Available online at: http://www.ijmtst.com/vol5issue08.html

International Journal for Modern Trends in Science and Technology
ISSN: 2455-3778 :: Volume: 05, Issue No: 08, August 2019

Method for Analysis of System Coverage and Capacity for a GSM Based Cellular Network

C.A.D Pahalson[1] | N.S. Tarkaa[2] | G.A.Igwue[3]

[1, 2, 3]Department of Electrical and Electronics Engineering, University of Agriculture, Makurdi, Nigeria

To Cite this Article
C.A.D Pahalson, N.S. Tarkaa and G.A.Igwue, "Method for Analysis of System Coverage and Capacity for a GSM Based Cellular Network", *International Journal for Modern Trends in Science and Technology*, Vol. 05, Issue 08, August 2019, pp.: 74-87.

Article Info
Received on 10-July-2019, Revised on 08-August-2019, Accepted on 14-August-2019, Published on 19-August-2019.

ABSTRACT

The cellular concept is a system level idea in which a single, high power transmitter is replaced with many low power transmitters to support many users and the service area is divided into cells. Users communicate via radio links to base stations in the cells. Base stations are distributed over the coverage area of the service provider, and the same part of the available frequency spectrum can be used at multiple base stations as long as the interference situation enables communication at sufficient quality. Performance degradation in the network affects the end users who depend on their personal communicating devices which come with different features and capabilities that demand a lot from the underlying network. The key characteristics of the cellular network provide the requisite inputs used by network designers to achieve coverage, capacity and quality of service for the subscribers. This paper presents a comprehensive analysis of system coverage and capacity using network parameters and operational data collected from a GSM network from the Apapa area of Lagos State of Nigeria. The methodology employed and the results obtained are quite revealing.

KEYWORDS: *Network capacity, Frequency reuse, Path loss models, Sectorization, System coverage*

I. INTRODUCTION

Cellular networks are now entering a new phase, driven by some major evolutional trends. Mobile technologies such as Global System for Mobile Communications (GSM) have truly altered people's lifestyles and expectations all over the world. Since the advent of mobile communications, the technology has evolved independently in different countries, principally in Europe, North America and Japan. The different standards are based mainly on frequency spectrum, modulation techniques, multiple access methods, and speech compression techniques. Prominent among the different types of cellular systems that have evolved are Frequency Modulation (FM) based on the Advanced Mobile Phone Service (AMPS) of the USA; Analog/digital frequency division multiple access (FDMA); Digital narrow band Time Division Multiple Access (TDMA) that is standardized as GSM in Europe, as IS-95 system in North America and now developed as Code Division Multiple Access (CDMA) 2000IX by Qualcomm in the U.S.

Among the existing cellular networks, Global System for Mobile communications (GSM) is the most popular cellular communication system all around the world [1]. GSM is comprised of several functional entities, whose functions and interfaces are specified. These entities of the GSM network intercommunicate to give the total functions and capabilities of the GSM communications. The GSM mobile cellular network is basically designed as a combination of three major subsystems, the network subsystem (NSS), the base station system (BSS), and the operation support subsystem (OSS). The radio network is the part of the network that includes the Base Transceiver Station (BTS) and the Mobile Station (MS) and the air interface between them. As this is the part of the network that is connected to the mobile user, it assumes considerable importance. The BTS has a radio connection with the mobile, and this base station should be capable of communicating with the mobile station within a certain coverage area, and of maintaining call quality standards. The radio network should be able to offer sufficient capacity and coverage.

In mobile networks, one base station can have many cells. In general, a cell can be defined as the area covered by one sector, i.e. one antenna system. Cellular systems use a hexagonal honeycomb structure of cells which arises from the best method of covering a given area remembering that radio coverage is ideally radial in nature [2]. The circular shapes are inconvenient as they have overlapping areas of coverage but in reality, their shapes can be very distorted and usually more like jigsaw puzzle shapes. A practical network will have cells of non-geometric shapes, with some areas not having the required signal strength due to various propagation problems. Coverage in an area is dependent on the area covered by the signal. The distance traveled by the signal depends on the radio characteristics in the given area. The whole land area is divided into three major classes-urban, suburban and rural based on human-made structures and natural terrains. The cell sites that are constructed in these areas can be classified as outdoor and indoor cells. These can be further classified as macro-cells, microcells or pico-cells.

The main aim of radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The radio network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage [2]. To achieve maximum capacity while maintaining an acceptable grade of service and good speech quality is the main focus in radio network planning. Planning for a network with a limited number of subscribers is not the major problem. The difficulty is to plan for a network that allows future growth and expansion. The objectives of radio network planning [2] can be summarized as: (i) To obtain sufficient coverage over the entire service area and to ensure that high quality voice services and data services with low error rates can be offered to the subscribers, (ii) To offer the subscriber traffic network capacity with sufficiently low blocking and call dropping rate, and (iii) To enable an economical network implementation when the service is established and a controlled network expansion during the life cycle of the network.

The radio network capacity issues are addressed during the frequency allocation phase of radio network planning. At first, the teletraffic distribution within the planning region is derived based on rough estimates on the land use and the demographic structure of the area. The distribution is then stored in a traffic matrix. In the next step, a hexagonal grid representing the cells is superimposed on the entire planning region. If, for a given frequency reuse pattern and for given interference distance constraints, all the cells of the area can be supplied with the required number of channels, the algorithm proceeds to radio network analysis. Otherwise the algorithm starts all over again. In this paper, a comprehensive analysis of system coverage and capacity using network parameters and operational data collected from a GSM network from the Apapa area of Lagos State, Nigeria is presented. The methodology is based on the analysis of radio propagation path loss as well as frequency reuse and sectorization analysis. The results obtained are quite revealing.

The rest of the paper is organized as follows: Section 2 is a description of GSM network configuration. Cellular network planning is discussed in section 3. The prediction of system coverage is presented in section 4, while section 5dicusses data collection and analysis. Lastly in section 6 is the conclusion.

II. GSM NETWORK CONFIGURATION

Among the existing cellular networks, Global System for Mobile (GSM) communications is the most popular cellular communication system all around the world [1]. GSM is comprised of several functional entities, whose functions and interfaces are specified. These entities of the GSM network intercommunicate to give the total functions and capabilities of the GSM communications. GSM is a mobile cellular network basically designed as a combination of three major subsystems: the network subsystem (NSS), the base station system (BSS), and the operation support subsystem (OSS).

The functional architecture of such subsystems is illustrated in Fig. 1 [3]. In order to ensure that the network operators will have several sources of cellular infrastructure equipment, GSM decided to specify not only the air interface, but also the main interfaces that identify different parts. There are three dominant interfaces, namely, A- interface between mobile switching center (MSC) and base station controller (BSC), A-bis interface between BSC and base transceiver station (BTS) and an Um-interface (Radio link) between BTS and mobile station (MS). In GSM, the available radio frequency band is divided between different subscribers using FMDA and TDMA techniques. In practice this means that up to 8 subscribers may operate on a single physical frequency, and the 8 users using

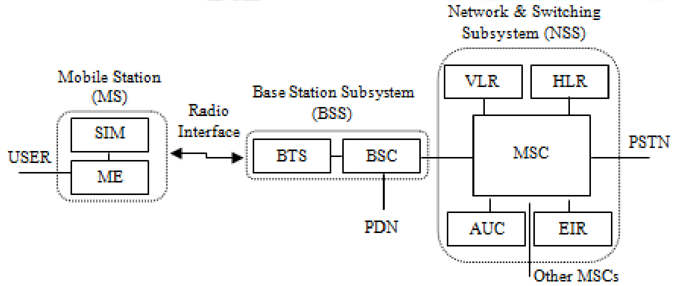

Figure 1: Cellular network subsystems

the same physical frequency are separated by allocating different time slots for each of the users. On a single physical channel, several logical channels operate in parallel in order to establish connections over the air interface.

III. CELLULAR NETWORK PLANNING

The main aim of radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The radio network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage [1]. Coverage in an area is dependent on the area covered by the signal. To achieve maximum capacity while maintaining an acceptable grade of service and good speech quality is the main focus in radio network planning.

Cells

In a mobile communication system, the mobile handset beams into a nearby radio receiver called the base station. The area around the base station is called the cell, and multiple base stations form what is known as cellular radio network structure [2].

Cellular systems use a hexagonal honeycomb structure of cells which arises from the best method of covering a given area remembering that radio coverage is ideally radial in nature. The circular shapes are inconvenient as they have overlapping areas of coverage but in reality, their shapes can be very distorted and usually more like jigsaw puzzle shapes. A practical network will have cells of non-geometric shapes, with some areas not having the required signal strength because of various propagation problems [2].

Typically, the centre of the city is the most populated area, with the suburbs gradually decreasing in population. This leads to the cells in the centre having a small diameter with a gradual increase in diameter when moving outward. Variations on the nominal plan would be necessary to account for irregular field strength contours caused by buildings and irregular terrain. So, while the hexagon is the hallmark of mobile radio technology, it is only the design starting point, and the final real-life cellular structure might bear little resemblance to multiple hexagons [2].

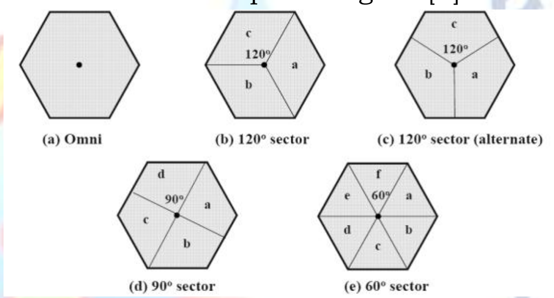

Figure 2: Sectoring of cells with directional antennas

Sectorization

Sectorization is primarily used as a technique to increase system capacity, although service coverage is generally improved at the same time as a result of the increased antenna gain associated with more directional antennas [4]. An antenna covers an area of 60 degrees or 120 degrees; these are called directional antennas each radiating within a specified sector. Different sizes of sectored cells are shown in Fig. 2 [4]. The effects of sectorization to spectrum efficiency are studied in [5]. The conclusion is that sectorization reduces cochannel interference and improves carrier-to-interference ratio (C/I) ratio of the desired link at the given cluster size. However, at the same time the trunking efficiency is decreased [2]. Due to the improved link quality, a tighter frequency reuse satisfies the performance criterion in comparison to the Omni-cellular case. Therefore, the net effect of sectorization is positive at least for large cells and high traffic densities.

Sector antennas produce beams of stronger intensity than omni-directional antennas; hence, sectoring greatly improves network coverage.

Apart from sectorization, other techniques exist that may be applied in different circumstances for enhancing system capacity. These include cell splitting, micro zoning, discontinuous transmission (DTX), intelligent underlay/overlay (IUO), and dual networks with dual-mode mobiles.

Spectrum efficiency of a cellular network

The main issues in the development of future wireless communication systems will be high data rates and mobility of terminals. A major challenge is the efficient use of available resources to achieve the QoS requirements. Hence, as traffic demands increase, the spectral efficiency of the network must also increase if the quality and availability of service is not to be degraded [6]. Some of the most often used methods to increase spectral efficiency are reusing frequencies at spatially-separated cells, use of cognitive radio and resource allocation schemes. The frequency reuse has been proposed to improve the spectral efficiency of radio systems that need to have reasonable cost and throughput services in networks growing very fast. The cell sizes, the ability of the radio links to withstand interference, and the ability of the cellular system to react to variations in traffic are the main factors that determine the spectral efficiency of a cellular system [7].

Frequency reuse

To enable the available bandwidth to be used efficiently and so increase the capacity of the system, a frequency reuse mechanism is built into the cellular structure [2]. In the diagram of Fig. 3 [8], the cells are clustered into groups of seven, each group having the same pattern of seven base station frequencies. The distance between different base stations using the same frequency is given as:

$$D = R\sqrt{3K} \quad (1)$$

or $\frac{D}{R} = Q = \sqrt{3K}$ (2)

where R = the cell radius
K= the number of cells per cluster
And Q = cochannel reuse factor

The formula determining the number of frequency reuse cells in a standard cellular configuration is obtained with propagation constant, γ = 4 based on 40dB propagation path loss.

$$\frac{C}{I} = \frac{(D/R)^4}{6} = \frac{\left(\sqrt{3K}\right)^4}{6} = \frac{3K^2}{2} \quad (3)$$

or $K = \sqrt{\frac{2}{3} C/I}$ (4)

Different clusters lead to different re-use distances. A small cluster means that the distance between the users and the interfering cells is smaller [2]. Therefore, the higher the re-use distance the higher the C/I ratio but less frequencies will be available per cell and the capacity will be smaller [2]. Another way to increase C/I ratio is by reducing the number of interferers on the network, which can be done by using sectored cells.

The number of frequency reuse cells is a function of the required C/I ratio in a hexagonal cellular radio system that uses omnidirectional antennas. As soon as the C/I ratio decreases, the signal strength start deteriorating, thereby reducing the cluster size. Equation (4) confirms that smaller frequency reuse pattern is required to enhance spectrum efficiency performance. For the hexagonal cell, the number of cells within a regular repeat pattern can be only 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, etc. Seven is the most usual choice for cellular radio systems, as a compromise between degradation due to cochannel interference and high system channel capacity [2].

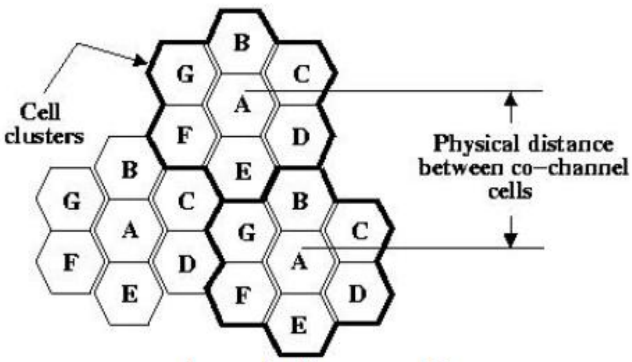

Figure 3: Ideal frequency reuse

Design specifications often require that a minimum C/I ratio, called the power protection ratio, must be achieved over a large percentage of the coverage area (90%) [9].

The mean $\frac{C}{I} = \gamma \log \sqrt{3K} - 10 \log I_o$ (5)

For the conventional cellular network systems, other tier cochannel interference are neglected, which holds because frequencies are less than

2GHz and cell size radii are 1.6 km (1mile) and above [10]. However, for emerging cellular communication system, frequencies are greater than 2GHz and cell size radii are less than 1km [11]. The C/I ratio is expressed by

$$C/I = 10\log\left[\frac{1}{I_o}\times\left(\frac{D}{R}\right)^{\gamma}\right] \quad (6)$$

Where, I_o is number of co-channel interferer (I_o = 6 in Omni directorial antenna, 2 and 1in sectoring cell (1st tier). γ is the propagation constant (γ = 4 in a cellular mobile environment), D is the frequency reuse distance which depends on many factors such as the number of co-channel cells in the vicinity of the center cell, the geography of the terrain, the antenna height, the transmitter power within each cell and R is the radius of the cell. According to [12], equation (6) may be written as:

$$C/I = 10\log\left[\frac{\left(\sqrt{3K}\right)^{\gamma}}{I_o}\right] \quad (7)$$

K = frequency reuse factor (Number of times a frequency can be reused in a network of cells).

Cellular deployments and cell size

In addition to spectral efficiency, an analysis of the capacity of an actual network across a coverage area must also include the number of cell sites. The calculation for network capacity is the capacity of each cell multiplied by the number of cells in a coverage area. The discussion above already explained that the capacity of a cell is the spectral efficiency value times the amount of spectrum used. In most cellular deployments, each base station is divided into three cell sectors. Thus, the capacity of a cellular coverage area is: (Spectral efficiency) × (amount of spectrum) × (number of cell sites) × (number of cell sectors/cell site, usually 3).

The cell size evaluation of the cellular network can be expressed as:

The traffic carried per site $= \nu \times t_o \times A$ (8)

Where ν = number of mobiles per km², t_o = traffic in Erlangs per mobile and A =area of hexagonal cell (i.e. $2.6R^2$)

Developed MATLAB codes are used to arrive at the number of mobiles per km² (V) = 916.0818 (for the Apapa Network area).

The traffic carried per cell site = 916.0818 x 0.02 x $2.6R^2$ =$47.6362536R^2$Erlangs

$$\text{Spectral Efficiency } (\eta_s) = \frac{\text{Traffic per cell} \times N_c}{B_t \times A} Erlangs/Km^2/MHz \quad (9)$$

Where;

B_t = Bandwidth of the network service

N_c = number of cell in the service (i.e. A/2.6R²) and

A = Area of service in km²

$$\text{Spectral Efficiency } (\eta_s) = \frac{\text{Traffic per cell}}{2.6R^2 \times BW} Erlangs/Km^2/MHz \quad (10)$$

$$\text{Radius (R)} = \sqrt{\frac{\text{carried traffic}}{47.6362536}} \quad (11)$$

Equation (10) gives a practical representation of the improvement in capacity achieved relative to cell sizes (and reuse distance) with available resources. If the reuse distance based on available resources per unit area becomes less, the resource utilization efficiency reduces. However, it reduces interference and improves system capacity. This is one of the significant performance indicators to compare different frequency planning schemes which certainly impacts cellular system design [13].

IV. PREDICTION OF SYSTEM COVERAGE

An accurate estimation of path loss is useful for predicting coverage areas of base stations, frequency assignment, proper determination of electric field strength interference analysis, handover optimization and power level adjustment [14]. Cellular systems information capacity changes due to propagation loss and system parameters. Therefore, for practical path loss prediction, propagation models are used. The empirical models used are: FSPL model, Hata model, COST-231 model and ECC-33 model which are applicable for GSM bands 900MHz and 1800MHz. The reason for a large part of dropped calls is due to the poor channel conditions. Path loss is a function of the frequency of operation, the distance between the transmitter and receiver, terrain of operation, and system parameters like antenna heights and antenna characteristics. GSM can be implemented of multiband antennas at 900MHz, 1800MHz and 2100MHz [15]. Multiband operation offers significant gains by bandwidth extension. According to [16], operators may consider to reuse 900MHz (occupied by the GSM networks) to enhance experience of the growing number of 3G users. The usage of 900MHz expands bandwidth available for transmission. This brings significant gains in coverage in terms of the cell edge users, who often suffer from heavy interference conditions.

Path loss models

The Hata model for urban areas, also known as the Okumura-Hata model for being a developed version of the Okumura model, is the most widely used radio frequency propagation model for predicting the behavior of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering in suburban areas and open areas. Hata model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications.

For specifications, Okumura-Hata has the following range: Carrier frequency: 150MHz ≤ f_c ≤1500MHz, Base station height: 30m ≤ h_b ≤ 200m, mobile station height: 1m ≤ h_m ≤ 10m, distance between mobile station: 1km ≤ d ≤ 20km [17].

The most important consideration in cellular network is the signal strength which can measure the power present in a received radio signal. The received signal strength level Rxd is given as:

$$Rxd = P_t + G_{tot} - P_L \tag{12}$$

For a known receiver sensitivity value, the maximum path loss can be derived as:

$$P_L = P_t + G_{tot} - Rxd \tag{13}$$

The propagation models dealing with path loss for mobile communication have been emphasized using the Okumura-Hata model best suitable for urban area propagation. Equation and supplied corrections for other types of area as stated in [17] is given as:

$$P_{Lurban}(d)[dB] = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_b - (ah_m) + [44.9 - 6.5\log_{10} h_b]\log_{10} d \tag{14}$$

Where $P_{Lurban}(d)$ $[dB]$ is the propagation path loss in urban areas, f_c is the carrier frequency in MHz, d is the distance in km, h_b is the height of base station in meters (m), and $a(h_m)$ is a correction term for the receiver antenna height (h_m) given by this formula.

For large cities:

$$a(h_m) = 8.29[\log(1.54h_m)]^2 - 1.1 \tag{15}$$

for 150MHz ≤ f ≤ 200MHz

$$a(h_m) = 3.20[\log(11.75h_m)]^2 - 4.97 \tag{16}$$

for 200MHz ≤ f ≤ 1500MHz

The correction factor, $a(h_m)$ in the basic equation differs as a function of the size of the coverage area. For small or medium sized cities (where the mobile antenna height is not more than 10 meters):

$$a(h_m) = 0.8 + (1.1\log f_c - 0.7)h_m - 1.56\log f_c \tag{17}$$

To obtain the path loss in suburban area, equation (13) is modified to:

$$Pl_{sub-urban}(d)[dB] = Pl_{urban}(d)[dB] - 2\left[\log\left(\frac{f_c}{28}\right)\right]^2 - 25.4 \tag{18}$$

And for open rural areas, it has:

$$Pl_{openrural}[d](dB) = Pl_{urban}(d)[dB] - 4.78\left[\log(f_c)^2\right] + 18.33\log f_c - 40.94 \tag{19}$$

The prediction of Hata model compares very closely with the original Okumura model as long as d exceeds 1km. This model is suitable for large cell systems, but not for personal communication systems that cover a circular area of approximately 1km in radius.

Substituting (14) into (12) and solving for distance yields the following Hata maximum distance equation:

$$d_{Hata} = \frac{\log_{10}10\{P_t + G_{tot} - R_x - 69.55 - 26.16\log_{10}(f_c + 13.82\log_{10} h_b + a(h_m)\}}{[449.9 - 6.55\log h_b]} \tag{20}$$

In Free Space Path Loss (FSPL) model, the wave is not reflected or absorbed [18]. By free Space is meant a clear and unobstructed line-of-sight transmitter-receiver. The free space propagation model predicts the received power decay as a function of the distance between the transmitter and the receiver raised to some power [19]. The generic FSPL equation is more usefully expressed logarithmically in dB [20] as:

$$P_l(dB) = 32.44 + 20\log f_c + 20\log d \tag{21}$$

Where $P_L(dB)$ is the FSPL in dB, f_C is the carrier frequency in MHz and d is the distance between transmitter and receiver in km. The FSPL can also be written as:

$$P_L(dB) = 92.44 + 20\log f_c + 20\log d \quad (22)$$

Where f_c is the frequency in GHz and d is the distance given the signal, P_L is power loss that takes place from the transmitting antenna to the receiving antenna.

The COST-231 model is also chosen because of its peculiarity which makes it useful for predicting signal strength in all environments [21] and its frequency range that extends to 2000 MHz [22] and its incorporated signal strength prediction of up to 20km from transmitter to receiver with transmitter antenna height ranging from 30m to 200m and receiver antenna height ranging from 1m to 10m [21]. Path loss in this model is given as:

$$P_{lurban}(d)[dB] = 46.33 + 33.9\log f_c - 13.82\log(h_b) - (ah_m) + [44{,}9 - 6.55\log h_b]\log d + X_m \quad (23)$$

Substituting (23) into (12) and solving for distance yields the following COST 231 maximum distance equation:

$$d_{COST-231} = \frac{\log_{10} 10\{P_t + G_{tot} - R_x - 46.33 - 39.9\log_{10}(f_c) + 13.82\log_{10} h_b + a(h_m)\} - X_m}{[44.9 - 6.55\log h_b]} \quad (24)$$

The parameter X_m is defined as 0dB for suburban environments and 3dB for urban environments. The frequency of measurement is up to the GHz frequency range.

The Path loss equation for ECC-33 Model is defined as:

$$P_l = A_{fc} + A_{bm} - G_b - G_r \quad (25)$$

Where A_{fc}, A_{bm} G_b and G_r are the free space attenuations, the basic median path loss, and the base station and mobile station height gain factors. They are individually defined as:

$$A_{fc} = 92.4 + 20\log(d) + 20\log(f) \quad (26)$$

$$A_{bm} = 20.41 + 9.83\log(d) + 7.894(f) + 9.56[\log(f)]^2 \quad (27)$$

$$G_b = \log\frac{h_b}{200}[13.958 + 5.8[\log(d)]^2] \quad (28)$$

For a medium city environment:

$$G_r = [42.57 + 13.7\log(f)][\log h_m - 0.595] \quad (29)$$

For large city environment:

$$G_r = 0.759h_m - 1.892 \quad (30)$$

Where; f =Frequency in GHz

d = Distance between base station and Mobile station in km

h_b = Base station antenna height in meters

h_m = Mobile station antenna height in meters

Table 1: Network parameters and their specifications

Type	GSM									
Area Types	High density urban									
Base Station	BTS 1	BTS 2	BTS 3	BTS 4	BTS 5	BTS 6	BTS 7	BTS 8	BTS 9	BTS 10
Operating frequency (MHz)	18,000	23,000	18,000	23,000	7200	18,000	23,000	15,000	18,000	18,000
Bandwidth (MHz)	14	14	14	14	14	14	14	14	14	14
Base station transmitter power (dBm)	16	5	18	17	17	14	18	14	18	15
Base station antenna height (m)	12	20	24	25	26	28	32	34	35	43
Mobile station antenna height (m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Transmitter antenna gain	36.0	40	32.70	14	30	32.70	34	42.70	39.20	39.2

(dBi)										
Rx Threshold level (dBm)	-69	-74	-74	-74	-69	-74	-74	-75	-74.00	-74
Free Space path loss (dB)	124.36	120.24	118.36	122.19	119.76	117.72	122.44	129.24	131.51	128.58
Net Path loss (Median)(dB)	53.23	42.44	55.02	56.45	54.76	53	56.70	52.07	55.38	52.38
R_X signal (dBm)	-37.23	-37.44	-57.20	-39.45	-37.24	-39.38	-38.70	-38.07	-37.38	-37.38
Effective Isotropic Radiated Power (EIRP) dBm	52.10	44.50	50.20	50.50	47.10	46.20	51.50	56.20	56.70	53.70

V. DATA COLLECTION AND ANALYSIS

From the foregoing, it is obvious that system coverage and capacity are interconnected and can both be evaluated from the principles of path loss, frequency reuse and sectorization. Thus MATLAB codes were developed and relevant data from Table 1 were used as simulation inputs for the path loss models. Likewise, statistical and demographic data from the MTN Apapa network area were used to estimate sector capacity related parameters. The result of the analysis is presented in Tables 2-9. Tables 2 to 5 show the results of the analysis of the radio propagation path loss models while Tables 6 to 9 are the results obtained from the frequency reuse and sectorization analysis.

Table 2: Effects of varying base station antenna height on path loss

		Path Loss (dB)			
Base Station	Base Antenna Height (m)	FSPL Propagation Model	Hata Propagation Model	COST-231 Propagation Model	ECC-33 Propagation Model
BTS1	12	124.36	123.2282	206.1943	257.7274
BTS2	20	120.24	132.4382	213.045	251.2994
BTS3	24	118.36	138.5982	217.6491	248.3896
BTS4	25	122.19	84.4482	162.5119	260.9916
BTS5	26	119.93	115.2382	193.606	250.4627
BTS6	28	117.72	109.7782	186.8748	254.2135
BTS7	32	122.44	124.6982	201.294	254.4088
BTS8	34	129.24	137.4682	214.20217	259.6793
BTS9	35	131.52	133.7782	208.9705	274.8904
BTS10	43	128.58	132.7782	209.2402	239.8643

Table 3: Various distances for FSPL, Hata, COST-231 and ECC-33 model for different base stations

	Distance (km)			
Base Station	FSPL Propagation Model	Hata Propagation Model	COST-231 Propagation Model	ECC-33 Propagation Model
BTS1	2.1914	0.0742	0.0072	0.00219
BTS2	1.3637	0.1455	0.0129	0.00136
BTS3	1.0983	0.2255	0.0193	0.00136
BTS4	1.33359	0.0058	0.0005	0.00110
BTS5	1.2904	0.0509	0.0043	0.00134
BTS6	0.7985	0.0301	0.0023	0.00129
BTS7	1.7568	0.0979	0.0079	0.00080
BTS8	4.6122	0.2641	0.0227	0.00176
BTS9	3.9064	0.1513	0.0109	0.00461
BTS10	8.9057	0.3617	0.0398	0.00391

Table 4: Effect on received signal strength by varying base station antenna height

Base Station	Base Antenna Height (m)	Received Signal Strength (dBm) FSPL Propagation Model	Hata Propagation Model	COST-231 Propagation Model	ECC-33 Propagation Model
BTS1	12	-72.26	-71.1282	-156.094	-205.627
BTS2	20	-75.74	-87.9382	-168.545	-206.799
BTS3	24	-68.16	-88.3982	-167.449	-198.19
BTS4	25	-71.69	-33.9482	-112.012	-210.492
BTS5	26	-72.66	-68.1382	-146.506	-203.363
BTS6	28	-71.52	-63.5782	-142.675	-208.013
BTS7	32	-70.94	-73.1982	-149.794	-202.909
BTS8	34	-73.04	-81.2682	-157.822	-203.479
BTS9	35	-74.81	-77.0782	-152.271	-218.19
BTS10	43	-74.88	-79.0782	-155.54	-186.164

Table 5: Effects of varying transmitted power on received signal strength

Base Station	Base Transmitted Power (dBm)	Received Signal Strength (dBm) FSPL Propagation Model	Hata Propagation Model	COST-231 Propagation Model	ECC-33 Propagation Model
BTS1	5	-108.36	-107.228	-192.194	-241.727
BTS2	14	-95.24	-107.438	-188.045	-226.299
BTS3	14	-106.96	-127.198	-206.249	-236.99
BTS4	15	-147,19	-109,448	-187.512	-285.992
BTS5	16	-111.76	-107.238	-185.606	-242.463
BTS6	17	-117.32	-109.378	-182.475	-253.813
BTS7	17	-106.44	-108.698	-185.294	-238.409
BTS8	18	-99.84	-108.068	-184.622	-230.279
BTS9	18	-105.11	-107.378	-182.579	-248.49
BTS10	18	-103.18	-107,378	-183.84	-214.464

Table 6: Performance evaluation of frequency reuse factors for omni cell

Frequency Reuse Factor (FRF)	Total Number of channels	Channel Per cell (spectrum efficiency)	Traffic (1%GoS) Erlang	Traffic (2% GoS) Erlang	Traffic (3% GoS) Erlang	Trunking Efficiency (2% GoS)	C/I (dB)
1	70	70	56.113	59.130	61.292	83	1.8
3	70	23	14.479	15.766	16.679	67	11.4
4	70	18	10.450	11.491	12.245	63	13.8
7	70	10	4.462	5.084	5.529	50	18.7
9	70	8	3.129	3.627	3.987	44	20.8
12	70	6	1.913	2.277	2.544	37	23.3

Table 7: Performance evaluation of frequency reuse factors for sectoring cell

Frequency Reuse Factor (FRF)	No of sectors	Number of Channels	Channel per cell	Traffic (1% GOS) Erlang	Traffic (2% GOS) Erlang	Traffic (3% GoS) Erlang	Trunking efficiency (1% GOS)	Trunking efficiency (2% GOS)	Trunking efficiency (3% GOS)	C/I (dB)
1	3	70	23	14.5	15.8	16.7	62	67	71	6.53
	4	70	18	10.5	11.5	12	57	63	65	
	6	70	12	5.9	6.6	7	48	54	57	
3	3	70	8	3	3.6	4	37	44	49	16.07
	4	70	6	1.9	2.3	2.5	31	38	41	
	6	70	4	0.9	1.1	1.3	22	27	32	
4	3	70	6	1.9	2.3	2.5	31	38	41	18.57
	4	70	4	0.9	1.1	1.3	22	27	32	
	6	70	3	0.5	0.6	0-7	16	20	23	

7	3	70	3	0.5	0.6	0.7	16	20	23	23.43
	4	70	3	0.5	0.6	0.7	16	20	23	
	6	70	2	0.2	0.2	0.3	10	10	15	
9	3	70	3	0.5	0.6	0.7	16	20	23	25.62
	4	70	2	0.2	0.2	0.3	10	10	15	
	6	70	1	0.0	0.0	0.0	0	0	0	

Table 8: Omni directional versus sectorized cellular system performance

System	FRF	Total number of channels	Channels per sectors	Offered load/cell (E)	Carried load/cell (E)	Trunking Efficiency GoS	Calls/hour/ cell(cell capacity)	Required cell radius R(km)	Spectral efficiency E/km²/ MHz	C/I in dB
Omni	1	70	70	59.1	57.9	83	1738	1.1029	1.3087	1.8
	3	70	23	15.8	15.5	67	464	0.5695	1.3087	11.3
	4	70	18	11.5	11.3	63	338	0.4862	1.3087	13.8
	7	70	10	5.1	5	50	149	0.3234	1,3087	18.7
	12	70	6	2.3	2.2	37	67	0.2164	1.3087	23.3
120^o	4	70	6	6.8	6.7	112	201	0.3749	1.3087	18.6
sector	7	70	3	1.8	1.8	60	53	0.1928	1.3087	23.4
	12	70	2	0.7	0.7	35	20	0.0117	1.3087	28.1
60^o	3	70	4	6.6	6.4	160	193	0.3671	1.3087	19.1
sector	4	70	3	3.6	3.5	117	106	0.2728	1.3087	21.6
	7	70	2	1.3	1.3	65	39	0.1659	1.3087	26.4

Table 9: Simulation results for re-use factor (Q), carrier to interference ratio (C/I), cluster size (*K*), and spectrum efficiency for omni and sectors cell

System	Cluster Size (K)	Carrier to interference ratio(C/I) dB	Re-Use Factor (Q)	Channel Bandwidth (KHz)	Spectrum Efficiency Channels/MHz/Km²
Omni	1	1.8	1.73	200	63.900
	3	11.3	3	200	25.504
	4	13.8	3.46	200	23. 078
	7	18.7	4.56	200	19.825
	12	23.3	6	200	17.761
120^0	4	18.6	3.46	200	19.893
sectors	7	23.4	4.56	200	17.723
	12	28.1	6	200	16.173
60^0sectors	3	19.1	3	200	19.617
	4	21.6	3.46	200	18.447
	7	26.4	4.50	200	16.686
	12	31.1	6	200	15.373

Table 10: Trunking efficiency of 10 base stations

Base Station	Number of Channels	Call attempts based on (BHT)	Calls Completed Based on (BHT)	Call Blocking Probability (%) (C-D)/C	Call completion rate (CCR) D/C	Offered Traffic in Erlang	Carried traffic in Erlang FxG	No of Dropped Call C – D	Trunking Efficiency (Utilization rate, %) H/B
A	B	C	D	E	F	G	H	I	J
BTS1	238	7800	7796	0.05	0.999	223.17	223.06	4	93.72
BTS2	400	11104	10298	7.26	0.927	367.05	340.40	806	85.10
BTS3	58	5016	4936	1.59	0.98	47.37	46.62	80	80.38
BTS4	400	11871	11647	1.89	0.98	372.62	365.59	224	91.40
BTS5	25	2830	2799	1.10	0.989	17.29	17.10	31	68.40
BTS6	19	2124	2094	0.94	0.991	11.80	11.69	20	61.53
BTS7	13	928	922	0.65	0.994	7.22	7.17	6	55.15
BTS8	42	1123	998	11.13	0.889	32.13	28.55	125	60.74
BTS9	4	195	193	1.03	0.99	0.81	0.80	2	20
BTS10	19	370	362	2.16	0.978	11.72	14.47	8	76.16

The result of the simulation as depicted in Fig. 4 reveals that the best performance of the network occurs at the base station antenna height 25m with the lowest path loss for COST-231 and Hata propagation models. However, FSPL model is the best performing model for all the base stations. Thus FSPL is the most suitable recommended for the Apapa network area. This is further confirmed by the plot in Fig. 5 where FSPL and Hata present the best performance for the network with FSPL being the overall best. However, it can be deduced from Figs. 4 and 5 that the path loss and received signal strength performance of the network remain appreciably fine at all antenna heights. The simulation results confirm that FSPL and Hata are the most ideal for future planning and optimization of the Apapa Area network. Fig. 6 shows the variation of the base station antenna height with cell radius as simulated in MATLAB. The plot shows that for the antenna height from 12m up to 28m, the cell radius is approximately constant dropping from a value of slightly above 2 km to about 1.5 km. While for all other models not visible on the graph, it implies they are not relevant for determination of the cell radius in this study. Beyond the base station antenna height of 28m, the cell radius increases rapidly and peaks at a value of 9 km at a base station height of 43m. This implies that to achieve a wider coverage area, the antenna is required to be sufficiently high. Further analysis of coverage considering only the influence of the propagation models was carried out and the result was as depicted in Fig. 7. From the graph, it is observed that the path loss remains approximately constant for all changes in the values of cell radius up to 9 km on average for the FSPL model. However, it can be noticed that as from the value of 4 km and above, the path loss increases slightly and remains constant for the rest of the values. Therefore, it is not advisable in an urban area like Apapa to use cell radii of above 4 km. It is also shown that all other propagation models are not relevant for the study of path loss and cell radius.

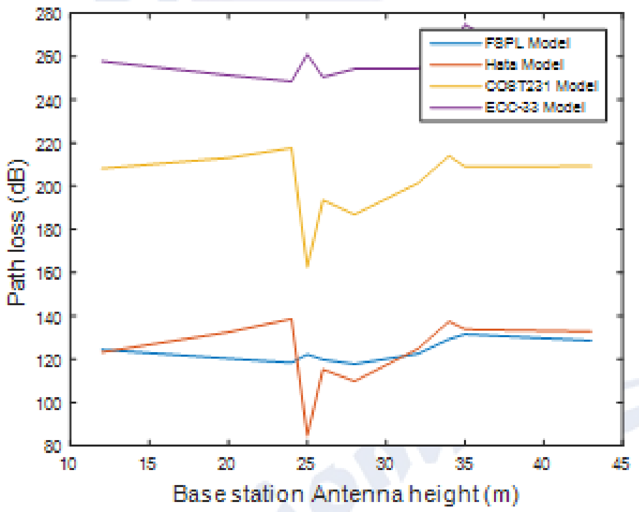

Figure 4: Variation of base station antenna height with path loss for the various empirical propagation models

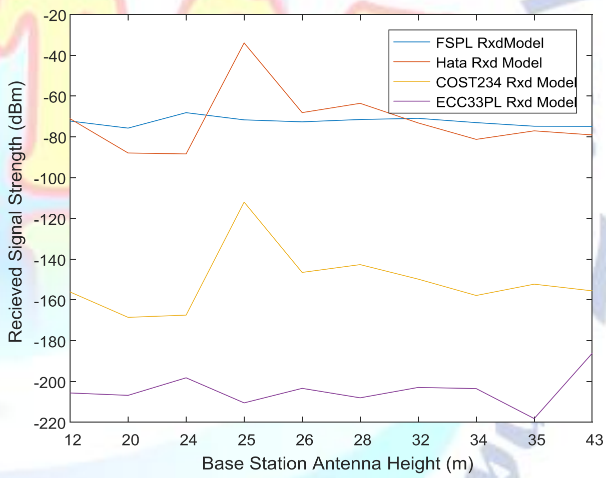

Figure 5: Plot showing base station antenna height with received signal strength for various empirical propagation models

Fig. 8 gives the variation of output power of base station with received signal strength as simulated in MATLAB. It shows that for the FSPL and Hata models, the received signal strength approaches -100dBm which gives an indication of a good signal.

Tables 6, 7 and 8 as well as the graph of Fig. 9 gives a clear analysis of the comparison between the effects of interfering signals on the mobile users in wireless network with sectoring. It can therefore be inferred that sectoring reduces co-channel interference which enhances the capacity of the cellular wireless system. It is also observed that for the same values of cluster size (K), 120° and 60° sectored cells give better carrier-to-interference ratio than non-sectored (omnidirectional, 360°) cells - the performance of improvement of the 60° sectored provides better coverage performance than 120° sectored and Omni. Considering the Apapa area network which uses 120° sectoring and 3 and 4 as cluster sizes, it can be inferred that the network is performing fairly well, though not optimally as it should at 60°. However, it is not recommended to use omnidirectional cells in the area because of the high interference that would be encountered.

It can be inferred from Fig. 10 that the cluster size and co-chemical reuse factor constitute some of the factors for a more efficient cellular network system which translates to a proportional increase in the number of users supported at the same load per user. It can be seen that co-channel reuse factor varies proportionally with cluster size while at the same time it is inversely proportional to spectrum efficiency. The point of intersection at the two curves thus provides the point of normal performance. However, MTN uses 3 and 4 as the co-channel factors throughout its Apapa network. It can be seen that the normal operating point occurs at 3.4 which implies the network has not had any significant degradation from its original plan.

In the case of MTN network in Apapa, the trunking efficiency performance is presented in Table 10 and plotted in Fig. 11. It can be seen that the best performing base stations are 7 and 9 having the lowest trunking efficiency. Base transceiver stations 2, 4, 1, 8 and 3 followed by 10, 5 and 6 trunking efficiencies are above 60% benchmark stated by NCC. Thus appropriate optimization measures are required to increase capacity.

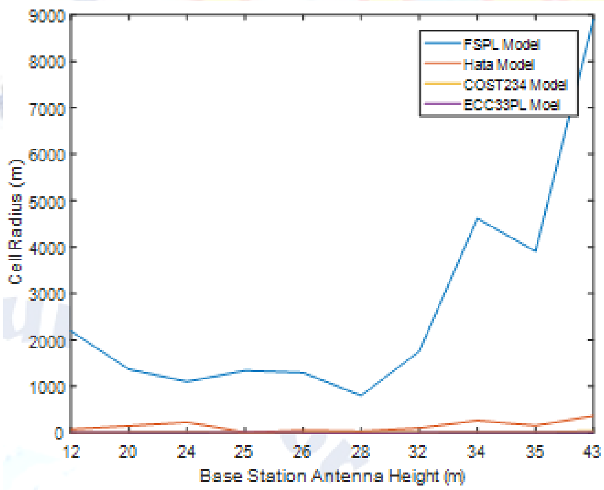

Figure 6: Variation of base station antenna height with cell radius

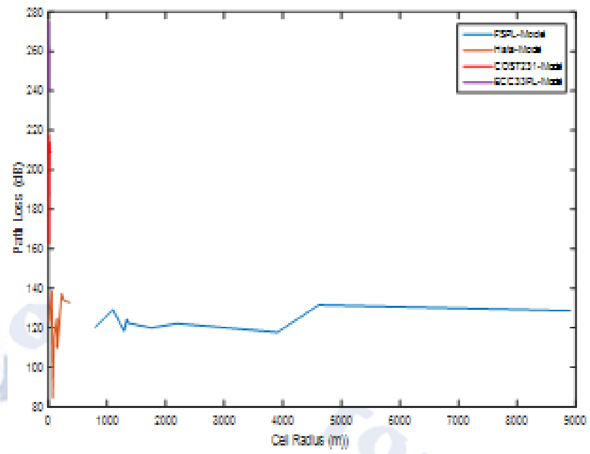

Figure 7: Variation of path loss with cell radius in an urban environment at varied frequencies

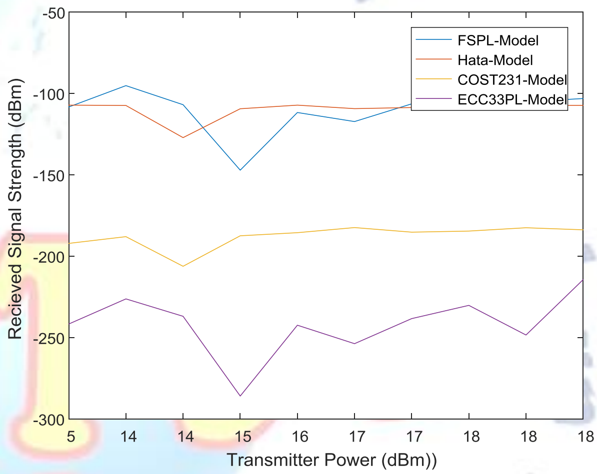

Figure 8: Coverage prediction plot showing the impact of transmitted power on received signal strength for urban area

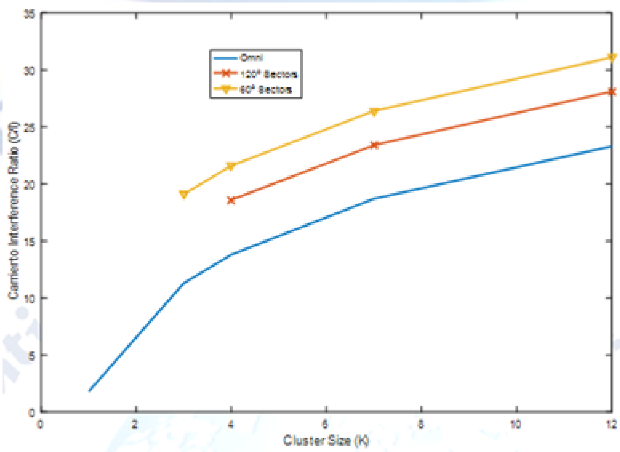

Figure 9: Variation of cluster size (K) with carrier to interference

ratio (C/I) for omni, 120^0 sectors and 60^0sectors

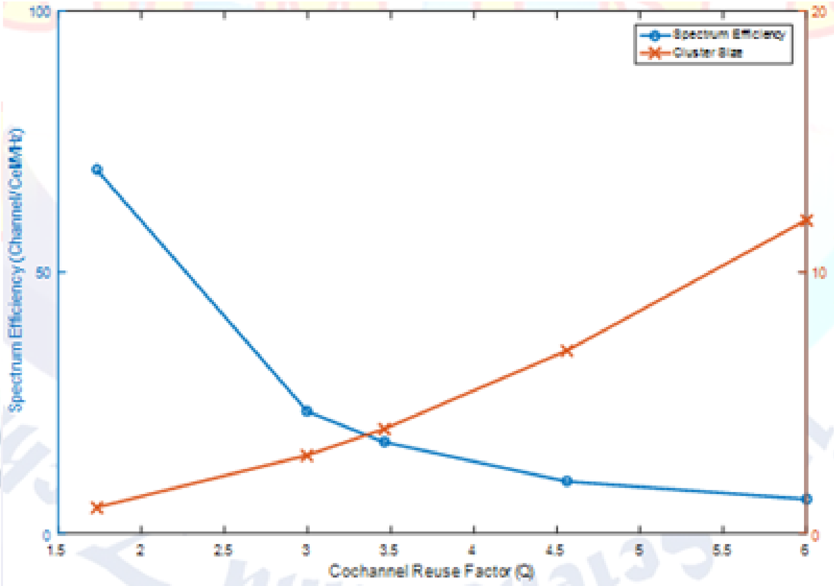

Figure 10: Shows plots for the cluster size and co-channel reuse factor and for spectrum efficiency versus co-channel reuse factor

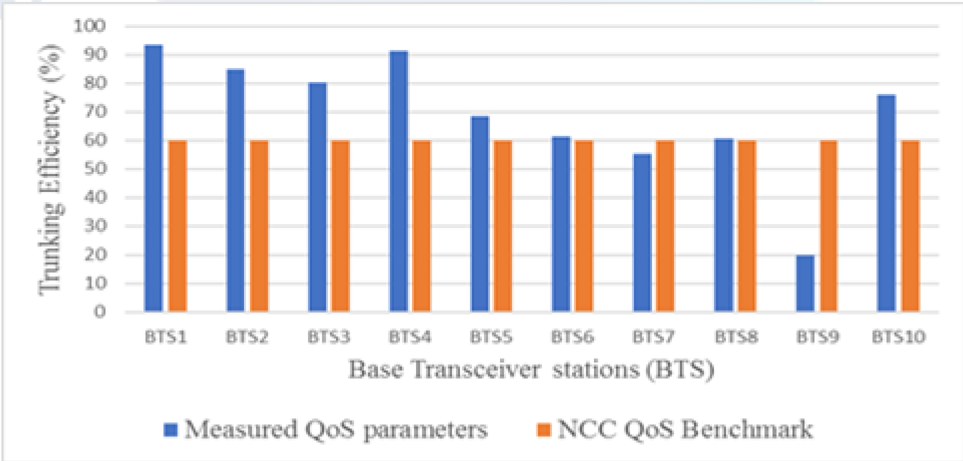

Figure 11: Comparison of NCC QoS benchmark and estimated trunking efficiency

VI. CONCLUSION

In this paper, a comprehensive analysis of system coverage and capacity using network parameters and operational data collected from a GSM network from the Apapa area of Lagos State in Nigeria is presented. The methodology is based on the analysis of radio propagation path loss as well as frequency reuse and sectorization analysis. The aim of this analysis is to determine the most suitable propagation model for providing sufficient coverage for the Apapa area. Furthermore, the frequency reuse and sectorization analysis is meant to provide a means of investigating the present state of the network with regard to capacity after many years of operation in a built up area with high population. The results obtained from the analysis show that the aims were achieved. The results revealed that the FSPL is the most suitable path loss model for the Apapa area. Also it was inferred from the results that the network has not experienced any significant degradation from its original plan. However, it was possible to discover the base stations that will require optimization. In addition, the inefficiency of the 120^o sectoring that is presently being implemented in the area was laid bare from the analysis and thus it was recommended to use a mixture of 60^o and 120^o. On the whole, the method of the analysis proved successful and may be applied for other similar networks too.

REFERENCES

[1] T.S. Rappaport, *Wireless communications Principles and Practice* (Prentice hall, USA, 2001).

[2] Nathaniel S. Tarkaa, Victor A. Agbo, Samuel O. Oglegba, Radio propagation path-loss analysis for an operative GSM

network, *The International Journal of Engineering and Science, 6(9),* 2017, 53-67.

[3] Robert G. Winch, *Telecommunication transmission systems* (McGraw-Hill, 1998).

[4] A. Pauraj, H. Seki and O.W. Ata, Capacity enhancement in quad-sector cell architecture with interleaved channel and polarization assignments, *IEEE International Conference on Communication (ICC),* Helsinki, Finland, 2001, 2317-2321.

[5] G.K. Chang, Effect of sectorization on the spectrum efficiency of cellular radio systems, *IEEE Transactions on Vehicular Technology*, 1992, 217-225.

[6] C.F. Ball, and H.K. Ivanov, Spectrum efficiency evaluation for different wireless technologies based on traffic modelling, *Proc. IEEE International Symposium on Personal Indoor, Any Mobile Radio Communication Workshops*, 2005, 2055-2061.

[7] K. Murota, Spectrum efficiency of GMSK land mobile radio, *IEEE Trans. on vehicular Technology*, 1985, 69-75.

[8] M.A. Ahaneku and V.C. Chijindu, Frequency reuse and implications of limited network resources in cellular mobile systems, *Global Advanced Journal of Engineering, Technology and Innovation*, 2(6), 2013, 167-172.

[9] M.D. Yacoub, *Foundations of Mobile Radio Engineering* (CRC Press, Boca Raton, FL, USA, 1993).

[10] Mac Donald, Advanced Mobile Service. The cellular concept, *The Bell System Technical Journal*, 58 (1), 1979, 15-41.

[11] G. Hernandiez-Valdez, F.A. Cruz-perez, and D. Rodnriguez-lara, Sensitivity of the system performance to the propagation parameters in los microcellular environments, *IEEE Trans. Veh. Tecnology*, 57(6), 3488-3508.

[12] S. Ki Tae Kimo, A universal frequency reuse system in a mobile cellular environment, *Vehicular Technology Conference (VTC)*, Spring, IEEE 65th, 2007, 2855-2859.

[13] M.S. Alouini and A.J. Goddsmith, Area spectral efficiency of cellular mobile radio systems, *IEEE Transactions on Vehicular Technology*, 48(4), 1999, 1047-1066.

[14] A. Obot, O. Simon and J. Atolayen, Comparative analysis of pathloss prediction models for urban microcellular, *Nigeria Journal of Technology*, 30 (3), 2011, 50-59

[15] S. Cela, B. Kamo, S. Cakaj, Q. Muka and R. M. Mitrushi, An algorithm for processing the measurement results of electromagnetic field near 2G and 3G base stations in Albanian territory. *Proceedings of the 21st IEEE International Conference on Software, Telecommunications and Computer Networks (SoftCOM)* Primosten, Croatia, 2013, 1-5.

[16] J. Lachowski, M. Maternia and, J. Gorzynski, Multiband and multicarrier operations in HSDPA". *Proceedings of the 8th International Symposium on Wireless Communication Systems (ISWCS*), Aachen, Germany, 2011, 725- 729,.

[17] S.E. Odongo, Heuristic for wireless metropolitan area network optimum performance: focus on terrain, A dissertation, Data Communication and Software Engineering of Makarere University, Kenya. 2008.

[18] Z. Nadir, N. El.fadhil and F. Touati, Path loss determination using Okumura – Hata Model and spline interpolation for missing data for O mars, *Proceeding of the World Congress on Engineering*, London, United Kingdom ,2008, 20-26.

[19] A.A. Ayeni, N. Faruk, L. Olawoyin, M.Y. Muhammad, and M.I. Gumel, Comparative assessments of some selected existing radio propagation models: A study of Kano City, Nigeria, *European Journal of Scientific Research*, 70 (1), 2012, 120-127.

[20] J. Doble, *Introduction to radio propagation for fixed and mobile communication* (Artech, House Inc, Norwood USA, 1996).

[21] A. Danladi, V.A. Natalia, Measurement and modeling of path loss for GSM signal in a sub urban environment over irregular terrain review, *International Journal of Science and Research (IJSR)* 3(8), 2014.

[22] J. Isabona, Maximizing coverage and capacity with QOS guarantee in GSM network by means of cell cluster optimization*, International Journal of Advanced Research in Physical Science* (IJARPS) 2(6), 2014, 44-55.