Sudan University of Sconce and Technology
College of Graduate Studies

Investigation of the effect of receiving Antenna height on cell coverage Area in Khartoum city center

تقصي أثر إرتفاع هوائي الإستقبال علي مساحة تغطية خلية في وسط مدينة الخرطوم

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of M.Sc in Electronic Engineer

(Communication Engineering)

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الأية

قال تعالي في محكم تنزيله :

" هوَ الَّذي جَعَلَ الشَّمْسَ ضِيَاءً وَالقَمَرَ نُوراً وَقَدَّرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَالسِنِينَ وَالحِسَاب مَا خَلَقَ

الله ذلكَ إلاَّ بِالحقِّ يُفصِّلُ الأياتِ لِقَومٍ يَعْلَمُون "

صدق الله العظيم

سورة يونس اية (5)

DEDICATION

I dedicated this thesis

To my parents, especially my mother who always asking God to reconcile me ………..

To my dear wife, which supported me, encouragement me and all time stood beside me ……….

ACKNOWLEDGMENT

I would like to express my special appreciation and thanks to my supervisor **Dr. Fath Elrhman Ismael khalifa**, I would like to thank him for the encouraging and advising in my research. I would also like to thank **Mr. Mussab Ibrahim Mohammed**, for his help and support.

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المستخلص

تَصمم إنظمة إتصالات الهاتف الجوال وفق حسابات نظرية تعتمد علي عدة محددات وقيم يتم ضبطها أو فرضها ، فمساحة تغطية الخلية تعتمد علي قوة الإشارة المرسلة ، قوة الإشارة المستقبلة وفقد المسار والظل ، الذي يأثر علي الإشارة المستقبلة ، يدخل تأثير البيئة والأبنية المحاطة بالخلية علي فقد المسار والظل فتعمل الأبنية الشاهقة والأشجار علي توهين الإشارة مما يزيد من مقدار فقد المسار والظل. في هذه الإطروحة تم جمع عينة لقراءات مستوي الإشارة عند نقاط مختلقة وذلك لإرتفاعين مختلفين في منطقة الرياض (وسط الخرطوم) عند التردد 415 MHz ومن ثم تم حساب معامل فقد المسار γ وجدت قيمته عند إرتفاع 1 متر = 4.7989 وعند إرتفاع 3.5 متر = 4.326 ، وعامل الظل δ ووجدت قيمته عند إرتفاع 1 متر =6.72 وعند إرتفاع 3.5 متر = 5.675 . ومن ثم تم حساب نموذج فقد المسار والظل عند كل إرتفاع وتحليل القراءات والنتائج . أخيرا تم حساب نسبة المساحة المغطاة بالخلية حيث وجد إنها تساوي 72.8% عند الإرتفاع 1 متر و 94 % عند الإرتفاع 3.5 متر.

ABSTRACT

The mobile communications systems designed according to the theory of studying depends on several parameters such as adjustable or imposed values, the cell coverage area depends on the transmit and received power, path loss and shadowing , which affects at the received signal. The growth of urban area and environment changing will affect to antenna performance, this growth will increase the path loss and shadowing which leads to decrease the cell coverage area.

In this thesis a sample of readings has been collected at several points, in the Riyadh region (middle of Khartoum) at the frequency 415 MHz, then the path loss exponent γ was calculated and it's achieved value height 1 meter = 4.7989 and at high (3.5 meters) = 4.326, and the shadow factor δ was also calculated and it's achieved value at height 1 meter = 6.72 and at height 3.5 meters = 5.675. Then the Simplified Path Loss Model for was plotted, readings and calculated values was Analyzed. Finally, the percentage of the cell coverage area was founded, and it is equal to 72.8% at the height of 1 meter and 94% at the height 3.5 meters.

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ABBREVIATION

BTS	Base Transceivers Station
COST	Cooperative for scientific and technical research
EM	Electromagnetic wave
GPS	Global positioning system
LMA	Local mean attenuation
LOS	Line-of-sight
MLS	Mobile location services
MMSE	Minimum mean square error
Ms	Mobile station
PL	Path loss
RF	Radio frequency
SF	Shadow fading
SNR	Signal to Noise Ratio

LIST OF SYMBOL

Ψ	Shadowing, Gauss-distributed random variable
C	Light velocity
μ_{Ψ}	Mean of Ψ
f	Operating frequency
γ	Path loss exponent
π	Pi
δ_{Ψ}	Standard deviation of Ψ
δ^2_{Ψ}	Variance of Ψ
λ	Wave length in meters
ξ	$= 10/ \ln 10$

1.1 Preface:

The concept of cellular communications was introduced by Bell Laboratories in 1947 to increase the communication capacity and coverage of mobile systems, coverage in a cell is dependent upon the area covered by the signal. There has been an increase in the demand for higher quality networks due to the rapid growth and competition for wireless subscribers. Wireless networks are designed for both coverage and capacity requirements, some common requirements for coverage and quality of service and some challenge will appear such as how to reduce the impact path loss and shadowing coming from Architectural changes in cities and residential areas[1].

Early schemes for radio telephones systems used a single central transmitter to cover a wide area. These radio telephone systems suffered from the limited number of channels that were available .Cellular systems are widely used today and cellular technology needs to offer very efficient use of the available frequency spectrum[2].

A cellular mobile communications system uses a large number of low power wireless transmitters to create cells. A cell is basic geographic service area of wireless communications system. Variable power level allow cell to be sized according to the subscribers density and demand within a particular region[3].

In modern cellular telephony, rural and urban regions are divided into areas according to specific provisioning guidelines. Deployment parameters, such as the amount of cell splitting and cell size, are determined by engineers experienced in cellular system design. Cluster is a group of cells with no channel are reused within a cluster , the number of cells in a culture system can help determine the numbers of users that can be accommodated, by making all the cells smaller it is possible to increase the overall capacity of the cellular system[3].

However a greater member of transmitter - receiver or base stations are required if cells are made smaller and this increase the cost of the operator. Macro cells and micro cells are most common type of cells used in cellular systems, macro cells are large cells that are usually used for remote or sparsely populated areas. These may be 10 km or possibly more in diameter. Micro cells are those that are normally found in densely populated areas which may have a diameter around 1kmor less[4].

1.2 Cell Coverage Area:

The actual radio coverage of a cell is known as the cell footprint, Irregular cell structure and irregular placing of the transmitter may be acceptable in the initial system design, for systematic cell planning, a regular shape is assumed for the footprint, coverage contour should be circular. However it is impractical because it provides ambiguous areas with either multiple or no coverage[5].

Due to economic reasons, the hexagon has been chosen due to its maximum area coverage; hence, a conventional cellular layout is often defined by a uniform grid of regular hexagons.

Antenna pattern, antenna power and antenna height all affect the cellular system design and coverage area. The antenna pattern can be omnidirectional, directional, or any shape in both the vertical and the horizon planes. Antenna gain compensates for the transmitted power. Different antenna patterns and antenna gains at the cell site and at the mobile units would affect the system performance and so must be considered in the system design, also the height of the cell-site antenna can affect the area and shape of the coverage in the system[6].

1.3 Problem Statement:

The growth of urban area and environment changing will change the cell coverage percentage, this growth will increase the path loss and shadowing which leads to decrease the antenna significant and reduction in cell coverage percentage.

The problem is how to investigate the real effect of shadowing and path loss at a given urban area, and represent their effect on path loss and cell converge percentage.

1.4 Proposed Solution:

Chosen a cell at urban area has characteristic match requirement to achieve the thesis goal, which is mean resident area which has obstacles and high buildings. Then calculate path loss and cell coverage percentage for two different receiving antenna heights these calculations will be done at many points inside the cell. In the last the result will discuss and analyze.

1.5 Objective:

This thesis is going to analyzing the effect of antenna height in the cell coverage area at urban area, also to prove that if the antenna height is high enough the signal will skip the buildings and trees, thus will decrease the path loss and shadowing effect and increasing the percentage of the cell coverage area.

1.6 Methodology:

Collecting measurements for two different heights of the receiving antenna, these measurements are received powers and positions coordinates.

At each position doing the following steps:

a. Calculating the distances between BTS antenna and MS antenna.
b. Calculating path loss exponent (γ).
c. Calculating shadow factor (δ).
d. Finally calculating path loss and cell coverage percentage, by using path loss models and cell coverage equation.
e. Repeating the previous steps with different MS antenna height.

1.8 Thesis Layout:

This thesis composed of five chapters their outline are follow:

Chapter one gives preface of cellular system and introduced cellular coverage area .Chapter two develop over view of Radio wave propagation and free space path loss followed by four path loss empirical models namely Okumura model, Hata model, Extended cost model and Simplified path loss model. Also gives over view of shadowing and cell coverage area. The methodology of data collection, calculation of distance and path loss exponent and shadow factor, and result analysis are explained in chapter three. Results and discussion were placed in chapter four. Chapter five contained conclusion and recommendations for future studies.

2.1 Radio wave Propagation:

A radio system transmits information to the transmitter. The information is transmitted through an antenna which converts the RF signal into an electromagnetic wave. The transmission medium for electromagnetic wave propagation is free space.

A signal, as it travels through the wireless free space Faces many kinds of propagation effects such as reflection, diffraction and scattering, due to the presence of buildings, mountains and other such obstructions. Reflection occurs when the EM waves impinge on objects which are much greater than the wavelength of the traveling wave.

Diffraction is a phenomena occurring when the wave interacts with a surface comparable in size to its wavelength.

Scattering occurs when the medium through the wave is traveling contains objects which are much smaller than the wavelength of the EM wave.

These varied phenomena's lead to large scale and small scale propagation losses. Due to the inherent randomness associated with such channels they are best describe with the help of statistical models. Models which predict the mean signal strength for receiver shadow fading and path loss[7].

2.2 Basic Methods of Propagation:

Reflection, diffraction and scattering are the three fundamental phenomena that cause signal propagation in a mobile communication system..

The most important parameter, predicted by propagation models based on above three phenomena, is the received power. The physics of the above phenomena may also be used to describe small scale fading and multipath propagation[7].

The following subsections give an outline of these phenomena.

2.2.1 Reflection:

Reflection occurs when an electromagnetic wave falls on an object, which has very large dimensions as compared to the wavelength of a propagating wave. Such objects can be the earth, buildings and walls. When a radio wave falls on another medium having different electrical properties, a part of it is transmitted into it, while some energy is reflected back. If the medium on which the E.M wave is incident is a dielectric, some energy is reflected back and some energy is transmitted. If the medium is a perfect conductor, all energy is reflected back to the first medium. The amount of energy that is reflected back depends on the polarization of the EM wave[8].

2.2.2 Diffraction:

Diffraction is the phenomenon due to which an E.M wave can propagate beyond the horizon, around the curved earth's surface and obstructions like tall buildings. As the user moves deeper into the shadowed region, the received field strength decreases, but the diffraction field still exists and it has enough strength to yield a good signal.
The propagation of secondary wave in the shadowed region results in diffraction. The field in the shadowed region is the vector sum of the electric field components of all the secondary wave that are received by the receiver[8].

2.2.3 Scattering:

The actual received power at the receiver is somewhat stronger than claimed by the models of reflection and diffraction. The cause is that the trees, buildings and lampposts scatter energy in all directions. This provides extra energy at the receiver[9].

Figure (2.1) shows the three phenomena, and how it arises. It is also show that in the LoS the signal reaches the receiver directly, Line of sight (LoS) is a type of propagation that can transmit and receive data only where transmit and receive stations are in view of each other without any sort of an obstacle between them[10].

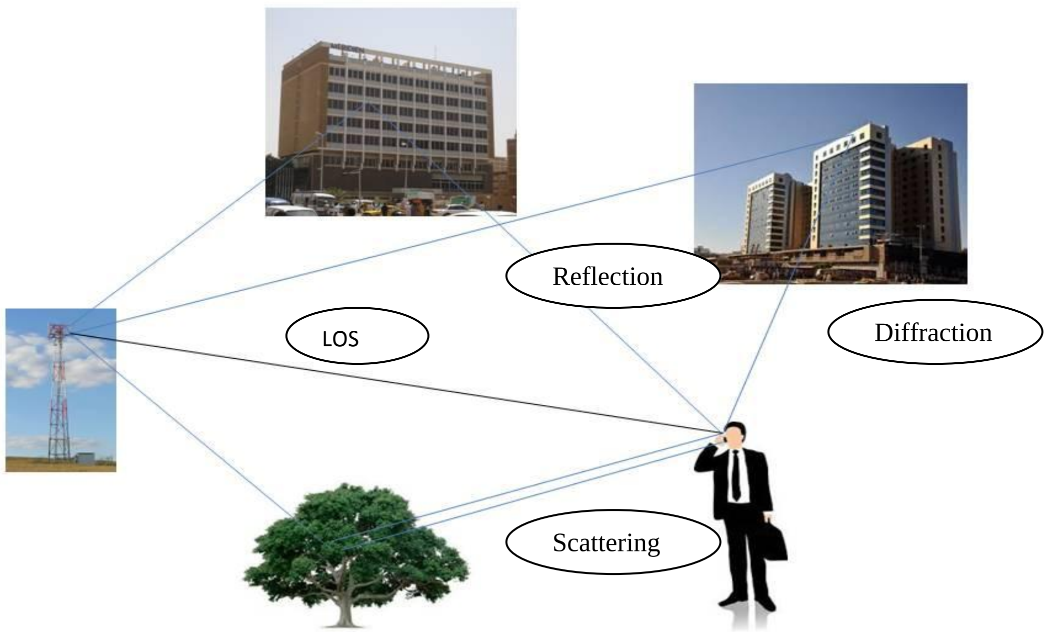

Figure (2.1) propagation phenomenas

2.3 Path Loss and Shadowing:

The Path loss is defined as the ratio of transmit power to receive power. Prediction of path loss is a significant element of system design at any communication system. There was a number of models use to predict the path loss, reliable propagation model is one which calculates the path loss with small standard deviation. Suitable models must be chosen for measurements of field strength and path loss as well as other parameters. An accurate and reliable prediction method helps to optimize the coverage area, transmitter power and eliminates interference problems of other radio transmitters as well.

The critical factor that affects path loss is the distance between the transmitter and receiver. It is known that signal power decreases as distance increases. The path loss represents the mean signal attenuation at a certain distance from the transmitter and can be predicted by the distance and other macroscopic parameters such as carrier frequency, transmitter and receiver antenna heights, and terrain contour and buildings concentration[11].

Suppose that a signal S(t) with power (P_t) is transmitted through a given channel, with corresponding received signal R(t) with power (P_r), where P_r is averaged over any random variations due to shadowing. We define the linear path loss (P_L) of the channel as the ratio of transmit power to receive power in equation (2.1) [11]:

$$P_L = \frac{P_t}{P_r} \quad 2.1$$

Where:

- P_t Transmitted power
- P_r Received power
- P_L Path loss

We define the path loss of the channel as the dB value of the linear path loss or, equivalently, the difference in dB between the transmitted and received signal power in equation (2.2):

$$P_L \ dB = 10 \ \log_{10}[P_t / P_r] \quad dB \quad 2.2$$

In general the dB path loss is a nonnegative number since the channel does not contain active elements, and thus can only attenuate the signal. The dB path gain is defined as the negative of the dB path loss:

$$P_G = -P_L \ dB = \ \log_{10}[P_t / P_r] \quad dB \quad 2.3$$

Where:

P_G Path gain

Which is generally a negative number, with shadowing the received power will include the effects of path loss and an additional random component due to blockage from objects.

2.3.1 Free Space Path Loss Model:

As a transmitted signal travels through vacuum or air, its power gets distributed over a larger and larger sphere and therefore attenuates as the square of the distance from the transmitter to the receiver.
Consider a signal transmitted through free space to a receiver located at distance (d) from the transmitter. Assume there are no obstructions between the transmitter and receiver and the signal propagates along a straight line between the two. The channel model associated with this transmission is called a line-of-sight (LoS) channel, and the corresponding received signal is called the LoS signal or ray.
The power in the transmitted signal S(t) is P_t, so the ratio of received to transmitted power expressed in equation (2.4)[12]:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad 2.4$$

Where:

- P_t Transmitted power
- P_r Received power
- G_t Transmitter antenna gain (dimensionless quantity)
- G_r Receiver antenna gain (dimensionless quantity)
- d T-R separation distance in meters
- λ Wave length in meters.

Thus, the received signal power is inversely proportional to the square of the distance (d) between the transmit and receive antennas. The received signal power is also proportional to the square of the signal wavelength, so as the carrier frequency increases, the received power decreases. This dependence of received power on the signal wavelength λ is due to the effective area of the receive antenna. However, directional antennas can be

designed so that receive power is an increasing function of frequency for highly directional links[13].
The ratio of received to transmitted power can be expressed as:

$$\frac{P_r}{P_t} = \left(\frac{\sqrt{G_L}\lambda}{4\pi d}\right)^2 \qquad 2.5$$

Where :

$\sqrt{G_L}$ Product of the transmit and receive antenna field radiation patterns in the LOS direction.

The received power can be expressed in dBm as:

$$P_r = P_t + 10 \log_{10} G_L + 20 \log_{10} \lambda - 20 \log_{10} 4\pi - 20 \log_{10} d \text{ dB} \qquad 2.6$$

Free-space path loss is defined as the path loss of the free-space model equations (2.7) and (2.8) show how to calculate PL in dB [13]:

$$P_L = 10 \log_{10} P_t/P_r = -10 \log_{10}[(G_L\lambda^2)/((4\pi)^2 d^2)] \qquad 2.7$$

$$P_L \text{ dB} = 22 + 20 \log_{10} d - 20 \log_{10} \lambda - 10 \log_{10} G_L \qquad 2.8$$

The free-space path gain is defined in Equation (2.9)[13]:

$$P_G = -P_L = 10 \log_{10}[(G_L\lambda^2)/((4\pi)^2 d^2)] \qquad 2.9$$

2.3.2 Empirical Path Loss Models:

Most mobile communication systems operate in complex propagation environments that cannot be accurately modeled by free-space path loss A number of path loss models have been developed over the years to predict path loss in typical wireless environments such as large urban macrocells, urban microcells, and, more recently, inside buildings .These models are mainly based on empirical measurements over a given distance in a given frequency range and a particular geographical area or building. However, applications of these models are not always restricted to environments in which the empirical measurements were made, which make the accuracy of such empirically-based models applied to more general environments somewhat questionable[14].

Nevertheless, many wireless systems use these models as a basis for performance analysis. In the following section we discuss the common models for urban macrocells, and then describe more recent models for outdoor microcells and indoor propagation.

Analytical models characterize P_t/P_r as a function of distance, so path loss is well defined. In contrast, empirical measurements over P_t/P_r as a function of distance include the effects of path loss, shadowing, and multipath. In order to remove multipath effects, empirical measurements for path loss typically average their received power measurements and the corresponding path loss at a given distance over several wavelengths. This average path loss is called the local mean attenuation (LMA) at distance d, and generally decreases with d due to free space path loss and signal obstructions. The LMA in a given environment, like a city, depends on the specific location of the transmitter and receiver corresponding to the LMA measurement. To characterize LMA more generally, measurements are typically taken throughout the environment, and possibly in multiple environments with similar characteristics. Thus, the empirical path loss P_L (d) for a given environment is defined as the average of the LMA measurements at distance (d), averaged over all available measurements in the given environment[13].

2.3.2.1 The Okumura Model:

The Okumura's model is an empirical model based on extensive measurements made in Japan (Tokyo 1968) at several frequencies within the range of 150 to 1500 MHz and further(extrapolated up to 3000 MHz). Okumura's models are developed for macrocells with the following specification:

- Cells diameters range from 1 to 100 km.
- The height of the BTS antenna is kept between 30-100 m.
- Frequency range from 150 to 1500 MHz.

The Okumura model has taken into account several propagation parameters such as the type of environment and the terrain irregularity[15].

Okumura developed a set of curves which gives the median attenuation relative to free space (A_{mu}), in an urban area over a quasi-smooth terrain with a base station effective antenna height (h_t) and a mobile antenna height (h_r). These curves were developed from extensive measurements using vertical omni-directional antenna at both the base and mobile. In this case curves are plotted as a function of frequency in the range of 100 MHz to 1920 MHz, and as a function of distance from the base station in the range from 1 km to 100 km. The path loss prediction formula according to Okumura's model is expressed in equation (2.10) [16]:

$$P_L dB = L\,(f,d) + A_{mu}(f,d) - G(h_t) - G(h_r\,) - G_{Area} \qquad 2.10$$

Where:

P_L	Value of propagation path loss (median)
$L\,(f,d)$	Free space propagation loss at distance d
$A_{mu}(f,d)$	Median attenuation relative to free space
$G(h_t)$	Base station antenna height gain factor
$G(h_r\,)$	Mobile antenna height gain factor
G_{Area}	Gain due to environment (obtained from Okumura’s empirical plots)

Equation (2.11) show how to calculate antenna gain, equations (2.12) and (2, 12) explain mobile antenna gain in different height.[11]

$$G(h_t) = 20\ \log_{10}[h_t/200] \qquad 1000\text{ m} > h_t > 30\text{ m} \qquad 2.11$$

$$G(h_r) = 10\ \log_{10}[h_r/3] \qquad h_r \leq 3\text{ m} \qquad 2.12$$

$$G(h_r) = 20\ \log_{10}[h_r/200] \qquad 10\text{ m} > h_r > 3\text{ m} \qquad 2.13$$

Okumura's model is considered to be the simplest and most excellent in terms of accuracy in path loss prediction for mature cellular and land mobile systems in cluttered environment. The main disadvantage of the Okumura model is its sluggish response to rapid changes in terrain condition. Consequently the model is fairly good in urban and suburban areas but not as good (suited) for rural areas[11].

2.3.2.2 The Hata Model:

The Okumura-Hata model (1980) is an empirical formulation of the graphical path loss data provided by Yoshihisa Okumura, and is valid from 150 MHz to 1500 MHz. The Hata model basically is a set of equations based on measurements and extrapolations from the curves derived by Okumura. Hata presented the urban area propagation loss as a standard formula, along with additional correction factors for application in other situations such as suburban and rural area. Only four parameters are required in the Hata model as a result the computation time is very short in this model. This is one of the main advantages of this model. However, the model neglects the terrain profile (condition) between the transmitter and receiver i.e. hills or other obstacles that exist between the transmitter and receiver were not considered. This is because both Hata and Okumura models have made the assumption that the transmitters would normally be located on hills. The basic formula for the median propagation loss given by Hata is determined in equation (2.14) [17]:

$$\mathrm{P_L}\ (\mathrm{urban})\ \mathrm{dB} = 69.55 + 26.16\ \log_{10}(fc) - 13.82\ \log_{10}(\mathrm{h_t}) - \mathrm{a}(\mathrm{h_r}) + (44.9 - 6.55\ \log_{10}(\mathrm{h_t}))\log_{10}\mathrm{d}\ \mathrm{dB} \qquad 2.14$$

The parameters in this model are the same as under the Okumura model, and $\mathrm{a}(\mathrm{h_r})$ is a correction factor for the mobile antenna height based on the size of the coverage area. For small to medium sized cities, this factor is given by equation (2.15) [13]:

$$\mathrm{a}(\mathrm{h_r}) = (1.1\ \log_{10}(fc) - 0.7)\ \mathrm{h_r} - (1.56\ \log_{10}(fc) - 0.8)\ \mathrm{dB} \qquad 2.15$$

And for larger cities at frequencies fc > 300 MHz by

$$\mathrm{a}(\mathrm{h_r}) = 3.2\ (\log_{10}(11.75\mathrm{h_r}))^2 - 4.97\ \mathrm{dB}$$

Corrections to the urban model are made for suburban and rural propagation, so that these models are, respectively determined by equation (2.16) and (2.17)[13] :

$$\mathrm{P_L}\ sub\ urban\ (\mathrm{d}) = \mathrm{P_L} urban\ (\mathrm{d}) - 2\ [\log_{10}(fc/28)]^2 - 4.5 \qquad 2.16$$

And

$$\mathrm{P_L}\ rural(\mathrm{d}) = \mathrm{P_L} urban(\mathrm{d}) - 4.78[\log_{10} fc]^2 + 18.33\ \log_{10} fc - \mathrm{k} \qquad 2.17$$

The Hata model does not provide for any path specific correction factors, as is available in the Okumura model. The Hata model well-approximates the Okumura model for distances d > 1 Km. Thus, it is a good model for first generation cellular systems, but does not model propagation well in current cellular systems with smaller cell sizes and higher frequencies. Indoor environments are also not captured with the Hata model[13].

2.3.2.3 Extended COST-231 Model:

This model (COST 231 final report 1999 cited in Tapan et al. 2003 and Zreikat and Al- Begain) is derived from the Hata model and depends upon four parameters for the prediction of propagation loss: frequency, height of a received antenna, height of a base station and distance between the base station and the received antenna. A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model. The COST-231 Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz. It also contains corrections for urban, suburban and rural (flat) environments[17]. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this particular frequency band. From equation (2.14), the urban model will given by equation (2.18):

$$P_L\ (\text{urban})\ \text{dB} = 46.3 + 33.9\ \log_{10}(fc) - 13.82\ \log_{10}(h_t) - a(h_r) + (44.9 - 6.55\ \log_{10}(h_t))\log_{10} d + \text{CM dB} \qquad 2.18$$

Where $a(h_r)$ the same correction factor as before and CM is 0 dB for medium sized cities and suburbs, and 3 dB for metropolitan areas. This model is referred to as the COST 231 extension to the Hata model[13], and is restricted to the following range of parameters:

- 1.5GHz < fc < 2 GHz,
- 30m < h_t < 200 m,
- 1m < h_r < 10 m,
- 1Km < d < 20 Km.

2.3.2.4 Simplified Path Loss Model:

The complexity of signal propagation makes it difficult to obtain a single model that characterizes path loss accurately across a range of different environments. Accurate path loss models can be obtained from complex analytical models or empirical measurements when tight system specifications must be met or the best locations for base stations or access point layouts must be determined. However, for general tradeoff analysis of various system designs it is sometimes best to use a simple model that captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway[13]. Thus, the following simplified model which is given by equation (2.19) for path loss as a function of distance is commonly used for system design:

$$P_r = P_t\, k \left[\frac{d0}{d}\right]^{\gamma} \qquad 2.19$$

Equation (2.20) show the received power in dB

$$P_r dBm = P_t\, dBm + K\, dB - 10\, \gamma\, \log_{10}\left[\frac{d}{d0}\right] \qquad 2.20$$

So the dB path loss is given by equation (2.21):

$$P_L\, dB = 10\, \gamma\, \log_{10}\left[\frac{d}{d0}\right] - K\, dB \qquad 2.21$$

Where:

- d0 Reference distance for the antenna far-field
- γ Path loss exponent
- d Transmission distances
- K Unit less constant

The value of K <1 is sometimes set to the free space path gain at distance d0 assuming omnidirectional antennas[13]:

$$\mathrm{K\,dB} = 20\ \log_{10}[\lambda/4\,\pi\,\mathrm{d0}] \qquad 2.22$$

The value of γ for more complex environments can be obtained via equation (2.23), a minimum mean square error (MMSE) fit to empirical measurements.

$$\mathrm{F}(\gamma) = \sum_{i=1}^{n}[\mathrm{P}_{measured}\,(di) - \mathrm{P}_{model}\,(di)]^2 \qquad 2.23$$

Where:

$\mathrm{P}_{measured}\,(di)$ Path loss measured at distance di.
$\mathrm{P}_{model}\,(di)$ Path loss that calculated by model.

2.4 Shadow Fading:

Shadow fading (SF), also called slow fading or log-normal shadowing it is random variation in average received power at given distance due obstacles in signal path such as buildings and trees. This log-normally distributed parameter is generally independent of path loss, Egli studied (1957) the error in a propagation model predicting the path loss, using only distance, antenna heights and frequency, For average terrain, he is reported a logarithmic standard deviation which giving random variation about the path loss at a given distance[18].
Experimental results show that the shadow fading can be fairly accurately modeled as a log-normal random variable (Okumura 1968), (Reudink 1972), (Black and Reudink 1972), (Ibrahim and Parsons 1983) and (Gudmundson 1991)[19].
Equation (2.24) show the log-normal distribution is expressed as:

$$\mathrm{P}(\Psi) = \frac{\xi}{\sqrt{2\pi}\,\boldsymbol{\delta}_{\Psi}\,dB}\exp\left[-\frac{(10\ \log_{10}\Psi - \boldsymbol{\mu}_{\Psi} dB)^2}{2\boldsymbol{\delta}^2_{\Psi}\ dB}\right] \qquad 2.24$$

And the distribution of the dB the value of value of Ψ is Gaussian with mean μ_{Ψ} and standard deviation δ_{Ψ} is given by equation (2.25)[13]:

$$P(\Psi)\ dB = \frac{1}{\sqrt{2\pi}\,\delta_{\Psi}\,dB} \exp\left[- \frac{(\Psi dB - \mu_{\Psi}\, dB)^2}{2\delta^2_{\Psi}\, dB}\right] \qquad 2.25$$

Where:

Ψ	Gauss-distributed random variable (0 - δ^2_{Ψ}) dB
ξ	= 10/ ln 10
μ_{Ψ}	Mean of Ψ
δ_{Ψ}	Standard deviation of Ψ
δ^2_{Ψ}	Variance of Ψ

Shadow fading is typically correlated in two ways. First, it is correlated with distance, where the shadow fading value changes slowly with movement of the subscriber. This distance is referred to as a de-correlation distance, is typically tens of meters in urban areas and a few hundred meters in suburban and rural areas. This distance is descriptive of the size of the clutter that obstructs the path to the subscriber. Individual buildings may be the main component of the clutter in urban areas, whereas city blocks or terrain changes may be the clutter in suburban areas[20].

2.5 Combined Path Loss and Shadowing:

This is combination of the simplified path loss model and the log-normal shadowing random process[13]. For such combined model the ratio of received to transmitted power is given by equation (2.26):

$$P_r = P_t\, K \left[\frac{d0}{d}\right]^{\gamma} \Psi \qquad 2.26$$

In dB as:

$$P_r\, dBm = P_t\, dBm + K\, dB - 10\,\gamma\, \log_{10}\left[\frac{d}{d0}\right] - \Psi \qquad 2.27$$

The dB path loss is:

$$P_L\ dB = 10\,\gamma\ \log_{10}\left[\frac{d}{d0}\right] - K\ dB + \Psi\ dB \qquad 2.28$$

Where:

d0	Reference distance for the antenna far-field
γ	Path loss exponent
d	Transmission distances
K	Unitless constant

The variations due to shadowing change more rapidly while simplified path loss slowly changing, and it can be obtained from equation (2.29)[13].

$$\delta^2{}_{\Psi}\, dB = 1/n \sum_{i=1}^{n} [P_{measured}\,(di) - P_{model}\,(di)]^2 \qquad 2.29$$

2.6 Cell Coverage Area:

The cell coverage area in a cellular system is defined as the expected percentage of area within a cell that receives power above a given minimum power (P_{min}) . The transmit power is designed for an average received power at the cell boundary. Thus, transmitting at different power levels leads to different coverage area sizes. Note that, all users within a cell require some minimum received Signal to Noise Ratio (SNR) for acceptable performance[13].

A cellular coverage is designed based on an average received power at P_R the cell boundary with cell radius R. The cell coverage area can be defined as the fraction of cell area where received power is above a given level P_{min}, which is also referred as receiver sensitivity. The cell coverage area (C) can be written as in equation [21]:

$$C = Q(a) + \exp\left(\frac{2-2ab}{b^2}\right)\, Q\left(\frac{2-ab}{b}\right) \qquad 2.30$$

Where, the Q-function is defined as the probability that a Gaussian random variable X with mean 0 and variance 1 is greater than z as it written in equation (2.31)[21].

$$Q(z) = \text{prob}\,(X \geq z) = 1\,\frac{1}{\sqrt{2}\pi}\int_{z}^{\infty} \exp\left(-\frac{x^2}{2}\right)\,dx \qquad 2.31$$

Equations (2.32) and (2.33) explain how we can get (a) and (b)[21] :

$$a = \frac{P_{min} - P_R}{\delta_\Psi} \qquad 2.32$$

$$b = \frac{10\,\gamma\,\log_{10} e}{\delta_\Psi} \qquad 2.33$$

Where:

P_{min} Minimum received power.
P_R Average received power at distance R

This chapter will give a brief overview on the selected area and explain the data collection methodology, measurements and calculations, in addition illustrate the calculations and analyses of the collected data, and how results will be represent in the following chapter. The next section will describe the selected area for data collection then will follow by a section that explains the data collection method and used tools. Then the analyzing of the collected data, describing how to calculate path loss exponent (Gamma γ), shadow factor (Sigma δ) and cell coverage area for each height. The last section will give the consultation of this chapter.

3.1 The Selected Area:

Alriyadh area was chosen for the data collection and measurement, where the BTS located in the north of Alriyadh, This area located in the center of Khartoum, the selected area is characterized by heavily buildings, companies, hospitals and residential high-rise buildings, the height of their building is around 15 meter. Also it has moderate tree with a flat land.

The selected area has good structure to make obstruction to the measured received power, the blockage from buildings and trees giving rise to random variations of the received power at a given distance, this random variation will effect on designed cell coverage area.

3.2 Data Collection Method:

The selected base station is 30 m antenna height and 3 km cell radius with center frequency 415 MHz.

The BTS consists of three sectors each sector has 120 degree directional antenna, The data collection was focused on one sector started from a point near to the BTS and then the position changed to points far away from the BTS but in one line, the received power and position coordinate are the recorded , the position was accurately recorded as pair of latitude and longitude that as given in appendix (A) table (2) using GPS device, at each position the received power was measured for two different height 1m and 3.5m above ground using portable stair 2 m , the received power measured using mobile device.

The total number of taken reading is around 33 measurements, that given in appendix (A) tables (3) and measurement site is shown in figure (3.1).

Figure (3.1) Google earth snap shoot, show the points where the readings recorded

3.3 Analysis And Calculations:

This section will summarize the steps of collected data analysis and explain how to calculate cell coverage area.

3.3.1 Distance Between Transmitter And Receiver:

The recorded latitude and longitude and given BTS coordinate are used to calculate distance between each position of receiver and the transmitter (BTS). The distance is calculated using Haversine formula[22]. The haversine formula is an important in navigation, giving distances between two points on a sphere from their longitudes and latitudes. This formula can be expressed in equation (3.1) [22]:

$$\mathbf{D} = \mathbf{a\,cos}(\mathbf{sin}(\mathbf{lat1}) * \mathbf{sin}(\mathbf{lat2}) + \mathbf{cos}(\mathbf{lat1})\,\mathbf{cos}(\mathbf{lat2}) * \mathbf{cos}(\mathbf{long2} - \mathbf{long1})) * \mathbf{R} \qquad 3.1$$

Where:

D	Distance between transmitter and receiver
acos	Arc cosine
cos	Cosine
sin	Sine
R	Earth's radius =6367 km
lat1	Latitude of transmitter in radian
lat2	Latitude of receiver in radian
long1	Longitude of transmitter in radian
long2	Longitude of receiver

The recorded longitude and latitude can be converting to radian by using equations (3.2) and (3.3):

$$\text{Latitude in radian} = \text{latitude} * \pi/180 \qquad 3.2$$

$$\text{Longitude in radian} = \text{longitude} * \pi/180 \qquad 3.3$$

In this thesis all recorded positions has the same longitude with the transmitter so

$$\text{long2} - \text{long1} = 0, \quad \text{Cos } 0 = 1$$

Equation can be rewritten as:

$$D = a\cos(\sin(lat1) * \sin(lat2) + \cos(lat1)\cos(lat2)) * R \qquad 3.4$$

The following example shows the distance calculation between BTS and first position of receiver:

BTS coordinates:	latitude 15.5768 - longitude 32.56464
First position coordinates:	latitude 15.57552 - longitude 32.56464

BTS:
Latitude in radian (lat1) = $15.5768 * \pi / 180 = 0.27187$ rad
First position:
Latitude in radian (lat2) = $15.57552 * \pi / 180 = 0.27184$ rad

$$D = a\cos(\sin(0.27187) * \sin(0.27184) + \cos(0.27187) * \cos(0.27184)) * 367 * 10^6 = 0.1422 \text{ km}$$

The all calculated distances are given in appendix (A) in tables (2).

3.3.2 Path Loss Exponent Calculation:

Using simplified path loss model in equation (3.5)[13]:

$$P_L \, dB = 10\,\gamma \log_{10}\left[\frac{d}{d0}\right] - K \, dB \qquad 3.5$$

Where:

d0	Reference distance for the antenna far-field
γ	Path loss exponent
d	Transmission distances
K	Unit less constant

Firstly the constant K can be calculated as follows:

$$K \, dB = 20 \log_{10}[\lambda / 4\,\pi\, d0] \qquad 3.6$$

$$d0 = 100m \quad \text{and} \quad \lambda = {}^{c}/_{f}$$

Where:

C	Light velocity ≈ $3 * 10^8$
f	Operating frequency = 415 MHz

$$K = 20 \log_{10} \left[\frac{3 * 10^8}{4 * \pi * 4.15 * 10^8 * 100}\right] dB$$

K= - 64.803 dB

Then the path loss as a function in distance will be:

$$P_L \, dB = 10\,\gamma \log_{10}\left[\frac{d}{d0}\right] + 64.803$$

The value of the path loss exponent (γ) can be obtained via a minimum mean square error (MMSE) fit to simplified path loss measurements for both heights is expressed in equation (3.7) bellow [13]:

$$F(\gamma) = \sum_{i=1}^{n} [P_{measured}(di) - P_{model}(di)]^2 \quad 3.7$$

Where:

$P_{measured}(di)$ Path loss measurement at distance di using given transmitted power and readied received power as shown in appendix (A) table(3). The all $P\ measured$ it were placed in the table (4) in appendix (A).

$P_{model}(di)$ Path loss calculated at distance di using simplified path loss model which is function in γ.

n The total number of measurement

The following explanation shows the calculation of γ for both heights

3.3.2.1 Path Loss Exponent at the Height 1 m:

$$F(\gamma) = \left(P_{measured}(d1) - P_{model}(d1)\right)^2 + \left(P_{measured}(d2) - P_{model}(d2)\right)^2 + \ldots\ldots.. + \left(P_{measured}(d33) - P_{model}(d33)\right)^2$$

$$F(\gamma) = 3991\gamma^2 - 38304.69\,\gamma + 93400.38$$

Then by differentiation $F(\gamma)$ relative to γ and equate the result with zero will got

$$\gamma = 4.7989$$

3.3.2.2 Path Loss Exponent at the Height 3.5 m:

$$F(\gamma) = 3991\gamma^2 - 34534.691\gamma + 75771.337$$

Then by differentiation $F(\gamma)$ relative to γ and equate the result with zero will got

$$\gamma = 4.326$$

Both value of path loss exponent is urban macrocells standard as table (3.1) shows the area is a typical [13]:

Table (3.1): Typical Path Loss Exponents

Environment	**γ range**
Urban macrocells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3

3.3.3 Shadow Factor Calculation:

The standard deviation of shadow fading (δ) can be extracted from the equation (2.29) which it can rewrite as the following formula:

$$\delta = \sqrt{\sum_{i=1}^{n}[P_{measured}\,(di) - P_{model}\,(di)]^2}$$

$$\delta = \sqrt{\frac{1}{33}\left(P_{measured}\,(d1) - P_{model}\,(d1)\right)^2 + \left(P_{measured}\,(d2) - P_{model}\,(d2)\right)^2 + \dots\dots.. + \left(P_{measured}\,(d33) - P_{model}\,(d33)\right)^2}$$

Where:

$P_{measured}$ Measured path loss

P_{model} Path loss calculated using simplified path loss and value of γ.

The following explanation shows the calculation of δ for both heights

3.3.3.1 Shadow Factor at the Height 1m:

$$\delta = \sqrt{0.0303\,[(82.5-71.897)^2+(92.5-85.234)^2\;+\;\ldots+\;(124.5-134.648)^2]}$$

$$\delta = 6.72$$

3.3.3.2 Shadow Factor at the Height 3.5m:

$$\delta = \sqrt{0.0303\,[(82.5-71.897)^2+(92.5-85.234)^2\;+\;\ldots+\;(124.5-134.648)^2]}$$

$$\delta = 5.675$$

3.3.4 Cell Coverage Area:

Finally, in this section we will obtain the step of calculate of the cell coverage area for both heights. The next chapter will discuss the results of these calculations. The cell coverage area will be calculated using the following equation[21]:

$$C = Q(a) + \exp\left(\frac{2-2ab}{b^2}\right)\, Q\left(\frac{2-ab}{b}\right) \qquad 3.8$$

Where, the Q-function is defined as the probability that a Gaussian random variable X with mean 0 and variance 1 is greater than z

$$\begin{aligned} Q(z) &= \text{prob}\ (X \geq z) \\ &= 1\frac{1}{\sqrt{2}\pi}\int_z^\infty \exp\left(-\frac{x^2}{2}\right) dx \end{aligned} \qquad 3.9$$

The conversion between the Q function and complementary error function is[13]

$$Q(z) = \frac{1}{2}\, erfc\, \left(\frac{z}{\sqrt{2}}\right) \qquad 3.10$$

And

$$b = \frac{10\,\gamma\ \log_{10} e}{\delta_{\Psi}} \qquad 3.11$$

And

$$a = \frac{P_{min} - P_R}{\delta_{\Psi}} \qquad 3.12$$

Where:

P_{min} The minimum received power = -95 dBm
P_R Average received power at distance R

The term P_R can be determined from equation (3.13) [13]:

$$P_R\ dBm\ =\ P_t\ dBm\ +\ K\ dB - 10\,\gamma\ \log_{10}\left[\frac{d}{d0}\right] \qquad 3.13$$

Where:

d Distance from BTS (here = R = 3000m)
d0 Reference distance = 100m
K Constant = - 64.803 dB
P_t Transmitted power = 38 dBm
P_R Received power at distance R

The P_R value will be function in γ as bellow:

$$P_R = -26.803 - 14.77\,\gamma \qquad 3.14$$

This chapter will show and discuss the results of cell coverage area that was previous chapter shows how to calculate it. The result will be shown as two plots. Section one will show and discuss path losses, section two gives cell coverage area calculations and discuss the first plot, the cell radius and cell coverage percentage are elements of the plot, section two will show and discuss another plot, this plot consists of a minimum received power and cell coverage percentage.

4.1 Path Loss:

This section will display graphic of measured and model path losses for both height.

4.1.1 Measured Path Loss:

The path loss was calculated from the following express:

$$P_{measuerd}\,\text{dB} = P_t - P_r \qquad 4.1$$

Where:

$P_{measuerd}$	Measured path loss
P_t	= 38.5 dBm

Pr: is received power which was recorded at 33 positions for both heights, that given in appendix (A) in tables (3).

Figure (4.1) shows the scattered plot of the measured path loss for both heights, the green scattered plot represent path loss for height 3.5 m while blue one is belong to short height. The figure clearly shows that the green one always gives the small measured value thus because the high height decrease the distance and the effect of shadowing. The last six measured values is better than the nearby previous measurements, this is because these positions are not surrounded by buildings which reduces the impact of the shadowing.

All values of measured path losses were placed in the table (4) in appendix (A)

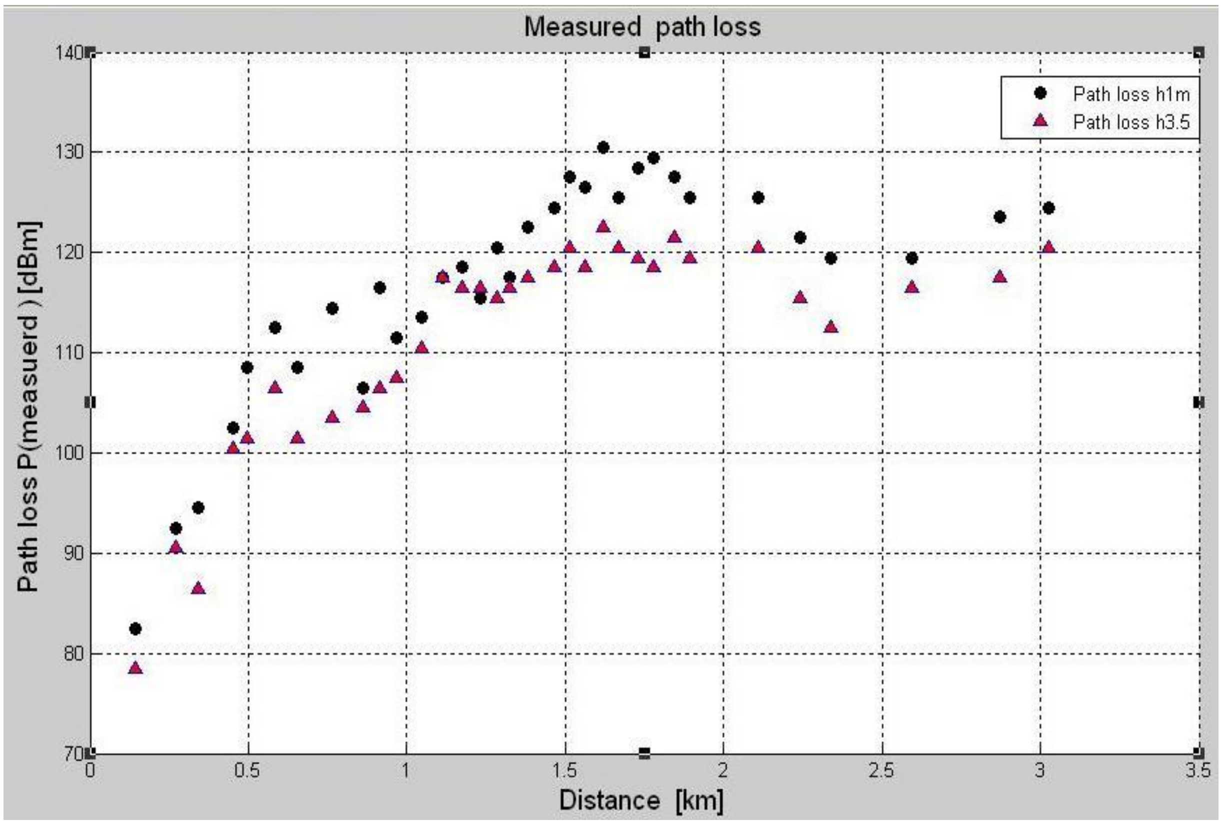

Figure (4.1): Measured path losses

4.1.2 Model Path Loss:

Model path loss means path losses were calculated under simplified path loss formula that was given in equation (2.21), where distance from BTS was gives in appendix (A) table (2), d0 is reference distance =100 m and the constant K calculated in previous chapter and it is equal -64.803.

The figure (4.2) displays plots of the model path loss for both heights where the black curve represents the height 3.5m and the red represents the second height. Graphic shows that the path loss is inversely proportional to the distance. Also height 3.5m all times has less value than height 1m.

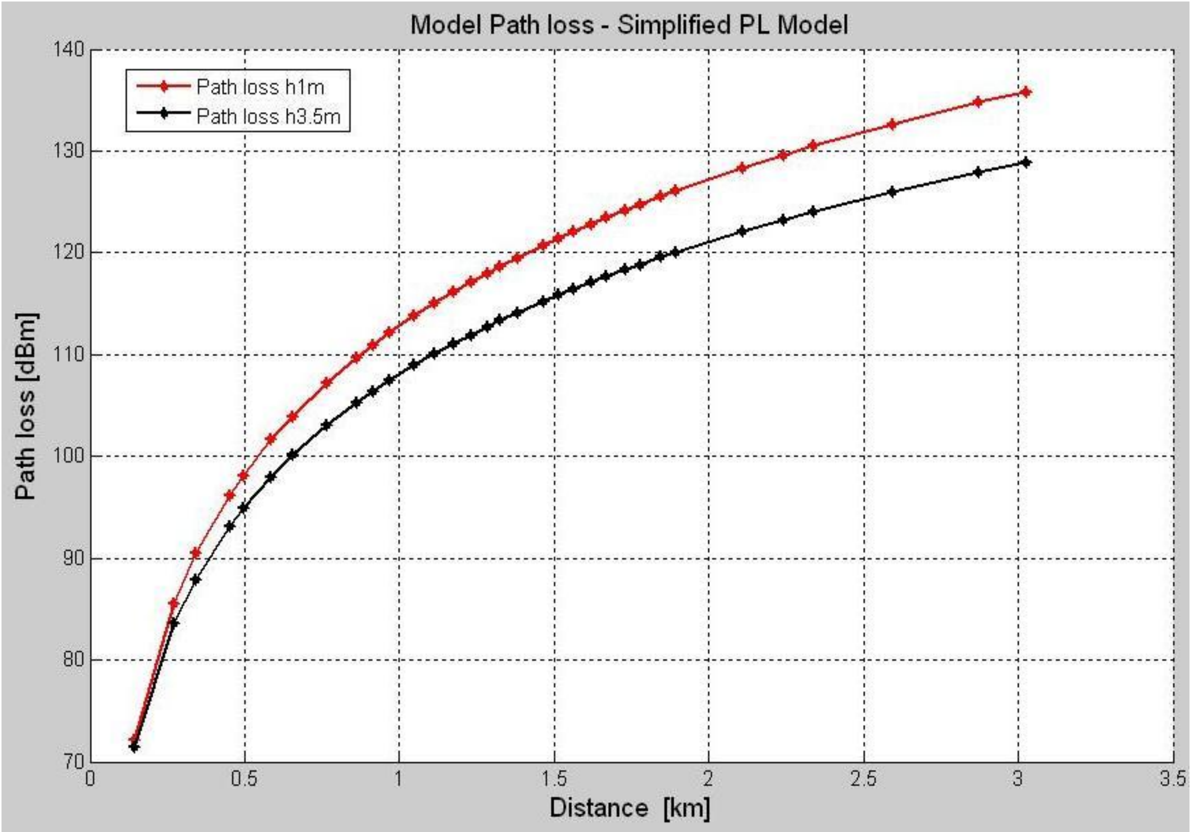

Figure (4.2): Model path loss

4.1.3 Compression Between Measured and Model PL:

Figure (4.3) shows compression between measured and model path loss. There was a little different between measured and model pass loss, the biggest difference when the cell radius equal 2m and it is approximately 10 dBm him is equal

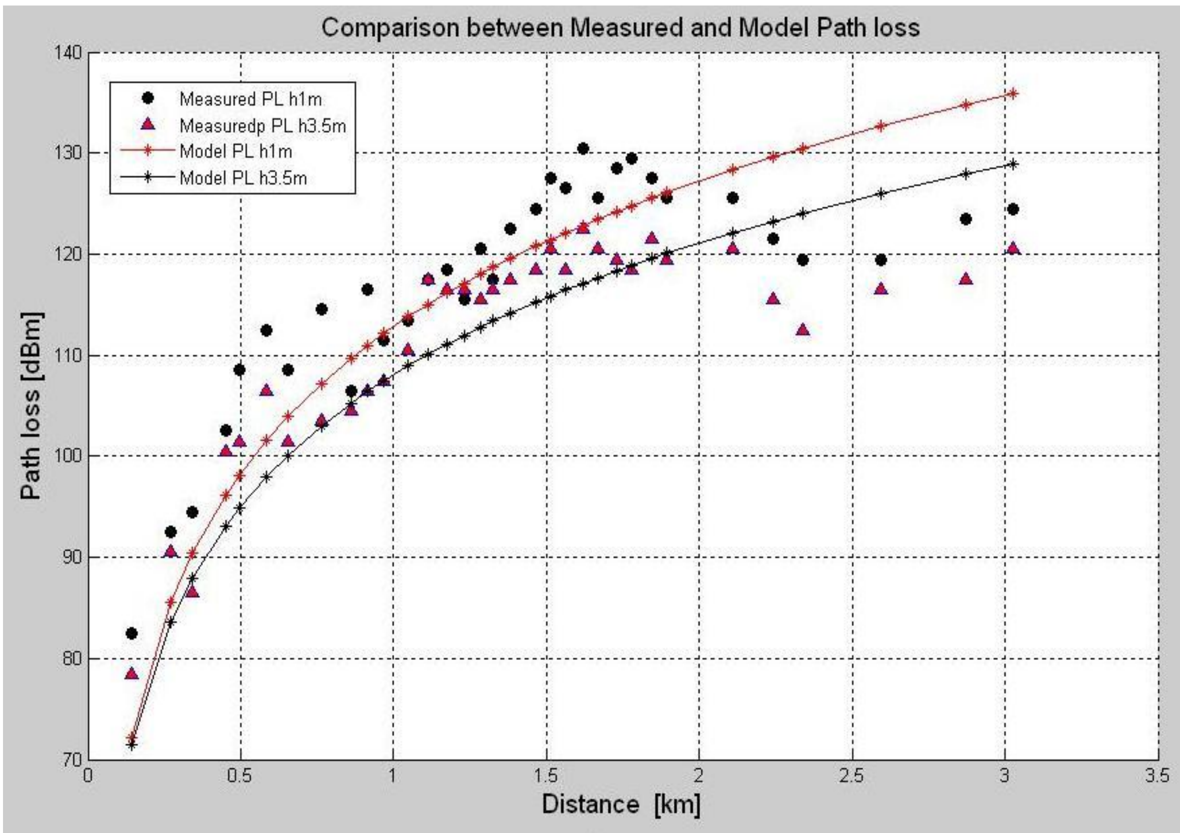

Figure (4.3): Compression between measured and model path loss

4.2 Cell coverage:

This section will show and discuss the result and calculation of the cell coverage percentage.

4.2.1 Cell Coverage in Different Cell Radius:

The theoretical cell radius is around 3 km, we will take values of cell radius in range (1- 5 km) to calculate the cell coverage percentage as it shown in figure (4.4). This gives different values of the average received power P_R that was given at the previous chapter in equations (3.13), and the value of P_{min} will be -95 dBm as the system designed.

In the figure (4.4) the horizontal axis is a distance from BTS in meters (cell radius), While the vertical axis represents the proportion of covered area.

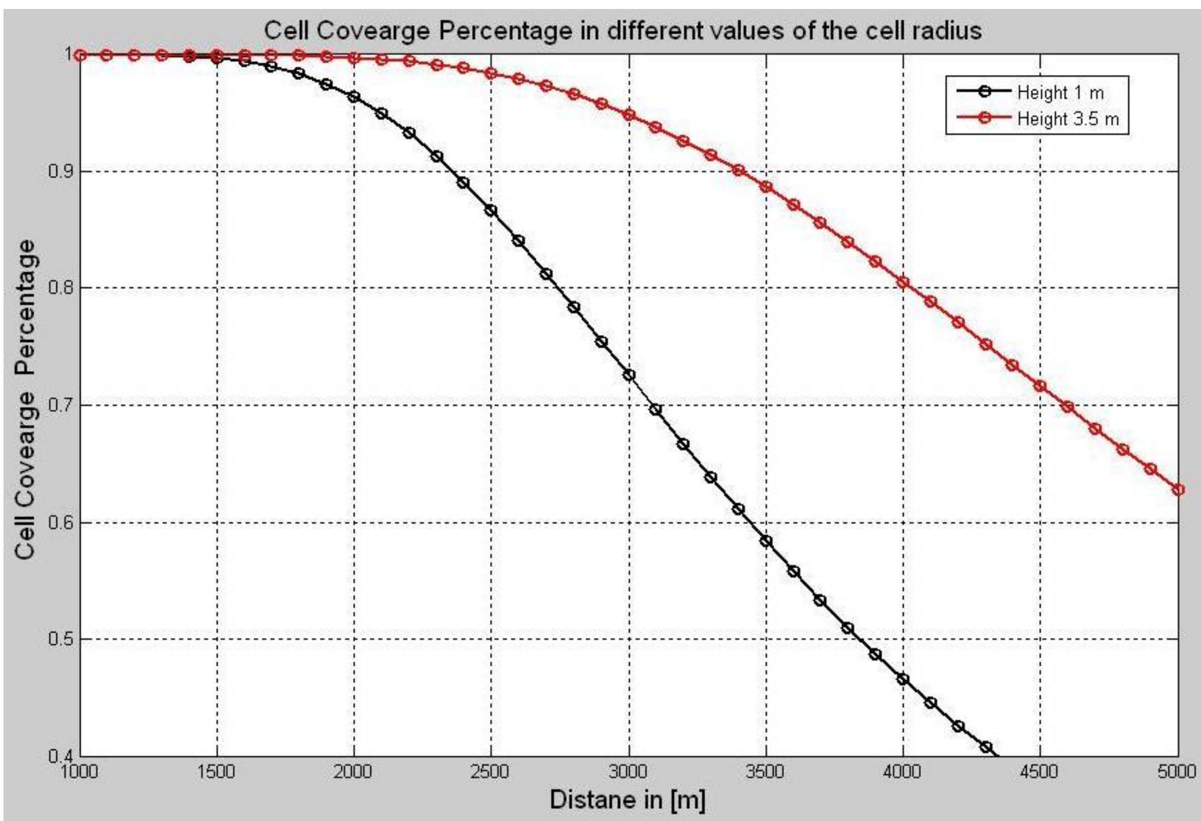

Figure (4.4): Cell coverage in different cell Radius

The following explanation shows the calculation of coverage area for both heights:

4.2.1.1 Cell Coverage at Height 1m:

For this height from the previous calculations found that:

$$\gamma = 4.7989 \qquad \text{And} \qquad \delta = 6.72$$

So by Compensate values of P_{min}, P_R , γ and δ in the equations 3.11 and 3.12 will get:

$$a = \frac{-95+97.68}{6.72} = 0.399$$

And

$$b = \frac{10*4.7989 \ \log_{10}(e)}{6.72} = 3.1$$

Then by offset the values of (a) and (b) in equation (3.8) the percentage of cell coverage area will be:

$$c = Q(0.399) + \exp\left(\frac{2 - 2*3.1*.399}{3.1^2}\right) Q\left(\frac{2 - 3.1*.399}{3.1}\right)$$

$$c = 0.728$$

4.2.1.2 Cell coverage at Height 3.5m:

For this height from the previous calculations found that:

$$\gamma = 4.326 \qquad \text{And} \qquad \delta = 5.675$$

By Compensate values of P_{min}, P_R, γ and δ the equations 3.11 and 3.12 will get:

$$a = \frac{-95 + 90.7}{5.675} = -0.758$$

$$b = \frac{10 * 4.326 * \; l\log_{10} e}{5.675} = 3.31$$

Then by offset the values of (a) and (b) in equation (3.8) the percentage of cell coverage area will be:

$$C = Q(-0.758) + \exp\left(\frac{2 + 2 * 3.31 * 0.758}{3.31^2}\right) Q\left(\frac{2 + 3.31 * 0.758}{3.31}\right)$$

$$C = 0.94$$

The cell coverage areas were calculated for both heights for all values of P_R that given in appendix (B-6), the result was displayed as plot which showed in figure (4.4).

The above figure shows percentage cell coverage area curve for two heights, the red color represented percentage of coverage for height 3.5m and the black on represented percentage of coverage for height 1m.

Table (4.1) evaluated and analyses values of cell coverage for an operational cellular system.

Table (4.1): cell coverage percentage classification

Cell coverage percentage	**Evaluations**
Less than .5	Poor coverage
.5 - .59	Very low coverage
.6 – .69	Low coverage
.7 - .79	Good coverage
.8 - .89	Very good coverage
.9 - 1	Excellent coverage

For height 3.5m (red color) we have acquired excellent coverage values when the cell radius approximately less than or equal 3.5 km. while the lowest value we get greater than .6 at cell radius equal 5 km, which mean low coverage value, and thus make customer unsatisfied. So the theoretical value of cell radius leads to excellent coverage.

For height 1m (black color) we have acquired excellent coverage values when the cell radius approximately less than or equal 2.5 km. and the lowest value we get is 0.4 at cell radius approximately equal 4.5 km, this value is unacceptable and Impractical.

4.3.2 Cell Coverage in Case of Different Minimum Received Powers:

This section will show and discuss cell coverage percentage calculated using multiple minimum received power.

The setting of minimum power is -95dBm, here we suppose values of minimum power received start from -87 and end in -105, this will make changes in the calculated cell coverage values, because it will gives several values of character (a) Which (a) is given by equation (3.11) Where: P_{min} takes discrete values from -87 to -105 dBm, the average received power P_R was calculated when R= 3 km and δ was calculated in pervious chapter for both heights.

The result was illustrate in figure (4.5) bellow, where red color represent cell coverage curve for height 3.5m and black color represent cell coverage curve for height 1m.

For height 3.5 m, the excellent coverage percentage when the minimum received power is equal or less than -93 dBm, and the lowest value at P_{min} = -87, which is equal 0.7, and it means good coverage.

For height 1m if minimum received set at -90dBm this will lead to very low percentage coverage, which is impractical for cellular system, because it means many customers will be out of coverage, and this will require additional cell to cover them. The excellent coverage when minimum received power is equal to -100 dBm or less.

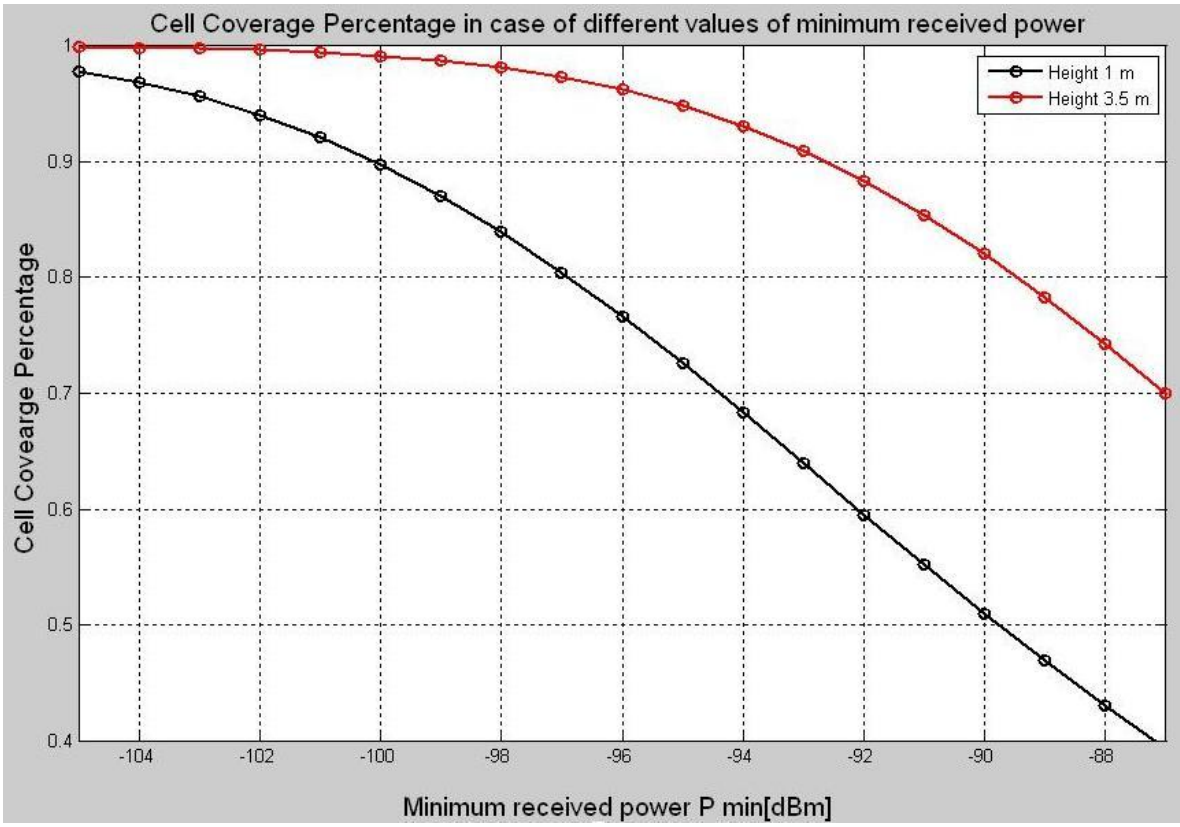

Figure (4.5): Cell coverage in case of different minimum received power

Compression between height one and two clearly shows that height 3.5 m always gives bigger coverage area at the same minimum received power, for example at P_{min} = -95 dBm the cell coverage percentage in height 3.5 is 0.95 and in height 1m is 0.73, this mean within height 3.5m we get excellent coverage percentage, but the value of coverage percentage will decrease when the height decrease.

CHAPTER FIVE CONCULUSION AND RECOMMUNDIATIONS

5.1 Conclusion:

In this thesis the percentage of cell coverage area has been found out for two different mobile heights, and the comparison between them have done.

The measurement collection of the received signal level also achieved, at the selected area (Alriayadh), then the simplified path loss and percentage cell coverage area has been founded for both heights. Firstly, the path loss exponents were founded, and it is achieved value is (4.326 for height 3.5m and 4.7989 for height 1m) that describe the urban environment with higher attenuation where this result agree with the assumption. Secondly, the shadow factors have been calculated where its values are (5.675 for height 3.5m and 6.72 for height 1m).

Then the measured path loss has been calculated at all positions where the received power has been read, and its graph has been figured. Secondly the model path loss calculated where the simplified path loss model was used, and then its values were plotted. And comparison between model path loss and simplified path loss was done. All of this has been done for both heights.

Finally the percentage of the cell coverage area were achieved, where its values has been plotted, this done in two way, firstly assumed constant value to the minimum received power (-95dBm as the net work theoretical designed) and multiple values to the cell radius. Secondly we assumed constant value to the cell radius (3 km as the net work theoretical designed) and multiple values to the minimum received power. All of this has been done for both heights, and the comparison between them have done.

Under theoretical design the percentage of the cell coverage area is achieved value is 0.728 at height (1m) and 0.94 at height (3.5m).so the highest height always gives best converge percentage.

5.2 Recommendations:

From the result of this thesis we recommended:

We strongly recommend for depth study taking into account more than two heights In order to discover empirical relation between height with cell coverage percentage and height with path loss.

Also we recommend covering another city or other residential areas, which have different characteristic and environments.

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Appendix A

Recorded and Measured Data

Table 1: BTS data

1	Base Station Name	Alriyadh
2	Base Station height	30 m
3	BTS Antenna type	Directional
4	BTS Transmitter Power	38.5 dBm
5	BTS Latitude	15.576819
6	BTS Longitude	32.564754

Table 2: Distances from BTS

Num	Latitude N	Longitude E	Distance in km
BTS	15.5768	32.56464	0
1	15.57552	32.56464	0.1422
2	15.57436	32.56464	0.2711
3	15.57372	32.56464	0.3422
4	15.57275	32.56464	0.4500
5	15.57234	32.56464	0.4956
6	15.57153	32.56464	0.5856
7	15.57091	32.56464	0.6545
8	15.56992	32.56464	0.7645
9	15.56906	32.56464	0.8601
10	15.56856	32.56464	0.9156

11	15.56809	32.56464	0.9679
12	15.56736	32.56464	1.0490
13	15.56678	32.56464	1.1134
14	15.56622	32.56464	1.1756
15	15.56572	32.56464	1.2312
16	15.56522	32.56464	1.2868
17	15.56486	32.56464	1.3268
18	15.56436	32.56464	1.3823
19	15.56361	32.56464	1.4657
20	15.56317	32.56464	1.5146
21	15.56272	32.56464	1.5646
22	15.56222	32.56464	1.6201
23	15.56178	32.56464	1.6690
24	15.56122	32.56464	1.7312
25	15.56080	32.56464	1.7779
26	15.56019	32.56464	1.8457
27	15.55975	32.56464	1.8946
28	15.55783	32.56464	2.1079
29	15.55664	32.56464	2.2402
30	15.55575	32.56464	2.3391
31	15.55347	32.56464	2.5924
32	15.55094	32.56464	2.8736

Table 3: Received powers

Num	Latitude N	Longitude E	H 3.5m Pr in dBm	H 1m Pr in dBm
1	15.57552	32.56464	-40	-44
2	15.57436	32.56464	-52	-54
3	15.57372	32.56464	-48	-56
4	15.57275	32.56464	-62	-64
5	15.57234	32.56464	-63	-70
6	15.57153	32.56464	-68	-74
7	15.57091	32.56464	-63	-70
8	15.56992	32.56464	-65	-76
9	15.56906	32.56464	-66	-68
10	15.56856	32.56464	-68	-78
11	15.56809	32.56464	-69	-73
12	15.56736	32.56464	-72	-75
13	15.56678	32.56464	-79	-79
14	15.56622	32.56464	-78	-80
15	15.56572	32.56464	-78	-77
16	15.56522	32.56464	-77	-82
17	15.56486	32.56464	-78	-79
18	15.56436	32.56464	-79	-84
19	15.56361	32.56464	-80	-86
20	15.56317	32.56464	-82	-89

21	15.56272	32.56464	-80	-88
22	15.56222	32.56464	-84	-92
23	15.56178	32.56464	-82	-87
24	15.56122	32.56464	-81	-90
25	15.56080	32.56464	-80	-91
26	15.56019	32.56464	-83	-89
27	15.55975	32.56464	-81	-87
28	15.55783	32.56464	-82	-87
29	15.55664	32.56464	-77	-83
30	15.55575	32.56464	-74	-81
31	15.55347	32.56464	-78	-81
32	15.55094	32.56464	-79	-85
33	15.549583	32.56464	-82	-86

Table 4: Path loss

Num	***Distance in km***	***H 3.5m Measured path loss***	***H 1m Measured path loss***
1	0.1422	78.5	82.5
2	0.2711	90.5	92.5
3	0.3422	86.5	94.5
4	0.4500	100.5	102.5
5	0.4956	101.5	108.5
6	0.5856	106.5	112.5
7	0.6545	101.5	108.5
8	0.7645	103.5	114.5
9	0.8601	104.5	106.5
10	0.9156	106.5	116.5
11	0.9679	107.5	111.5
12	1.0490	110.5	113.5
13	1.1134	117.5	117.5
14	1.1756	116.5	118.5
15	1.2312	116.5	115.5
16	1.2868	115.5	120.5
17	1.3268	116.5	117.5
18	1.3823	117.5	122.5
19	1.4657	118.5	124.5
20	1.5146	120.5	127.5

21	1.5646	118.5	126.5
22	1.6201	122.5	130.5
23	1.6690	120.5	125.5
24	1.7312	119.5	128.5
25	1.7779	118.5	129.5
26	1.8457	121.5	127.5
27	1.8946	119.5	125.5
28	2.1079	120.5	125.5
29	2.2402	115.5	121.5
30	2.3391	112.5	119.5
31	2.5924	116.5	119.5
32	2.8736	117.5	123.5
33	3.0244	120.5	124.5

Appendix B

Matlab Code of Calculations

1-The function that calculated Distance between transmitter and receiver

```
% Program to calculate surface distance between two points
% on Earth given the latitude and longitude
% Alreiad lat1 and lon1

lat1= 15.5768;
lon1= 32.56464;

%lat2 33 position were pr have been taken

lat2=
[15.57552,15.57436,15.57372,15.57275,15.57234,15.57153,15.57091,15.56992,15.
56906,15.56856,15.56809,15.56736,15.56678,15.56622,15.56572,15.56522,15.5648
6,15.56436,15.56361,15.56317,15.56272,15.56222,15.56178,15.56122,15.56080,15.
56019,15.55975,15.55783,15.55664,15.55575,15.55347,15.55094,15.549583];

latrad1 = lat1*pi/180

latrad2=zeros(1,33);

for i=1:33
   latrad2(i)=lat2(i)*pi/180

end

distrad=zeros(1,10);
distnaut=zeros(1,10);
dist=zeros(1,10);

for k=1:33
distrad(k) = acos(sin(latrad2(k))*sin(latrad1)+cos(latrad2(k))*cos(latrad1))
distnaut(k) = distrad(k) * 3437.74677;
dist(k) = distnaut(k) * 1.852*1000
end
```

2- The function that calculated Measured Path loss

A-height 1m

```
function [ploss]=measuredPL()
% Prh1 = received powers at height 1

Prh1 = [-44,-54,-56,-64,-70,-74,-70,-76,-68,-78,-73,-75,-79,-80,-77,-82,-79,-84,-86,-89,-88,-92,-87,-90,-91,-89,-87,-87,-83,-81,-81,-85,-86];

for i = 1:33
   % path loss = transmit power - received power
   ploss(i) = 38.5 – Prh1(i)
end
end
```

B-height 3.5m

```
function [ploss]=measuredPL()
 Prh2 = received powers at height 2

Prh2 = [-40,-52,-48,-62,-63,-68,-63,-65,-66,-68,-69,-72,-79,-78,-78,-77,-78,-79,-80,-82,-80,-84,-82,-81,-80,-83,-81,-82,-77,-74,-78,-79,-82];


for i = 1:33
   ploss(i) = 38.5 - Prh2(i);
end
end
```

3- The function that calculated Path loss exponent

```
function [S,fgamma,dist,samples]=simplified()
%gamma it is path loss exponent which characterize the environment
clear
clc
syms gma;

 k = - (20*log10((4*pi*100*415*10^6)/(3*10.^8)));
```

```
dist= [0.1422,0.2711,0.3422,0.4500,0.4956,    0.5856,    0.6545,    0.7645,
0.8601,0.9156    ,0.9679,    1.0490,    1.1134 ,    1.1756 ,    1.2312 ,    1.2868  ,  1.3268  ,
1.3823, 1.4657 ,    1.5146    ,1.5646    , 1.6201  ,  1.6690    , 1.7312 ,    1.7779    , 1.8457 ,
1.8946, 2.1079    , 2.2402    , 2.3391  ,  2.5924    ,2.8736    ,3.0244]

for d=1:33
    x=dist(d);
       PL(d)=  gma.*round(10.*log10((x.*1000)/(100)))-k
       % PL is simplified path loss formula
end

At= PL

 fgamma=vpa(At)  % Variable Precision Arithmetic Vpa symbolic tool convert to
decimal rather than rational

[ploss]=measuredPL();

for i= 1:33
   Fgama(i)= (ploss(i)-fgamma(i))^2
end
E=expand(Fgama)   % expand the full square and add them together
s = sum(E) % sum the elements of matrix together in one 2nd order equation
dif=diff(s)   % differentiation the gama function
S=solve(dif,gma)% find the path loss exponent by solving the 1st order equation
gamm2=fgamma;
end
```

4- The function that calculated Shadow Factor

```
function []=test(S,fgama,dist)
clear all
clc

[S,fgama,dist]= gama()

[ploss]=measuredPL()

%gama = path loss exponent
H=fgama
syms gma
  nn=S;
iii=(subs(H, gma, nn)) % substitute gama value to find the predicted path loss

% to calculate the variance of shadow fading
for k= 1:33
```

```
  Fgama(k)= (ploss(k)-iii(k))^2
end
sigma2= sqrt(0.0303.*sum(vpa((Fgama)))) % standard deviation  0.0189 it is 1\53
end
```

5- Path Loss functions

A- Model Path loss

```
clear all
clear
clc
d =
[0.1422,0.2711,0.3422,0.4500,0.4956,0.5856,0.6545,0.7645,0.8601,0.9156,0.9679,1.04
90,1.1134,1.1756,1.2312,1.2868,1.3268,1.3823,1.4657,1.5146,1.5646,1.6201,1.6690,1.7
312,1.7779,1.8457,1.8946,2.1079,2.2402,2.3391,2.5924,2.8736,3.0244];

k=-64.803;
gamma1=4.7989;
gamma2=4.326;

for i=1:33

   plossm1(i)=10*gamma1*log10(d(i)*10)-k;
   plossm2(i)=10*gamma2*log10(d(i)*10)-k;

end

grid on
 axis([0 3.5 70 140]);
grid on
hold on
title('Model path loss')
plot(d,plossm1,'o-r','LineWidth',2)
hold on
plot(d,plossm2,'o-k','LineWidth',2)
x=xlabel('distance  [km]');
set(x,'Fontsize',11);
y=ylabel('Path loss [dBm]');
set(y,'Fontsize',11);
legend('path loss h1','path loss h2')
```

B- Measured Path loss

```
clear all
clear
clc

pr1 = [-44,-54,-56,-64,-70,-74,-70,-76,-68,-78,-73,-75,-79,-80,-77,-82,-79,-84,-86,-89,-
88,-92,-87,-90,-91,-89,-87,-87,-83,-81,-81,-85,-86];
pr2 = [-40,-52,-48,-62,-63,-68,-63,-65,-66,-68,-69,-72,-79,-78,-78,-77,-78,-79,-80,-82,-
80,-84,-82,-81,-80,-83,-81,-82,-77,-74,-78,-79,-82];

d =
[0.1422,0.2711,0.3422,0.4500,0.4956,0.5856,0.6545,0.7645,0.8601,0.9156,0.9679,1.04
90,1.1134,1.1756,1.2312,1.2868,1.3268,1.3823,1.4657,1.5146,1.5646,1.6201,1.6690,1.7
312,1.7779,1.8457,1.8946,2.1079,2.2402,2.3391,2.5924,2.8736,3.0244];

k=-64.803;
gamma1=4.7989;
gamma2=4.326;
pt=38.5;

for i=1:33
   plossl1(i) = pt - pr1(i);
   plossl2(i) = pt - pr2(i);

end

grid on
 axis([0 3.5 70 140]);
 scatter(d,plossl1)
grid on
hold on
scatter(d,plossl2)
grid on
hold on
title('Measured  path loss')
legend('path loss h1','path loss h2')
x=xlabel('distance  [km]');
set(x,'Fontsize',11);
y=ylabel('Path loss [dBm]');
set(y,'Fontsize',11);
```

C- Model and Measured Comparison

```
clear all
clear

pr1 = [-44,-54,-56,-64,-70,-74,-70,-76,-68,-78,-73,-75,-79,-80,-77,-82,-79,-84,-86,-89,-88,-92,-87,-90,-91,-89,-87,-87,-83,-81,-81,-85,-86];
pr2 = [-40,-52,-48,-62,-63,-68,-63,-65,-66,-68,-69,-72,-79,-78,-78,-77,-78,-79,-80,-82,-80,-84,-82,-81,-80,-83,-81,-82,-77,-74,-78,-79,-82];

d =
[0.1422,0.2711,0.3422,0.4500,0.4956,0.5856,0.6545,0.7645,0.8601,0.9156,0.9679,1.0490,1.1134,1.1756,1.2312,1.2868,1.3268,1.3823,1.4657,1.5146,1.5646,1.6201,1.6690,1.7312,1.7779,1.8457,1.8946,2.1079,2.2402,2.3391,2.5924,2.8736,3.0244];

k=-64.803;
gamma1=4.7989;
gamma2=4.326;
pt=38.5;

for i=1:33
   plossl1(i) = pt - pr1(i);
   plossl2(i) = pt - pr2(i);
   plossm1(i)=10*gamma1*log10(d(i)*10)-k;
   plossm2(i)=10*gamma2*log10(d(i)*10)-k;
end

grid on
 axis([0 3.5 70 140]);
 scatter(d,plossl1)

grid on
hold on
scatter(d,plossl2)
grid on
hold on
plot(d,plossm1,'o-r','LineWidth',2)
hold on
plot(d,plossm2,'o-k','LineWidth',2)
title('Comparison between Measured and Model Path loss')
legend('Measured PL h1','Measuredp PL h2','Model PL h1','Model PL h2')
```

```
x=xlabel('distance  [km]');
set(x,'Fontsize',11);
y=ylabel('Path loss [dBm]');
set(y,'Fontsize',11)
```

6- Cell coverage functions

A- In different Cell Radius

```
%cov is the cell coverage area which is calculate by the following
%equation c=Q(a)+exp((2-2ab)/b^2 )  Q((2-ab)/b)
clear all;
clc

 gamma1=4.865;
 sigma1=5.514;
 gamma2=4.326;
 sigma2=5.675;
 Pmin=-95;
 k=-64.8;
 i=1;
 cov1=zeros(1,40);
 cov2=zeros(1,40);
 dd=zeros(1,40);
 for d=10:50
  dd(i)=d ;
  %::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  %::::
 PavgrR=38.5+k-(10*gamma1*log10(d));
 %Pavgr(R)is Received power at cell boundary = Pt + K dB + 10gamalog10 [d/d0]
 a=(Pmin-PavgrR)/sigma1;
 b=(10*gamma1*log10(2.72))/sigma1;
 H=(2-a*b)/b;
 I=(2-2*a*b)/b^2;
 E=0.5*erfc(a/sqrt(2));
F=0.5*erfc(H/sqrt(2));
G=exp(I);

 C=E+F*G;
 cov1(i)=C;
  %::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

 PavgrR=38.5+k-(10*gamma2*log10(d));
 %Pavgr(R)is Received power at cell boundary = Pt + K dB + 10gamalog10 [d/d0]
 a=(Pmin-PavgrR)/sigma2;
 b=(10*gamma2*log10(2.72))/sigma2;
 H=(2-a*b)/b;
```

```
 I=(2-2*a*b)/b^2;
 E=0.5*erfc(a/sqrt(2));
F=0.5*erfc(H/sqrt(2));
G=exp(I);

 C=E+F*G;
 cov2(i)=C;
  i=i+1;
  end

  figure(1);
  plot(dd*100,cov1,'o-k','LineWidth',2);

   hold on

  plot(dd*100,cov2,'o-r','LineWidth',2);
  hold on

  grid on
  axis([1000 5000 .4 1]);
  title('cell Covearge Percentage in different values of the cell radius
')
legend('Height 3.5 m','Height 1 m')

x=xlabel('Distane in [m]');
set(x,'Fontsize',11);
y=ylabel('Covearge  %');
set(y,'Fontsize',11);
```

B- With different minimum received power

```
%cov is the cell coverage area which is calculate by the following
%equation c=Q(a)+exp((2-2ab)/b^2 )  Q((2-ab)/b)
clear all;
clc

 gamma1=4.865;
 sigma1=5.514;
 gamma2=4.326;
 sigma2=5.675;
 D=30;% D=d/d0 = 3000/100
 k=-64.8;
 i=1;
 cov1=zeros(1,-105);
 cov2=zeros(1,-105);
 dd=zeros(1,-105);
 for Pmin=-105:-85
```

```
 dd(i)=Pmin ;
 %::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
 %::::
PavgrR=38.5+k-(10*gamma1*log10(D));
%Pavgr(R) is Received power at cell boundary = Pt + K dB + 10gamalog10 [d/d0]
a=(Pmin-PavgrR)/sigma1;
b=(10*gamma1*log10(2.72))/sigma1;
H=(2-a*b)/b;
I=(2-2*a*b)/b^2;
E=0.5*erfc(a/sqrt(2));
F=0.5*erfc(H/sqrt(2));
G=exp(I);

C=E+F*G;
cov1(i)=C;
 %::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

PavgrR=38.5+k-(10*gamma2*log10(D));
%Pavgr(R)is Received power at cell boundary = Pt + K dB + 10gamalog10 [d/d0]
a=(Pmin-PavgrR)/sigma2;
b=(10*gamma2*log10(2.72))/sigma2;
H=(2-a*b)/b;
I=(2-2*a*b)/b^2;
E=0.5*erfc(a/sqrt(2));
F=0.5*erfc(H/sqrt(2));
G=exp(I);

C=E+F*G;
cov2(i)=C;
i=i+1;
end

figure(1);
plot(dd,cov1,'o-k','LineWidth',2);

 hold on

plot(dd,cov2,'o-r','LineWidth',2);
hold on

grid on
axis([-105 -87 .4 1]);
title('cell Covearge Percentage In different values of the Pminimum ')
legend('Height 3.5 m','Height 1 m')

x=xlabel('powermini [dBm]');
```

```
set(x,'Fontsize',11);
y=ylabel('Covearge Percentage  %');
set(y,'Fontsize',11);
```