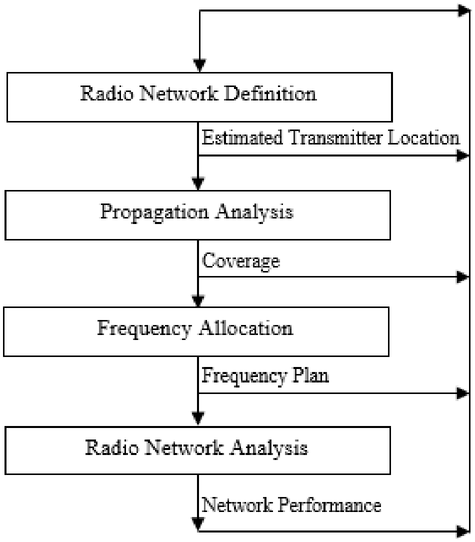


Figure 2: Conventional approach of cellular network planning

The Radio Network Analysis calculates the quality-of-service values of the area with regard to blocking and hand-over dropping probabilities. Again, stochastic channel characteristics as well as user demand estimates from the traffic data-base are used to calculate the network performance. If grade-of-service specifications are met, the task is accomplished; otherwise the algorithm has to be restarted.

The major disadvantage of the analytical approach is its restriction to the RF design objectives. Network and capacity issues are more or less neglected by the approach. The Integrated Approach to cellular network planning overcomes the shortcomings of the conventional approach by organizing the cellular design constraints and quality objectives.

In wireless communication systems, transfer of information between the transmitting antenna and the receiving antenna is achieved by means of electromagnetic radio waves. The interaction between the electromagnetic waves and the environment reduces the signal strength sent from transmitter to receiver, which causes path loss. The existing propagation model tries to evaluate this path loss as a means of improving the radio wave propagation during network planning.

When the network is commissioned for commercial operation, however, the traffic increases and the operator faces new situations in which the system cannot serve the increased traffic. This requires some changes to the network configuration and is usually accomplished by means of optimization. From an operational point of view, the optimization process should be treated as part of the ongoing network planning and all these activities should be performed over the whole network operation period.

With an ever increasing complexity of real networks, planning and optimization requires the use of sophisticated software tools. Their sole task is to assist the planning Engineer process the enormous amount of information into a comprehendible form.

V. TYPES OF PROPAGATION MODEL

Models for path loss can be categorized into three types: Empirical Models, Deterministic Models, and Stochastic Models. Propagation models can further be classified into: Theoretical Models and Empirical Models. In general, path loss can be expressed as:

$$Path\ loss\ (L_p) = \frac{Power\ Transmitted}{Power\ Received}\quad in\ dB \qquad (2)$$

5.1 Theoretical Propagation Model

The theoretical propagation models can be divided into the following common types: free space propagation, flat or smooth earth propagation model, diffraction effect propagation model, plane earth propagation model etc. Theoretical models predict transmission losses by mathematical analysis of the path geometry of the terrain between the transmitter and the receiver and the refractivity of the troposphere. Geometric optics techniques are used to predict signal strengths within the radio horizon while diffraction losses over isolated obstacles are estimated using Fresnel-Kirchhoff knife edge models [11].

5.2 The Free Space Model

This model predicts a clear and unobstructed line of sight transmission to reception terrain. The wave is not reflected or absorbed but radiated equally in all directions. The model also stipulates that the received power decays as a function of the distance between the transmitter and the receiver raised to an exponent. The generic free space path loss can be obtained as follows:

$$P_d = \frac{P_t}{4\pi d^2} \qquad (3)$$

Where P_t is the transmitter power (W/m^2), and P_d the amount of power at a distance d from the antenna.
The amount of power captured by the antenna at the required distance *d*, depends upon the effective aperture of the antenna and the power flux density at the receiving element [12]. Actual power received by the antenna depends on the following:
(a) The aperture of receiving antenna *Ao*,
(b) The wavelength of received signal λ,
(c) And the power flux density at receiving antenna *Pd*.
The effective area A_e of an isotropic antenna is:

$$A_e = \frac{\lambda^2}{4\pi} \qquad (4)$$

While power received is:

$$P_r = P_d \times A_e = A_e \times \frac{P_t}{4\pi d^2} \qquad (5)$$

Equation (6) illustrates the path loss:

$$L_p = Power\ transmitted\ (P_t) - Power\ received\ (P_r) \qquad (6)$$

When substituting (5) in (6), it yields (7):

$$L_p(dB) = 20log_{10}(4\pi) + 20log_{10}(d) - log_{10}(\lambda) \qquad (7)$$

Then substituting (λ (in km) = 0.3 / *f* (in MHz)) and rationalizing the equation produces the generic free space path loss formula, which is stated in (8):

$$L_p(dB) = 32.5 + 20log_{10}(d) + 20log_{10}(f) \qquad (8)$$

Where L_p = path loss in dB, d = distance of measured power from the transmitter (km), *f* = frequency of propagation (MHz).
As stated earlier, propagation path loss is a function of distance. Accordingly the propagation path loss is given by an expression [13]:

$$L_p(dB)d^{\alpha} \qquad (9)$$

Expression of (9) is further simplified in terms of logarithmic form as:

$$L_p(dB) = L_p + \alpha log_{10}(d) \qquad (10)$$

Where L_p is now the propagation constant known as the free space loss.

5.3 The Empirical Propagation Model

At times it is impossible to explain a situation by a mathematical model. In that case, the use of some data to predict the behavior approximately is applied. By definition, an empirical model is based on data used to predict, not explain, a system and are based on observations and measurements alone. Common empirical propagation models include: the Okumura, Hata, Cost 231, Walfisch-Ikegami Model, Stanford University Interim (SUI) Models, etc.

5.3.1 Hata's Propagation Model

Hata model was based on Okumura's field test results and predicted various equations for path loss with different types of clutter. The limitations of Hata Model: due to range of test results from carrier frequency (f) 150MHz to 1500MHz, the distance from the base station ranges from 1km to 20km, the height of base station antenna (h_b) ranges from 30m to 200m and the height of mobile antenna (h_m) ranges from 1m to 10m. Hata created a number of representative path loss mathematical models for each of the urban, suburban and open country environments, as illustrated in (11)-(14), respectively. Hata model is not suitable for micro-cell planning where antenna is below roof height and its maximum carrier frequency is 1500MHz. It is not valid for 1800MHz and 1900MHz systems.

5.3.2 The Okumura Model

The Hata model for suburban Areas, also known as the Okumura-Hata model for being a developed version of the Okumura model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions in city outskirts and other rural areas. This model incorporates the graphical information from Okumura model and develops it further to better suit the need. This model also has two more varieties for transmission in urban areas and open areas [14].

5.3.3 The COST 231 Model

The European Co-operative for Scientific and Technical Research formed the COST 231 committee to develop an extended version of the Hata model such that applicability to 2GHz is possible [11]. The model is applicable for mobile station antenna height up to 10m, base station antenna height of 30m to 100m and link distance up to 20km.

5.3.4 Stanford University Interim (SUI) Model

IEEE 80.16 Broadband Wireless Access working group proposed the standard for the frequency band below 11GHz containing the channel model developed by Stanford University, namely SUI model. This prediction model come from the extension of Hata model with larger than 1900MHz [15]. The base station height of SUI model can be used from 10m to 80m; receiver antenna height is from 2m to 10m; the cell radius from 0.1km to 8km [15]. The SUI model describes three types of terrain; they are terrain A, terrain B, and terrain C. There is no declaration about any particular environment. Terrain A can be used for hilly area with moderate or very dense vegetation. This terrain presents the highest path loss.

The SUI model is widely used in calculating the path loss for the following reasons:

- Simplicity in computing path loss.
- Extended range of carrier frequency.
- Applicable for higher base and mobile station height as compared to other models.

Thus the SUI model is also applied for this study. In this study, terrain A is considered as a dense populated urban area. Terrain B is characterized for the hilly terrains with rare vegetation, or flat terrains with moderate or heavy tree densities. This is the intermediate path loss scheme and the model is considered for suburban environment. Terrain C is suitable for flat terrains or rural with light vegetation, here path loss is minimum.

The basic path loss expression of the SUI model with correction factors is presented as [15]:

$$P_L = A + 10\gamma \log_{10}\left({}^{d}/_{d_o}\right) + X_f + X_h + s \quad for\ d > d_o \qquad (19)$$

Where,

d, the distance between base station and receiving antenna (m)

d_o = 100 (m)

λ, Wavelength (m)

X_f, Correction for frequency above 2GHz (MHz)

X_h, Correction for receiving antenna height (m)

s: Correction for shadowing (dB)

γ : Path loss exponent

The parameter A is defined as [15]:

$$A = 20\log_{10}(4\pi d_o/\lambda)$$

And the path loss exponent γ:

$$\gamma = a - b\, h_b + (c/h_b)$$

Where the parameter h_b, is the base station antenna height in meters, this is between 10 and 80 m. The constant *a*, *b*, and *c* depend upon the types of terrain that are given in Table 1.

Table 1: Parameters for Different Terrain

Model Parameter	***Terrain A***	***Terrain B***	***Terrain C***
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The frequency correction factor X_f and the correction for receiver antenna height X_h for the model is expressed in [13] as:

$X_f = 6.0 \times log_{10}(f/2000)$
$X_h = -log_{10}(h_r/2000)$ for terrain type A and B
$X_h = -20.0log_{10}(h_r/2000)$ for terrain type C

Where, *f* is the operating frequency in MHz, and h_f is the receiver antenna height in meters.
For the above correction factors, this model is extensively used for the path loss prediction of all three types of terrain in rural, urban and suburban environments.

VI. EXPERIMENTAL DATA COLLECTION AND ANALYSIS

The data used for the path-loss analysis was collected from a GSM operator, Globacom Nigeria Limited in Makurdi town. Globacom Nigeria limited (Makurdi branch) comprises of 26 base stations. Table 2 gives the name of each of the base stations, their location, height, and frequency of propagation. Other parameters collected from the GSM Company are shown in Table 3.

Table 2: Base Station Parameters for Globacom Makurdi

S/No	***Name***	***Location***	***Height(m)***	***Frequency(GHz)***
1	MAK 001	Ankpa Close HL	36	13
2	MAK 002	Con oil BSU	36	18
3	MAK 003	Conoil NB	70	13
4	MAK 004	Pila Village UAM	36	13
5	MAK 005	Ankpa Road	50	18
6	MAK 006	Rice Mill, Wurukum	36	18
7	MAK 007	Sokoto Street Wadata	36	18
8	MAK 008	Katungo Junction NB	36	13
9	MAK 009	Top Choice Bakery Nyiman Layout	36	18
10	MAK 010	Judges Quarters Gboko Road	36	13
11	MAK 011	NAF Base	36	18
12	MAK 012	New GRA	50	13
13	MAK 013	Agboor Village Behind Modern Market	50	13
14	MAK 014	Behind Zenith Bank	36	18
15	MAK 015	Off Old Lafia Road NB	24	18
16	MAK 016	Ikpayongo	36	13
17	MAK 017	Behind BERNADA	36	18
18	MAK 018	International Market Behind Vaatia College	36	13
19	MAK 019	Behind Federal Pay Office, Nyiman Layout	24	18
20	MAK 020	MOPOL Barack, Naka Road	36	13
21	MAK 021	Gbajimba Road	36	18
22	MAK 022	Little Angel School, UAM Road.	36	18
23	MAK 023	Lower Benue	36	13

24	MAK 024	Tilley Gyado College NB	36	13
25	MAK 025	Commissioners Qtrs.	36	13
26	MAK 026	Lobi Qtrs.	36	13

Table 3: Parameters and Values Used in Simulation

Parameters	***Values***
TX power (watts)	0.25
TX power (dBm)	24.00
RX threshold level (dBm)	-92.00
Maximum receive signal (dBm)	-15.00
RX signal (dBm)	-39.29
Frequency (MHz)	13000 and 18000
Path length (km)	10.87
Net path loss (dB)	63.29
Free space loss (dB)	135.47
Antenna Height (m)	24, 36, 50 and 70
Reference Mobile Station Height (m)	2
Effective Isotropic Radiated Power, EIRP (dBm)	55.70
Interference Margin	1.00
Effective Fade Margin (dB)	52.67

The analysis will be carried out with the aid of simulation using MATLAB. Firstly, simulation will be done to ascertain the effect of path loss with varying the RX to TX distance for a distance of 0–12km between the Mobile Station (RX) and Transmitter (TX). All other parameters like frequency and base station height will be kept constant. The frequency for the Ideal Situation is 10GHz while that for the Practical Situation is 13GHz or 18GHz depending on the base station considered.

Secondly, simulation will be done to study the effect of varying the frequency with path loss while maintaining every other parameter constant. The simulation input parameters are given in Table 3. The SUI path loss model used for the simulation is given in (19). A comparison will be made between the Ideal Model Situation and the Practical Situation of the Stanford University Interim (SUI) Model of Path Loss. The analysis will be carried out for selected base stations as follows:

i. MAK 026: Lobi Quarters
ii. MAK 013: Behind Modern Market
iii. MAK 002 Conoil, North Bank
iv. MAK 019: Nyiman Layout
v. MAK 007: Sokoto Street, Wadata
vi. MAK 005: Ankpa Road

6.1 Variation of Path Loss with Distance

Figs. 3 to 5 represents the simulation results showing the variation of the path loss with variation in Mobile Station (MS) or Receiver (RX) to Base Station (BS) or Transmitter (TX) distance for the base stations: MAK 026, MAK 013, MAK 002, MAK 019, MAK 007, and MAK 005 respectively.

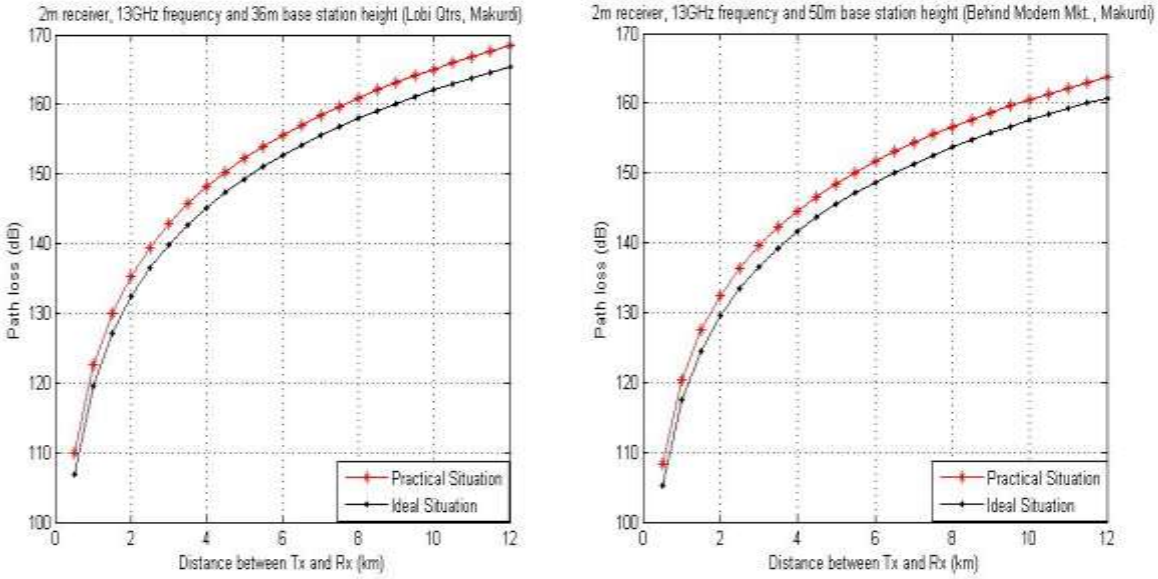


Figure 3: Change in path loss with distance (MAK 026 and MAK 013)

Fig. 3 shows the variation of the path loss with variation in mobile station to base station distance for MAK 026 and MAK 013. These base stations transmit at 13GHz with an antenna height of 36m and 50m respectively.

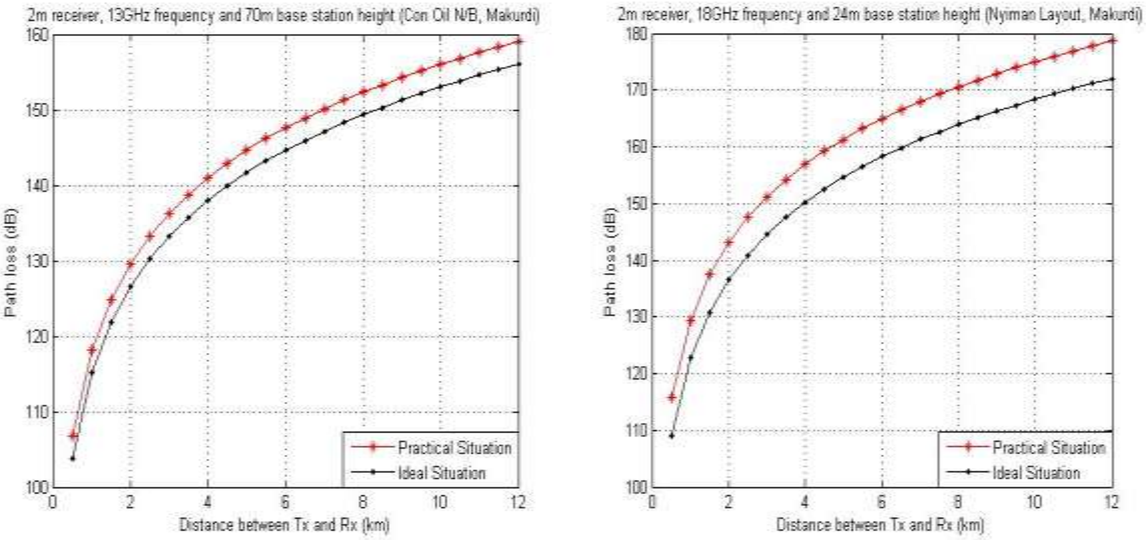


Figure 4: Change in path loss with distance (MAK 002 and MAK 019)

Fig. 4 shows the variation of the path loss with MS to BS distance for MAK 002 and MAK 019. These base stations transmit at 13GHz and 18GHz respectively with an antenna height of 70m and 24m respectively.

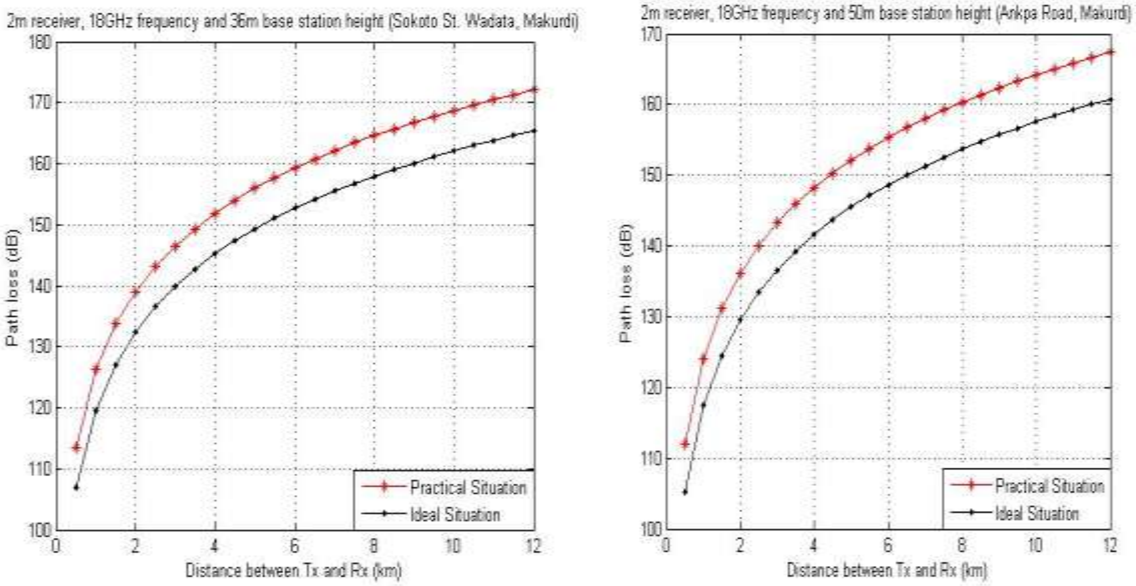


Figure 5: Change in path loss with distance (MAK 006 and Road, MAK 005)

Fig. 5 shows the variation of the path loss with MS to BS distance for MAK 006 and MAK 005. These base stations transmit at 18GHz respectively with an antenna height of 36m and 50m respectively.

6.2 Variation of Path Loss with Frequency

Figs. 6 and 7 represents the simulation results showing the variation of frequency with path loss while maintaining every other parameter constant for the base stations: MAK 026, MAK 002, MAK 019, and MAK 005 respectively. Here, in the Ideal Situation, the distance between MS and BS is 8km while in the Practical situation, it is 10.87km (see Table 3).

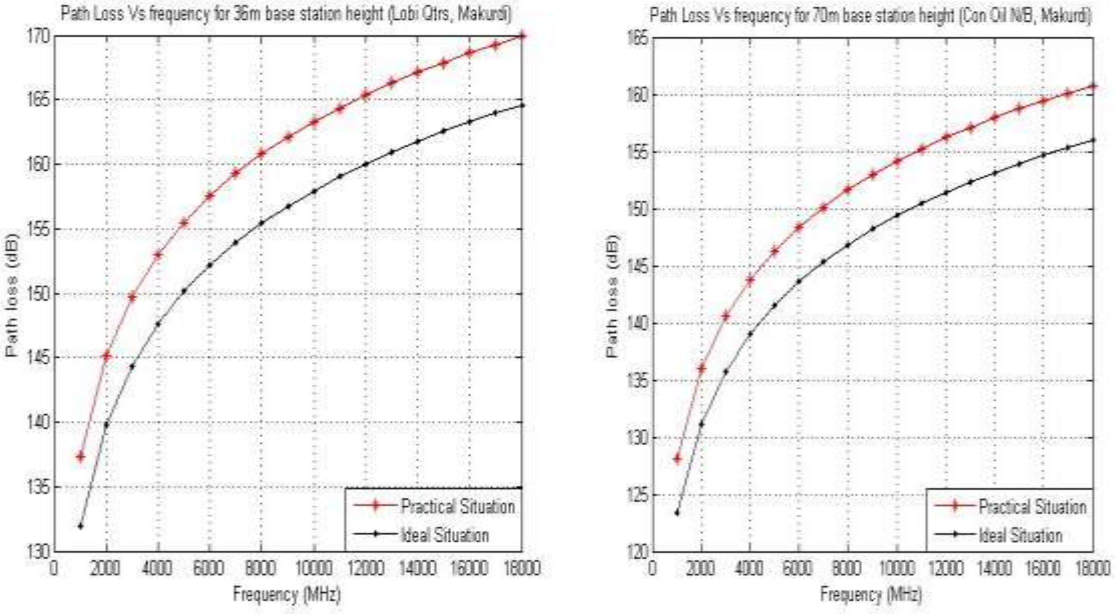


Figure 6: Change in path loss with frequency (MAK 026 and MAK 002)

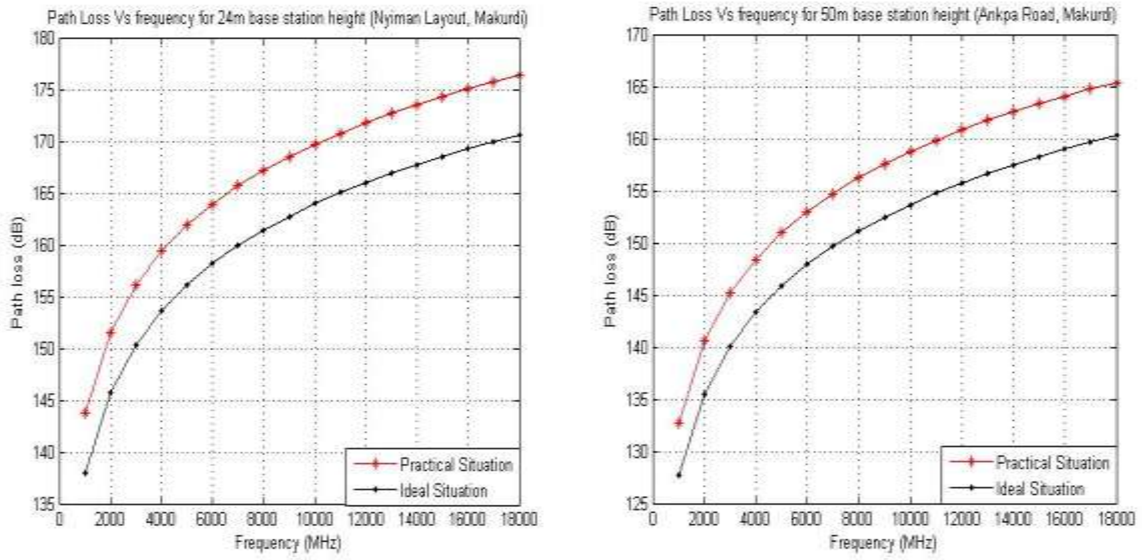
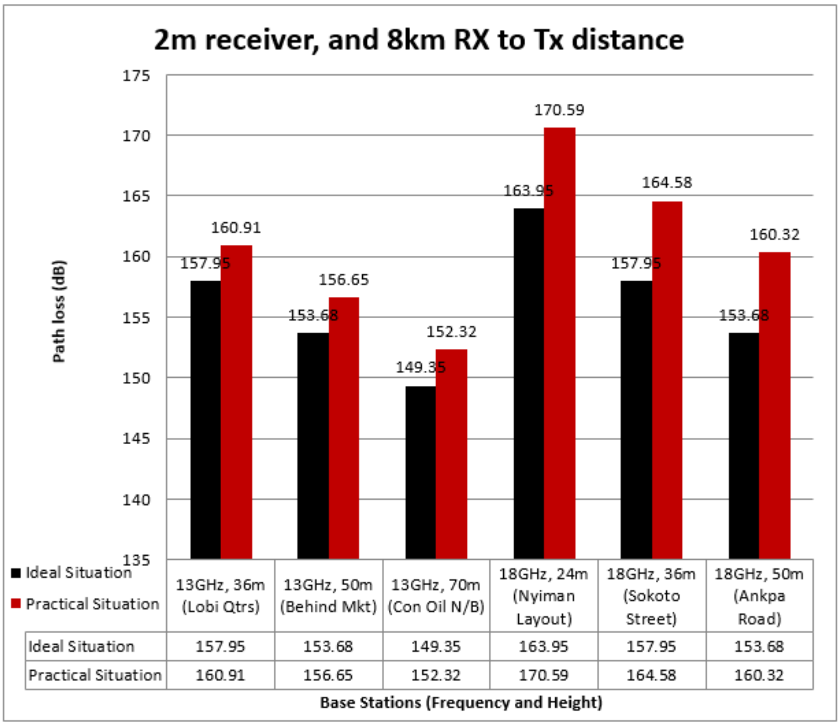


Figure 7: Change in path loss with frequency (MAK 019 and MAK 005)

6.3 Analysis of Simulation Results

Fig. 8 represents the bar chart for the variation of frequency with path loss for ideal and practical situations for a 2m receiver (mobile station) at a distance of 8km from the transmitter (base station). It is worth noting that the Path loss is lowest when transmitting at a frequency of 13GHz using an antenna of 70m and highest when using a frequency of 18GHz with a transmitting antenna height of 24m.

Similarly Fig. 9 shows the bar chart for the variation of frequency with path loss for ideal and practical situations for a 2m receiver (mobile station) at a distance of 10.87km from the transmitter (base station). It is worth noting that here too, the path loss is lowest when transmitting at a frequency of 13GHz using an antenna of 70m and highest when using a frequency of 18GHz with a transmitting antenna height of 24m.



	13GHz, 36m (Lobi Qtrs)	13GHz, 50m (Behind Mkt)	13GHz, 70m (Con Oil N/B)	18GHz, 24m (Nyiman Layout)	18GHz, 36m (Sokoto Street)	18GHz, 50m (Ankpa Road)
Ideal Situation	157.95	153.68	149.35	163.95	157.95	153.68
Practical Situation	160.91	156.65	152.32	170.59	164.58	160.32

Figure 8: Analysis of simulation results at 8km RX to TX distance

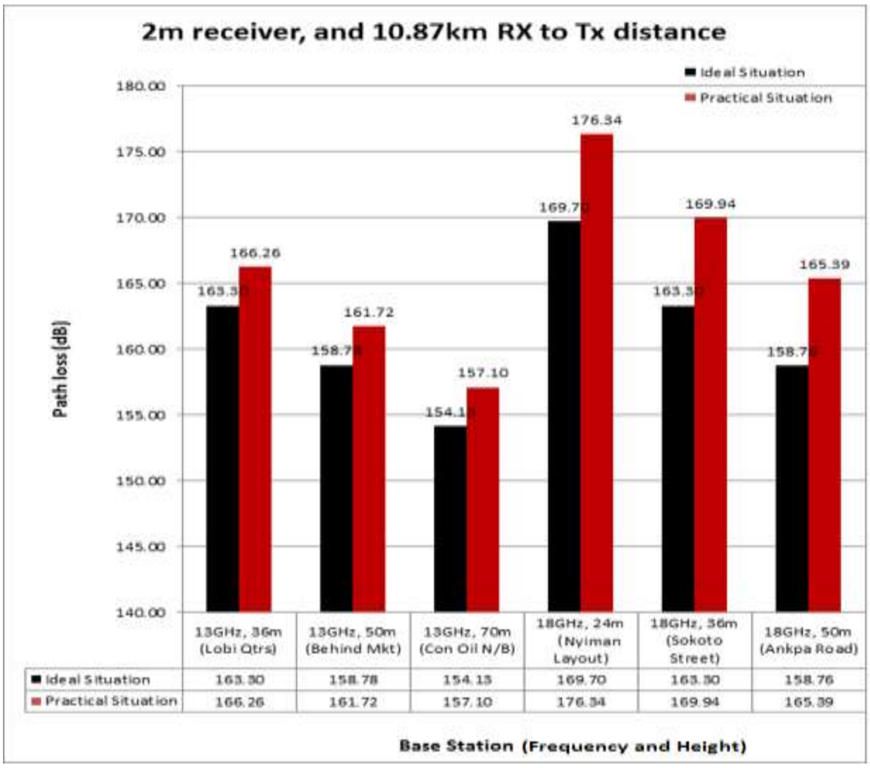


Figure 9: Analysis of simulation results at 10.87km RX to TX distance.

6.4 Received Signal Strength

Received signal strength is a strength which is used to measure the power between the received radio signals [16]. The received signal strength is given as:

$$\mathrm{Pr} = \mathrm{Pt} + \mathrm{Gt} + \mathrm{Gr} - \mathrm{PL} - \mathrm{A} \qquad (20)$$

Where,
Pr is received signal strength in dBm
Pt is transmitted power in dBm
Gt is transmitted antenna gain in dBm
Gr is received antenna gain in dBm
PL is total path loss in dBm
A is connector and cable loss in dBm

The value of Gr can be calculated from the following equation [16]:

$$R_s = EIRP - L_p - I_m - F_m - L_c - G_r \qquad (21)$$

Using the Nyiman base station for an example, the path loss (P_L) at a distance of 10.87km (path length) is 176.34dB. Table 3 gives the values of the other parameters needed to compute the received signal strength. Using Equation (20):

$\mathrm{Pr} = 24 + 41.7 + 31.97 - 176.34 - 10 = -88.67\mathrm{dBm}$ (Received Signal Strength)

Table 4 shows the path losses for the ideal and practical situation and their corresponding received signal strength for all the base stations considered for mobile station to base station distance of 10.87km.

Table 4: Path Loss and the Received Signal Strength at 10.87km MS (RX) to BS (TX) Distance

Base Station	*Path Loss dB (Ideal situation)*	*Path Loss dB (Practical situation)*	*Received Signal Strength, dBm (Ideal situation)*	*Received Signal Strength, dBm (Practical situation)*
MAK 026	163.30	166.26	-75.63	-78.59
MAK 013	158.78	161.72	-71.11	-74.05
MAK 002	154.13	157.10	-66.46	-69.43
MAK 019	169.70	176.34	-82.03	-88.67
MAK 007	163.30	169.90	-75.63	-82.23
MAK 005	158.76	165.39	-71.09	-77.72

VII. CONCLUSION

The analysis of radio propagation for a GSM operative network seeks to ascertain the signal strength within a giving cell during the planning stage of the GSM network. The frequency of operation of the GSM network lies within the SHF range which has several advantages for line-of-sight transmission. However, transmission at such a range within the radio network experiences great losses during its propagation. This research work made use of the SUI propagation model to determine the path loss for 6 selected base stations out of 26 for an operative GSM network. The base stations were selected to represent all the possible extreme situations of path loss in the network coverage area. The calculated path loss was further used in estimating the received signal strength which eventually translates to the determination of coverage of the GSM network within the specified cell size. From the analysis of the simulation results, the following conclusions are made on the variation of path loss with parameters like distance between Mobile Station and Base Station, frequency of propagation, and height of base station: Path loss increases with increasing distance between the MS and BS and increasing frequency of propagation; and decreases with increasing base station height. The highest path loss of 176.34dB gave an estimated received signal strength of -88.67dBm which is greater than the threshold value (-92dBm). Since the received signal is still of good quality within the 10.87km path length of the cell, it can be concluded that the network of the GSM network (Globacom Nigeria Limited) in the Makurdi area is optimized in terms of coverage despite the path losses experienced. The path loss analysis presented in this study thus provides a veritable approach for performance evaluation of an operative GSM network.

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