STATISTICAL ANALYSIS OF RECEIVED POWER IN AN ANTENNA DOWN-TILT ON CELLULAR NETWORKS

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ABSTRACT: *Although cellular networks have been largely deployed by various mobile communication service providers all over the developing world, to cope with the ever increasing demand for mobile and wireless data services, poor services such as congestion, call drops and cell interference just to mention a few, have made their real impact on the populace unnoticeable. This article presents among others, analysis on how antenna down tilting can be used to improve on the performance of cellular networks. Radio Wave Propagation Models such as Hata-Okumura and COST-231 Hata Models that are important for proper cellular network planning, interference estimations, frequency assignments and cell parameters have been discussed. The effect of antenna down tilting on Received power (Received Signal Code Power) at the Mobile Station (MS), and signal- to-noise ratio (Ec/No) or signal-to-interference ratio (Ec/Io) on the network have been investigated. Data for this work was collected at some selected 3G cellular sites through drive test data-collection approach. Plots were used to stimulate the results from the studies before and after the parameter adjustments were made to prove that antenna down tilting plays significant role in cellular network performance.*

KEY WORDS*:* Cellular Networks, Radio Wave Propagation, COST-231 Hata Models, Signal-to-Interference Ratio, Antenna, Received Power and Network

1. INTRODUCTION

Wireless delivery of information and services play a crucial role to facilitate growth and prosperity. Today, it is one of the key measures to our modern day quality of life. The multiple access techniques or schemes that are employed by majority of the cellular telephony industry are: Frequency-Division Multiple Access (FDMA), Code-Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA) and Non-Orthogonal Multiple Access, (NOMA). FDMA are used in the second generation (2G) systems, CDMA in the third generation (3G) systems, OFDMA in the 4G systems and NOMA in the 5G systems. Multiple Access Scheme is a process that enables multiple users to gain access to the wireless network and use it simultaneously.

The system capacity of any cellular multiple access techniques or schemes is vulnerable to other-cell interference. Hence, in the planning process of multiple access radio network, the major aim is to plan the network in such a way that, cell interference is minimised in order to maximize network capacity. Maximization of network capacity can be realised if network topology is optimized. One important phase of the topology planning is the definition of antenna configuration and especially, antenna down tilt angle.

Antenna down-tilting is a method of effectively adjusting the vertical radiation pattern of the antenna in order to increase the amount of power radiated downwards. Antenna downtilt has two different concepts—mechanical downtilt (MDT) and electrical downtilt (EDT). Electrical downtilting is when the antenna is tilted in such a way that the radiation patterns are horizontal. In mechanical downtilt (MDT), the antenna element is physically directed towards the ground. By utilizing antenna down tilt, signal level within a cell can be improved and interference radiation towards other cells can also be effectively reduced. But, if the downtilt angle exceeds certain degree, it may lead to ''cell border areas'' coverage problems. Hence, it is important to specify the optimum downtilt angle distinctive for each site and antenna configuration. Antenna downtilting is paramount for all cellular telephony generations (2G, 3G, 4G and 5G).

The initial deployment of a cellular system is based on extensive drive tests and computer simulations. Later on, the system parameters are fine-tuned based on collected statistics and fault reports taken in the field. Unfortunately, this approach does not cope with real-time changes in traffic and propagation conditions. The efficiency of a cellular network depends on its correct configuration and adjustment of radiant systems: transmit and receive antennas. The effects of adjusting antenna height and tilt in cellular networks are well known in radio network planning and optimization. There is substantial reductions in path-loss, delay spread, transmitted power, and system interference when suitable height and antenna tilt are selected for a static system **[1].** The need for adapting antenna settings to the expected traffic distribution and cell size cannot be over emphasized.

1.1 Second Generation Mobile Network (2G)

The second generation cellular system is digital unlike the first generation which is analog. The 2G for a large extend corrected the limitations of 1G. The 2G also has advantages such as:

- ✓ Improved spectral utilization, achieved by using advanced modulation techniques.
- ✓ Lower bit rate voice coding enabled more users getting the services simultaneously.
- ✓ Reduction of overhead in signaling, paved way for capacity enhancement.
- ✓ Good source and channel coding techniques, make the signal more robust to Interference.
- ✓ New services like SMS were included.
- ✓ Improved efficiency of access and hand-off control were achieved.

The network topology of second generation cellular system is as shown in figure 1.

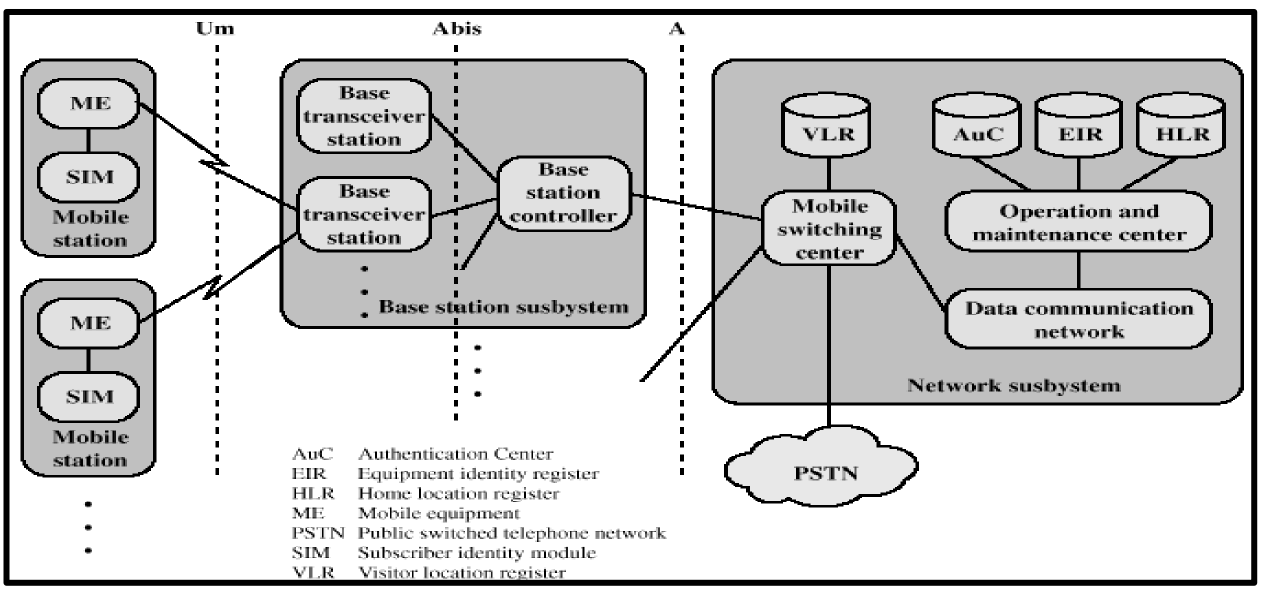

Fig 1: 2G Cellular System

It should be noted that, with 2G one has no access to the internet; to correct this disadvantage, node such as General Packet Radio Service (GPRS) was incorporated into the 2G system. With this introduction, the 2G became 2.5G. There were other add ons such as Enhanced Data Rates for Global Evolution or Enhanced Data Rate for GSM Evolution (EDGE). This add-on improved the effectiveness of internet connectivity to cellular telephony system.

1.3. Third Generation Mobile Network (3G)

The need for higher capacity, faster data rates, better Quality of Service (QoS) and solving the incompatibilities problems between GSM and CDMA are some of the basis for evolution of Third Generation Cellular System (3G). Some of the standards of 3G are based on Wideband Code Digital Multiple Access (W-CDMA) which is also called Universal Mobile Telecommunications Systems (UMTS). In 3G (UMTS) the Base Station Controller (BSS) is renamed RNS (Radio Network System), The Base Transceiver Station (BTS) is called Node B, its function is to convert data flows over the interfaces to the User Equipment (UE) and the Core Network (CN). The BSC functionality is replaced by Radio Network Controller (RNC). The function of the RNC is to route voice message to the Mobile Switching Centre (MSC) and data packet to the Serving GPRS Support Node (SGSN). The Core Network includes the same elements as in 2.5G network and support circuit services via the Mobile Switching Centre (MSC) and packet services via Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). This accession is depicted in figure 2. A 3G terminal can simultaneously receive data from multiple cells and combine them into a better signal. 3G supports different levels of service as defined by 3GPP's (Third Generation Partnership Project).

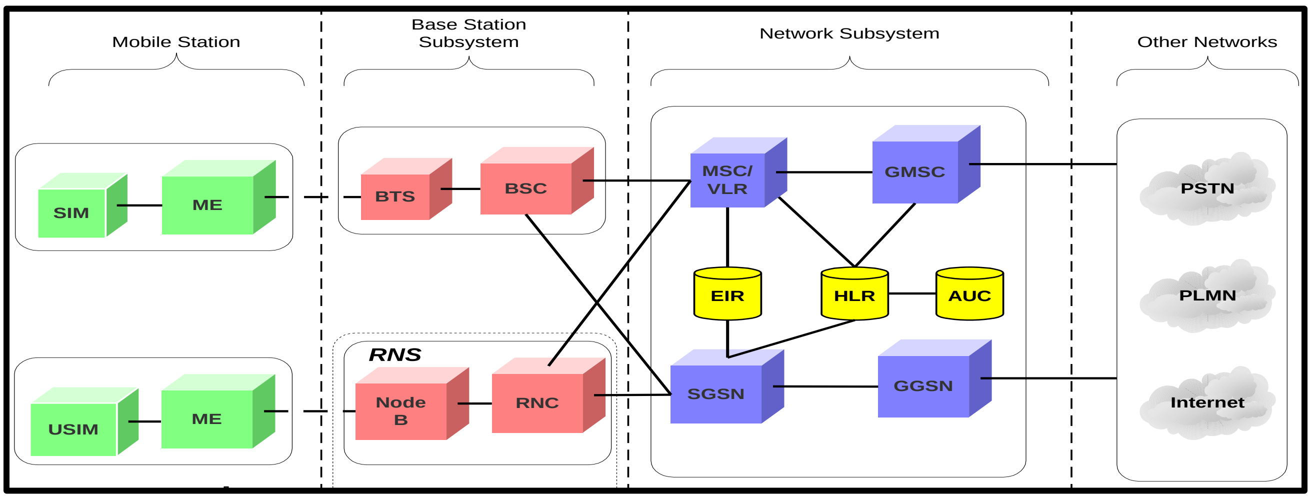

Fig 2: 2G/ 3G Architecture

1.4 Fourth Generation Mobile Network (4G)

In the quest to derive high quality of video streaming and data speed, ranging from 100Mbps to 1Gbps among others from cellular telephony, the fourth generation mobile system was borne and launched in 2009. In general, the 4G cellular network is made up of two major subsystems; these are the Radio Access Network (RAN) and the Mobile Core. The radio access network basically consist of the User Equipment (cellular phone) and the Base Station known as Evolved Node B (eNodeB or eNB). The function of RAN is to manage the radio spectrum, making sure it is used efficiently and meets the quality-of-service (QoS) requirements of every user **[2]**.The Mobile Core Network is a generic term and in 4G, it is known as Evolved Packet Core (EPC). Some of the important nodes under this core network are: Mobility Management Entity (MME), Home Subscriber Server (HSS), Policy & Charging Rules Function (PCRF), Serving Gateway (SGW) and Packet Gateway (PGW). The functionality of the mobile core network include: providing Internet protocol (IP) connectivity for both data and voice services, ensuring this connectivity fulfills the promised QoS requirements, tracking user mobility to ensure uninterrupted service and tracking subscriber usage for billing and charging **[3]**. A simple 4G network topology is depicted in figure 3.

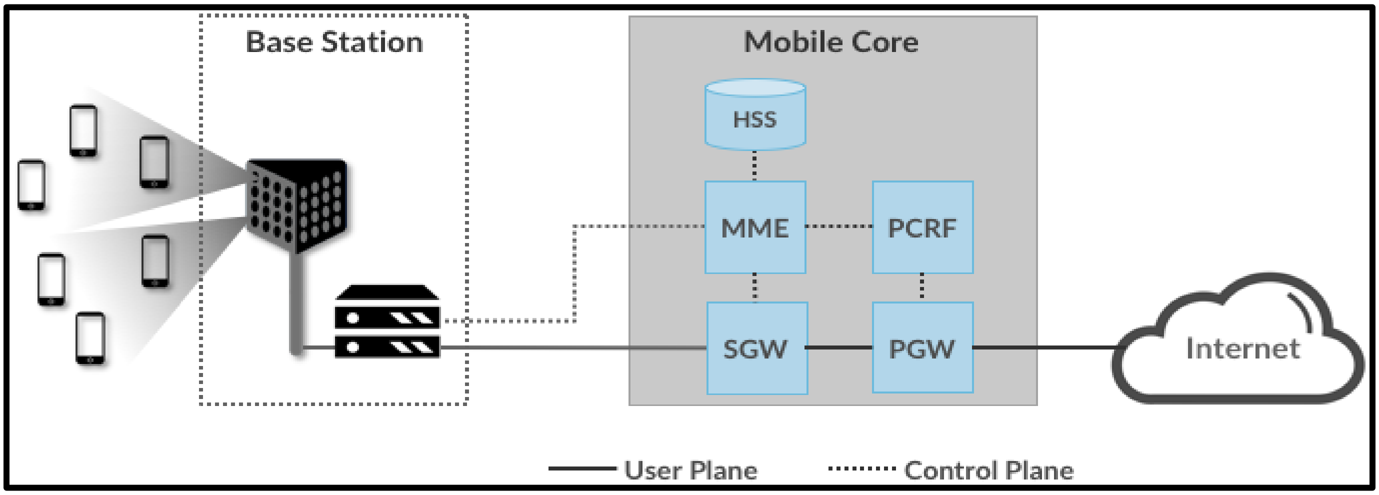

Fig 3: 4G Mobile Core Network

1.5 Fifth Generation Mobile Network (5G)

5G is the fifth generation technology standard for broadband cellular networks which cellular phone companies began deploying worldwide since 2019 **[4].** The 5G network is the planned successor to the 4G network which provide connectivity to most current cellphones. The fourth generation mobile telephony system has drawbacks such as: high battery usage and expensive equipment required to implement next generation network. The 5G networks are not limited to cellular networks only, but used as general internet service providers for laptops and desktop computers. It is also used for new applications such as internet of things (IoT) and machine to machine (M2M) communications. The 5G system architecture is mainly composed of User Equipment (UE), Next Generation Node B (gNB or gNodeB) and Evolved Packet Core (EPC). UE is the cellular device, gNB is the base station for 5G, just as eNB is the base station for 4G, NodeB the base station for 3G and BTS the base station for GSM networks (2G and 1G). Next Generation Node B (gNB) is the 5G NR (New Radio) RAN and EPC is the 5G Mobile Core (NG-Core) Network. The function of the RAN (Radio Access Network) is to provide radio access and harmonize cellular system resources through user equipment (UE). The 5G NR is the global air interface standard for 5G networks that was developped by 3GPP with operational frequency from below 1GHz to more than 40GHz **[5].** The functions of EPC network is to provide mobility management, IP connection, QoS management, and billing management to the system. It consists of AMF (Core Access and Mobility Management Function), SMF (Session Management Function), PCF (Policy Control Function), UDM (Unified Data Management), AUSF (Authentication Server Function), SDSF (Structured Data Storage Network Function), UDSF (Unstructured Data Storage Network Function), NEF (Network Exposure Function), NRF (NF Repository Function), NSSF (Network Slicing Selector Function) and UPF (User Plane Function) as depicted in figure 4.

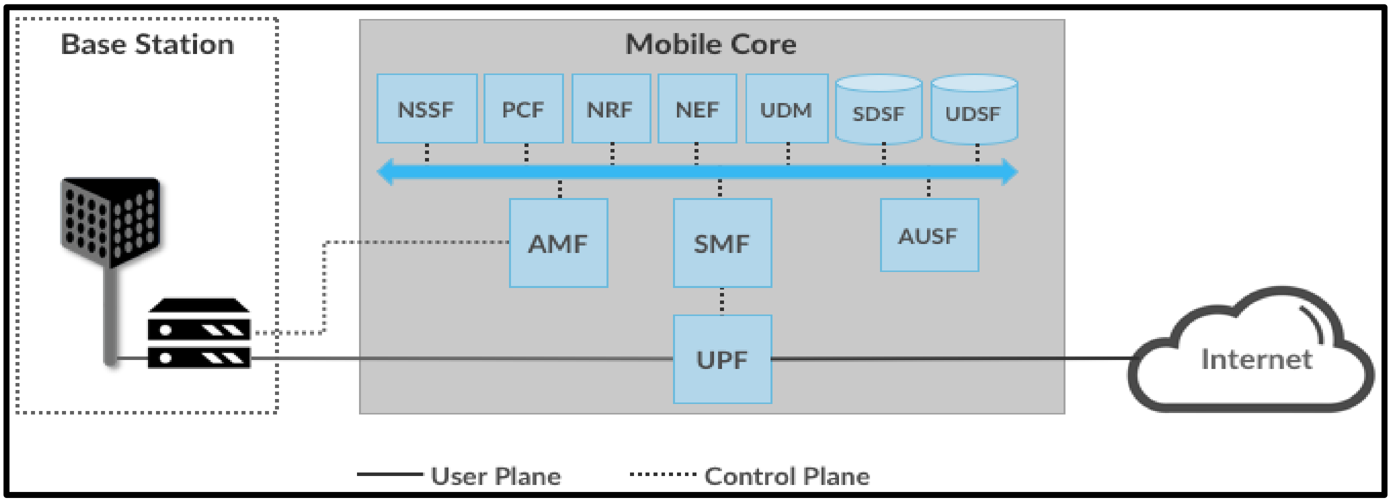

Fig 4: 5G Mobile Core Network

2 ANTENNA DOWN TILT, RECEIVED POWER and RADIO PROPAGATION MODELS

Antenna down Tilt, Received Power and Radio Propagation play paramount role in the good network performance in mobile telephony be it 1G, 2G, 3G,4G or 5G.

2.1 Antenna down Tilt

Antenna down-tilting is a powerful method for improving network performance in cellular network. Down-tilting of antenna can improve certain performance aspects, especially those related to signal quality on the network. Utilizing the correct elevation angle on each cell in a cellular network is important to ensure that the signal level is maximized within the dominance area of a cell and minimized everywhere else. Consequently, by deploying the most appropriate tilt angle, the Carrier to Interference (C/I) ratio within the dominance area of a cell is maximized, leading to optimum system performance.

However, constant network evolution due to variation of subscriber density and addition of new cells require on-going modification of the tilt angle to ensure that cell performance is constantly maximized. The optimum down-tilt angle with empirical formula of Base Station sector of macro-cell depends on the Geometrical Factor (θ_{geo}) and on Antenna Vertical Beam Width Factor (θ_{VerB}), this can also be expressed as θ_{-3dB} for either Mechanical Down-Tilting (MDT) or Electrical Down-Tilting (EDT) **[6].** Figure 5 shows Mechanical Down -Tilt.

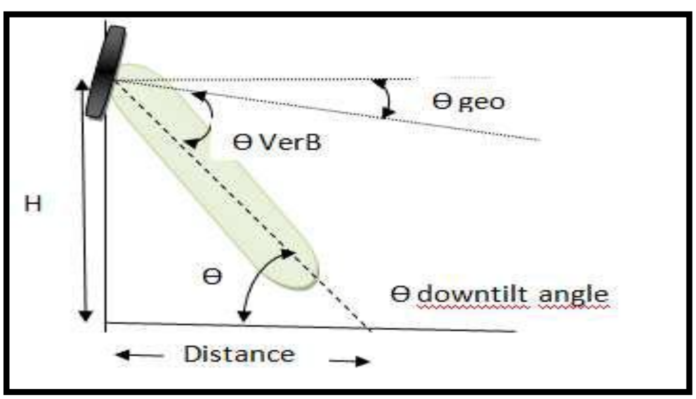

Fig. 5: Mechanical Down-Tilt

θ = Macro-Cell Down-Tilt Angle and is Related to the above Quantities

$$\theta = \theta_{-3dB} + \frac{\theta_{-3dB}}{2} \quad 2.1$$

The Geometrical factor, is calculated as

$$\theta_{geo} = arctan\frac{H-hMS}{d} \quad 2.2$$

Where:

H= Transmitter (BTS) Height

h_{MS} = Mobile Station (MS) Height

The distance between the transmitter (BTS) Height, H and the Mobile Station (MS) Height, h_{MS} is given by:

$$d = \frac{\Delta h}{tan\theta geo} \quad 2.3$$

Where:

$$\Delta h = H - h_{MS} \quad 2.4$$

Wu and Yuan (1996) method of calculating down-tilt angle as expressed in Equation 2. 1 either overestimates or underestimates the Base Station Sector down-tilt angle. From a simulation work performed using Monte Carlo approach; an empirical equation for an optimum down-tilt angle selection was derived with a standard deviation error of 0.5 corresponding to 1 to 3 degrees **[7].** This derivation is expressed in Equation 2.5.

$$\theta_{opt} = 3[In(h_{BTS} - d^{0.8}]log_{10}(\theta_{-3dB}) \quad 2.5$$

This value was found to be in the range of 3.5 degrees to 10.5 degrees.

Where:

θ_{opt} = Optimum Down-Tilt Angle

h_{BTS} = Effective Height of the Base Station (BS), m

d = Cell Radius, km

θ_{-3dB} = Antenna Half Beam Power, dB

The formula is simple and fast in computation; however it does not give information about the cell interference area.

2.2.1 Calculation of Antenna Tilt from a 3D Antenna Pattern

Antenna gain of base station for a specific user depends on antenna pattern, antenna orientation (azimuth and tilt) and user's coordinates with respect to base station. If α is the angle of Mobile Station (MS) location with respect to the minimum attenuation and β the antenna tilt angle with respect to the horizontal plane, r the distance between Mobile Station (MS) location and the Base Station (BS); if the Base Station antenna has a height of h, then the mechanical angle tilt (vertical angle tilt) of a 3D antenna pattern will be given as:

$$\boldsymbol{\varphi} = \arctan\left(\frac{\cos\alpha\sin\beta - \frac{h}{r}\cos\beta}{\cos\alpha\sin\beta + \frac{h}{r}\sin\beta}\right) \quad 2.6$$

The electrical angle tilt (horizontal angle tilt) of a 3D antenna pattern would be given as:

$$\psi = arctan\left(\frac{sin\beta}{cos\alpha cos\beta + \frac{h}{r} sin\beta}\right) \quad 2.7$$

The above formula was proposed using antenna orientation geometry method. Many Researchers have all conducted studies on antenna down-tilting **[8].** In coverage limited environments such as in rural areas, mechanical tilting is more useful where as in capacity-limited environments such as in a city centre, electrical down-tilt could provide better performance. Electrical tilt performed better than mechanical tilt in variation of the target Carrier to Noise Interference Ratio (CIR). Network performance was evaluated under different load in antenna down-tilting situation in Mobile Telecommunication Systems where Hata-Okumura model of propagation was applied **[9].** The results indicated lower CIR at distances close to Base Station (BS), due to the fact that antenna was emitting its power more to the cell boundary.

2.2 Received Power in Antenna

The Received Power (P_{rx}) at a Mobile Station (MS) from a Base Station (BS) sector depends on the Transmit Power (P_{tx}), the BS sector Antenna Gain, transmitter (G_{tx}), the handset Antenna Gain, receiver (G_{rx}), and the path loss (Lp). Using Friis transmission equations for mobile communication, the Received Power (P_{rx}), will be given for free space path loss (FSPL) as:

$$\frac{P_{rx}}{P_{tx}} = G_{rx} * G_{tx} * \text{ FSPL} \quad 2.8$$

Where:

$$\text{FSPL} = \left[\frac{4\pi d}{\lambda}\right]^2 \quad \Rightarrow \quad \frac{P_{rx}}{P_{tx}} = G_{rx} * G_{tx} * \left[\frac{4\pi d}{\lambda}\right]^2 \quad 2.9$$

$$\text{But} \quad \boldsymbol{\lambda} = \frac{\mathbf{c}}{\mathbf{f}} \quad \Rightarrow \quad \frac{P_{rx}}{P_{tx}} = G_{rx} * G_{tx} * \left[\frac{4\pi df}{c}\right]^2 \quad 2.10$$

λ= wavelength in m

c= velocity of electromagnetic waves in the free space ($3 * 10^8$ m/s)

d= Antenna Separation Distance between Transmitter and Receiver (Base Station and Mobile Station)

f= Carrier Frequency, MHz

In logarithmic form,

$$P_{rx} = P_{tx} + G_{rx} + G_{tx} + 20\log\frac{4\pi df}{c} \quad 2.11$$

Since

$$20\log\frac{4\pi df}{c} = 20\log d + 20\log f + 32.45 \quad 2.12$$

Then

$$\mathrm{P_{rx}} = \mathrm{P_{tx}} + \mathrm{G_{rx}} + \mathrm{G_{tx}} + 20\log(\mathrm{d}) + 20\log(\mathrm{f}) + 32.45 \quad 2.13$$

It should be noted that the Gain has a unit of dB while the Power has a unit of dBm or dBW. It is assumed that, the expression in equation 2.13 has antenna gain of one, which implies that the antenna is completely Omni-directional, and radiating uniformly in all directions; this is an example of a purely isotopic antenna. But, there is no such thing as a purely isotopic antenna in practice. Assuming the antenna needs down tilting since it is affected by impedance mismatch, misalignment of the antenna pointing, polarization or absorption; then, the Received Power can be determined by the expression in equation 2.14:

$$P_{rx} = P_{tx}\left[G_{tx}(\theta_{tx}\emptyset_{tx}) * G_{rx}(\theta_{rx}\emptyset_{rx})\left[\frac{\mathrm{c}}{4\pi \mathrm{df}}\right]^2 (1-|\Gamma \mathrm{tx}|^2)(1-|\Gamma \mathrm{rx}|^2)|\mathrm{atx} * \mathrm{arx}|^2 e^{-ad}\right] \quad 2.14$$

Where:

- ✓ $G_{tx}(\theta_{tx}\emptyset_{tx})$ = the gain of the Base Station transmit antenna in the direction $(\theta_{tx}, \emptyset_{tx})$ in which it sees the Mobile Station receive antenna.
- ✓ $G_{rx}(\theta_{rx}\emptyset_{rx})$ = the gain of the Mobile Station receive antenna in the direction $(\theta_{rx}, \emptyset_{rx})$ in which it sees the Base Station transmit antenna.
- ✓ Γtx and Γrx = the reflection coefficients of the BS transmit and MS receive antennas, respectively
- ✓ atx and arx = the polarization vectors of the BS transmit and MS receive antennas, respectively, taken in the appropriate directions.
- ✓ α = the absorption of the intervening medium.

In an urban settlement the mobile network would be affected by multipath and often there would be No clear line of sight, the average ratio of the received power to the transmitted power could be given by:

$$\frac{P_{rx}}{P_{tx}} \propto G_{tx} * G_{rx}\left(\frac{\mathrm{c}}{\mathrm{fd}}\right)^{\gamma} \quad 2.15$$

Where:

γ = Path Loss Exponent and ranges between 2 and 8

Now

Consider a situation whereby the mobile network is operating in an unobstructed area, the received power would be given by:

$$P_{rx} = \frac{P_{tx}G_{tx}G_{rx}\lambda^2}{(4\pi \mathrm{d})^2} \quad 2.16$$

Since

$$\lambda = \frac{\mathrm{c}}{\mathrm{f}} \quad \Rightarrow \quad P_{rx} = \frac{P_{tx}G_{tx}G_{rx}c^2}{(4\pi \mathrm{df})^2} \quad 2.17$$

The above Friis Transmission Equation shows that more power is lost at higher frequencies and hence it is said that the path loss is higher for higher frequencies.

2.2.1 Received Power of Antenna Using Circularly- Polarized Array Antenna

The electromagnetic power received by an antenna system is determined by both the antenna efficiency and its receive diversity. To increase the received power of an antenna system, several diversity types can be utilized. Received power of an antenna system can be increased by combining space diversity, polarization diversity and frequency diversity. A square Microstrip antenna on a *xy* plane has a unidirectional transmit pattern at φ direction and a directional characteristic at angle θ direction due to the existence of a ground plane **[10].** Here the Microstrip antenna was designed so that the polarization is nearly circular.

Let L, the length of the antenna therefore the resonant frequency of the antenna can be determined by:

$$f_r = \frac{1}{2L_eff\sqrt{\mu_0\varepsilon_eff}} = \frac{V_0}{2[L+\Delta L]\sqrt{\varepsilon_eff}} \quad 2.18$$

The length of the antenna can be derived as:

$$L = \frac{V_0}{2f_r\sqrt{\varepsilon_e ff}} - 2\Delta L \quad 2.19$$

The right triangles at the diagonal corners of the antenna are cut off, where the length, c of the two sides of the triangle is equal and c is calculated using:

$$c = \sqrt{\Delta S} \quad 2.20$$

ΔS = Area of the Triangle, which can be stated as:

$$\frac{\Delta S}{S} = \frac{1}{Q} \quad 2.21$$

Where:

S = Area of the Antenna Patch

Q = Quality Factor of the Antenna Patch

$$\delta eff = \frac{1}{Q} \quad 2.22$$

δeff can also be determined using:

$$\delta eff = \delta + \frac{\Delta}{h} + \frac{P_r}{2\omega_0 We} \quad 2.23$$

$$\Delta = 503\sqrt{\frac{\rho}{\mu_r f_r}} \quad 2.24$$

Where:

Δ = Skin Depth

ρ = Conductor Resistivity

f_r = Resonance Frequency

μ_r = Medium Permeability

δeff = Effective Loss Tangent

The electrical energy w_e at resonance is

$$w_e = \frac{\varepsilon_0 \varepsilon_r ab{V_0}^2}{8h} \quad 2.25$$

Where:

V_0 = Antenna Output Voltage

According to Pozar and Schaubert (1995), the Radiated or Received Power, P_r can be calculated using:

$$P_r = \frac{{V_0}^2 A\pi^2}{192R_0}\left[(1-B)\left(1-\frac{A}{15}+\frac{A^2}{420}\right)+\frac{B^2}{5}\left(2-\frac{A}{7}+\frac{A^2}{189}\right)\right] \quad 2.26$$

Where:

R_0 = Intrinsic Impedance of Free-Space

With

$$A=\left[\frac{\pi\,(a + 2\Delta a)}{\lambda o}\right]^2 \text{ and } B=\left[\frac{\pi(n+2\Delta b)}{\lambda o}\right]^2 \quad 2.27$$

Since a square antenna is used; a = b = L.

2.3 Radio Propagation Models

Radio propagation is the way radio signals are transmitted from one point to another inside the earth's atmosphere or free space. Its predictability is never 100% that is why strong probabilistic concepts come into play while transmitting signals. The mode in which propagation of radio waves or signals is adapted depends strongly on the distance between the transmitter and the receiver. These signals are predisposed or influenced by the objects in their path and the medium through which they propagate.

2.3.1 Analysis of Large-Scale Radio Propagation Models for Mobile Communications in Urban Area.

In mobile radio systems, path loss models are necessary for proper planning, interference estimations, frequency assignments and cell parameters which are the basic for network planning process as well as Location Based Service (LBS) techniques. Path loss is the reduction in power of an electromagnetic wave as it propagates through space. Large-scale propagation models are propagation models that predict the mean signal strength for an arbitrary transmitter-receiver separation distance which is useful in estimating the radio coverage area of a transmitter. Small scale propagation models or fading models characterize the rapid fluctuations of the received signal strength over very short travel distances or short time durations. It is well known phenomena that cellular radio systems operate in urban areas where there is no direct line-of-sight path between the transmitter and the receiver and where the presence of high rise buildings cause severe diffraction loss. Path loss is important in wireless communications and signal propagation, it occurs due to free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height of antennas. This path loss in wireless communications is represented by values known as path loss exponent.

2.3.2 Path Loss Exponent Value

For propagation in free space, path loss exponent is 2.

For relatively lossy environments path loss exponent is 4.

For buildings, stadiums and other indoor environments, the path loss exponent can range between 4 and 6.

For tunnel (may act as a waveguide), the path loss exponent is less than 2.

The free-space path loss is denoted by L_p (d), which is given by:

$$\bar{L}_p(dB) = -20\log_{10}\left[\frac{c/f_c}{4\pi d}\right] \quad \Rightarrow L_p(dB) = -20\log_{10}\left[\frac{c}{4\pi d f_c}\right] \quad 2.28$$

Where:

c = Velocity of Light,

f_c= Carrier Frequency

d = Distance between Transmitter and Receiver

For long-distance path loss with shadowing, the path loss is denoted by L p (d), which is expressed as:

$$Lp\,(d) \propto [\frac{d}{d0}]^n d \geq d_0 \quad 2.29$$

Equivalently,

$$L_p(d) = L_p(d_0) + 10\log_{10}\frac{d}{d_0}(d_\beta), d \geq d_0 \quad 2.30$$

Where:

n = Path Loss Component,

d_0 = Close-Tin Reference Distance (Typically 1 Km for Macrocells, 100m for Microcells),

d = Distance between Transmitter and Receiver

In cities such as Accra, Johannesburg, Lagos, Kenya, Cairo etc where the density of people is so high, an accurate path loss or path attenuation prediction model will be of great help for BTS or NodeB or eNodeB or gNodeB mapping for optimum network design. The most significant propagation models providing the foundation for cellular communication services are **[11]:**

- Hata-Okumura model
- COST 231 model
- ECC 33 model
- ✓ **Hata-Okumura Model**

Okumura model is Radio propagation model that is used for Urban Areas and for signal prediction **[12].** The frequency coverage of this model is in the range of 200 MHz to 1900 MHz and distances of 1 Km to 100 Km. It can be applicable for base station effective antenna heights (ht) ranging from 30 m to 1000 m. It is used to measure the radio signal strength in buildup areas. It is a perfect model for measuring radio propagation in cities having dense and tall structure.

The Hata model is an empirical formulation of the graphical path-loss data provided by the Okumura and is valid over roughly the same range of frequencies, 150-1500MHz. This empirical formula simplifies the calculation of path loss because it is closed form formula and it is not based on empirical curves for the different parameters. The Okumara-Hata model is the combination of both the above models.

The standard formula for empirical Path Loss (PL), dB in urban areas under the Okumara-Hata model is given by:

$$PL\ dB = A + B\log(d) \quad 2.31$$

Where:

d = Distance, Km.

A = Fixed Loss Depends on Frequency, f.

These parameters are given by empirical formula:

$$A = 69.55 + 26.16\log f - 13.82\log(h_b) - \alpha(h_m) \quad 2.32$$

$$B = 44.9 - 6.55\log(h_b) \quad 2.33$$

Where:

f = frequency measured, MHz

h_b = height of base station antenna, m.

h_m = height of mobile station antenna, m;

a (h_m) = Correlation Factor in dBm.

- ✓ **COST-231 Hata Model**

Hata model is used for frequency range of 150 MHz to 1500 MHz to predict the median path loss for the distance d from transmitter to receiver antenna up to 20 km, and transmitter antenna height is considered 30 to 200 m and receiver antenna height is 1 to 10 m. COST stands for Co-operative for Scientific and Technical Research, this research work is an European initiative that came up with the COST 231 model. It is used to extend Hata-Okumura- model for personal communication system (PCS) applications operating at 1800 to 2000 MHz. COST 231 model is also initiated as an extension of Hata model which is used to predict the path loss in the frequency range 1500 MHz to 2000 MHz. This model provides simple and easy ways to calculate the path loss even at higher frequency range (3.5 GHz) due to its simplicity and correction factors.

The standard formula to calculate path loss in urban areas under COST-231 Hata model is given by:

$$PL\ (dB) = 46.33+33.9 \log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log_{10}(h_b)] \log_{10} d \qquad 2.34$$

- ✓ **ECC-33 Model**

ECC-33 Model is extrapolated from original measurements by Okumura and modified its assumptions so that it is more closely represents a fixed wireless access (FWA) system. The ECC 33 path loss model is developed by Electronic Communication Committee (ECC). The original Okumura model does not provide any data greater than 3 GHz. Based on prior knowledge of Okumura model an extrapolated method is applied to predict the model for higher frequency greater than 3 GHz. In this model path loss is given by:

$$PL\ (dB) = Af_s + Ah_m - G_t - G_r \qquad 2.35$$

Where:

Af_s = Free Space Attenuation

Ah_m = Basic Medium Path Loss.

G_t = BS Height Gain Factor.

G_r = Received Antenna Height Gain Factor.

3 SCOPE AND OBJECTIVES

The researchers limited the work to 3G; where the cellular generation density is very high in developing countries as compare to 4G and 5G. The argument for this work was based on COST-231 Hata propagation Model where the connection frequency levels range between 900 MHz and 2100 MHz. For this work, a carrier frequency of 1800 MHz (1.8 GHz) was employed. The environment under which data was collected for the research is urban settlement; a path loss exponent of 3-3.5 underpinned the work. The distance range of the model adopted is between 1.5 to 2.5km and the base station antenna heights ranging from 30 m to 45 m. The Received Power at the Mobile Station from each Base Station (BS) sector depended on the Transmit Power, the BS sector Antenna Gain, the handset Antenna Gain and the Path Loss. The researchers used three sectorised antenna directions and antenna azimuth orientation. The best configuration for a three sectorised site would be 0^0, 120^0 and 240^0 and the worst is 90^0, 210^0 and 330^0. The objective of the research is to demonstrate how antenna down-tilting can improve network coverage area and increase the received power at the mobile station.

4 METHODOLOGY

This section of the paper discussed the optimum downtilt angle between sites of base station selected for the research. Drive testing mechanism method was used to collect data for the work.

4.1 Optimum Downtilt Angle

The optimum down tilt angle is mainly a function of the site-to-site distance, base station antenna height and the vertical beamwidth of that antenna. The optimum downtilt angle range varies between 3^0 and 6^0 for site-to-site, distances between 1.5 and 2.5 km, base station antenna heights between 30 and 34m. The optimum downtilt angle decreases as the site separation increases and increases as the antenna height increases. The change of optimum tilt angle is more sensitive to antenna height changes than to site-to-site distance modifications.

4.2 Drive Testing Mechanism or System

The measurement mechanism for the study was based on the drive testing system. Drive Testing is a method of measuring and assessing the coverage, capacity and Quality of Service (QoS) of a mobile radio network. The drive test is also a procedure adopted in cellular networks for all the available technologies (CDMA, GSM, UMTS, LTE, 5G NR etc.) which involve collecting data on a moving vehicle. It is conducted by checking coverage criteria of a cell site with Radio Frequency (RF) drive test tool. The following are the tools that were used for the drive test: Laptop with drive test software and Global Positioning System (GPS) connection capability and data cables, multi-connector port, Vehicle, Drive test Mobile Phone, GPS device, Extension board, M2000, MapInfo, Google Earth, Inverter and Probe (software uses for data analysis). The data collected by drive test tool as Log files was analyzed to evaluate various RF parameters of the network. The procedure allowed the cellular network operators (the researchers) to examine and evaluate the network coverage in particular geographical areas, put in measures to improve on it. The geographical areas adopted for the research were: Accra Newton_OT, Accra Newton_EP, Caprice_ Kpehe, and Kokomlemle cell sites. These sites are indicated in figure 6; the drive test routes. The Key Performance Indicators (KPIs) that were captured during the drive testing procedure were Received Signal Code Power, RSCP (Received Power) data in dBm, and Signal–To-Noise Ratio (E_C/N_O) or Signal-To-Interference-Ratio (Ec/Io).

Fig. 6: Drive Testing Routes

4.2 Data Collection and Processing

The measurement setup was designed to collect enough data to enable the researchers to extract the typical behaviour of the channels in a cluttered environment, such as urban, areas. The measurements were done while driving using the drive test terminal inside the vehicle. The drive test terminal fitted with the software to collect data at the various 3G sites as the vehicle was moving. Data collected was grouped by collection software and stored in an output files. The data stored in the output files was skillfully sieved and processed with the help of Microsoft office Excel Sheet and finally by the probe software (software assistant used for data analysis).

The GPS collected the data of latitude and longitude of each point as shown in table 1It was also useful as a guide for following the correct routes. Google Earth helped in tracing the routes using the easy paths or polygons. The mobile phone performed or made calls to a specific number from time to time, configured in the Collecting Software. The calls test were two types: long and short durations. The average short calls duration was 180 seconds. It only served to check whether the calls were being established and successfully completed. Long calls duration (10-15mins) served to verify if the handovers (continuity between the cells) of the network were working effectively or were dropping call, possibly caused by antenna not aligning well and needed down tilting.

Table 1: Network Parameters for the Network

3G Cell Sites	Longitude (Degree)	Latitude (Degree)	Antenna Height(m)	Azimuth(^{0})	E_(^{0})	M_(^{0})	Environment
Accra Newton_OT	-0.20719200	5.58158194	30	90/210/330	5	0	Urban
Accra Newton_EP	-0.24353512	5.59372644	32	75/140/305	6	0	Urban
Caprice_ Kpehe	-0.21118055	5.60393756	34/30/30	90/210/330	4	0	Urban
Kokomlemle	-0.21721000	5.58389000	34/31/31	70/170/305	4	1	Urban

Where:

E_ (^{0}) = Electrical Tilt Angle

M_ (^{0}) = Mechanical Tilt Angle

After the initial analysis of the drive test, it was observed that Accra Newton_EP site was functioning fairly well. Accra Newton_OT, Caprice_ Kpehe and Kokomlemle sites were having different short comings. Accra Newton_OT and Caprice_ Kpehe needed adjustment on the mechanical antenna angle. It was also detected that, their azimuths had deviated to the worst values (90°/210°/330°) and needed to be rectified. Electrical and Mechanical antenna angles downtilting were needed at Kokomlemle site.

5. PRESENTATION OF RESULTS AND DISCUSSION

The analysis after the drive test indicated that, the received power (RSCP) and signal-to-interference ratio (E_C/I_O) were good along the routes and service areas where Accra Newton_EP site, is situated. Hence, the site was functioning well and therefore there was no need for any alteration on its parameters.

The analysis also indicated good received power (RSCP) along the routes where Accra Newton_OT and Caprice_ Kpehe sites are situated. However, the two sites exhibited characteristics of overshooting resulting from bad signal-to-interference (E_C/I_O) and creating call drops problems along the catchment areas of the sites. Therefore mechanisms of antenna down-tilting and azimuth change of the affected sites were implemented in order to improve the signal situation. Accra Newton_OT and Caprice_ Kpehe sites' azimuth were changed from 90/210/330 to 70/220/310 degrees. Mechanical antenna downtilt angle from 0^0 to 3.5^0 and electrical antenna downtilt angle from 4^0 to 5^0 were effected at Caprice_ Kpehe cell site. On Accra Newton_OT cell site, 3^0 were added to the mechanical antenna down tilt angle.

Kokomlemle site exhibited call drops and congestion emanating from improper handovers the analysis revealed. To rectify the problem both mechanical and electrical antenna downtilting were carried out after antenna height shifting upward has been done. Both mechanical and electrical antennas down tilts were increased by 2^0 while the antenna height was shifted by two metres (34/31/31) upwards. These adjustments improved the received power and the overall quality of service at the catchment areas of the site. Table 2 depicted the parameters of the sites after the changes were effected.

Table 2: Parameters of Cell Sites after the Change

3G Cell Sites	Longitude (degree)	Latitude (degree)	Antenna Height(m)	Azimuth(^{0})	E_(^{0})	M_(^{0})	Environment
Accra Newton_OT	-0.20719200	5.58158194	30	70/230/300	5	3	Urban
Caprice_ Kpehe	-0.21118055	5.60393756	34/30/30	75/220/310	5	3.5	Urban
Kokomlemle	-0.21721000	5.58389000	34/31/31	70/170/305	6	3	Urban

After the changes, drive test was conducted again at the affected sites to check on the received power (RSCP) and the signal-to-interference ratio (Ec/Io) levels. It was observed that, there were vast improvement in these two KPIs. A plot of the drive testing statistical data of the received power after the adjustments of the parameters of the three cell sites is illustrated in chart 1. The received power chart clearly indicated that, the counts mainly fell within good RSCP range of above -95 dBm along the paths where the test was carried out. In simple term, the received power for the three sites were good.

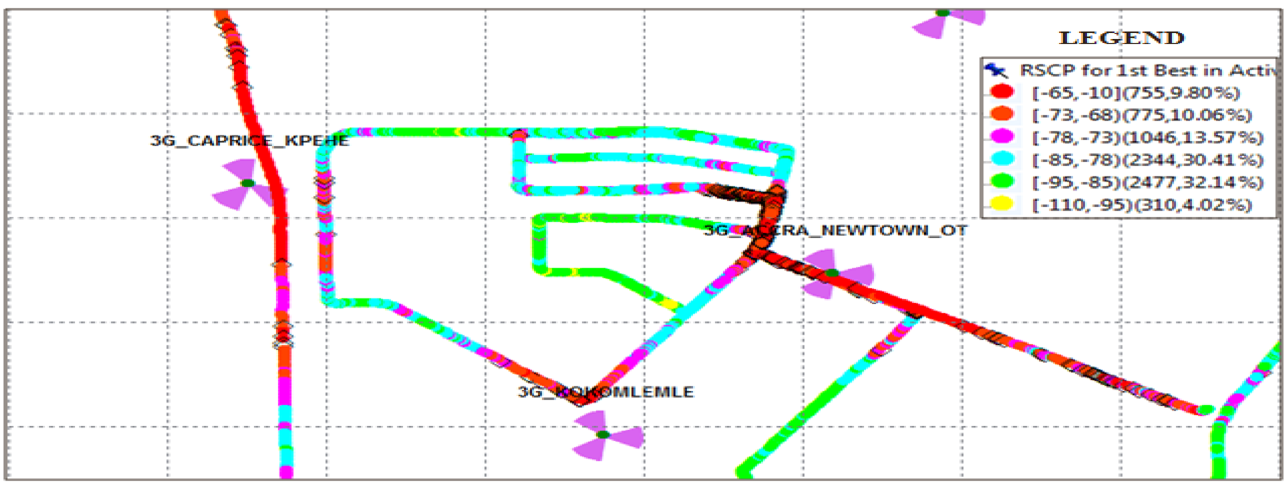

Chart. 1: A Plot of Received Power (RSCP) Statistical Data Captured After the Changes

There was significant improvement in the quality of service (enhanced coverage area and general network performance) at all the three sites. Chart 2, shows a plot of signal-to-interference ratio (Ec/No) statistical data captured after the change. It could be seen clearly that, statistical data recorded counts fell mainly within the good range of aggregate Ec/Io level (Aggregate Ec/Io level poor < -12dB). In simple term, the signal-to-interference ratio (Ec/Io) for the three sites were good.

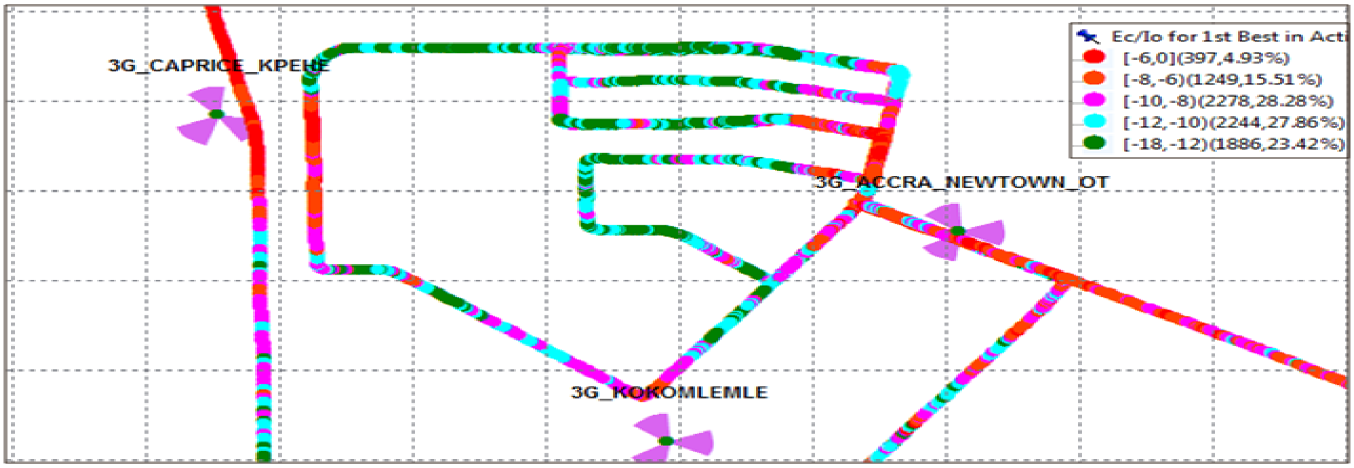

Chart 2: A Plot of Signal-To-Interference Ratio (Ec/Io) Statistical Data Captured After the Changes

6. CONCLUSION

In this research, the impact of antenna down-tilt on the performance of cellular network has been studied. Extensive drive testing measurements were performed in urban settlement environment. Antenna downtilting is very important in the life of any cellular site irrespective of the technology used (GSM, CDMA, UMTS, LTE, 5G NR etc), without it, cellular network problems such as congestion, pilot pollution, drop calls and many others would continue to plague the cellular communication industry.

After the adjustment of the parameters, the received power at the mobile station became efficient and the impact at the cell sites was excellent. The base station sites where the changes were effected had their optimum downtilt angle that culminated to having better coverage capacity. It should be well noted that the two concepts of antenna down tilting namely electrical and mechanical downtilting have been used to resolve network problems at the three sites. In down-tilting, a less co-channel interference is observed for far-end users, this contributes to highly increase system capacity but in contrast decrease the cell service radius.

This study used large volumes of real drive test data to project the behaviour of the radios. Meaningful data was extracted from this enormous drive test data to statistically analyse the received power and signal-to-interference ratio to predict the user pattern and identify coverage and capacity challenges. Every technology is underpinned by theories or models, mobile communications is no exception, COST-231 Hata model and Friis Equations findings were of relevant for this work. Although these experiments were conducted several years ago, their discoveries such as: antenna height (30 to 100 m), site radius (1 to 100 Km) and carrier frequency (900 to 2100 MHz) are still relevant to today's cellular network planning and management.

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