Optimization of Signal Coverage Area in Mobile Communication Networks

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

This study presents the optimization of signal coverage area in third generation WCDMA technology of mobile communication networks, aim at improving signal coverage area or overcoming the presence dead zone in mobile communication network. Various parameters that affect Signal coverage area in mobile communication network were determined. Optimization mathematical model based on Lagrange mathematical method was developed in line with the necessary parameters and characteristics. The developed mathematical model was simulated using MATLAB and Wolfram Mathematical Software using data obtain from mobile communication Network 'A' at Asaba, Delta State. The obtained data were number of duplex channels, frequency, load capacity of the base station, interference, distance power received, power transmitted etc. The result obtain are the critical points with fade-off of the radio signal. The coverage area indicates a non-linear function, therefore to minimize threshold parameter such as interference; pathloss and power received values will increase as the coverage area of the base station increases.

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1. INTRODUCTION

In recent times, signal strength and its coverage areas has been a global issue in mobile communication in which subscribers complain about loss of signals. This has been a growing phenomenon and concern among network subscribers. The presence of dead zone have reduce the Quality of Service (QoS) witnessed from mobile communication network in Nigeria. This study focused on the ability to reduce the presence of dead zone in mobile communication network.

Base station optimization is a highly important issue in achieving availability of signals and good QoS. It is expected that fourth generation wireless systems will provide a great QoS and other variety of services. Various studies, on how to improve on the signal coverage area in mobile communication networks are discuss.

Ouamri Mohamed Amine and Abdelkrim Khireddine [1], presents a study on Base Station (BS) placement and cell planning problem, involves choosing the position and infrastructure configuration for cellular networks.This problem is considered to be a mathematical optimisation problem and will be optimized using genetic algorithms. The various parameters such as site coordinates (x, y), transmitting power, height and tilt are taken as design parameters for BS placement. The study takes signal coverage, interference and cost as objective functions and handover, traffic demand and overlap as a very important constraint. Receiving field strength testing services for all items is calculated using simulations and path loss is calculated using Hata model [1-3].

Edoardo Amaldi et al. [4], investigate mathematical programming models for supporting the decisions on where to install new base stations and how to select their configuration (antenna height and tilt, sector orientations, maximum emission power, pilot signal, etc.) so as to find a trade-off between maximizing coverage and minimizing costs. The overall model takes into account signal quality constraints in both uplink and downlink directions, as well as the power control mechanism and the pilot signal [4-5]. Ref. [6], carried out a drive test in dedicated mode with the goal of collecting measurement data as a function of location and to identify the eventual black spots or dead zone in the GSM radio network. The data collected were analyzed in

post-processing software tool (MapInfo Professional) to identify the causes of problems and determine how these problems can be solved effectively and efficiently. Poor network coverage and degradation in QoS were encountered in some parts of the city. This performance was due to the land topology and the presence of physical obstructions in the propagation environment. The Hand-Over (HO) failures were mainly due to Base Station Controller (BSC) synchronization issue. Therefore, additional Base Stations were planned to be deployed in those areas; and the BSC synchronization issue was resolved. This will resolve frequent network complaints that lead to customers' dissatisfaction and boost the revenue of the mobile network provider [6-8]

Schmidt-Dumont.T and Vuuren Van JH [9], study establishes a mathematical modelling framework, based on these two placement criteria, for evaluating the effectiveness of a given set of radio transmitter locations. In the framework, coverage is measured according to the degree of obstruction of the so-called 'Fresnel zone' that is formed between handset and base station, while signal strength is modelled taking radio wave propagation loss into account. This framework is used to formulate a novel bi-objective facility location model that may form the basis for decision support aimed at identifying high-quality transmitter location trade-off solutions for mobile telecommunication network providers. But it may also find application in various other contexts (such as radar, watchtower, or surveillance camera placement optimisation), [10-12].

It suggests a new representation describing the BS placement. The proposed representation can determine not only the locations of the base stations but also the number of base stations antennas with other parameters used in this work such as pathloss, power received, power transmitted, distance of the base stations, number of duplex channels and height [4,13-14]. The application method of deep coverage technology is proposed by ref. [15], which fully demonstrates that the application level of deep overlay network technology has been improved, but with the increasing number of users and the increasingly complex scenes, further deepening coverage is needed.

This research employed the use of Lagrange method of optimization and Wolfram mathematical software to solve the problem of coverage signal strength of a base station using

Delta State as case study. The coverage area which possesses nonlinear characteristics was also examined in the course of this study.

2. METHODOLOGY

2.1 Lagrangian Method of Optimization

In this section, thorough analysis on the optimal control of the coverage area of base station using Lagrange method is discussed. Lagrange multipliers are very useful technique in multivariable parameters. In general, Lagrange multiplier is useful when some of the variables in the simplest description of a problem are made redundant by the constraint. Optimization problems, which seek to minimize or maximize a real functional play an important role in the real world.

This is attainable by minimizing the formulated mathematical model of the threshold parameters (N, A, P_r, I, P_l) .

Table 1. Modeling parameters

S/N	Parameters Used for the Optimization	Symbols
1	Number of Antennas	N
2	Number of duplex channels (Loads)	A
3	Power Received	Pr
4	Power Transmitted	Pt
5	Interference	I
6	Heights of the Base Stations	H
7	Distances from the Base Stations	x

Based on first principle; a cell which collectively uses the complete set of available frequencies is called a cluster. If a cluster is replicated N times within the system, the total number of duplex channels 'A' can be used as a measure of capacity and it is given by

$$C = N^2 + 3A^2 + p_r^2 \tag{1}$$

P_r is the average power at a distance'd' from the transmitting antenna is approximated by

$$p_r = p_o \left(\frac{d}{d_o}\right)^{-n}, \tag{2}$$

p_o is the average power received, "-n" shows decrease in antenna attenuation, "d" is final distance.

2.2 Formulation of Model

(a) Pathloss: This is the reduction in power density (attenuation) of an electromagnetic wave (signal) as it propagates through space. When power is transmitted at a low frequency it is observed that the pathloss decreases as the power transmitted increases, i.e

$$\frac{dP_l}{df} \propto P_t \tag{3}$$

Introducing pathloss constant $'\rho'$ Equation (3) become

$$\frac{dP_l}{df} = \rho P_t P_l \tag{4}$$

$$Where \rho = P_t - P_r \tag{5}$$

But the relationship between P_r and P_t is given as

$$.P_r = \frac{P_t \lambda^2}{4\pi d^2} \text{ (Power transmitted through free space)} \tag{6}$$

Substitute Equation (5) and (6) into (4), the resultant output is given as

$$\frac{dP_l}{df} = \left(1 - \frac{\lambda^2}{4\pi d^2}\right) P_t P_l = \left(1 - \frac{v^2}{(4\pi df)^2}\right) P_t P_l \quad \text{since}$$

$$v = \lambda f \tag{7}$$

The consistency of equation (7) is satisfied if $\frac{v^2}{(4\pi x f)^2} > 1$. That is to say that the free space pathloss must exceed 1 (one).

The pathloss is further decrease due to height gain by the transmitter and receiver at rate θ_t and θ_r respectively. Thus Equation (7) becomes:

$$\frac{dP_l}{df} = \left(1 - \frac{v^2}{(4\pi df)^2}\right) P_t P_l - \theta_t P_l - \theta_r P_l. \text{ r} \tag{8}$$

(b) Power Received: depending on the environment, the power received at a distance "x" increases as the distance of the pathloss exponent increases i.e x^σ increases. Mathematically:

$$\frac{dP_r}{dx} \propto \frac{P_t}{x^\sigma}. \tag{9}$$

Introducing constant L_o, Equation (9) becomes

$$\frac{dP_r}{dx} = L_o \frac{P_t}{\left(\frac{x}{x_o}\right)^\sigma} \tag{10}$$

The power received (transmission quality) increases as the height gained by the antenna receiver increases $\theta_r P_l$. The transmission quality is reducing by the Signal to Interference and Ratio (SIR)

$$.\frac{P_r}{P_I + P_N}.$$ Thus equation becomes (10)

$$\frac{dP_r}{dx} = L_o \frac{P_t}{(\frac{x}{x_o})^\sigma} P_r + \theta_r P_l - (\frac{1}{P_I + P_N}) P_r. \quad (11)$$

Where: "σ" is called the pathloss exponent whose value is defined in the interval $2 \le \sigma \le 4$.

L_o, is the computed at a reference distance x_o. L_o equal 1m in indoor areas and 100m in outdoors areas.

(c) Interference (I): This is the combination of two or more electromagnetic signal to form a resultant signal in which displacement is either reinforced or cancelled. To reduce interference co-channel interference must be separated by a minor distance i.e the dynamics of the interference depends on the co-channel re-use ratio. Mathematically

$$\frac{dI}{dN} \propto I \quad (12)$$

Introducing constant 'Q' Equation (12) becomes

$\frac{dI}{dN} = -QI$. It is established for hexagonal geometry Q=$\sqrt{3N}$. Also the signal to interference and noise ratio increases the interference. Thus Equation (12) becomes:

$$\frac{dI}{dN} = -\sqrt{3N}I + \left(\frac{1}{P_I + P_N}\right) P_r. \quad (13)$$

(d) Capacity of Duplex Channel: The capacity of the duplex channel (A) is maximally served if the traffic is trunked in N channels, i.e

$$\frac{dA}{dU} = \frac{U\lambda HA}{N}. \quad (14)$$

A small value of Co-channel reuse ratio will increase the capacity of the duplex structure. Thus Equation (14) becomes:

$$\frac{dA}{dU} = -\frac{U\lambda HA}{N} + \sqrt{3N}I. \quad (15)$$

Where: $\lambda(requestrate)$: Average number of call request per unit time.

H (holding time): Average duration of typical call. U: Numbers of users that can be supported per cell.

Finally

$$\frac{dN}{d\lambda} = -\frac{U\lambda HA}{N}. \quad (16)$$

2.3 Optimization of the Coverage Area of Base Station

Since the coverage area (Ca) is the objective function of the threshold parameters. Thus,

$$C_a = f(N, A, P_r, I, P_l) = N^2 + 3A^2 + P_r{}^2 + I^2 + P_l{}^2. \quad (17)$$

From Table 1, where 'f' is the function or summation of the given threshold parameters of Coverage Area (Ca).

The lagrange optimization function is defined as:

$$L(x, y) = f(x, y) - \sum_{i=1}^{k} \lambda_i [g_i(x, y) - k)]. \quad (18)$$

Since the relative constraints are a continuous system (O.D.E), the constant k will be zero.

Where $i = 1, 2, \dots k$ and k=5.Thus the relative constraints are:

$$g_1 = \frac{dN}{d\lambda} = -\frac{U\lambda HA}{N}. \quad (19)$$

$$g_2 = \frac{dA}{dU} = \frac{U\lambda HA}{N} + \sqrt{3N}I. \quad (20)$$

$$g_3 = \frac{dP_r}{dx} = L_o \frac{P_t}{(\frac{x}{x_o})^\sigma} P_r + \theta_r P_l - (\frac{1}{P_I + P_N}) P_r. \quad (21)$$

$$g_4 = \frac{dI}{dN} = -\sqrt{3N}I + \left(\frac{1}{P_I + P_N}\right) P_r. \quad (22)$$

$$g_5 = \frac{dP_l}{df} = \left(1 - \frac{v^2}{(4\pi df)^2}\right) P_t P_l - \theta_t P_l - \theta_r P_l. \quad (23)$$

Putting all together with the cost parameters to get the desired model for the Lagrange optimization function for the coverage area of base station: it is given as;

$$L(N, A, P_r, I, P_l) = C_1 N^2 + 3C_2 A^2 + C_3 P_r{}^2 + C_4 I^2 + C_5 P_l{}^2 - \lambda_1 \left(-\frac{U\lambda HA}{N}\right) - \lambda_2 (\frac{U\lambda HA}{N} + \sqrt{3N}I - \lambda_3 (L_o \frac{P_t}{(\frac{x}{x_o})^\sigma} P_r + \theta_r P_l -$$

$$(\frac{1}{P_I + P_N}) P_r) - \lambda_4 (-\sqrt{3N}I + \left(\frac{1}{P_I + P_N}\right) P_r) - \lambda_5 \left(\left(1 - \frac{v^2}{(4\pi df)^2}\right) P_t P_l - \theta_t P_l - \theta_r P_l\right). \quad (24)$$

Where λ_i adjoint variables, for all $i = 1,2,..5$.

C_i is the cost parameter, for all $i = 1,2,..5$, therefore differentiating the threshold parameters with Lagrange, the resultant Equations are below:

$$\frac{\partial L}{\partial N} = 2C_1N - \lambda_1\frac{U\lambda HA}{N^2} - \lambda_1\frac{I}{2\sqrt{3N}} + \lambda_2\frac{U\lambda HA}{N^2} + \lambda_4\frac{I}{2\sqrt{3N}} \quad (25)$$

$$\frac{\partial L}{\partial A} = 6C_2A - \lambda_1\frac{U\lambda H}{N} + \lambda_2\frac{U\lambda H}{N} \quad (26)$$

$$\frac{\partial L}{\partial P_r} = -\lambda_3 L_o\frac{P_t}{(\frac{x}{x_o})^\sigma} + \frac{\lambda_3}{P_I+P_N} + 2C_3P_r - \frac{\lambda_4}{P_I+P_N} \quad (27)$$

$$\frac{\partial L}{\partial I} = 2C_4I - \sqrt{3N}I\lambda_1 + \sqrt{3N}I\lambda_4 \quad (28)$$

$$\frac{\partial L}{\partial P_l} = 2C_5P_l - \lambda_3\theta_r - \lambda_5\left(1 - \frac{v^2}{(4\pi df)^2}\right)P_t + \lambda_5\theta_t + \lambda_5\theta_r. \quad (29)$$

2.4 Wolfram Mathematical Software

Using the Wolfram mathematical software tools (Analysis tool box), values where obtained recommend publications and WCDMA technology of mobile communication Network 'A' office Asaba, Delta State for the adjoint variables($\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$) as follows with the following given values in the Table 2:

Table 2. Parameters used for the full simulation using wolfram mathematical software

S/N	Symbols	Full meaning of parameters	Nominal values
1	j	Indoor Distance	100.00
2	f	Frequency	15000.00
3	b	Number of Duplex Channels	19.00
4	U	The number of users that can be supported per cell	700000
5	y	Power of Interference	0.24
6	A	Load Capacity of the Base Station	800.00
7	e	Interference	5.00
8	z	Power of Noise	0.35
9	H	Average duration of typical calls	0.05
10	xo	Initial distance	0.10
11	x	Distance	2.5
12	q	Power Received	25.00
13	C_1	Cost Variable 1	0.00005
14	C_2	Cost Variable 2	0.000023
15	C_3	Cost Variable 3	0.000045
16	C_4	Cost Variable 4	0.000021
17	C_5	Cost Variable 5	0.00005
18	w	Power Transmitted	30.00
19	v	Speed of light	300000000
20	Өt	Height gain by the antenna transmitter	50.00
21	€	Pathloss Exponent	2.5
22	Өr	Height gain by the antenna receiver	20.00
23	α	Average number of call request per unit time	2.00

$se1 = 2*C1*b - \lambda1*U*\lambda*H*A/(b^2) - \lambda1*e/(2\sqrt{3}b) + \lambda2*U*\lambda*H*A/b^2 + \lambda4*e/(2\sqrt{3}b)$

$se2 = 6*C2*A - \lambda1*U*\lambda*H/(b) + \lambda2*U*\lambda*H/b$

$se3 = -\lambda3*j*q/(((x/xo))^\sigma) + \lambda3/(z+y) + 2*C3*w - \lambda4/(z+y)$

$se4 = 2*C4*e - \sqrt{3}b*e*\lambda1 + \sqrt{3}b*e*\lambda4$

$se5 = 2*C5*z - \lambda3*\theta r - \lambda5*(1 - v^2/((4\pi(x*f))^2))q + \lambda5*\theta t + \lambda5*\theta r$

$Solve[\{se1 == 0, se2 == 0, se3 == 0, se4 == 0, se5 == 0\}, \{\lambda1, \lambda2, \lambda3, \lambda4, \lambda5\}]$

$Solve[\{0.019 - 8725.837739993869\lambda1 + 8725.761772853186\lambda3 + 0.0759671406828455\lambda4 == 0,$

$0.06210000000000001 - 3684.2105263157896\lambda1 + 3684.2105263157896\lambda2 == 0,$

$$0.027 + 0.8949152542372882\lambda3 - 1.6949152542372883\lambda4 == 0,$$

$$0.0021000000000000003 - 164.54482671904333\lambda1 + 164.54482671904333\lambda4 == 0,$$

$$0.00035 - 20.\lambda3 + 1058.211836423378\lambda5 == 0.$$

$\lambda1 \rightarrow 0.03377460347299526, \lambda2 \rightarrow 0.03375774775870955, \lambda3 \rightarrow 0.03377242612378891, \lambda4 \rightarrow 0.03376184099336054, \lambda5 \rightarrow 0.0006379616058326524$

2.5 Critical Point

The critical point of the threshold parameters also known as tolerance value of the coverage area are the points where the performance of the radio signal will have a forward effect in a given area. Decreasing the values of the threshold parameters below their critical points will result to fade-off of the radio signal.

With much rigorous exercise, and the used of Wolfram mathematical software, the obtained critical (minimum) points and their values as follows:

$$.N = -[\frac{(\lambda_2-\lambda_1)U\lambda AH}{2\sqrt{3}(C_1 4\sqrt{3}+I(\lambda_4-\lambda_1)}]^{\frac{1}{3}} = 534.7341663267282$$

$$.A = \frac{(\lambda_2-\lambda_1)U\lambda AH}{2C_2} = 299.99999999999994$$

$$.p_r = [\lambda_3 L_o \frac{P_t}{(\frac{x}{x_o})^\sigma} - \frac{\lambda_3-\lambda_4}{P_I+P_N}]\frac{1}{2C_3} = -11798.999999997062$$

$$.I = \frac{(\lambda_4-\lambda_1)\sqrt{3N}}{2C_4} = -10.000000000001787$$

$$.p_l = \frac{\lambda_3\sqrt{3N}}{2C_5} - \frac{\lambda_5}{2C_5}[\theta_t + \theta_r - (1 - \frac{v^2}{(4\pi df)^2})p_t].$$

$$=4359.6873271790255.$$

3. RESULTS ANALYSIS AND DISCUSSION

The function of the coverage area with other parameters in Equation 24 was simulated using MATLAB software. From Fig. 1, it is observed that the coverage area possess a non linear function. In addition, it is observed that minimize threshold parameter such as interference, pathloss and power received increases as the coverage area of the base station increases. The interval (10, 40) in Fig. 1 below depicts the behavior of the coverage area at the critical point of the minimize threshold parameters. Bifurcation at this point implies that the minimize threshold parameters have exceeded their limiting values, thus the asymptotic nature of the coverage area tends to fade-off and becomes linear with increase values of the threshold parameters.
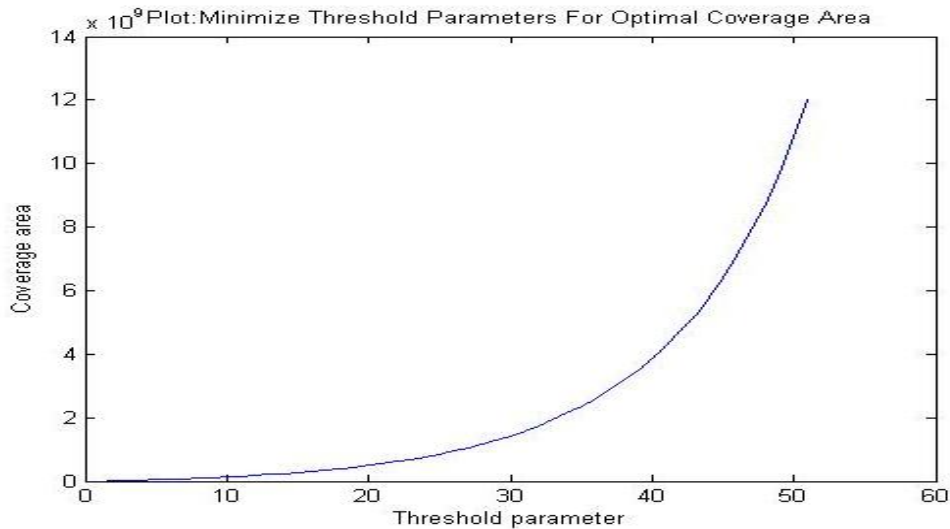

Fig. 1. Coverage area against threshold parameter

It can be deduced from the plot (Fig.1) that coverage area increases as threshold parameter increases.

The contour plot in Fig. 2, indicates that the coverage area of the base station increases with increases with the number of antennas. So, if seven hundred subscribers are observed for the simulation, then the coverage area will fade-off when 4 to 5 antenna is used as the average power received increases.
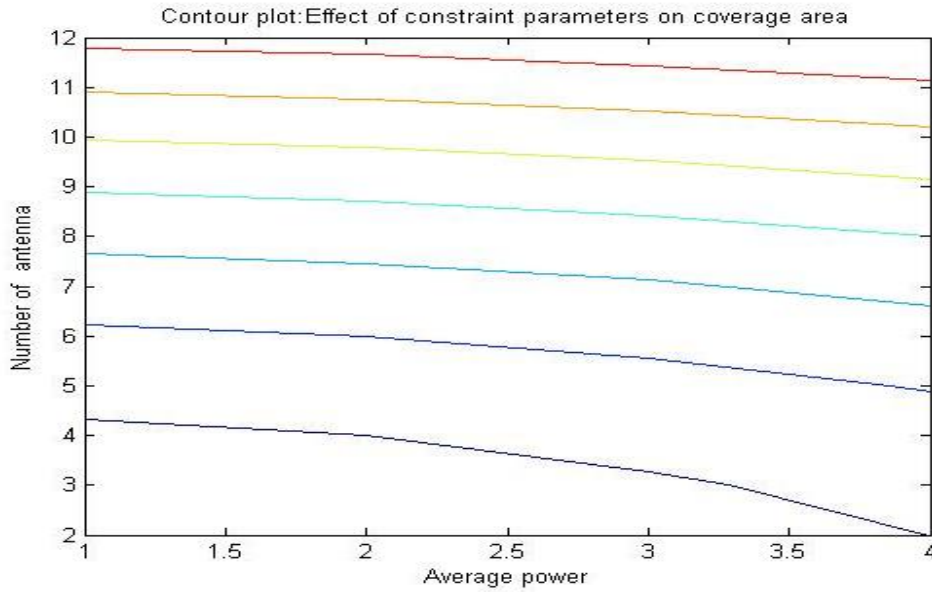

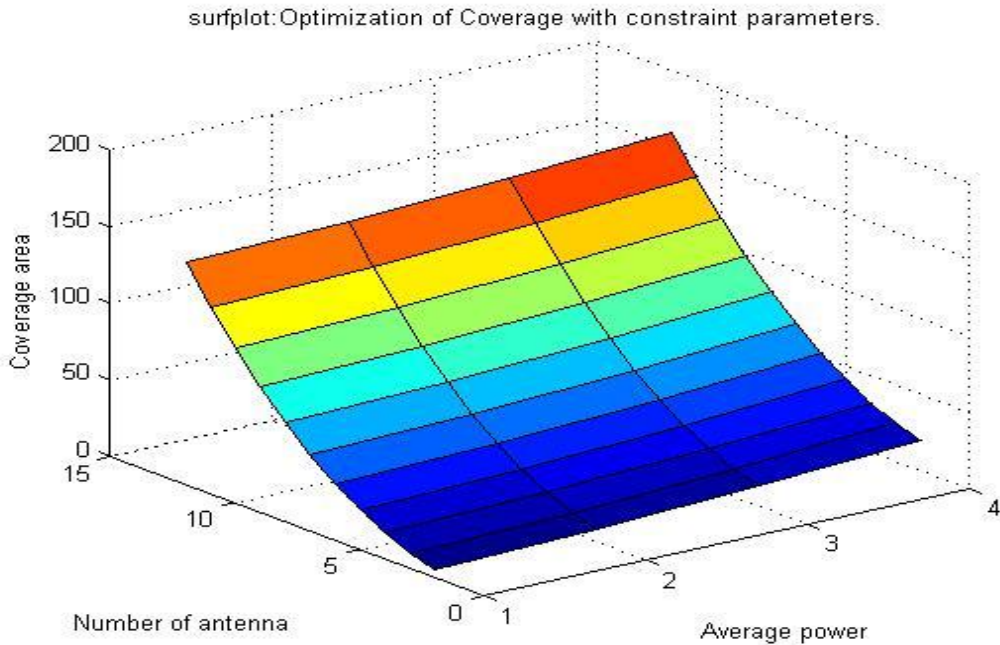**Fig. 2. Contour plot of number of antennas against average power**

Fig. 3. The coverage area, number of antennas and average power received

In Fig. 3, the dynamics of the coverage area with respect to the minimized number of antennas and the power received. Since they have increasing effects on the coverage area, the functional labels can interfere from the 3D plot minimum interval of the minimized antennas to attain the maximum coverage area. For 700 subscribers is [2,3] interval, then the average power received is approximately 4dbm. In order to minimize cost a minimum value of 2dbm of the threshold parameter (antenna) is required to produce signal strength with the coverage area value of 150 km that will accommodate the 700 subscribers.

From Fig. 4, it can deduce that power received as a single minimizing parameter for the optimal coverage area increases as the coverage area decreases. This is due to crowding effect (body loss) and interference.

In Fig. 5, the corresponding value of the coverage area against load traffic intensity of the mobile system. For example, at 30erlang (load), the coverage area (150) will accommodate 750 subscribers but at 40erlang, the coverage area (200) will accommodate 1000 subscribers.
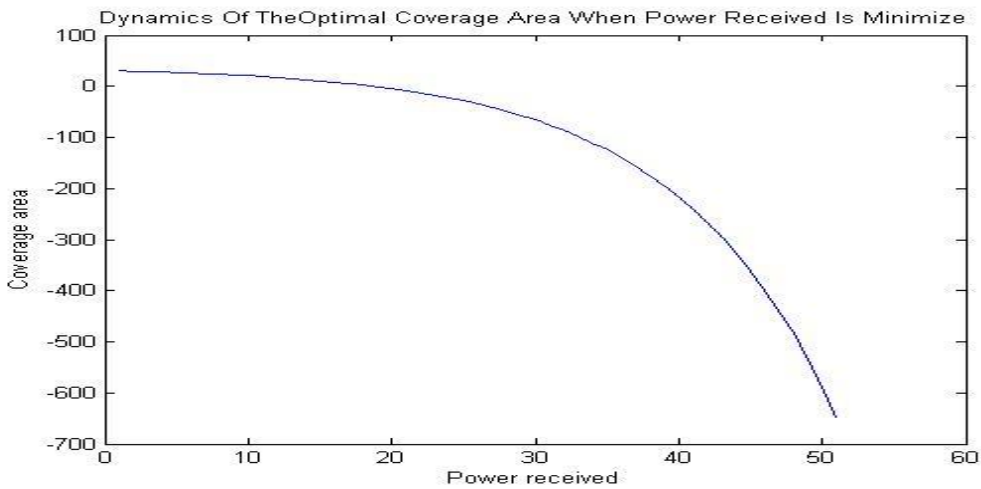
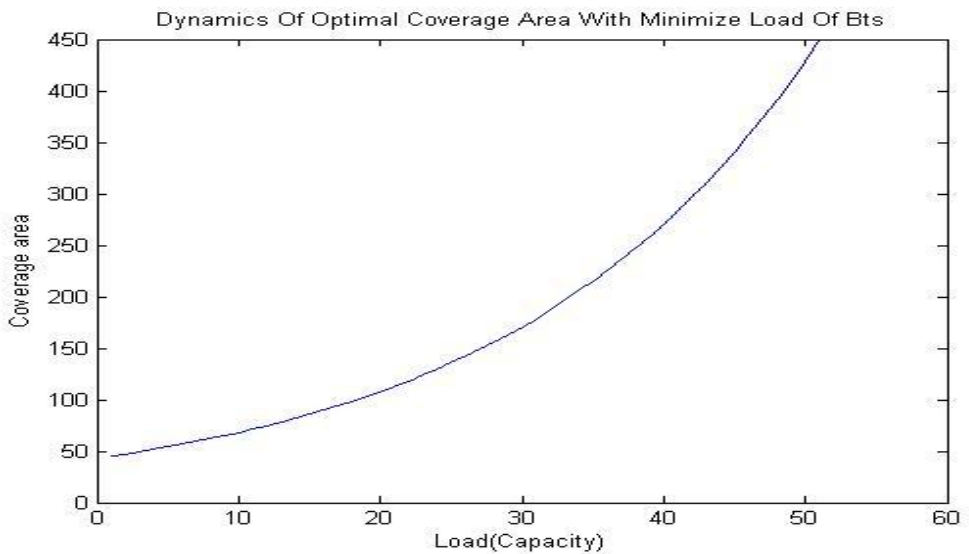

Fig 4. Coverage area against average power receive

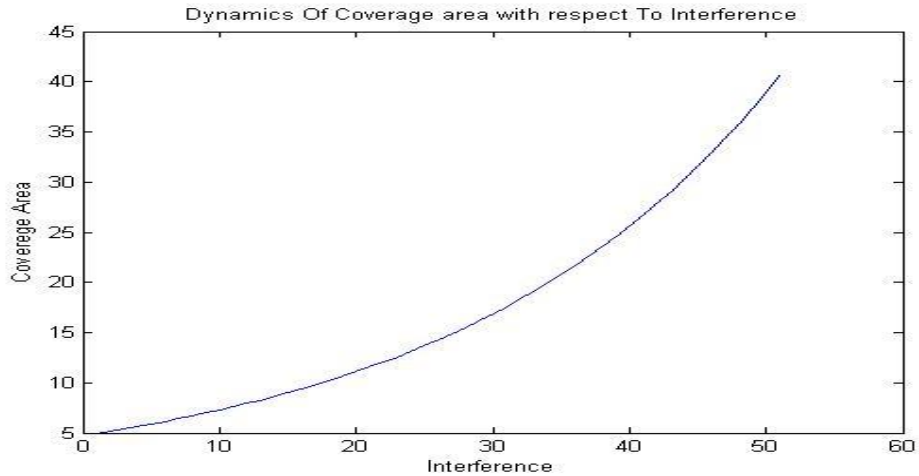**Fig. 5. Coverage area against load (capacity)**

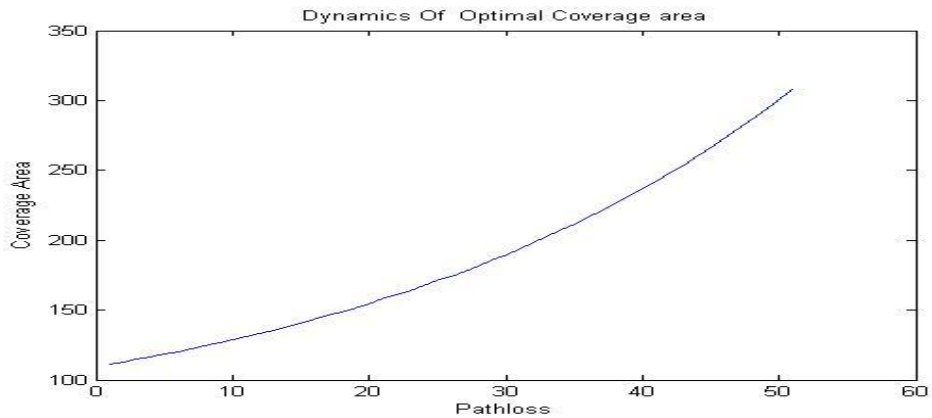**Fig. 6. Coverage area against interference**

Fig. 7. Coverage area against pathloss

In Fig 6, indicates the increasing effect of the minimized interference on the coverage area. A sharp exponential growth witnessed for the coverage area will occur at [50, 60] in level. From this deduction, it is containable to say that a good condition of the signal strength is attainable when the minimized value of the interference is defined in the interval [0,40].

From Fig. 7, it is observed that the minimized threshold parameter (pathloss) increases, its effect increases the coverage area that is to say that power transmitted minus power received also have effects on coverage area. For example, with 300 subscribers, 50dbm will be actualized value.

This study has contributed to knowledge in the following ways: a mathematical optimization model for investigating and improving the signal strength of base station are established with the corresponding signal parameters. The simulation of the developed mathematic model, were successful carry out using MATLAB and Wolfram Mathematical Software

4. CONCLUSION

A mathematical model based on Lagrange method for the threshold parameter was formulated. This is to investigate the optimal coverage signal area of the base station using the Lagrange principle. The model is rigorously analyzed to gain insight into dynamic features. Relevant base station parameters like the capacity of the duplex channels, power received, power transmitted, interference and the number of antennas are used to simulate the model and

assess the significance of the minimized threshold parameter for optimal coverage signal area. The mathematical model has equilibrium points; which define the limit value of each threshold parameter for optimal coverage area. The nature of the signal strength was investigated using the characteristic polynomial of the jacobian matrix. The plot of the coverage signal area with universal threshold parameters is nonlinear and was stimulated using MATLAB software 2015 version. From the graph, it is deduce that there exists an interval [10, 40] which depicts the behavior of the coverage area at the limiting values of the minimized threshold parameters.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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