Comparative Analysis for Radio Channel Propagation Models in the City of Tripoli/ Libya for 4G/LTE Networks

Asma Abdurahman[1,*], Monera Salah[2], Khalid Aljledi[3], Maram Salah Alrezzagi[1]
[1]Department of Electrical and Electronic Engineering, Gharyan University, Gharyan, Libya
Email: asma.abdurahman@gu.edu.ly, maram.alrezzagi@gmail.com
[2]TeleWorld Solutions, Chantilly, VA, USA
Email: monera.salah@teleworldsolutions.com
[3]Great Made River Project, Tripoli, Libya
Email: khalidaljledi@gmail.com
[*] *Corresponding author*

Abstract: **The accurate prediction of radio channel propagation is one of the most important factors for the design and optimization of wireless communication systems. Path loss is the key element to design appropriate propagation model. There are different propagation models used to predict path loss, however, inaccurate propagation model may result in unsatisfactory services for the Global System for Mobile communications (GSM) network. These include low data rates, high co-channel interference, and wasted received power.**

This paper presents a comparative analysis of radio channel propagation models specifically for urban environment. The aim is to evaluate and compare the performance of various models and accurately predict path loss and signal behavior in urban settings. The research focuses on adapting the Okumura-Hata model which is used by the Libya Telecom and Technology Company (LTT) for Long Term Evolution (LTE) technology in the GSM Band. This study is based on real time measurements collected in downtown Tripoli in Libya. It suggests considering other models, such as Standard Propagation Model (SPM), Cost-231, and Ericsson. Using MATLAB for simulation, the findings indicate that SPM model is the best fit especially when distance is over ~22 Km.

Keywords: **4G/LTE, Path loss, Okumura Hata, Propagation Models**.

I. INTRODUCTION

The rapid evolution of wireless communication technologies has propelled the widespread deployment of Fourth Generation (4G) and Long-Term Evolution (LTE) systems, catering to the increasing demand for high-speed data transmission. A critical aspect of designing and optimizing these networks revolves around understanding radio channel propagation. Radio channel propagation models play an undisputable role in predicting and analyzing the behavior of wireless signals as they traverse from the transmitter to the receiver in diverse environments, urban, suburban or rural. These models provide valuable insights into signal strength, path loss, fading, and interference, enabling network planners and engineers to make informed decisions for network design and optimization [1].

Since LTE utilizes a range of frequency bands across different regions, there are numerous radio propagation models that can be employed in various terrains. These propagation models can be categorized into three distinct groups. The first category consists of empirical models, such as the Okumura models, Hata models, and log-distance models, which rely on measurements specific to a particular region. While these models provide simple representation of the obstacles encountered by the signal during its transmission from the transmitter to the receiver, as well as accounting for multipath and shadowing effects, they tend to lack precision. The second category comprises semi-empirical models, which combine appropriate statistical factors with the representation of physical phenomena. Examples of such models include the two-ray model and Cost-231 models. By adjusting the parameter values, the accuracy of these models can be enhanced. The third and final category encompasses deterministic models that necessitate comprehensive information about the 3D terrain map in order to calculate the received signal strength at specific points. The ray-tracing model is an example of such models. These models are characterized by complex mathematical expressions and take into consideration all obstacles encountered by the transmitted signal, as well as the environmental conditions [2,3].

The study involves both the empirical and semi-empirical propagation models to determine the pathloss, for LTE/4G networks in an urban environment with 800 MHz frequency band. Different radio propagation models are used in this work such as Okumura, Hata, Okumura-Hata, Cost-231, Ericsson and SPM, to determine the most appropriate model for The Libya Telecom and Technology Company (LTT) and compare it with the one used by the company, the Okumura-Hata model. This study is based on real time measurements collected in downtown Tripoli in Libya. MATLAB software is used for simulation.

The comparison is primarily based on factors such as distance between the transmitter and the receiver, in the first scenario, and the antenna height, in the second scenario. The theoretical calculations will explore alternative models for urban terrain. These findings may be considered by LTT in their future practical LTE network layout designs.

II. RADIO WAVE PROPAGATION MODELS

In recent years, significant advancements have been made in the field of radio channel propagation modeling for 4G/LTE systems. Researchers have developed and studied various models that aim to capture the complex characteristics of wireless signals in different propagation environments, such as urban, suburban, and rural areas. These models consider an array of factors, including distance, terrain, building structures, and interference sources, to accurately characterize the wireless channel [3]. The selection of an appropriate radio channel propagation model depends on several factors, including the frequency band, geographical region, and deployment scenario of the wireless network. Network planners must carefully evaluate these factors to choose the most suitable model for accurate predictions and optimal network performance. This ensures that the network is designed and optimized to provide reliable and high-quality wireless services [4]. These models are based on empirical data and formulas are developed to match the collected data. However, these formulas are only accurate within certain ranges of the data, which limits their predictive capability. The accuracy of the model also depends on parameters such as antenna heights, carrier frequency, and the type of environment. Macroscopic propagation models, which are used to predict coverage areas in cellular networks, can be categorized into basic, statistical, and deterministic models [5]. Basic propagation models provide a simple estimation of path loss and serve as a foundation for understanding more advanced models that will be discussed in this paper.

A. Okumura Model

Okumura model is one of the most widely used models for signal prediction. It can be used for frequencies in the range of 200–1925 MHz (it can be expanded up to 3000 MHz [2]). The distance between transmitter and receiver can be around 100 km while the receiver height can be 3 m to 10 m [2,6]. While this model is not suitable for urban areas, it serves as the foundation upon which other models were developed. Therefore, it is crucial to begin with this model despite its limitations. The path loss in Okumura model can be calculated as [1]:

$$PL[dB] = L_F + A(m,n)(f,d) - G(h_b) - G(h_r) - G_{Area} \quad (1)$$

Here L_F is the free space path loss and it is calculated by:

$$L_F = -20\log(\frac{\lambda}{4\pi d}) \quad (2)$$

Where, λ is the wavelength in (m), d is the distance in (km). $G(h_b)$ and $G(h_r)$ are the base station and the receiver antenna gain factors. They can be calculated as follows:

$$G(h_b) = 20\log\left(\frac{h_b}{200}\right) \quad (3)$$

$$G(h_r) = 10\ log\left(\frac{h_r}{3}\right) \quad (4)$$

Where, h_b and h_r are the heights of base station and receiver receptively. A(m, n)(f,d) is called as median attenuation factor. Different curves for median attenuation factor are used depending on the frequency and the distance between the transmitter and receiver, Fig. 1(a). G_{Area} is based on type of area along with median attenuation factor from Fig. 1(b) [3].

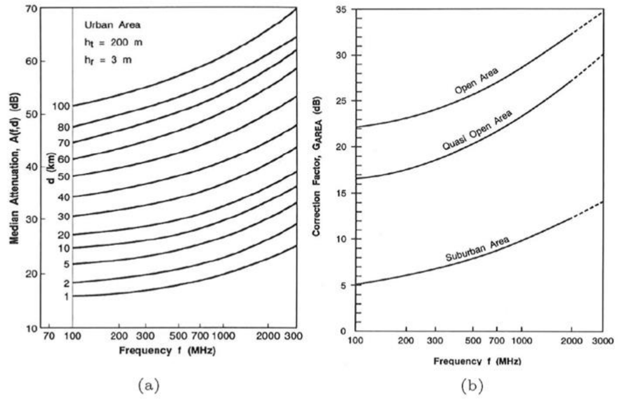

Fig. 1. (a) Median attenuation factor for Okumura model, and (b) correction factor for Okumura model [3].

B. Hata Model

In 1980, Masher Hata made advancements to the Okumura model by creating a simplified version with a set of equations. This simplification reduced the number of parameters required from the user to only four. By considering the frequency, transmitted distance, height of the base station antenna, and height of the mobile antenna, one could reasonably predict the propagation loss expected in the original Okumura model. However, it should be noted that the calculated losses using the Hata model start to differ from the Okumura curves beyond certain limits [3,6].

For this model, Median path loss in urban areas is given by [6]:

$$P_L(dB) = 46.3 + 33.9\log(f) - 13.02\log(h_b) - a(h_r) + [44.9 - 6.55\log(h_b)\ logd + c] \quad (5)$$

Where, F represents the frequency in MHz, d denotes the distance between the transmitter and receiver, h_b and h_r the correction factors for base station height and receiver height respectively. The parameter c is zero for suburban and rural environments while it has a value of 3 for urban area. And the function $a(h_r)$ for urban area is defined as [7]:

$$a(h_r) = 3.2(\log(11.75h_r))^2 - 4.97 \quad (6)$$

And for rural area it is given by:

$$a(h_r) = (1.1\log(f)) - 0.7h_r - (1.58\log(f) - 0.8 \quad (7)$$

C. Okumura-Hata Model

The Okumura-Hata model is probably one of the most extensively used path loss models globally when it comes to cellular applications [8,9].

Two forms of the Okumura-Hata model are available. In the first form, the path loss [10]:

$$PL = PL_{free\ space} + A_{exc} + H_{cb} + H_{cm} \quad (8)$$

Where $PL_{free\ space}$ is the free space path loss, A_{exc} is the excess path loss (as a function of distance and frequency).

H_{cb} and H_{cm} are correction factors.

The more common form is a curve fitting of Okumura's original results. In that implementation, the path loss is written as:

$$PL = A + Blog(d) + C \quad (9)$$

Where A, B, and C are factors that depend on frequency and antenna height, measured as following:

$$A = 69.55 + 26.16\log(f_c) - 13.82\log(h_b) - a(h_m) \quad (10)$$

$$B = 44.9 - 6.55\log(h_b) \quad (11)$$

Where, fc is given in MHz and d in km. The function a(hm) and the factor C depend on the environment:

- Small and medium-size cities:

$$a(h_m) = (1.1\log(f_c) - 0.7)h_m - (1.56\log(f_c) - 0.8) \quad (12)$$

$$C = 0 \quad (13)$$

- Metropolitan areas

$$a(h_m) = \begin{cases} 8.29(\log(1.54h_m)^2 - 1.1)\ for\ f \le 200MHz \\ 3.2(\log(11.75h_m)^2 - 4.97)\ for\ f \ge 400MHz \end{cases} \quad (14)$$

D. Cost-231 Model

The model, commonly referred to as COST-Hata, is an extension of the Hata model developed by the European Co-operative for Scientific and Technical research (EURO-COST). The COST231 working committee was established by EURO-COST to introduce this model, which is specifically designed to be applicable up to 2 GHz. The frequency range covered by the COST-231 model is 1500 MHz to 2000 MHz. This model is widely utilized for estimating the median path loss in mobile wireless systems, and its formula is provided by [6]:

$$P_L(dB) = A + Blog(d) + C_m - a(h_m) \quad (15)$$

Where A and B are defined as follow:

$$A = 46.3 + 33.9\log(f) - 13.82\log(h_b) \quad (16)$$

$$B = 44.6 - 6.55(h_b) \quad (17)$$

f, h_b , h_m, and d are the same as defined in Hata model, $a(h_m)$ is defined in the previous model, and,

$$C_m[dB] = \begin{cases} 0\ for\ median\ sized\ city\ and\ suburban\ areas \\ 3\ for\ metropolian\ centers \end{cases} \quad (18)$$

The COST231 model is restricted to frequency range from 1500 MHz to 2000 MHz, transmitter antenna height from 30 to 200m, receiver antenna height from 1 to 10m, and distance between transmitter and receiver around 1 to 210 Km [6].

E. Ericsson Model

To predict path loss, network planning engineers utilize a software known as the Ericsson model, developed by the Ericsson company. This model is based on a modified version of the Okumura Hata model, which enables adjustments to the parameters based on the specific propagation environment [8,10].

Path loss according to this model is given by:

$$PL = a_0 + a_1\ log\ (d) + a_2\ log\ (h_b) + a_3\ log\ (h_b).\ Log(d) - 3.2\ (log10\ (11.75h_r)^2) + g(f) \quad (19)$$

Here,

$$g\ (f) = 44.49\ (log(f) - 4.78(log\ (f))^2 \quad (20)$$

Where; d is the distance between the base stations and users (km), h_b is the height of the base station ranged from 30 to 200 m, h_r is the height of the receiver ranged from *1 to 10m, and* f is the frequency ranged from 150 to 1500 MHz. The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrain are given in Table I [11,12].

TABLE I. THE DEFAULT VALUES OF THE PARAMETERS a_0, a_1, a_2 AND a_3 FOR DIFFERENT TERRAIN TYPES [11,12].

Terrain	a_0	a_1	a_2	a_3
Urban	36.2	30.2	-12.0	0.1
Suburban	43.20	68.93	-12.0	0.1
Rural	45.95	100.6	-12.0	0.1

F. Standard Propagation Model

The Standard Propagation Model (SPM), incorporated within the Atoll software, is specifically designed for LTE systems operating in densely populated urban areas. This model is well-suited to handle the communication environment in such settings. The SPM is derived based on the following formula [13]:

$$Path\ Loss = K_1 + K_2\ log(d) + K_3\ log(H_{Txeff}) + K_4\ x\ Diffractionloss + K_5\ log(d)\ x\ log(H_{Txeff}) + K_6\ (H_{Rxeff}) + K_7\ Log(H_{Rxeff}) + K_{clutter}\ f(clutter) \quad (21)$$

Where, d is the distance between receiver and transmitter (m). H_{Txeff} is the effective height of the transmitter antenna (m). H_{Rxeff} is the effective mobile antenna height (m). f(clutter) is the terrain loss, average of weighted losses due to landforms. It is worth noting that the model calculates the loss f(clutter) caused by the ground features, which is a weight loss due to the ground features passing from the transmitter to the receiver. The weighting method is also optional. K_1 is the constant related to frequency, constant offset in (dB). K_2 is the distance fading constant, a multiplying factor for log(d); this value indicates how fast the field strength changes with distance. K_3 is the revision coefficient of mobile station antenna height or a multiplying factor for log(H_{Txeff}); this value indicates the field strength changes with the antenna height. K_4 is a multiplying factor for diffraction calculation, K_4 must be positive number. K_5, K_6 are the revision coefficients of base station height; where K_5 is a multiplying factor for log(d) x log(H_{Txeff}) and K_6 is a multiplying factor for H_{Rxeff} . K_7 is the revision coefficient of diffraction, a multiplying factor for log(H_{Rxeff}). $K_{clutter}$ is a multiplying factor for f(clutter), this value represents the weight of ground loss [13].

III. RECEIVED SIGNAL STRENGTH CALCULATION

The Received Signal Strength Indicator (RSSI) or Signal Strength is a measure of how strong the most recent signal was when it reached its destination. The RSSI value ranges from 0 to 255. Higher RSSI values indicate a stronger signal. Reliable communication can best be achieved with RSSI values greater than 70. If the RSSI is too low the wireless communications may become intermittent or fail entirely [1]. The received signal strength can be calculated as the following formula indicates.

$$P_r = P_t + G_t + G_r - PL - A + PM \quad (22)$$

Where, P_r is the received signal strength in dBm. P_t is the transmitted power in dBm. G_t is the transmitted antenna gain in dBm. G_r is received antenna gain in dBm. PL is the total path loss in dBm. A is connector and cable loss in dBm on the transmitter and receiver side. In this paper, connector and cable loss are not taken into consideration. And PM is the Planning Margin of values between 10-25 dB added for fading, prediction errors and additional losses [1].

Table II. shows the downlink budget parameters for the calculation of the received signal strength according to the values used by the LTT Company.

TABLE II. DOWNLINK BUDGET PARAMETERS USED BY LTT COMPANY FOR RECEIVED SIGNAL STRENGTH CALCULATIONS.

Parameter	Value
Transmitter – UE	
Transmitted power, pt, (dBm)	49
Transmitted antenna gain, Gt, (dBi)	17
Body loss (dB)	0
EIRP (dBm)	34.71
Reciever – eNode B	
Noise Figure, NF, (dB)	7
Thermal noise NB (dBm)	-93.2
Rx noise floor (dBm)	-97
SINR (dB)	-1.46
Rx sensitivity (dBm)	-98.46
Interference Margin (dB)	4.39
Connector and Cable Losses, Lc, (dB)	0
Received antenna gain, Gr, (dBi)	17
Maximum Allowed path loss (dB)	134.98
Noise Figure, NF, (dB)	7
Thermal noise NB (dBm)	-93.2

IV. DATASET

This paper aims to compare various statistical models of wave propagation in order to identify the most accurate path loss values suitable for LTE technologies in the urban area of Tripoli, Libya. The study involved visiting the LTT Company to determine the appropriate model used for calculating losses, and a comparison was made with theoretical results.

The dataset used in this study is specific to the city of Tripoli. The following parameters were considered: a base station height of 30 meters, a mobile station height of 1.5 meters, a transmission-reception antenna range of 1.9 kilometers, and a frequency of 800 MHz. These parameters were both generated and practically applied.

The company has established a specific frequency of 800 MHz and set the maximum allowable path loss value at 134 dB for the conducted studies in order to select the appropriate model. After conducting the studies, the Okumura Hata model was chosen as the suitable model for LTE/4G in the city of Tripoli. The theoretical simulations using MATLAB software, including the Okumura Hata model, confirmed that the path loss value obtained from the company was indeed 134 dB. During the simulation, it was observed that the losses imposed by the Okumura Hata model matched the value of 134 dB that was specified.

V. RESULTS AND DISCUSSION

The selected RF propagation models described in the second section have been implemented in Matlab. Two scenarios are adopted, namely, changing the distance between the base station and mobile station, and changing the transmitter height. Communication systems use different frequencies so user frequency must be determined, however most designs accept frequencies in range from 800 to 3000 MHz. The height of the transmitter is often between 30 and 200 m. While the user height varies from 1 to 10 meters. The distance between transmitter and receiver changes from one design to another and measured in kilometers. For all models, urban area type was used, to get a fair comparison.

A. *Input Parameters*

The following table, Table III., shows the input parameters for the calculation of path loss according to the values used by the LTT Company, for each cluster.

TABLE III. INPUT PARAMETERS USED BY LTT COMPANY FOR PATH LOSS CALCULATIONS.

Variable	Input Value
Frequency in (MHZ)	800
Height of base station in (m)	30
Height of mobile station in (m)	1.5
Distance in (Km)	1.9

The following table, Table IV., indicates the values for the distance between transmitter and receiver, transmitter height, receiver height and frequency. These values are used for the two scenarios, for plotting the path loss in each situation. Those are the most applicable values that can be used for each model, to get the most appropriate results.

TABLE IV. INPUT PARAMETERS USED FOR PATH LOSS PLOTTING FOR THE TWO SCENARIOS USED IN SIMULATION.

Variable	Range value
Frequency in (HZ)	1000-3000
Height of base station in (m)	30-200
Height of mobile station in (m)	1-10
Distance in (Km)	1-100

B. *The First Scenario*

In this scenario, the calculation for path loss as a function of distance between the transmitter and receiver was plotted, while the other variables remain as constant values.

As it can be seen from Fig. 2., path loss vs distance for different models was plotted. It is found that the values of path loss for all models are very close and difficult to distinguish except the Okumura model, since its value is low due to the use of suburban environment, where this model was not designed for the urban environment. In addition, the Ericsson model underestimates the attenuation of the signal. As the parameter a_2 has the value of (-12) according to references [10,11]. This leads to lower value of path loss as its multiplied by the base station height, ($\log(h_b)$). It can be observed that the loss values for Cost231 and Okumura Hata designs are the lowest at distance below 22 Km where losses are less than 175 dB. While as the distance increases, SPM losses are the lowest. Taking into account all the distances, the Cost231 and Okumura Hata designs give lower losses.

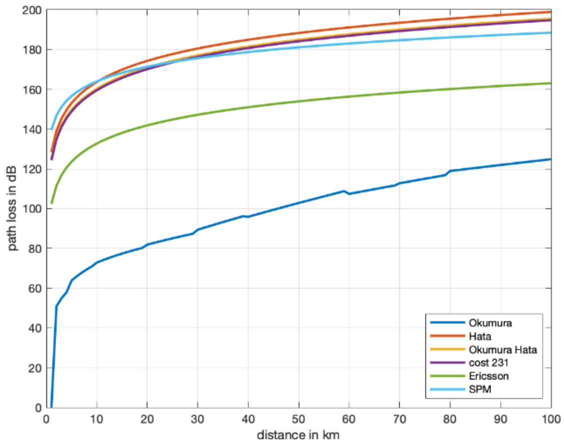

Fig. 2. Path loss VS Distance for different models.

From Fig. 3. It's clear that the path losses of both designs, Okumura Hata and SPM, are close and equal at a distance of approximately 22 Km. Before reaching this distance, Okumura Hata losses are the lowest. After 22 Km, SPM model losses are the lowest and kept lower than the Okumura Hata model tell the end of the plot, 100 Km.

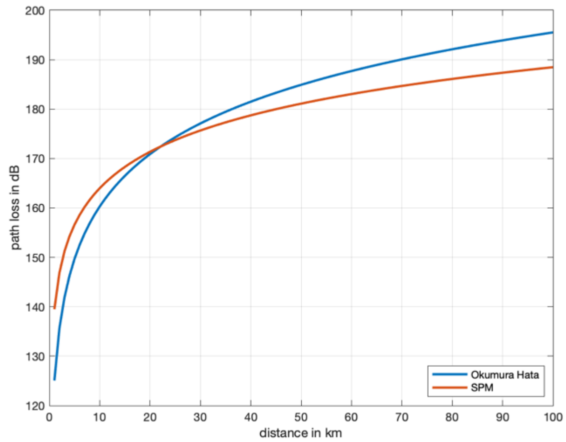

Fig. 3. Path loss verses Distance for Okumura-Hata and SPM models.

Fig. 4. shows the relationship between distance and signal strength. The comparison between the two designs shows that the Okumura Hata design has a stronger signal than the SPM at a distance less than 22 Km, however, at a distance greater than 22 Km, the signal strength of the SPM design becomes the strongest.

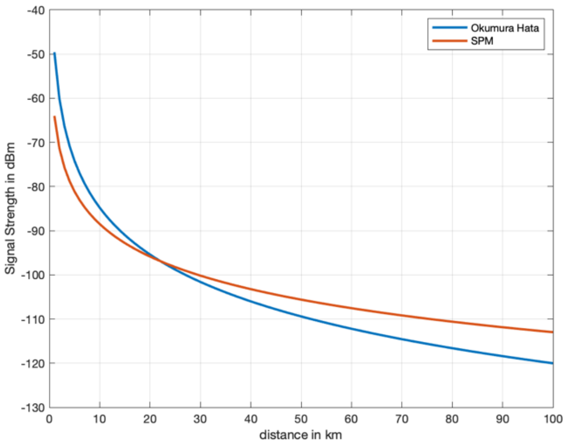

Fig. 4. Signal Strength verses distance for Okumura-Hata and SPM models.

C. *The Second Scenario*

In this scenario, the calculations for path loss as a function of base station height was conducted in contrast, the other variables remain as constant values. Path loss vs transmitter height for different models is illustrated in Fig. 5.

Cost231, Okumura Hata and Hata designs are parallel and the losses are the lowest. The losses are reduced with the increase in base station height. The losses in the Ericsson model are underestimated values as in the first scenario. The SPM design is less affected by the change in height of transmitter. The SPM model is widely used in field measurements of radio propagation in urban areas. However, when the transmitter height increases, the path loss value almost remains constant. This is because the higher the transmitter is, the more likely the signal will be obstructed by buildings or other structures. As a result, the signal will experience more attenuation as it travels through the urban environment, leading to path loss kept at high values as constant as transmitter height increases.

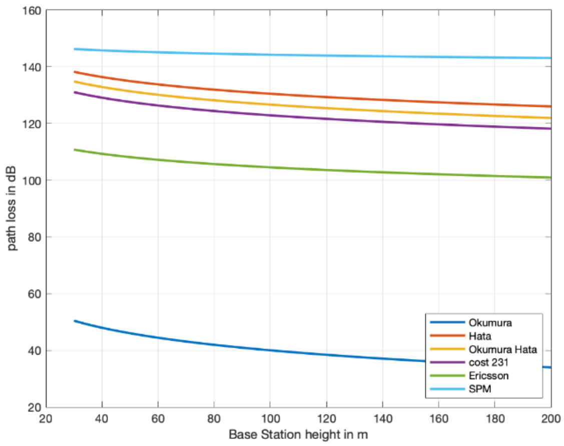

Fig. 5. Path loss verses transmitter height for different models.

Additionally, as the transmitter height increases, the signal may encounter more reflections and diffraction, which can also contribute to an increase in path loss. This is because the signal will interact with more surfaces and obstacles as it propagates through the environment, resulting in more attenuation. It is important to note that the relationship between transmitter height and path loss is not always straightforward and can depend on a variety of factors, such as the frequency of the signal, the density of buildings in the area, and the terrain.

Fig. 6., shows the relationship between the path loss and the height of the transmitter station for the design of Okumura Hata and Cost231 model, as the best case for all models used in comparison.

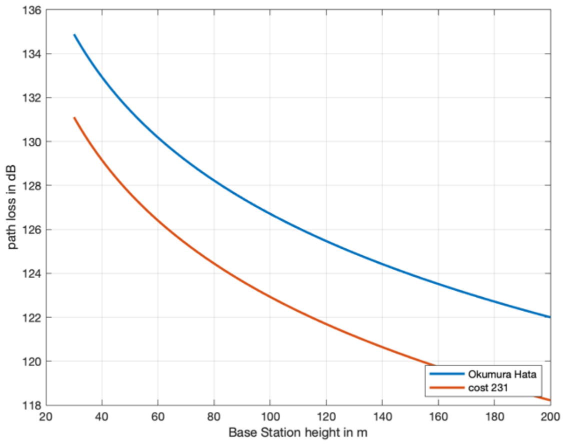

Fig. 6. Path loss VS transmitter height for two nearest values models.

As evidence, losses in the Cost231 design are the best (least) in the range of height from 30 to 200 m. The design of Okumura Hata shows greater losses and the difference in losses remains almost constant in all periods.

However, for the previous input parameters the following values, in Table V., was obtained for path loss, for each model.

The cumulative path loss of the urban area is shown in Table V. It can be seen from the table that the cost231 model has the lowest predicted path loss (131.19 dB) in urban environment. While the SPM model has the highest loss in the field (146.39 dB) in urban environment. While the Okumura Hata model has a loss of (134.19 dB).

TABLE V. THE PATH LOSS OUTPUT FOR EACH MODEL.

Model Name	Path Loss (dB)
Hata	138.38
Okumura -Hata	134.97
Cost231	131.19
Ericsson	110.91
SPM	146.39

Fig. 7, shows the signal strength curve for the height of the transmitter station for different designs. Cost231 design is clearly the best of the three designs followed by the design of Okumura Hata where, unlike the losses, the signal strength increases with the increase of the transmitter station. The lowest in this format is the design of Hata, which gives poor performance compared to other designs.

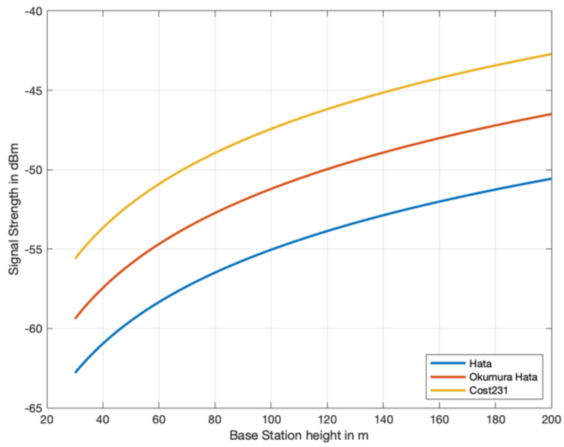

Fig. 7. Path loss VS Base station height for different models

VI. CONCLUSIONS

The study makes a significant contribution by comparing various statistical models of wave propagation to determine the most suitable path loss values for LTE technologies in the urban area of Tripoli, Libya. The researchers visited the LTT Company to identify the appropriate model used for loss calculation and compared it with theoretical results. The dataset used is specific to Tripoli, Libya. The parameters such as base station height and antenna range were considered in the study. By setting a maximum allowable path loss value and conducting extensive studies, the Okumura Hata model was identified as the most appropriate model for 4G/LTE in Tripoli. The theoretical simulations validated the chosen model by confirming that the path loss value obtained from the company matched the expected value. Overall, this research contributes valuable insights for optimizing LTE network planning in urban areas, specifically in Tripoli.

The results that have been obtained from the simulation are almost equal to the realistic results as shown in Fig. 5. It was clear that distance between the transmitter and the receiver has been enhancing the path loss as their values increase. Whereas the changing of transmitter height has been diminishing the path loss for all models. Some models show better results than others in each one of the two factors, depending on the design parameters for each model.

However, for enhancing factors of path loss, distance changing, it was clear that SPM has reaches 190 dB. Another point of view, that for changing of distance, SPM model shows almost the best values for distances greater than 22 Km. According to Fig. 3. the Okumura-Hata model is widely used for urban and suburban areas, it provides reasonably accurate results for distances up to several tens of kilometers. Its accuracy may decrease for larger distances due to several reasons, namely, validity range, terrain consideration and frequency consideration. Whereas the SPM model is based on fundamental physical principles and assumptions and can be provide accurate results for long distances. On the other hand, both Cost231 and Okumura Hata models showing almost the same trend. Moreover, the SPM model is still under consideration by the LTT Company and till this date the company has not use it, while it will have better results than Okumura-Hata model after calibration with software like Atoll.

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