SEASONAL VARIATION OF MOBILE RADIO PROPAGATION CHARACTERISTICS IN KADUNA METROPOLIS AND ENVIRONS: A CASE STUDY OF MTN AND AIRTEL

BY

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A Thesis submitted to the Department of Electrical Engineering, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of the Degree of Master of Science (M.Sc.) in Electrical Engineering.

MAY 2011

DECLARATION

I, OYESOLA, Olayinka Olusola, hereby declare that this thesis "Seasonal Variation of Mobile Radio Propagation Characteristics in Kaduna Metropolis and Environs: A Case Study of MTN and Airtel" is entirely my work and has not been submitted anywhere before for any form of degree whatsoever. All sources of knowledge used have been duly acknowledged by way of references.

…………………………………. ……………………….

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CERTIFICATION

This is to certify that this thesis titled "Seasonal Variation of Mobile Radio Propagation Characteristics in Kaduna Metropolis and Environs: A Case Study of MTN and Airtel" meets the requirements governing the award of a Master of Science (M.Sc.) Degree in Electrical Engineering of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my beloved wife **Mrs Adebukola Oyesola**, to my children and household, **Samuel, Ope, Dieko and Hadijat**, for their love, understanding and support during the course of this work. It is also dedicated in loving memory of my beloved daughter, **Ayomikun**, who passed on to glory while this work was going on.

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ABSTRACT

This research investigated the effects of greater ground conductivity and increased foliage on mobile networks. The wet season is known to be characterised by greater ground conductivity and increased foliage due to the increased moisture content. Global System for Mobile Communications (GSM) signal strength measurements of two networks were taken during the dry season at particular points and these measurements were repeated during the rainy season. These data were then processed to determine the relationship between the signal strength and ground conductivity and foliage. To ensure greater accuracy of results, two networks (Airtel and MTN) were evaluated. Furthermore, signal strength measurements were conducted in rural areas around Kaduna. The results obtained were compared with those of Kaduna Metropolis. GSM signals were discovered to suffer greater losses during the rainy season due to increased foliage and greater ground conductivity. Losses of between 5 dBm and 10 dBm were observed in rural/suburban areas while the losses observed in the metropolis were between 0dB and 4 dBm. These losses, though not significant in urban areas, were quite significant in the rural/suburban areas. An inverse relationship was also established between increased foliage/greater ground conductivity and GSM signal strength within a particular environment. Finally, the results obtained were compared with the Wiessberger and Iternational Telecommunication Union (ITU) models and reasonable agreement with these foliage models was observed.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABU: Ahmadu Bello University.

BTS: Base Station.

CCIR: Consultative Committee on International Radio.

dB: Decibel.

dBm: Decibel milliwatts.

EIRP: Effective Isotropic Radiated Power .

f: Frequency

GSM: Global System of Mobile Communications.

Hz: Hertz.

ITU: International Telecommunication Union.

ITU-R: International Telecommunication Union Recommendation.

LOS: Line of Sight.

MTN: Mobile Telecommunications Network.

NLOS: Non-Line of Sight.

TP: Test Point.

UHF: Ultra High Frequency.

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND INFORMATION

Since the introduction of GSM into Nigeria in August 2001 mobile telecommunications industry has grown tremendously. This growth made it possible for urban as well as rural dwellers to gain access to mobile phones. However, this growth came with attendant problems. Some of which include poor signal reception at various points, dropped calls, and congestion. GSM service providers in Nigeria have thus been trying to evolve methods of tackling these problems. Some of these problems are not peculiar to any specific region whereas others are. For instance, the vegetation cover in the area where these networks are deployed could pose specific problems to the operators and thus solutions peculiar to these environments need be sought. Nigeria as a country has a varied vegetation which ranges from thick vegetation in the South to the savannah grassland in the middle belt to the semi-desert or Sahel savannah regions of the extreme North.

The middle belt region of Nigeria experiences between 4 to 6 months (between April and October) of rainy season every year. The increased earth moisture content during this period gives rise to greater ground conductivity and increased foliage. This condition is likely to affect GSM signal strength. For GSM operators to ensure all year round quality service delivery, the relationship or effects of greater ground conductivity and increased foliage on signal strength needs to be understood particularly in the specific region where such networks are deployed.

1.1 PROBLEM DEFINITION

The optimal performance of wireless communication systems depends to a large extent on signal strength. Various propagation losses are experienced by wireless networks within the wireless channel. Some of these losses include: free space losses, foliage losses and losses due to refraction and scattering. This research focuses on losses due to increased foliage and ground conductivity.

1.2 THESIS OBJECTIVES

Various researches have been conducted with a view to ensuring optimization of mobile networks. These researches focussed on traffic analysis, congestion and path loss with distance. With the ever increasing demand for quality service delivery in the Nigerian mobile communication industry newer approaches have to be sought to ensure network optimization. For a more comprehensive understanding of wireless channel the effect of greater ground conductivity and increased foliage on GSM signals in Nigeria needs to be studied. This research will thus seek to address the following:

a. Is there a relationship between greater ground conductivity/increased foliage and GSM signal strength?

b. Does greater ground conductivity/increased foliage have a significant effect on GSM signal strength?

c. What is the difference in the propagation characteristics between urban and rural networks?

d. Does seasonal variation affect mobile networks propagation characteristics?

1.3 MOTIVATION

Nigeria's GSM industry is one of the fastest growing and largest GSM industry in Africa. The focus of GSM operators is gradually shifting from providing coverage to providing quality service. The euphoria of owning a phone set is gradually giving way to complaints of dropped calls and congestion (Ireti, 2005). The extensive period of rainy season in Nigeria and its attendant effects on signal strength is a critical factor that must be considered in planning and ensuring quality of service by any operator.

1.4 SCOPE OF WORK

This research is conducted in Kaduna Metropolis and environs. This region lies in the savannah grassland area of Nigeria. Furthermore, GSM 900 signals of two telecommunications networks, Mobile Telecommunications Network (MTN) and Airtel, were considered. The base station transmitting frequency of MTN is from 950 – 955 MHz , while that of Airtel is from 955 -960 MHz (NCC, 2010). Thus this work is limited to investigating the effects of greater ground conductivity and increased foliage on GSM 900 signals in a typical savannah grassland terrain.

1.5 THESIS OUTLINE

This work presents the results of an investigation on the effect of seasonal variation on GSM propagation characteristics. Chapter one gives a general introduction to the subject and outlines the research objectives, statement of the problem and the motivation for this work. In chapter two, a review of relevant literature is made as well as a theoretical background to the research. In chapter three the methodology used in this work is presented while chapter four contains the results obtained and the analysis. Interpretation of the results was also presented in chapter four. Finally, chapter five highlights the limitations and problems encountered during the research. It ends with conclusions and recommendations for further work.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.0 INTRODUCTION

This chapter gives a short literature review of similar researches and then lays a theoretical foundation for this study. The basic theory of radio propagation would be discussed as well as the effect of ground conductivity. In looking at the effect of increased foliage on radio propagation characteristics, various foliage models would be considered.

2.1 LITERATURE REVIEW

Some researches have been carried out on network optimization of GSM Networks in Nigeria. Abdullahi (2008), in his work, concentrated on the network features and their effects on radio quality. His emphasis was on how to manipulate these features to improve network quality. Olagoke (2005) carried out traffic analysis of the NITEL GSM network. To ensure network optimization, the prime concern was monitoring and forecasting the network usage by measuring, analysing and interpreting traffic data. Ibrahim (2008) carried out measurement of radio wave propagation on the M-TEL network within Kaduna Metropolis. The effects of various forms of propagation losses on GSM signals were studied and an appropriate signal prediction model (the Lee model) was selected. Similarly, Shittu (2006) studied cellular mobile radio propagation characteristics within urban and rural environments. The work brought to the fore the effect of various propagation losses on GSM signals. None of these studies, however, considered in great details the effect of greater ground conductivity and increased foliage occasioned by the rainy season on radio networks. As such measurements were not deliberately taken during the rainy season.

Bruce (2006) conducted some research into the prediction of seasonal trends in cellular dropped call probability in the United States. The work which focussed on the effect of atmospheric refraction concluded that the effect of foliage path loss would be greater during wet seasons. Helhel et al. (2009) investigated the effect of dry and wet earth on GSM signals. The research was conducted in Turkey within a forested area. The main losses/effects observed were foliage losses. The intensity of these losses during the dry and wet seasons were compared and were found to be greater during the wet season. Fraizer (1984) stated that determining the effects of foliage on the propagating signal requires detailed knowledge of the environment and posited that in some cases, foliage may improve the signal propagation. However the usual effect is increased attenuation relative to the median. Mohammed et al. (2006) carried out measurements and analysis for signal attenuation through Date Palm trees in North Abu Dhabi, United Arab Emirates. This region is an arid/semi desert region. The results obtained showed significant additional losses of up to 20 dB due to foliage. These measurements were however taken at a frequency of 2.1 GHz which is much higher than the frequency used by mobile networks in Nigeria. Douglas (1973) in a research carried out during two different seasons in a suburban area of the United States of America found that the presence of increased foliage reduced the received signal strength to typical values of about 10 dB. In the same vein, Batariere M.D. et al. (2004) found an average excess path loss of between 3 and 7 dB due to tree foliage for a carrier frequency of 3.676 GHz in a suburban setting outside Chicago, Illinois. All these works were carried out in regions whose vegetations are different from the guinea savannah vegetation predominant in the middle belt region of Nigeria.

Urban and rural areas differ in many ways. For instance rural areas generally have more foliage than urban areas due to vast undeveloped land areas. Urban areas on the other hand have more high-rise buildings which could constitute obstacles to GSM signals. These differences, particularly as they relate to increased ground conductivity and foliage, are likely to cause differences in radio propagation characteristics between urban and rural areas. Bruce (2006) posited that the effect of foliage losses would be higher in rural areas. Bruce's studies however did not focus on this difference. Douglas (1973) posited that foliage is a significant feature which affects propagation in suburban and rural areas but can be neglected in most urban areas. The difference in the propagation characteristics between urban and rural areas would thus also be investigated in this research.

2.2 BASIC THEORY OF MOBILE RADIO PROPAGATION

Mobile radio operates in the UHF band hence its signals are propagated as a space waves. Space wave can however arrive at the receiver's end via two or more routes; the direct line of sight wave and the reflected waves. This is illustrated in Figure 2.1.

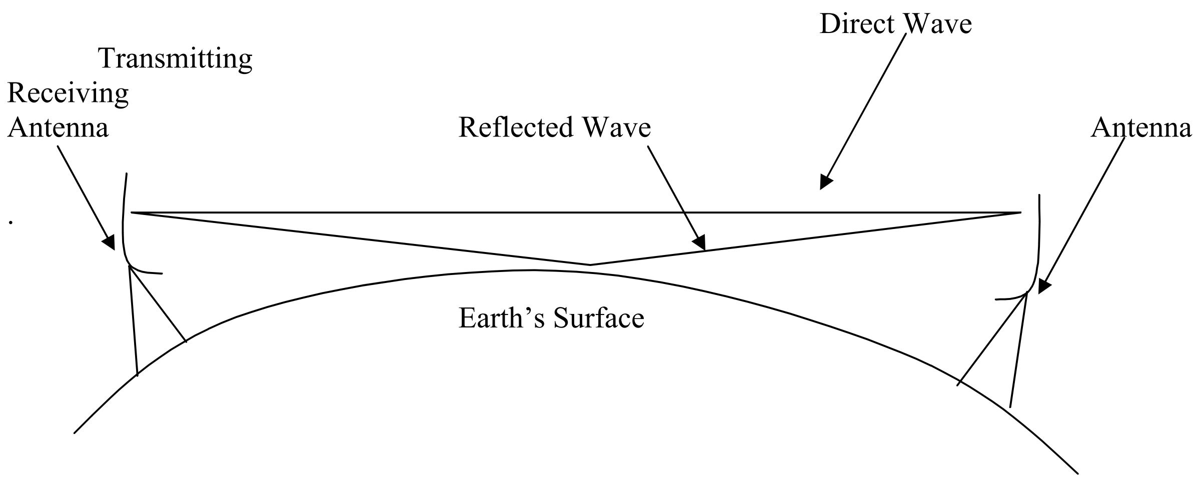

Fig 2.1 Space wave propagation

Radio propagation varies from region to region and needs to be studied carefully. As the signal travels from the transmitter to the receiver, it experiences propagation losses. Propagation loss or attenuation between the transmitter and the receiver may be attributed to various phenomena. These include diffraction, reflection, absorption, or scattering (Seybold, 2005). Before going on to discuss propagation losses, these phenomena would be briefly discussed.

2.2.1 Diffraction

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 (Mishra, 2004). This phenomenon allows reception of radio signals when the LOS conditions are not satisfied. Such a condition is referred to as a Non-Line of Sight (NLOS) case and occurs in both urban and rural environments (Shittu, 2006). In urban areas where there are many high rise buildings, for example, the signal undergoes diffraction as it travels from the base station antenna to the mobile antenna which is at a much lower height. This phenomenon is also known as ‘shadowing’ as the mobile receiver is in the shadow of these structures (Mishra, 2004).

2.2.2 Reflection

Reflection occurs when a radio wave impinges on an object whose dimensions are very large compared to the radio wave’s wavelength. Reflection can result in either a decrease or an increase of signal level at the receiving end depending on whether the reflected wave is in phase or out of phase with the main wave. At a place where many reflected waves exist, the received signal level tends to be very unstable (Ibrahim, 2008).

2.2.3 Scattering

Scattering occurs when a radio wave encounters an obstacle whose dimensions are small compared to its wave length. Scattering is similar to diffraction except that in scattering the radio waves are scattered in a greater number of directions. Common obstacles that may cause radio waves to scatter include street signs, street lamps and trees (Ibrahim, 2008).

2.3 PROPAGATION LOSSES IN THE MOBILE ENVIRONMENT

Propagation losses in the mobile environment are due to several factors many of which are not within the scope of this work. Of interest to this study however are some of the most common factors or sources such as free space losses and foliage losses.

2.3.1 Free Space Loss

Any signal that is transmitted by an 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 square of the distance covered by the signal. This can be understood by using the concept of an isotropic antenna. An isotropic antenna is an imaginary antenna that radiates power equally in all directions. As the power is radiated uniformly, we can assume that a sphere of power is formed. The surface area A of this power sphere is

$$A = 4\pi R^2 \tag{2.1}$$

The power density S at any point at a distance R from the antenna can be expressed as:

$$S = P\,G/A \tag{2.2}$$

Where P is the power transmitted by the antenna, and G is the antenna gain. Thus the received power P_r at a distance R is:

$$P_r = P\,G_t\,G_r\,(\lambda/4\Pi r)^2 \tag{2.3}$$

Where G_t and G_r are the gain of the transmitting and receiving antennas respectively. On converting this to decibels we have:

$$P_r(dB) = P(dB) + G_t(dB) + G_r(dB) + 20\log(\lambda/4\Pi) - 20\log d \tag{2.4}$$

The last two terms in equation 2.4 are together called the path loss in free space, or the free-space loss. The first two terms (P and G_t) combined are called the effective isotropic radiated power (EIRP). Thus:

$$\text{Free-space loss (dB)} = EIRP + G_r(dB) - P_r(dB) \tag{2.5}$$

The free-space loss (L_{dB}) can then be given as:

$$L_{dB} = 92.5 + 20\log f - 20\log d \tag{2.6}$$

Where f is the frequency in GHz and d is the distance in km.
Equation 2.6 is the signal power loss that takes place from the transmitting antenna to the receiving antenna (Mishra, 2004).

The decibel (dB) is the favoured unit for such studies as it readily shows when a signal has gained or lost strength. It measures the relative strengths of two signals or one signal at two different points. It is negative if the signal is attenuated and positive if the signal is amplified. It is defined in power at two respective points as (Seybold, 2005):

$$dB = 10 \log_{10} \frac{P_2}{P_1} \tag{2.7}$$

Where the P_1 and P_2 are the powers of the signal at points 1 and 2, respectively. The decibel can also be defined in voltage. The decibel would be used in the course of this research.

2.3.2 Foliage Loss

Foliage loss is caused by propagation of the radio signal over or through vegetation, principally forests. Foliage loss is a very complicated topic that has many parameters and variations. The variation in signal strength depends upon many factors such as the type of trees, trunks, leaves, branches, their densities, their distribution and their heights relative to the antenna heights. The texture and thickness of the leaves are also factors. For system design, therefore, the estimate of the signal reception due to foliage loss does not need any degree of accuracy. A rough estimate should be sufficient for the purpose of system design (William, 2005). Foliage loss depends on the signal frequency and varies according to the season (Mishra, 2004; Joshi et al., 2005). As foliage loss is of paramount importance to this research a few foliage models would be considered.

2.4 FOLIAGE MODELS

Various models to predict foliage loss have been developed over the years. This section presents a few of the better known foliage models. These models provide an estimate of the additional attenuation due to foliage that is within the LOS path. There are a variety of different models and a wide variation of foliage types. It is therefore valuable to verify a particular model's applicability to a given region based on historical use or comparison of the model prediction to measured results (Seybold, 2005). Two of the known foliage models would be discussed in the following sections.

2.4.1 Weissberger's Model

Weissberger's modified exponential decay model is given by:

$$L(dB) = \begin{cases} 0.45f^{0.284}\, d_f^{\,0.588}, & 14 < d_f \leq 400 \text{ m} \\ 0.45f^{0.284}\, d_f, & 0 < d_f \leq 14 \text{ m} \end{cases} \tag{2.8}$$

Where:

L is signal strength loss along the LOS path.

d_f is the depth of foliage along the LOS path in metres.

f is the frequency in GHz.

The attenuation predicted by Weissberger's model is in addition to free-space (and any other non-foliage) loss. Weissberger's modified exponential decay model applies when the propagation path is blocked by dense, dry, leafed trees. It is important that the foliage depth be expressed in metres and that the frequency is in GHz. This model covers the frequency range from 230 MHz to 95 GHz (Seybold, 2005). Weissberger's modified exponential decay model given in equation 2.8 is applicable where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates. It is applicable in situations where propagation is likely to occur through a grove of trees rather than by diffraction over the top of the trees (Mishra, 2004). Equation 2.8 reveals that foliage loss would increase as frequency and foliage depth increase.

2.4.2 Early ITU Vegetation Model

The early International Telecommunication Union, (ITU), foliage model was adopted by the Consultative Committee on International Radio (CCIR) in 1986 and is also known as the ITU Recommendation (ITU-R). While the model has been superseded by a more recent ITU recommendation, it is an easily applied model that provides results that are fairly consistent with the Weissberger's model. The model is given by (Seybold, 2005):

$$L(dB) = 0.2f^{0.3}\, d_f^{0.6} \text{ dB} \tag{2.9}$$

Where:

L is signal strength loss along the LOS path.

f is the frequency in MHz.

d_f is the depth of the foliage along the LoS path in metres.

The ITU-R was developed from measurements carried out mainly at Ultra High Frequency (UHF), and was proposed for cases where either the transmitter or the receiver is near to a small grove of trees (foliage depth < 400 m). Thus a large portion of the signal propagates through the trees (Meng et al., 2009). Equation 2.9 indicates that foliage loss would increase with foliage depth and frequency. This is consistent with Weissberger's Model.

2.4.3 Updated ITU Vegetation Model

The current ITU models are fairly specific and do not cover all possible scenarios. Nonetheless they are valuable and represent a recent consensus. One of the key elements of the updated model, which should also be considered in applying other models is that there is a limit to the magnitude of the attenuation due to foliage, since there will always be a diffraction path over and/or around the vegetation (Seybold, 2005).

2.4.3.1 Terrestrial Path with One Terminal in Woodland

The scenario covered by this model is one in which woodland or vegetation cover occurs only at the receiving end of the communications channel (Seybold, 2005). Excess attenuation due to vegetation (A_{ex}) is given by:

$$A_{ex} = A_m(1-e^{dy/Am}) \quad \text{dB} \qquad (2.10)$$

Where:

d is the length of the path that is within the woodland in metres.

y is the specific attenuation for very short vegetative paths (dB/m).

A_m is the maximum attenuation for one terminal within a specific type and depth of vegetation (dB)

The excess attenuation due to vegetation is added to the free-space loss and the losses from all other phenomena to determine the total predicted path loss.

2.4.3.2 Single Vegetative Obstruction

If neither end of the link wireless channel is within woodland, but there is vegetation within the path, the attenuation can be modelled using the specific attenuation of the vegetation. For this model to apply, the vegetation must be of a single type as opposed to a variety of vegetation and the frequency is at or below 3 GHz. The vegetation loss model is (Seybold, 2005):

$$A_{et} = dy \tag{2.11}$$

Where:

d is the length of the path that is within the vegetation in metres.

y is the specific attenuation for very short vegetative paths (dB/m).

$A_{et} \leq$ the lowest excess attenuation for any other path (dB).

This model is not applicable to this research work as the area of study covers a variety of vegetation.

CHAPTER THREE
METHODOLOGY

3.0 INTRODUCTION

In order to achieve the objectives of this investigation, a series of measurements of mobile radio signal strengths using Airtel and MTN base stations as reference points were carried out within Kaduna metropolis and environs. The method employed in this research was a systematic approach of collecting and collating relevant data. Thereafter, detailed analysis of the data was carried out from which valuable results were obtained. Part of the research objectives was to compare the propagation characteristics of urban and rural/suburban environments. Thus Kaduna metropolis and three other surrounding rural/suburban areas were chosen. Furthermore, two sets of measurements were taken; one during the dry season and the other during the rainy season. Care was taken to ensure that these measurements were taken at the same points during each measurement.

3.1 RESEARCH STEPS

The various steps taken in the course of this research were as follows:

a. Signal strength measurements of Airtel and MTN networks at various points in Kaduna Metropolis and environs during the dry season.

b. Signal strength measurements of same networks at same points during the rainy season.

c. Evaluation, analysis and comparison of data using graphs..

d. Comparison of measurement results with existing prediction models on effects of wet season on GSM signals.

3.2 CHOICE OF EXPERIMENT SITES

The experiment involved taking signal strength measurements from a reference base station up to a maximum distance of 5 km. Thus in making the choice of the experiment sites, the following criteria were used:

a. Availability of straight or nearly straight roads close to the base stations.

b. Access to the base stations.

These criteria were chosen so as to ensure that measurements could be taken with relative ease and accuracy.

3.2.1 Kaduna Metropolis

After a careful consideration of the criteria specified above, the following places/roads in Kaduna metropolis were selected:

a. Western By-pass.
b. Independence Way.
c. Ali Akilu Way .

3.2.2 Suburban/Rural Areas

Three rural/suburban areas on three of the main exit routes out of Kaduna were chosen. These were Rijana village along the Kaduna-Abuja Expressway, Kachia town and Zango village along the Kaduna-Zaria Expressway. All these areas had a good stretch of straight or nearly straight road and easy access to the base stations.

3.3 DESCRIPTION OF THE MEASUREMENT ENVIRONMENTS

3.3.1 Kaduna Metropolis

Ali Akilu Way and Independence Way are both characterised by moderate/high rise buildings, paved surfaces, such as asphalt roads, concrete floors and bare grounds with a few trees lining the road sides. The predominant tree in both areas was the Eucalyptus tree. This tree usually is green all year round.

On the other hand, Western By Pass is characterised by irregular terrain, scattered trees, some cultivated areas, buildings of various heights. Most of the surfaces along this road are not paved and thus have vegetation cover. The description of theses measurement sites are summarised in Table 3.1.

Table 3.1 Description of Measurement Sites within Kaduna Metropolis

Serial	Site/Route	Environmental Description
1.	Ali Akilu Way (NDA to Abakpa)	Straight road, storey buildings, overhead bridge at Ungwan Sarki, single line of eucalyptus trees on one side of the road and heavy vehicular and human traffic.
2.	Independence Way	Striaght road, storey buildings, paved surfaces and a line of trees at some points along the road.
3.	Western By Pass (Mando Round about to Badiko)	Irregular terrain, scattered trees, open fields (cultivated and uncultivated), buildings of various heights and moderate vegetation cover.

3.3.2 Suburban/Rural Areas

Zango is a rural community (47 km from Kaduna) along Kaduna-Zaria Expressway. The area is an open terrain which has unpaved surfaces except for the expressway and there are no storey buildings. The site is characterised by cultivated farmlands and a line of trees on left side of the road as one moves from Zaria to Kaduna. On the other side of the road, the terrain is generally devoid of vegetation cover due to the kind of soil cover, although there are a few farmlands.

Rijana is also a rural community, 47 km from Kaduna, along the Kaduna – Abuja Expressway. Both sides of the road have similar characteristics. There are scattered trees, open ground covered by vegetation and no storey buildings.

Kachia can be described as a suburban area. The measurement site is along the Kachia – Kaduna Road from the Local Government Secretariat towards Kaduna. The terrain is generally irregular, open and covered with vegetation. There are scattered trees, some farmlands and scattered buildings most of which are bungalows. Table 3.2 summarizes the description of these sites.

Table 3.2 Description of Suburban/Rural Measurement Sites

Serial	Site/Route	Environmental Description
1.	Zango (Along Kaduna – Zaria Expressway)	Open terrain, unpaved surfaces, no storey buildings. Cultivated farmlands and a line of trees on left side of the road as one moves from Zaria to Kaduna. On the other side of the road, the terrain is generally devoid of vegetation
2.	Rijana (Along Kaduna – Abuja Expressway)	Scattered trees, open ground covered by vegetation and few low buildings.
3.	Kachia (Along Kaduna – Kachia Road)	Irregular terrain, scattered trees, open fields (cultivated and uncultivated), buildings of various heights and unpaved surfaces with vegetation cover.

3.4 MEASUREMENT EQUIPMENT AND PARAMETERS

The equipment used for taking the measurements of the signal strength measurement is the Sagem OT 290 phone. It is a specialised equipment used by many telecommunications companies in Nigeria for monitoring their networks. It is capable of measuring received signal power in decibel miliwatts (dBm) (SAGEM, 2003). The equipment has the facility to indicate the particular base station whose signal strength is being measured. Hence care can be taken to avoid measuring signal strengths from different base stations at the same point on different occasions. Details of the features of this equipment are shown in Appendix A. A picture of the measurement apparatus is shown in figure 3.1 below.

The base station (BTS) antenna is a tri sector vertical dipole directional antenna mounted at 37 m above the ground for the GSM 900. The transmitted power is 42 dBm while the antenna gain (G_T) is 18.5 dB and a minimum received power level for good links is from -90dBm (Hauwei Technology, 2003)

Figure 3.1 Picture of SAGEM OT 290 while taking a measurement.

3.5 MEASUREMENT PROCEDURE

Before conducting signal strength measurements, the particular base station of interest is identified and a signal strength measurement is taken at the base station. Thereafter, further measurements are taken at progressive intervals /test points (TPs) of 1 km from the station up to a maximum of 5 km for rural areas. Within Kaduna Metropolis however, further measurements were taken at a progressive interval of 200 metres. To ensure greater accuracy, measurements were taken 2 to 3 times at each test point and a mean value was recorded.

3.5.1 Wet Season Measurements

Wet season measurements were taken between the months of October and November 2009. This period (about one month after the peak of the rainy season) was chosen for the wet season measurements because it was observed as the period when foliage cover and the earth's moisture content would be greatest. This was to ensure that the characteristic variations between both seasons were aptly captured. Furthermore, care was taken to ensure that measurements were not conducted when it was raining. This is because GSM signals are susceptible to additional losses due to rain fall.

3.5.2 Dry Season Measurements

A period of about 2 to 3 months after the last set of rains was chosen to conduct the dry season measurements. This was to give considerable time for the earth's moisture content and the foliage cover to reduce significantly. Thus the dry season measurements were taken between the months of January and March 2010.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND RESULTS

4.0 INTRODUCTION

In this chapter an analysis of the data obtained would be carried out. A comparison of the results obtained from the analysis would also be made with some existing foliage models so as to validate the results.

4.1 WET SEASON MEASUREMENTS

The data obtained from measurements carried out during the wet season are as shown in Tables 4.1 to 4.7. For ease of analysis, these measurements were plotted on graphs using Microsoft Excel. The plots are shown in Appendix B.

Table 4.1 Signal Strength Measurements along Kaduna Western Bye-Pass (MTN R-184) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-54
TP 2	1000	-60
TP 3	2000	-65
TP 4	3000	-67
TP 5	4000	-76

Table 4.2 Signal Strength Measurements in Zango Village (MTN Site T1012) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-58
TP 2	1000	-66
TP 3	2000	-78
TP 4	3000	-85
TP 5	4000	-89

Table 4.3 Signal Strength Measurements in Rijana Village (MTN) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-73
TP 2	1000	-82
TP 3	2000	-105
TP 4	3000	-109
TP 5	4000	-116

Table 4.4 Signal Strength Measurements along Ali Akilu Way Kaduna (Airtel KAD 055) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-54
TP 2	200	-61
TP 3	400	-62
TP 4	600	-67
TP 5	800	-68
TP 6	1000	-70
TP 7	1200	-73
TP 8	1400	-80
TP 9	1600	-86

Table 4.5 Signal Strength Measurements along Independence Way Kaduna (Airtel KAD 016) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-41
TP 2	200	-58
TP 3	400	-60
TP 4	600	-64
TP 5	800	-73
TP 6	1000	-75
TP 7	1200	-76
TP 8	1400	-82
TP 9	1600	-84

Table 4.6 Signal Strength Measurements within Zango (Airtel ZAGY 001) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-55
TP 2	1000	-76
TP 3	2000	-87
TP 4	3000	-93
TP 5	4000	-90
TP 6	5000	-102

Table 4.7 Signal Strength Measurements Within Kachia (Airtel) – Wet

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-52
TP 2	1000	-69
TP 3	2000	-93
TP 4	3000	-98
TP 5	4000	-92
TP 6	5000	-102

4.2 DRY SEASON MEASUREMENTS

The data obtained from measurements carried out during the dry season are as shown in tables 4.8 to 4.14. For ease of analysis, these measurements were plotted on graphs using Microsoft Excel. The plots are shown in Appendix C.

Table 4.8 Signal Strength Measurements along Kaduna Western Bye-Pass (MTN R-184) – Dry

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-47
TP 2	1000	-60
TP 3	2000	-63
TP 4	3000	-63
TP 5	4000	-69

Table 4.9 Signal Strength Measurements in Zango Village (MTN SITE T1012) – Dry

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-59
TP 2	1000	-61
TP 3	2000	-67
TP 4	3000	-75
TP 5	4000	-80

Table 4.10 Signal Strength Measurements in Rijana Village (MTN) – Dry

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-45
TP 2	1000	-58
TP 3	2000	-64
TP 4	3000	-65
TP 5	4000	-73

Table 4.11 Signal Strength Measurements along Ali Akilu Way Kaduna (Airtel KAD 055) – Dry

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-58
TP 2	200	-60
TP 3	400	-64
TP 4	600	-65
TP 5	800	-70
TP 6	1000	-70
TP 7	1200	-73
TP 8	1400	-74
TP 9	1600	-87

Table 4.12 Signal Strength Measurements along Independence Way Kaduna (Airtel KAD 016) – Dry

Test Point	**Distance from Base Station (m)**	**Received Signal Strength (dB)**
TP 1	0	-41
TP 2	200	-60
TP 3	400	-70
TP 4	600	-70
TP 5	800	-74
TP 6	1000	-74
TP 7	1200	-72
TP 8	1400	-75
TP 9	1600	-79

Table 4.13 Signal Strength Measurements within Zango (Airtel ZAGY 001) - Dry

Test Point	**Distance from Base Station (m)**	**Received Signal Strength (dB)**
TP 1	0	-56
TP 2	1000	-74
TP 3	2000	-81
TP 4	3000	-93
TP 5	4000	-91
TP 6	5000	-94

Table 4.14 Signal Strength Measurements within Kachia (Airtel) – Dry

Test Point	Distance from Base Station (m)	Received Signal Strength (dB)
TP 1	0	-52
TP 2	1000	-61
TP 3	2000	-88
TP 4	3000	-91
TP 5	4000	-84
TP 6	5000	-98

4.3 COMPARISON OF WET AND DRY EARTH MEASUREMENTS

In this section empirical analysis of the data collected would be conducted. The data collected during the rainy season would be compared with those collected during the dry season and the relationship between both sets of data would be brought to the fore. This would then be used to draw conclusions. For ease of analysis both sets of measurements have been plotted on graphs as shown in Figures 4.1 to 4.7.

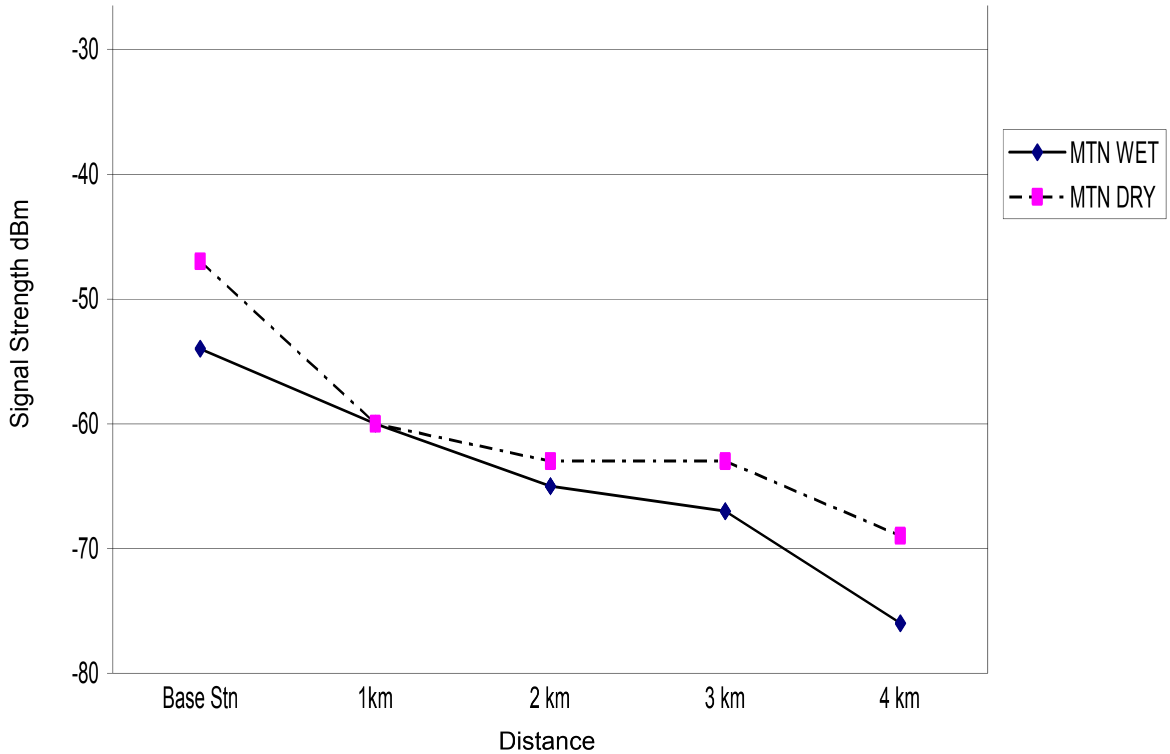

Figure 4.1 Graph of signal strength measurements along Kaduna Western Bye-Pass (MTN Wet & Dry)

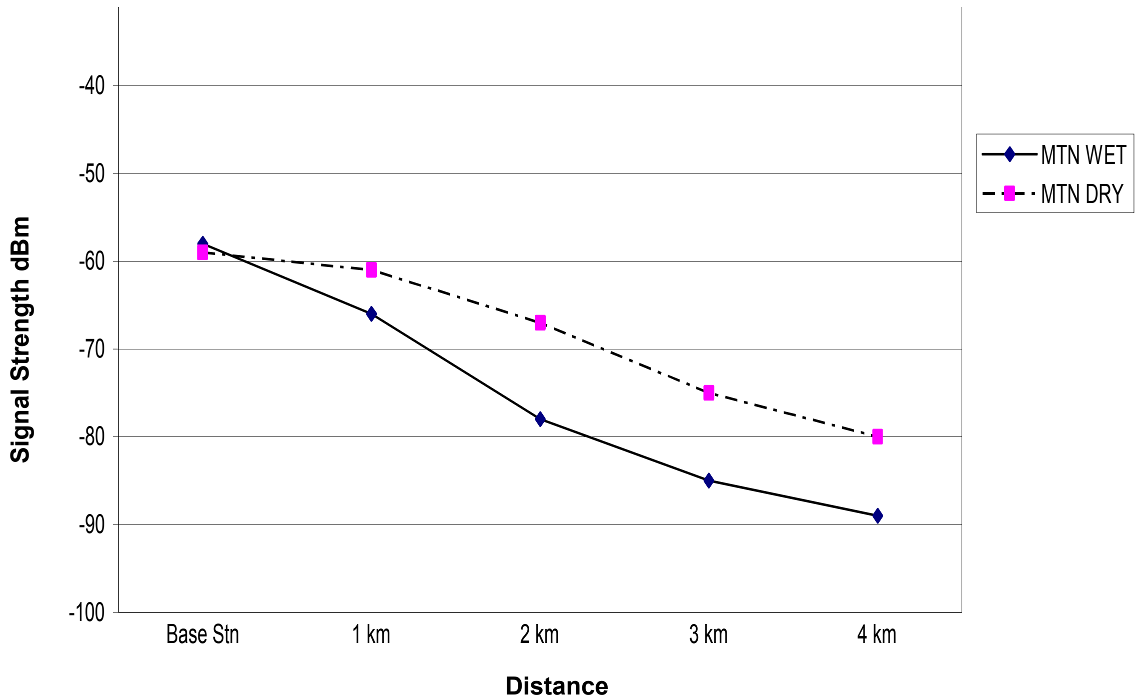

Figure 4.2 Graph of signal strength measurements along Zango Village (MTN)

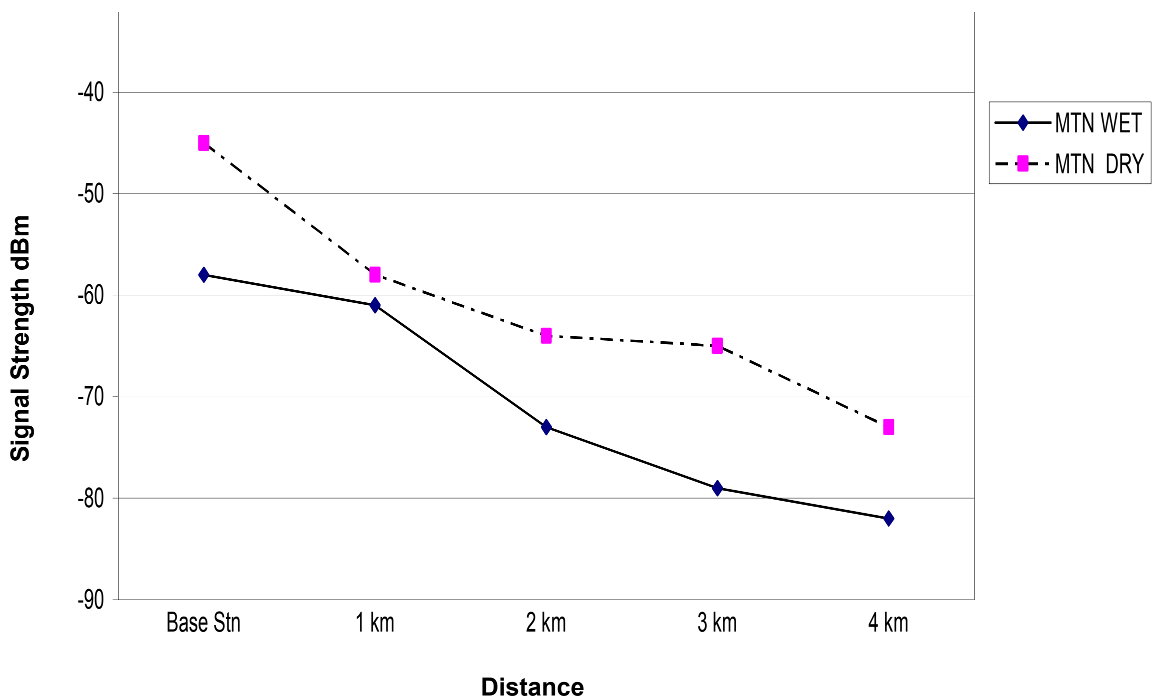

Figure 4.3 Graph of signal strength measurements within Rijana Village (MTN)

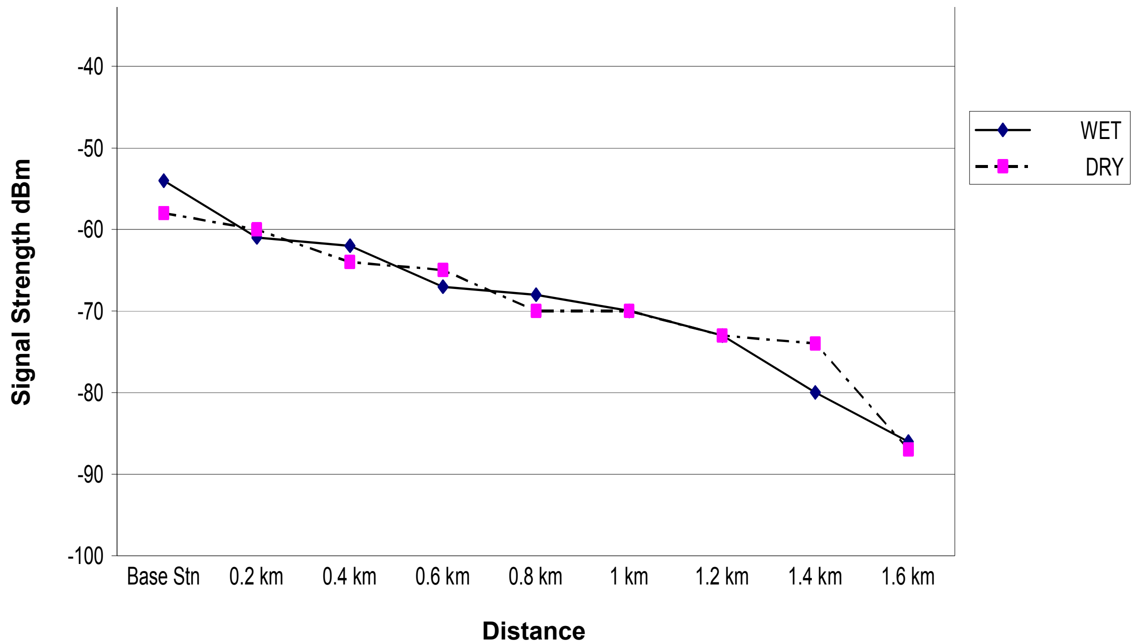

Figure 4.4 Graph of signal strength measurements along Ali Akilu Way Kaduna (Airtel)

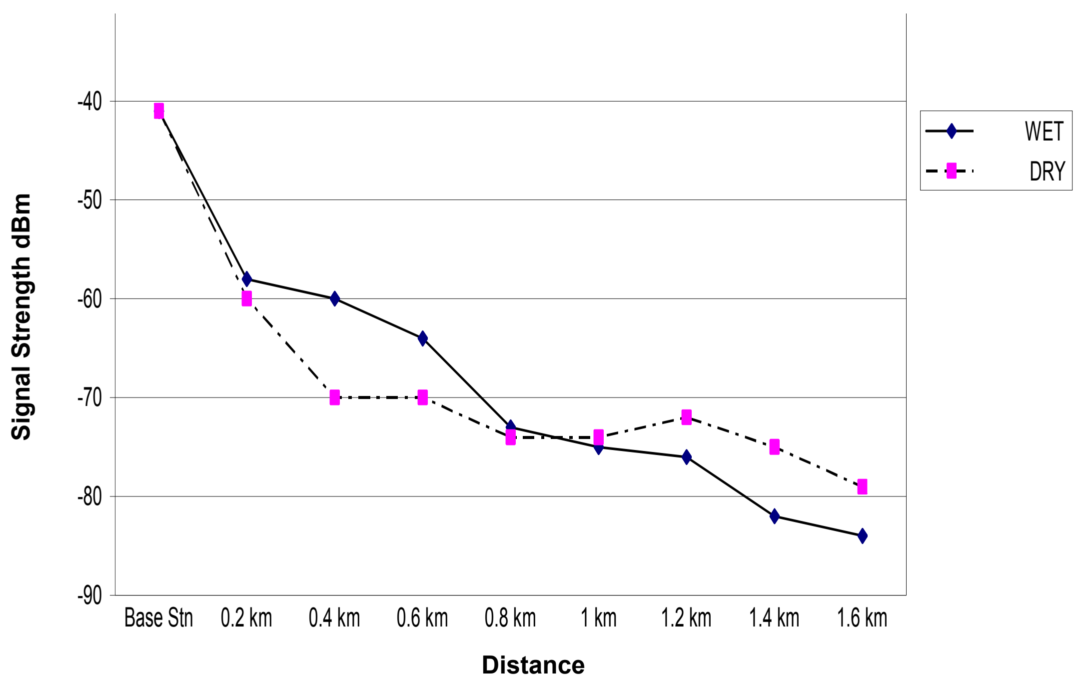

Figure 4.5 Graph of signal strength measurements along Independence Way Kaduna (Airtel)

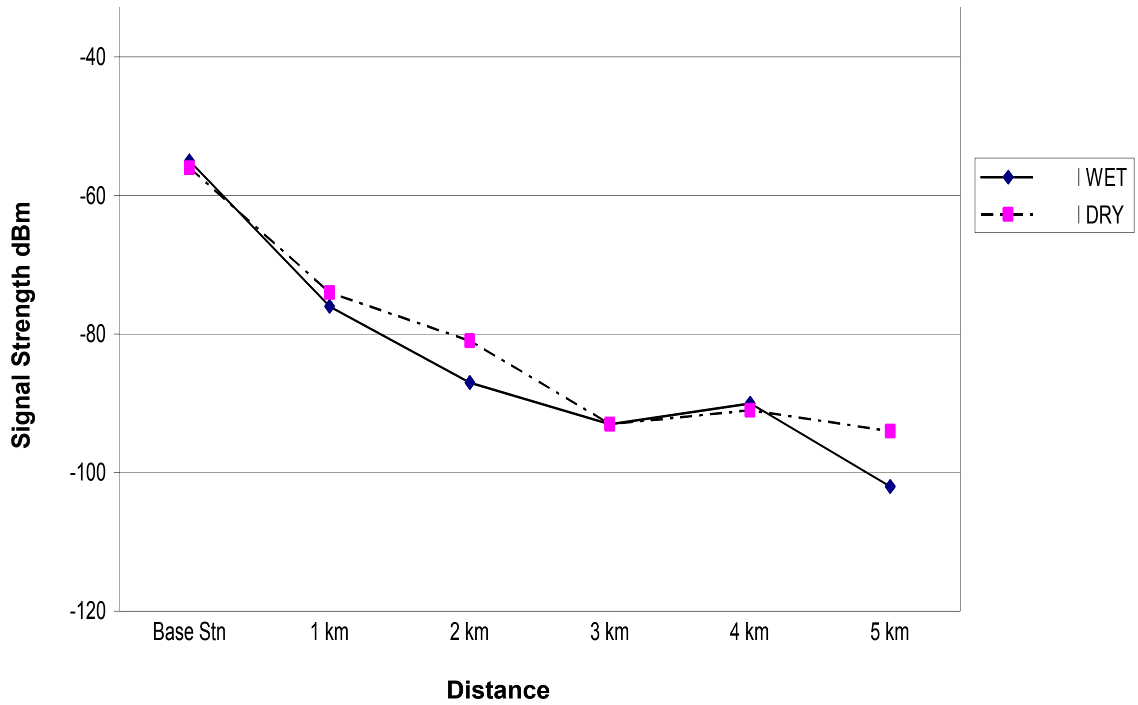

Figure 4.6 Graph of signal strength measurements within Zango Village (Airtel)

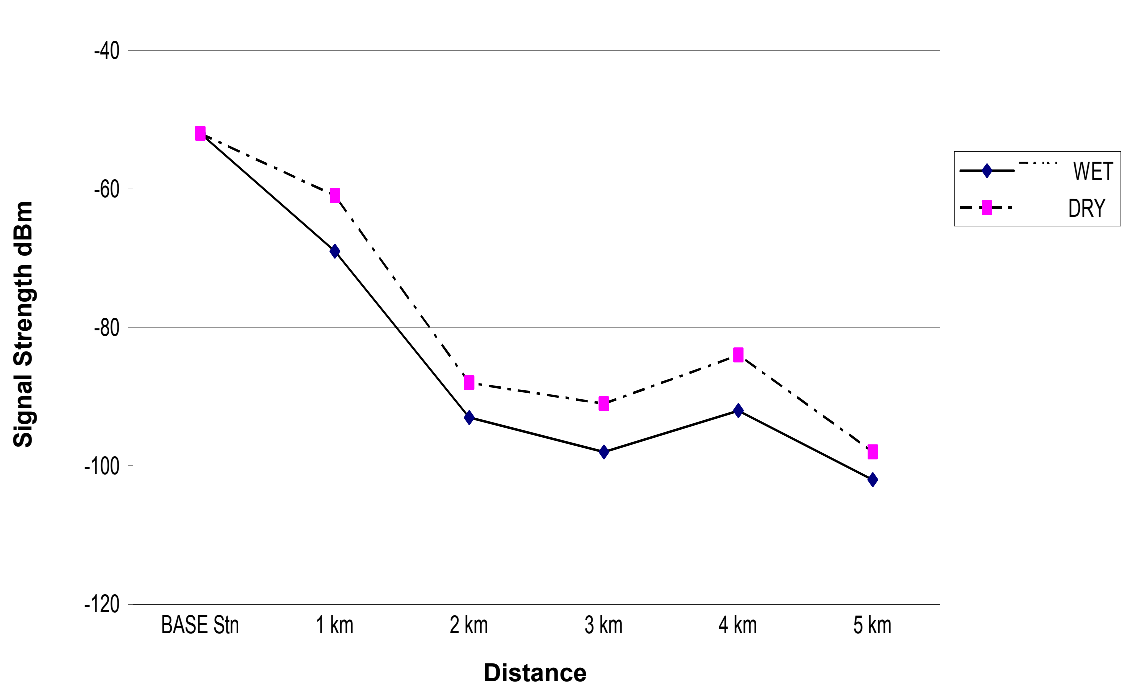

Figure 4.7 Graph of signal strength measurements within Kachia (Airtel)

In Figures 4.1 to 4.3 and Figure 4.7, it is evident that the signal strength measurements obtained during the dry season are significantly greater than those obtained during the rainy season. It is therefore obvious that mobile radio signals suffer greater attenuation during the rainy season than during the dry season. There are two main factors that distinguish between the dry and rainy seasons. These are the increased foliage and the increased ground conductivity which are experienced during the rainy season.

The plots in Figures 4.4 to 4.6 however do not present any significant differences between both measurements. Two of these plots (Figures 4.4 and 4.5) represent measurements taken in urban areas. One reason can be adduced for this insignificant difference; the fact that the farthest distance from the transmitting antennas in both cases was 1.6 km as opposed to the 4 km or 5 km maximum distance in other plots. The inability to take measurements beyond 1.6 km in both cases was due to two reasons:

> The first reason being the absence of a stretch of road that exceeds this distance within the metropolis.
>
> Secondly, it was practically impossible to proceed beyond 2 km within the metropolis and not enter into the signal field of another base station. This is because urban BTS are micro BTS with a maximum range of 3km.

These limitations not withstanding some important deductions can be made from these plots. From the plots obtained in rural areas (Figures 4.2, 4.3 and 4.7) significant differences of between 5 and 8dBm can be observed at a distance of 1 km from the transmitting antenna. This is not the case for plots obtained in the urban area where the maximum difference was 1 dBm. Various reasons can be given for this difference.

> Firstly, in urban areas there are fewer trees and less vegetation compared to rural areas. Thus, urban areas would have less foliage than rural areas.
>
> Secondly, there are more paved surfaces such as asphalt roads and concrete floors in urban areas than in rural areas. These surfaces do not retain moisture readily and gives rise to an almost constant value of ground conductivity all year round in urban areas.

One can thus safely deduce that the effect of increased foliage and increased ground conductivity is greater in rural areas than in urban areas.

Figure 4.6 represents measurements in a rural environment (Zango) on the Airtel Network. The plot does not show much significant difference between measurements taken during the rainy and dry season. However, it can be seen that on the average, the signal suffered more attenuation during the rainy season. Moreover, Figure 4.2, which is a plot taken in the same area but on the MTN network, shows significant difference between measurements taken during the rainy and dry season. A careful examination of the site (Zango) revealed the reason for the difference between the propagation characteristics of the two networks. The base stations of both networks are on either side of the Kaduna – Zaria Express Way. On the side of the road where the MTN base station is located there is a line of trees which are within the line of sight of the signal propagation as one travels from Zaria to Kaduna. Whereas the other on the side of the road, where the Airtel base station is located, the terrain is free of trees but rather has a group of scattered cultivated farmlands for short crops, such as groundnuts, interspersed with barren ground. Signal measurements were taken for both networks in the same direction (Zaria – Kaduna axis). Thus the MTN network suffered the effect of foliage loss more significantly than the Airtel network due to this line of trees and greater vegetation along its LOS path.

4.4 DIFFERENCE IN SIGNAL STRENGTHS BETWEEN WET AND DRY EARTH

The difference in signal strengths between both sets of data collected would be analysed in this section. Tables 4.15 to 4.21 show these differences. These differences represent additional propagation losses due to foliage (foliage loss) and increased ground conductivity. These values would be compared with those expected from existing foliage models in the subsequent section. Furthermore, the mean difference in the signal strength measured was also calculated and is shown in the tables.

Table 4.15 Comparison of Measurements along Kaduna Western Bye-Pass (MTN)

Test Point	Distance from Base Station (m)	Received Signal Strength (Wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-54	-47	-7
TP 2	1000	-60	-60	0
TP 3	2000	-65	-63	-2
TP 4	3000	-67	-63	-4
TP 5	4000	-76	-69	-7
Mean Signal Strength Difference (dBm)				**-4.0**

Table 4.16 Comparison of Signal Strength Measurements in Zango Village (MTN)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-58	-59	1
TP 2	1000	-66	-61	-5
TP 3	2000	-78	-67	-11
TP 4	3000	-85	-75	-10
TP 5	4000	-89	-80	-9
Mean Signal Strength Difference (dBm)				**-6.8**

Table 4.17 Comparison of Signal Strength Measurements in Rijana Village (MTN)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-58	-45	-13
TP 2	1000	-61	-58	-3
TP 3	2000	-73	-64	-9
TP 4	3000	-79	-65	-14
TP 5	4000	-82	-73	-9
Mean Signal Strength Difference (dBm)				**-9.6**

Table 4.18 Comparison of Signal Strength Measurements along Ali Akilu Way Kaduna (Airtel)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-54	-58	4
TP 2	200	-61	-60	-1
TP 3	400	-62	-64	2
TP 4	600	-67	-65	-2
TP 5	800	-68	-70	2
TP 6	1000	-70	-70	0
TP 7	1200	-73	-73	0
TP 8	1400	-80	-74	-6
TP 9	1600	-86	-87	1
Mean Signal Strength Difference (dBm)				**0**

Table 4.19 Comparison of Signal Strength Measurements along Independence Way Kaduna (Airtel)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-41	-41	0
TP 2	200	-58	-60	2
TP 3	400	-60	-70	10
TP 4	600	-64	-70	6
TP 5	800	-73	-74	1
TP 6	1000	-75	-74	-1
TP 7	1200	-76	-72	-4
TP 8	1400	-82	-75	-7
TP 9	1600	-84	-79	-5
Mean Signal Strength Difference (dBm)				**0.22**

Table 4.20 Comparison of Signal Strength Measurements within Zango (Airtel)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-55	-56	1
TP 2	1000	-76	-74	-2
TP 3	2000	-87	-81	-6
TP 4	3000	-93	-93	0
TP 5	4000	-90	-91	1
TP 6	5000	-102	-94	-8
Mean Signal Strength Difference (dBm)				**-2.33**

Table 4.21 Comparison of Signal Strength Measurements within Kachia (Airtel)

Test Point	Distance from Base Station (m)	Received Signal Strength (wet) (dBm)	Received Signal Strength (dry) (dBm)	Signal Strength Difference (dBm)
TP 1	0	-52	-52	0
TP 2	1000	-69	-61	-8
TP 3	2000	-93	-88	-5
TP 4	3000	-98	-91	-7
TP 5	4000	-92	-84	-8
TP 6	5000	-102	-98	-4
Mean Signal Strength Difference (dBm)				**-5.33**

From Tables 4.16, 4.17 and 4.21, a mean difference of -6.8 dB, -9.6 dB and -5.33 dB was observed between the received signal strengths measured during the wet and dry seasons in Zango, Rijana and Kachia respectively. These three places are rural/sub urban areas. These mean differences represent additional propagation losses due to increased foliage and greater ground conductivity. The comparison of similar measurements in the urban area shows a smaller margin of difference. From Tables 4.15, 4.18 and 4.19 mean differences of -4dB, 0dB and 0.22dB were observed between the received signal strengths measured during the wet and dry seasons along Western Bypass, Ali Akilu Way and Independence Way in Kaduna Metropolis respectively. It is thus evident that mobile networks experience greater losses due to increased foliage and greater ground conductivity in rural/suburban areas than in urban areas.

From the foregoing, the following conclusions can be drawn:

(i) There is an inverse relationship between increased foliage/greater ground conductivity and GSM signal strength.

(ii) Greater ground conductivity/increased foliage have a significant effect on GSM signal strength especially in rural areas.

4.5 COMPARISON OF RESULTS WITH FOLIAGE MODELS

The differences in signal strengths between the measurements taken during the dry and rainy seasons computed in Tables 4.15 to 4.21 constitute the additional losses due to increased foliage and greater ground conductivity. The mean signal strength difference obtained from these tables would be compared with the results computed using some foliage models for both urban and rural areas.

One of the major differences between the urban and rural areas is the depth of foliage. The depth of foliage along the LOS path in rural areas is generally greater than in urban areas. This is because there are more trees and more vegetation cover in rural/suburban areas than in urban areas. It was not feasible to obtain accurate values for foliage depth in this research considering that the vegetation types were not uniform and signal strength was measured over long distances. However, for the purposes of comparison, various values of foliage depth were applied in computing the additional losses due to foliage using two common models (Weissberger and the ITU models). The foliage depths that produced values nearest to the measured additional loss values were then adopted. The computations are shown in the following sections.

4.5.1 Comparison of Results with Weissberger's Model

Weissberger's modified exponential decay model is given by:

$$L(dB) = \begin{cases} 0.45f^{0.284} d_f^{\ 0.588}, & 14 < d_f \leq 400 \text{ m} \\ 0.45f^{0.284} d_f, & 0 < d_f \leq 14 \text{ m} \end{cases} \qquad (4.1)$$

Where:

L is signal strength loss along the LOS path.

d_f is the depth of foliage along the LOS path in metres.

f is the frequency in GHz.

It was discovered that the values of foliage depth that produced results closest to the measured values were between 1 m and 2 m for urban areas and about 13 m for rural areas.

(a) For Urban Areas

For an average depth of foliage of 1m along the LOS path and frequency of 0.9 GHz
$L(dB) = 0.45(0.9)^{0.284}(1) = 0.46$ dB

For an average depth of foliage of 2m along the LOS path and frequency of 0.9 GHz
$L(dB) = 0.45(0.9)^{0.284}(2) = 0.87$ dB

(b) For Rural Areas

For an average depth of foliage of 13m along the LOS path and frequency of 0.9 GHz
$L(dB) = 0.45(0.9)^{0.284}(13) = 5.68$ dB

The Weissberger model shows greater losses for greater foliage depth.

4.5.2 Comparison of Results with ITU Model

The ITU model is given by:

$$L(dB) = 0.2f^{0.3} d_f^{0.6} \text{ dB} \tag{4.2}$$

Where:

L is signal strength loss along the LOS path.

f is the frequency in MHz.

d_f is the depth of the foliage along the LOS path in metres.

Using the ITU Model, the values of foliage depth that produced results closest to the measured values were between 1 m and 2 m for urban areas and a foliage depth of 8 m for rural areas. The computations are shown below.

(a) For Urban Areas

For an average depth of foliage of 1m along the LOS path and frequency of 900 MHz

$$L(dB) = 0.2(900)^{0.3}(1)^{0.6} = 1.54 \text{ dB}$$

For an average depth of foliage of 2m along the LOS path and frequency of 900 MHz

$$L(dB) = 0.2(900)^{0.3}(2)^{0.6} = 2.33 \text{ dB}$$

(b) For Rural Areas

For an average depth of foliage of 8 m along the LOS path and frequency of 900 MHz

$$L(dB) = 0.2(900)^{0.3}\,(8)^{0.6} \quad = 5.36\ dB$$

The results obtained from the ITU Model are in agreement with those obtained from the Weissberger's Model. Both models revealed that mobile network signals suffer greater losses when there is increased foliage. Furthermore, both models required significantly greater values of foliage depth to produce losses of about 5 dB experienced in the rural/suburban areas. This validates the deduction that the greater losses experienced by mobile networks in rural areas are as a result of increased foliage. Lastly, both models show that there is an inverse relationship between increased foliage and GSM signal strength. They could thus be used to approximate losses due to foliage in the area of this study.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 INTRODUCTION

This Chapter gives a summary of the results obtained and its applications. The limitations/problems encountered in the course of the research are also outlined here. Finally, conclusion and recommendations for further work are presented.

5.1 SUMMARY OF RESULTS

In this research, it was discovered that mobile radio propagation characteristics are affected by variation in seasons. A significant difference was observed between the signal strength measured during different seasons of two mobile networks (MTN and Airtel) in Kaduna Metropolis and environs. Additional losses with mean values of between -5.33 dB and -9.6 dB were observed in the rural/suburban areas during the wet season. These represent additional propagation losses due to increased foliage and greater ground conductivity which are the two main features that characterize the wet season. Conversely, additional losses with mean values of between 0dB and -4dB were observed in the urban centre during the wet season. From the foregoing, mobile networks experience greater losses due to increased foliage and greater ground conductivity in rural/suburban areas than in urban areas.

When the obtained results were compared with both the Weissberger and ITU models an agreement was seen. Both models revealed that mobile network signals suffer greater losses when there is increased foliage. The comparison also validated the deduction that the greater losses experienced in the rural/suburban areas were as a result of the greater foliage in these environments as compared with the urban centres.

The results obtained from this research can therefore be summarized as follows:

Mobile radio networks suffer greater attenuation during the wet/rainy season due to increased foliage and greater ground conductivity.

The effect of increased foliage and increased ground conductivity is greater in rural areas than in urban areas due to the presence of more foliage cover and unpaved surfaces in the rural areas.

There is an inverse relationship between increased foliage/greater ground conductivity and GSM signal strength.

Greater ground conductivity/increased foliage have a significant effect on GSM signal strength especially in rural areas within the savannah grassland region.

5.2 SIGNIFICANCE OF RESULTS AND APPLICATION

Available literatures on propagation losses indicate that foliage losses are experienced in forested areas. This research has brought to the fore that losses due to foliage can be significant even in savannah grassland areas during the rainy/wet season. Moreover, this work reveals that variations of seasons affect mobile radio propagation characteristics. The results obtained from this research reveal the reason certain mobile phone users experience problems in receiving or making calls at certain areas during the wet season; a phenomenon which is not experienced during the dry season.

This research provides mobile network planners with useful information for optimizing their networks particularly in the savannah grassland areas of Nigeria. Valuable data of additional losses networks are likely to suffer during the wet season are herein available to network planners operating in the savannah grassland region of Nigeria and other countries with similar vegetation. Thus provision could be made for these additional losses at the planning stages of base station deployments particularly if the deployments are to be done during the dry season. With careful planning, mobile operators can avoid situations where certain subscribers would be unable to receive or make calls in their homes during the wet season.

5.3 LIMITATIONS/PROBLEMS ENCOUNTERED

In the course of the research, some limitations were experienced. Some of the limitations experienced by the researcher are as follows:

> There was also the limitation posed by the curvature of the roads and the topography of the earth surface in certain rural areas. Some of the roads were not completely straight but had some slight curves while some surfaces were slightly undulating. These would have an effect on the accuracy of the distance measurements from the base stations. This limitation was however overcome by the fact that care was taken to ensure that both sets of measurements (wet and dry) were taken at the same spots, thus eliminating the possibility of obtaining different results due to slight errors in distance measurements.
>
> Lack of a device that could be used to ascertain the base stations' transmitter power during the period of taking measurements. The transmitter power for both the MTN and Airtel BTS were thus assumed to be constant. These results are therefore valid as long as the BTS radiated power remains constant.

5.4 CONCLUSION

This research investigated the effect of variation of seasons on mobile radio propagation characteristics within Kaduna Metropolis and environs, a savannah grassland region in Nigeria. Increased foliage and greater ground conductivity which are two phenomena that differentiate the wet and dry seasons were the main factors considered. The results from the research revealed that mobile radio signals suffered additional losses during the wet season due to increased foliage and greater ground conductivity. These additional losses were found to be more significant in the rural/suburban areas. The reason for the difference in propagation characteristics between the rural/suburban areas and urban centres is the fact that rural areas have greater vegetation cover and more unpaved surfaces which are capable of retaining more moisture than urban centres. The results obtained were compared with some foliage models and an agreement was seen.

5.5 RECOMMENDATION FOR FURTHER WORK

This research simply established the fact that variations in seasons affect mobile radio propagation due to differences in foliage cover and ground conductivity. Furthermore, it revealed certain differences between mobile radio propagation characteristics in urban centres and rural/suburban areas. Though the results were compared with some foliage models emphasis were not laid on ascertaining the model that best suits the savannah grassland region. Further work could concentrate on ascertaining or deriving a foliage model that best suits this environment. Moreover, other networks could be used for prediction studies in the studied environment or in other environments.

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APPENDIX A

TECHNICAL FEATURES OF THE SAGEM OT 290 PHONE

SAGEM OT 200 PRODUCT LINE

2 and 2,5G capability

The SAGEM test tools are designed to fulfil the operators and integrators requirements and to provide the best solution to operate and maintain GSM and GPRS networks.

Real time network monitoring

SAGEM OT 200 range gives all trace information for investigation or quality monitoring. GSM/GPRS software provided with the mobile enables visualisation, recording and replay of all information.

Open interface for external trace processing and logging

The physical interface, based on standard serial interface, makes easier the use of the terminal in trace or transfer mode.

Trace storage

Capability to store in the mobile alone measuments made in real time. The datas are download in a computer using the data interface in trace mode.

GSM/GPRS range:

SAGEM OT 290 (GSM-DCS/PCS)

Technical features:

- MMS
- WAP 1.1 over CSD/GPRS
- Protocol analysis
- Quality of service information (GSM/GPRS)
- Class 10 (4+1/3+2)
- Simultaneous data transfer and trace information
- GSM/GPRS forcing functions (Ch, Band,...)
- C/I measurement
- Scanning capabilities
- Radio environment survey

SAGEM OT 230 (GSM-DCS/GSM-PCS)

- A field oriented product for easy testing and performance analysis
- Data session with GSM/GPRS trace information available on the mobile display
- The engineering realtime cost effective solution
- Graphical color display

GSM range:

SAGEM OT 260 (GSM-DCS/PCS)

Technical features:

- Serial port for data transfer (CSD) or trace information
- GSM forcing functions (Ch, Band,...)
- Scanning capabilities
- WAP 1.1 over CSD
- MMS
- Protocol analysis
- Quality of service information
- E-GSM supported
- C/I measurement
- Radio environment survey

GSM/GPRS Trace visualisation software:

SAGEM OT Drive compatible with OT 260 and 290

A real time investigation tool for easy testing and performance monitoring:

- Complete trace display in information windows
- Session logging and replay for post analysis
- Forcing functions and scanning control

SAGEM OT 200 PRODUCT LINE

Technical features

Engineering capability

Forcing functions
- BCCH
- Cell bar access
- Frequency band (GSM/PCS/DCS)
- Handover
- GPRS coding scheme
- GPRS multislot class

Scanning
- Scanning(by band or by set of frequencies)
- BSIC

Layer 3 message control
- Suppress, modify, create

2G trace description

Radio environment information
- Received level
- C/I measurement
- Serving/neighbouring cell frequency
- Cell reselection parameters

Mobility management information
- Authentication
- Ciphering
- Location (Cell Identity, LAC, MCC, MNC)

Protocol messages monitoring
- Layer 2: LAPD-m
- Layer 3: RR, MM, CM

Quality of Service
- Downlink signaling counter
- Frame Erasure Rate
- Codec state (HR, FR, EFR,AMR)
- DTX state

2,5G trace description

Radio environment information
- Received level
- Serving/neighbouring cell frequency
- Cell reselection parameters

GPRS Mobility management information
- Identity
- Location (Cell Indentity, RAC, LAC, MCC, MNC)

GPRS Session management information
- PDP QoS
- IP Address
- Location (Cell Identity, RAC, LAC, MCC, MNC)

RLC/MAC information
- Packet channel information: frequency, timing advance, time slots
- Radio quality information: BER, Sign var, C value

Protocol messages monitoring
- RLC/MAC: control blocks, data blocks
- GMM/SM: GPRS attach, PDP activation

Quality of Service
- RLC throughput, Block error rate, Block retransmission rate
- LLC throughput, frame retransmission rate

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APPENDIX B

GRAPHICAL REPRESENTATIONS OF WET SEASON MEASUREMENTS

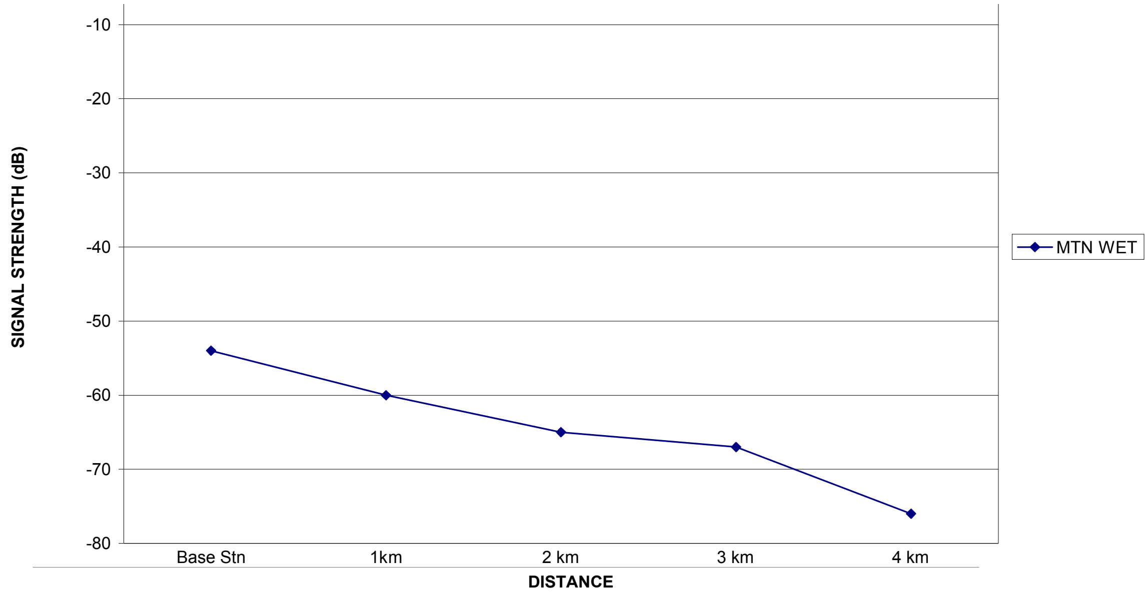

Figure B.1 Graph of Signal Strength Measurements along Kaduna Western Bye-Pass - MTN (Wet)

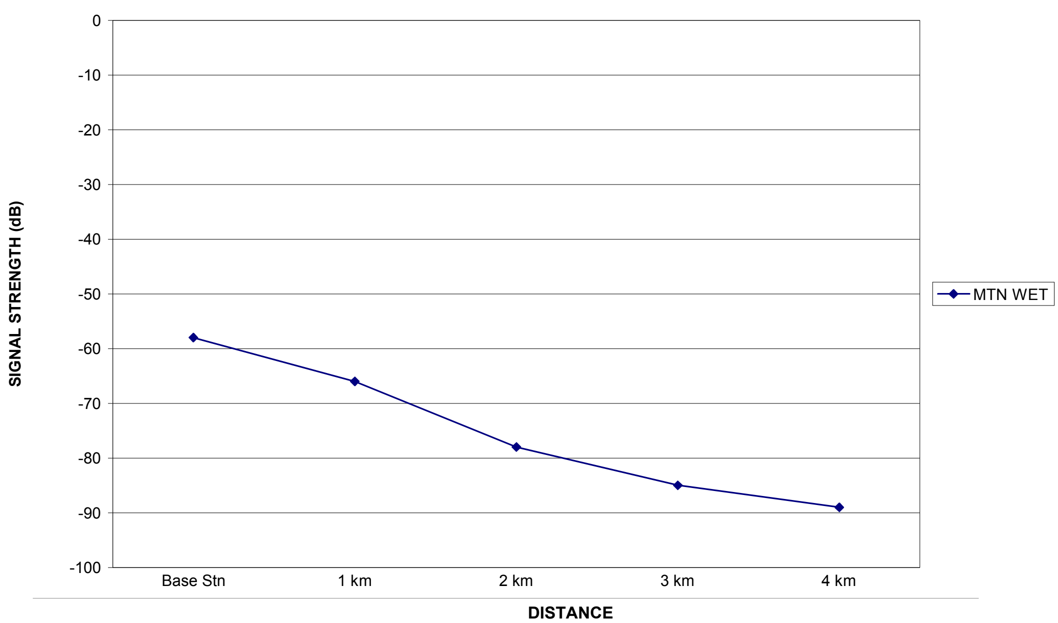

Figure B.2 Graph of Signal Strength Measurements along Zango Village – MTN (Wet)

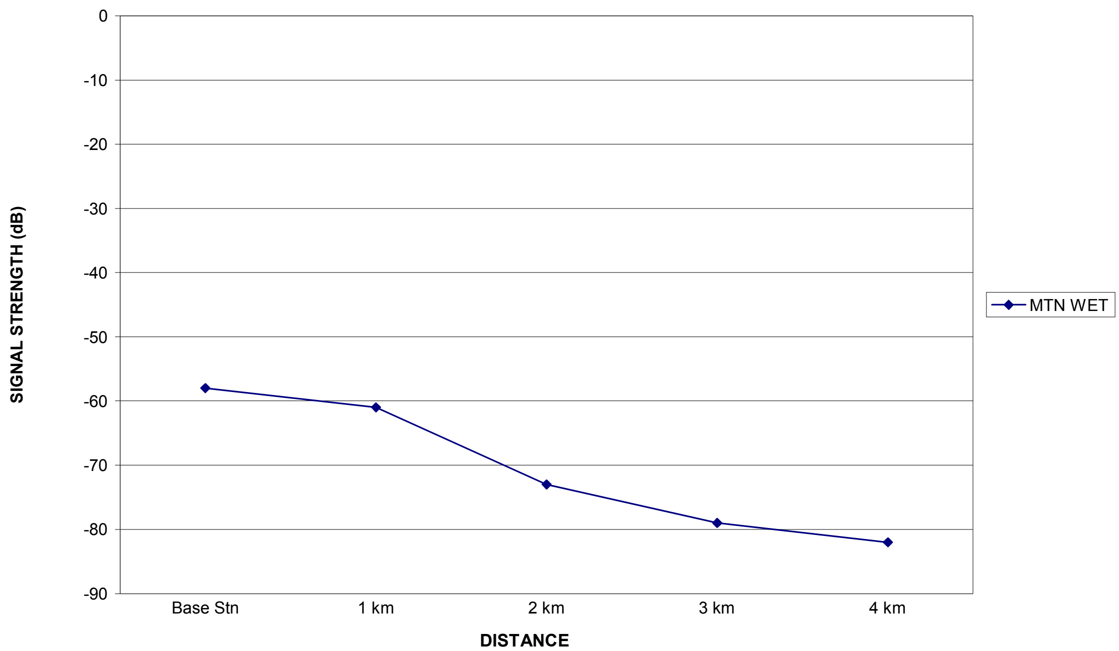

Figure B.3 Graph of Signal Strength Measurements within Rijana Village -MTN (Wet)

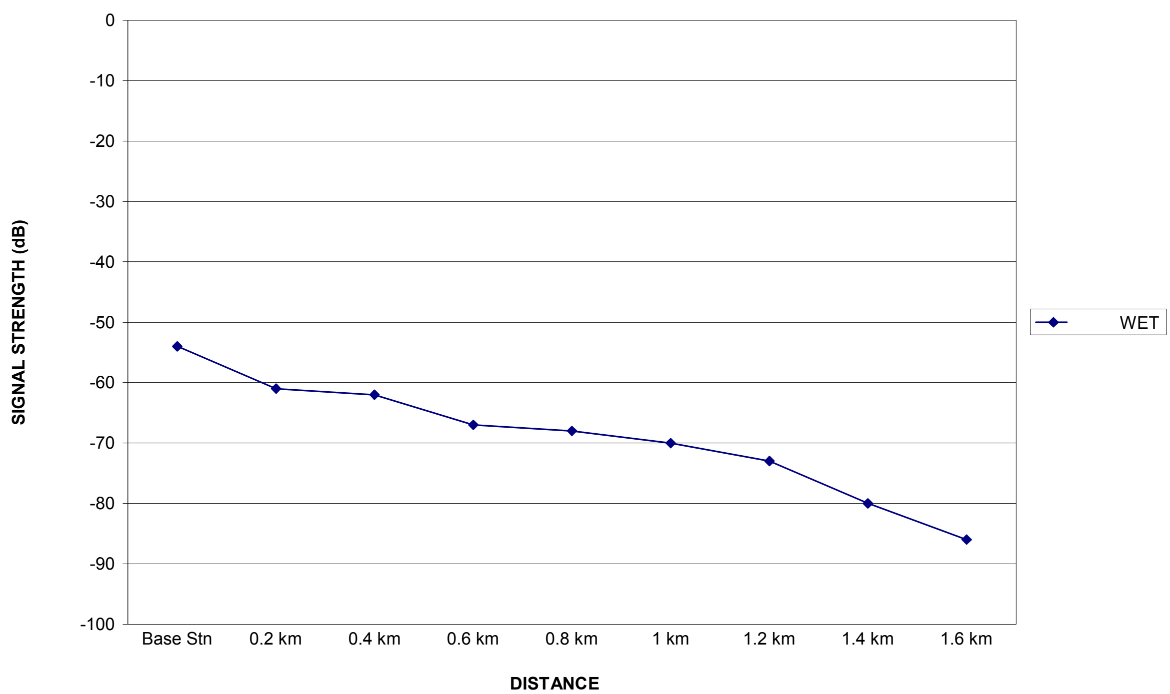

Figure B.4 Graph of Signal Strength Measurements along Ali Akilu Way Kaduna – Airtel (Wet)

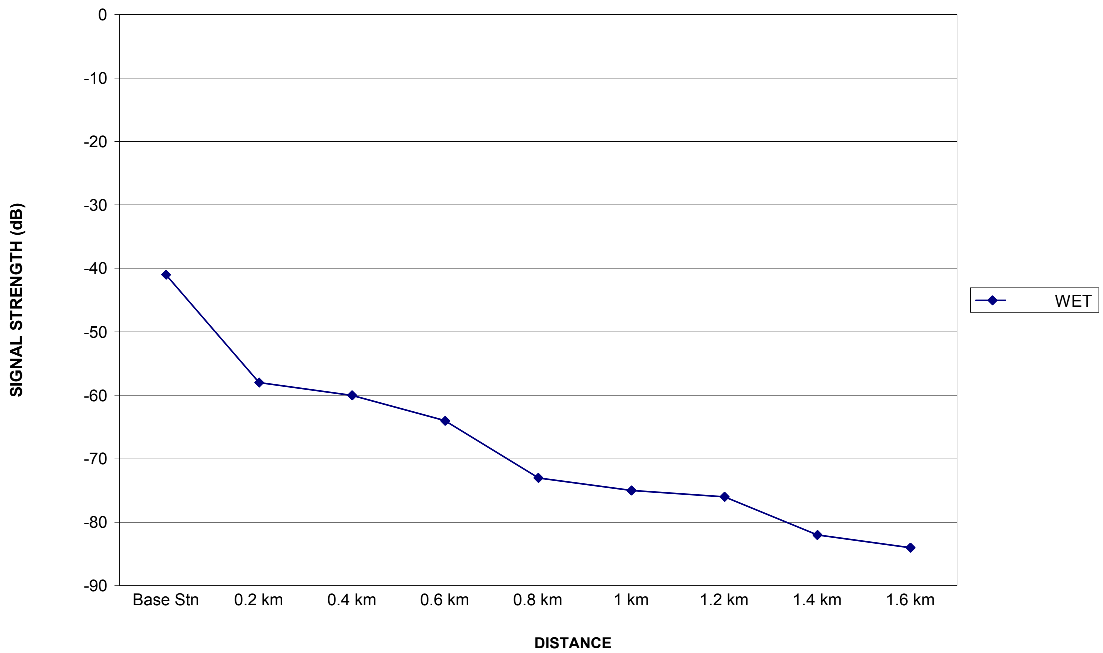

Figure B.5 Graph of Signal Strength Measurements along Independence Way Kaduna – Airtel(Wet)

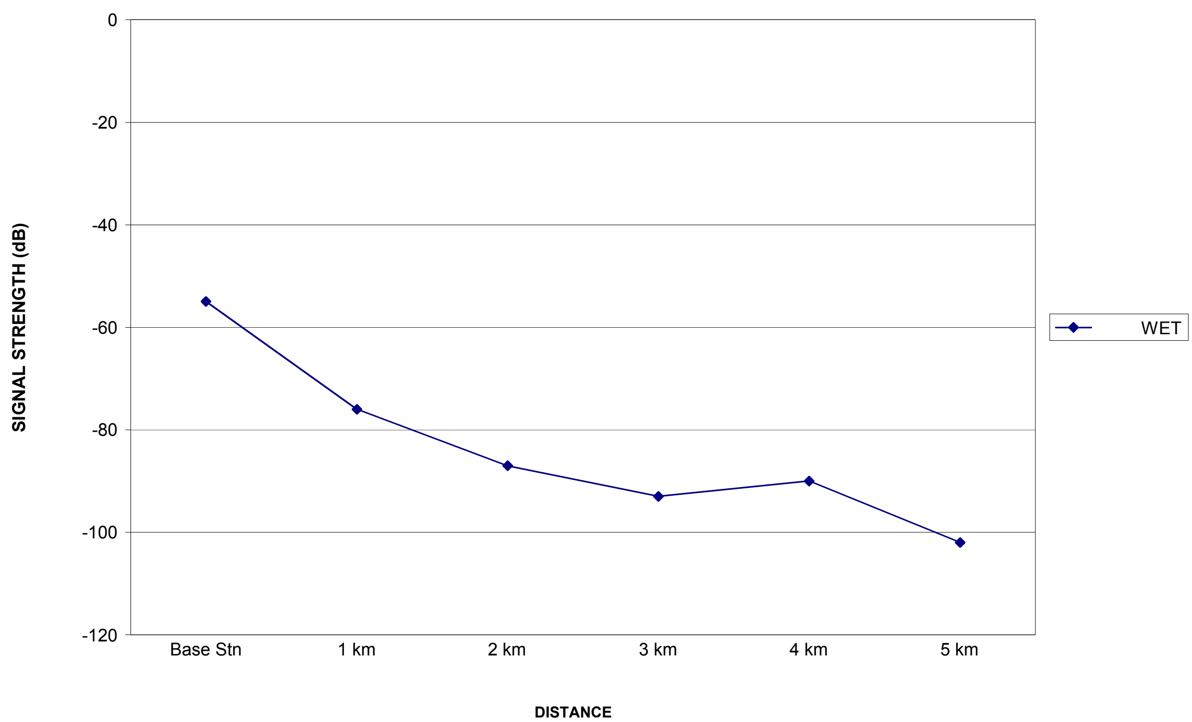

Figure B.6 Graph of Signal Strength Measurements within Zango Village – Airtel (Wet)

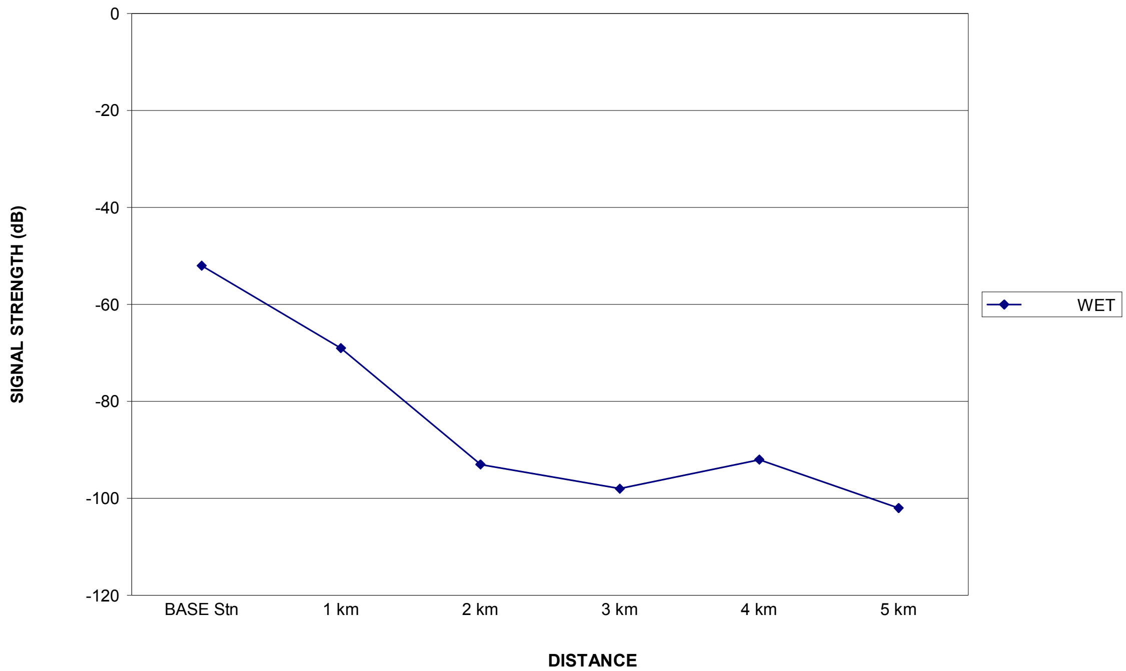

Figure B.7 Graph of Signal Strength Measurements within Kachia – Airtel (Wet)

APPENDIX C

GRAPHICAL REPRESENTATIONS OF DRY SEASON MEASUREMENTS

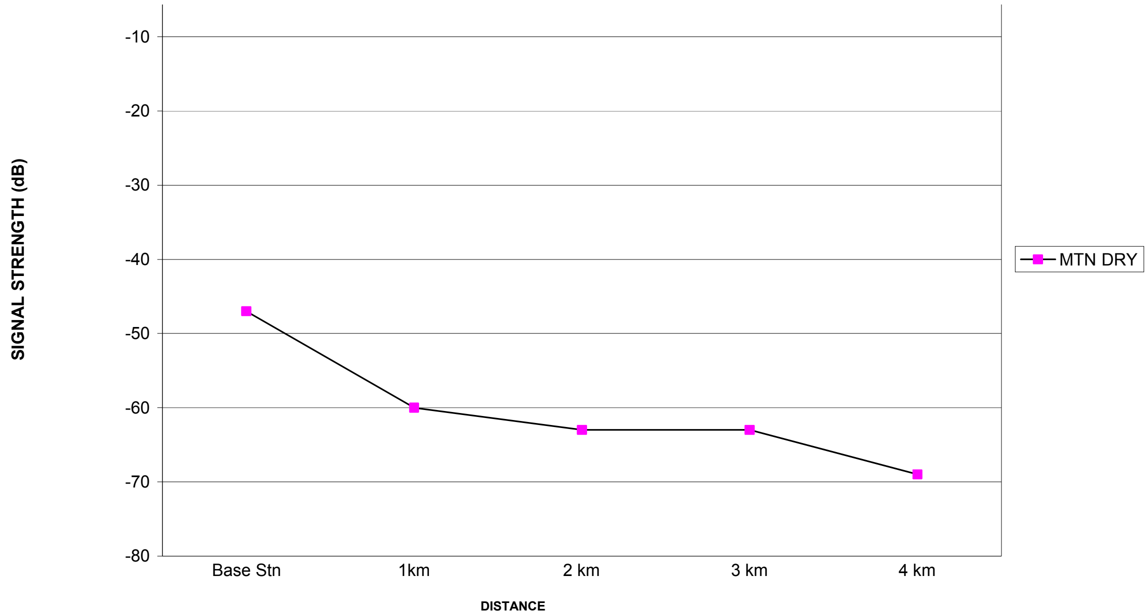

Figure C.1 Graph of Signal Strength Measurements along Kaduna Western Bye-Pass –MTN (Dry)

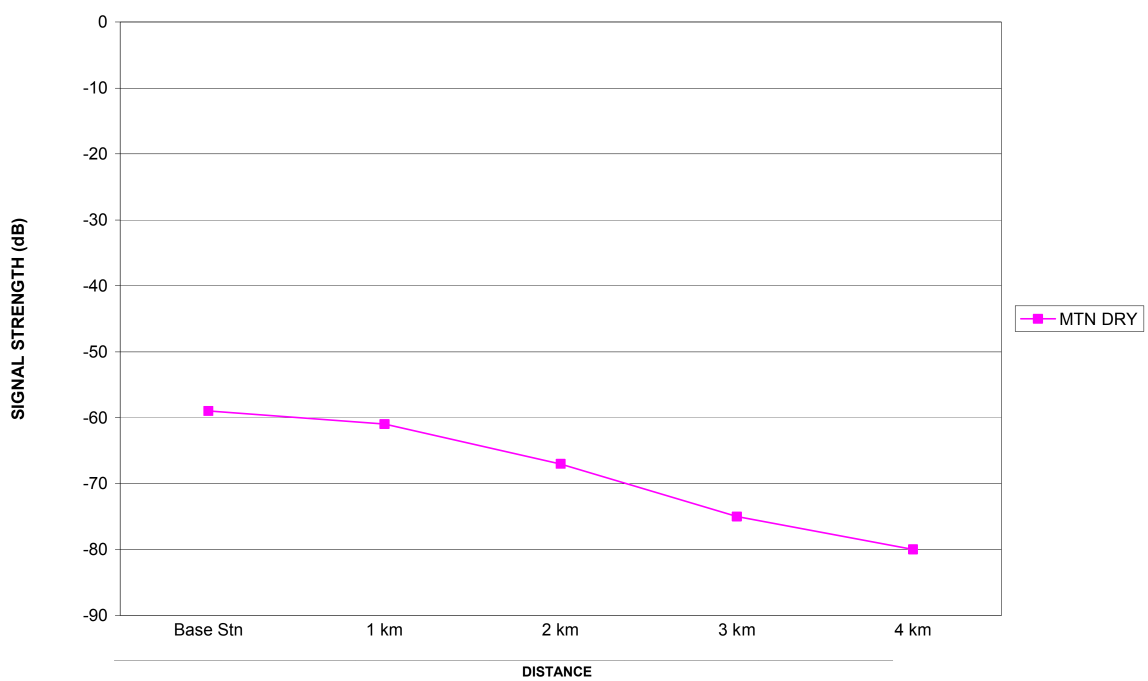

Figure C.2 Graph of Signal Strength Measurements along Zango Village –MTN (Dry)

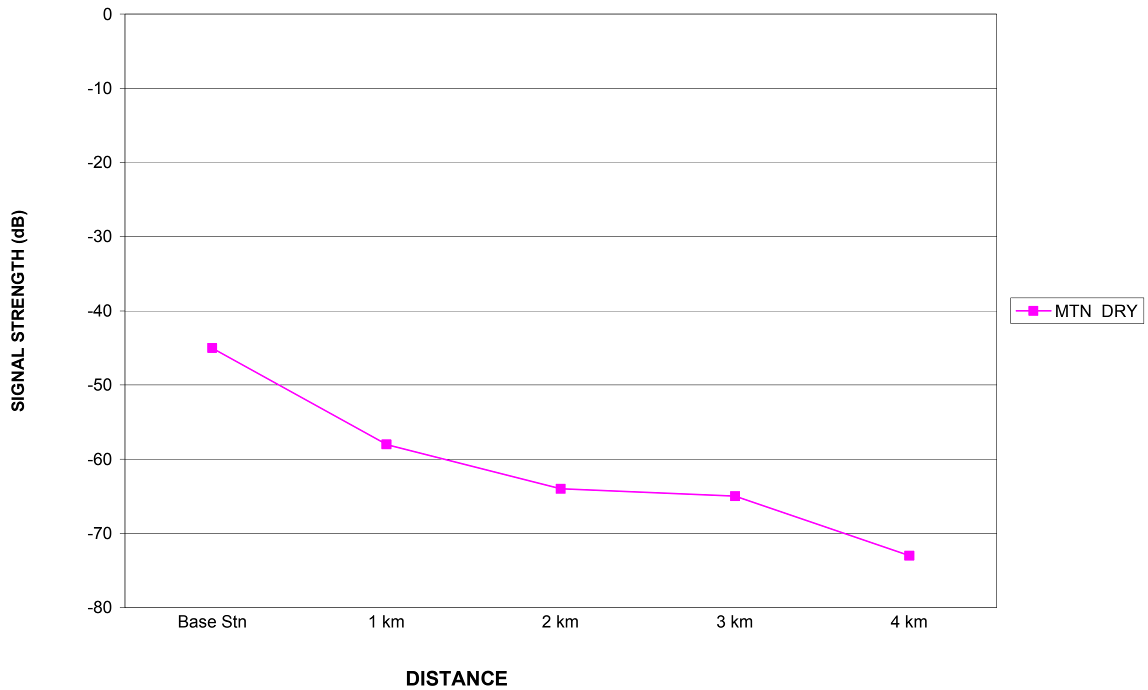

Figure C.3 Graph of Signal Strength Measurements within Rijana Village – MTN (Dry)

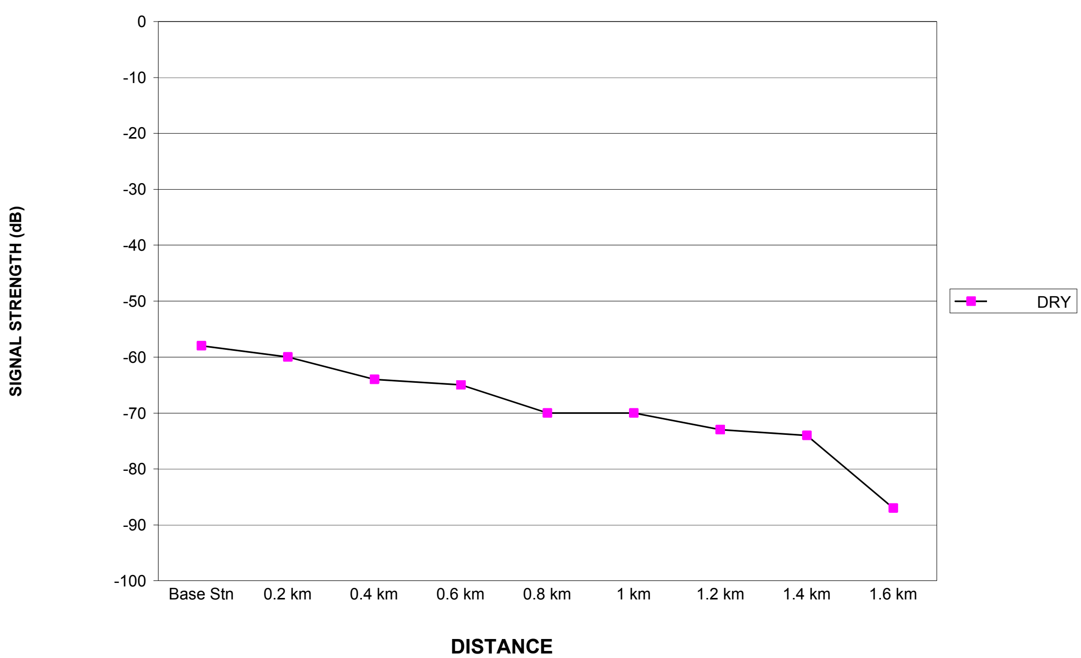

Figure C.4 Graph of Signal Strength Measurements along Ali Akilu Way Kaduna – Airtel (Dry)

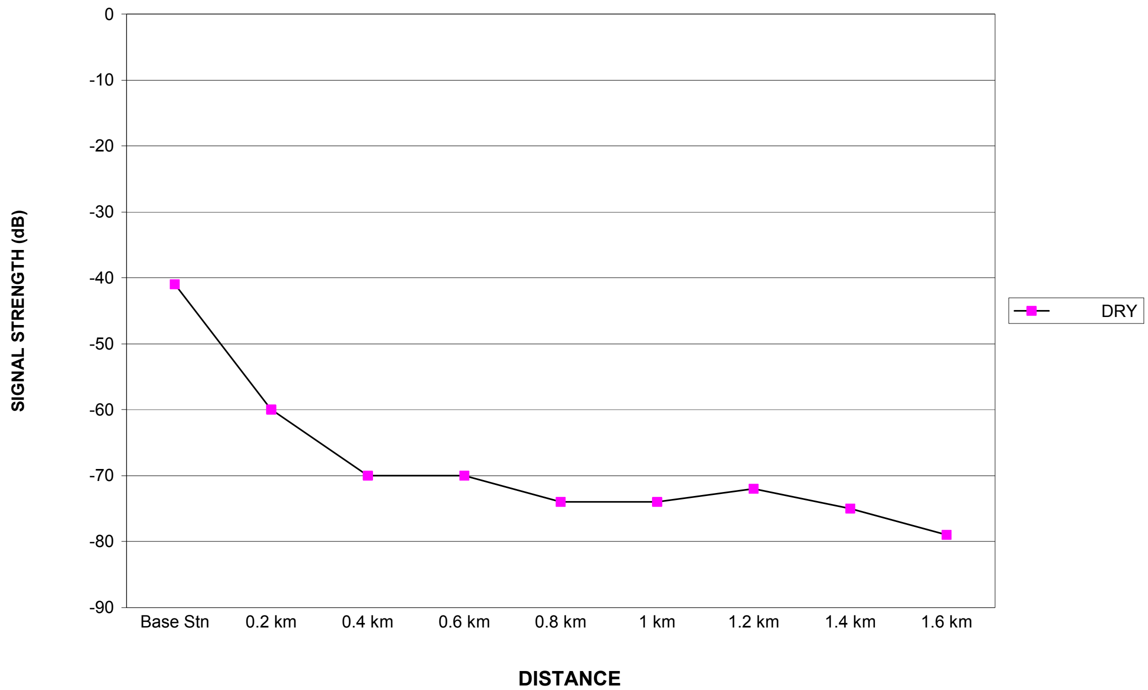

Figure C.5 Graph of Signal Strength Measurements along Independence Way Kaduna – Airtel (Dry)

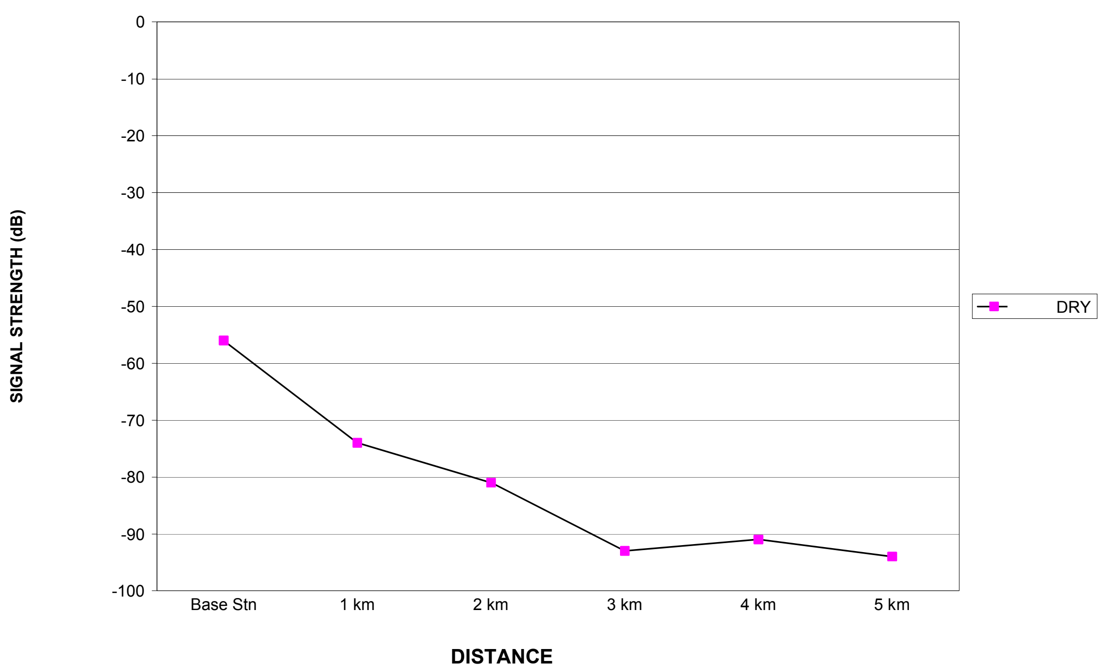

Figure C.6 Graph of Signal Strength Measurements within Zango Village – Airtel (Dry)

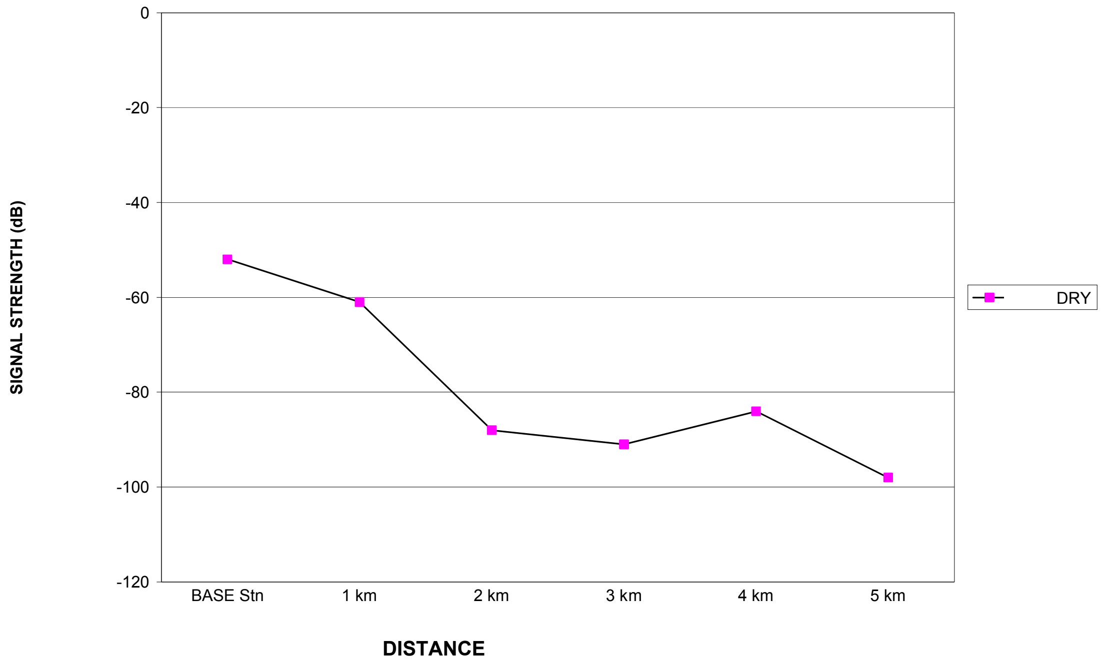

Figure C.7 Graph of Signal Strength Measurements within Kachia – Airtel (Dry)