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Long Term Evolution (LTE) Network Dimensioning using Radio Propagation Models

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Abstract— This paper deals with radio propagation models used for 4th Generation of cellular networks known as Long Term Evolution (LTE). Path loss models are very important in dimensioning any wireless network. Computation of path loss for different terrains like urban, suburban and rural has been carried using Matlab that is based on simulation for prediction methods such as Stanford University Interim (SUI) model, Cost-231 Walfish Ikegami model and Cost-231 HATA model. This work carries a comparative analysis of path loss for these radio propagation models used for 4G wireless networks at 800 MHz and 1800 MHz. Results show that the COST-231 Hata model gives the best path loss values in urban, suburban and rural environments compared to the COST-231 Walfish Ikegami model and SUI Model.

Keywords- **Long Term Evolution (LTE); Path loss; Radio Propagation Models; Stanford University Interim (SUI) model;Cost-231 Walfish Ikegami model; Cost-231 HATA model.**

I. INTRODUCTION

Long Term Evolution (LTE) is the successor of the third (3rd) Generation cellular network. It is also known as 4th generation (4G) service. Third (3rd) Generation Parternership Project (3GPP) has developed some standards such as HSDPA (High Speed Packet Downlink Access), HSUPA (High Speed Packet Uplink Access) and HSPA (High Speed Access). LTE is based on 3GPP standards.

The main objectives of LTE are as follows:

- Increased Downlink and Uplink peak data rates.
- Scalable bandwidth.
- Improved Spectral efficiency.
- Includes all IP Networks.
- Multitude of user types are supported by standard's based interface [6].

LTE has been developed for frequency bands ranging between 800 MHz and 3, 5 MHz. The channel will be having a scalable bandwidth from 1 MHz to 20 MHz. Both, Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are supported by LTE. LTE has a downlink Speed of 100 Mbps and an uplink of almost 50 Mbps.

These data rates can be further increased by using multiple antennas (MIMO Antennas: Multiple Input Multiple Output antennas) both at the transmitter and the receiver. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink [2].

The 4G technology mainly aims to provide high speed, high quality, high capacity and low cost services (for example voice, multimedia and internet over IP) [9]. From a world-wide perspective, many operators have already deployed and operated on commercial LTE network.

This paper is organized as follows. Section II provides an overview of the LTE theoretical performances, outlining the major improvements introduced by the Long Term Evolution of Universal Mobile Telecommunications System (UMTS). Section III describes various propagation models used in LTE system. Section IV consists of Simulation scenarios and corresponding results. Section V concludes the paper.

II. PROPAGATION PATH LOSS MODELS

Radio propagation models are very useful for wireless network dimensioning. The radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It gives a relation between the distance of transmitter and path loss [1].

Path loss models are very useful for predicting coverage area, frequency assignments and traffic parameters which are primordial elements for dimensioning mobile networks. Path loss refers to the attenuation of power signals transmitted from the base station towards the mobile station. It is due to constraints of propagation such as reflexion, refraction, diffraction and absorption of the signal by objects in the environment. Path loss depends on different types of environment (i.e. urban, suburban and rural), operating frequency, variations of transmitter and receiver antenna heights and the distance between the transmitter and the receiver [4].

To analyze these losses, three types of models for path loss prediction are proposed in [3]:

- The empirical model.
- The Stochastic model: statistical model also known as Semi Deterministic Model.
- The Deterministic Model.

The empirical models are based on field measurements data which are taken in the urban, suburban and rural environment. The deterministic models are derived from the electromagnetic wave equation to determine the received signal power. The statistical models use probability analysis by finding the probability density function [3]. The selection of a suitable radio propagation model is fundamental for dimensioning LTE network. In this paper a comparison is made between different radio propagation models in different fields to find out the model having the least path loss in a particular terrain for LTE networks.

A. Stanford University Interim(SUI) Model

This model was developed under the IEEE 802.16 working group as part of a proposed standard for frequency bands below 11 GHz [11]. For this propagation model, three different types of terrains are considered [5]. These are referred to as terrain A, B and C. Terrain A represents an area with highest path loss, it can be a very dense populated region, while terrain B represents an area with moderate path loss, a suburban environment. Terrain C has the least path loss and represents a rural or flat area. In table I, different factors concerning these three types of terrains used in SUI model are described.

Table I: Different terrains and their parameters

Parametrs	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
B	0.075	0.065	0.05
C	12.6	17,1	20

Path loss in the SUI model can be given as:

$$PL = A + 10\gamma l \log_{10}\left(\frac{d}{d_0}\right) + X_f \quad (1)$$

Here PL represents path loss in dBs, d is the distance between the transmitter and the receiver, d_0 is the reference distance (here its value is 100), X_f is the frequency correction factor, X_h is the correction factor for base station height. S is the shadowing factor and γ is the path loss component [6].

The path loss component is described as:

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (2)$$

Where h_b is the highest of the base station and a, b and c represents the terrain for which the values are selected from the above table.

The free space loss is given as:

$$A = 20\log_{10}\left(\frac{4\Pi d_0}{\lambda}\right) \quad (3)$$

Where d_0=100 m and λ, is the wavelength. The frequency correction factor is given as:

$$X_f = 6\log_{10}\left(\frac{f}{2000}\right) \quad (4)$$

Where, f is frequency in MHz. The correction factor for base station height is:

$$X_h = -10.8\log_{10}\left(\frac{h_r}{2000}\right) \quad (5)$$

Where, h_r is the height of the receiver antenna. The above expression is used for terrains A and B. For terrain C, the below expression is used.

$$X_h = -20\log_{10}\left(\frac{h_r}{2000}\right) \quad (6)$$

The shadowing factor S is given as follows:

$$S = 0.65\ \log_{10} f - 1.3\log_{10}(f) + \alpha \quad (7)$$

Here, α=5.2 dB stands for rural and suburban environments (Terrain C and Terrain B) and 6.6 dB for urban environment (Terrain A) [1].

B. Cost-231 Hata Model

The COST-231 Hata radio propagation model is an extension of the Hata-Okumura model, to cover a more elaborated range of frequencies. It is the most often cited model. This model is available for these constraints:

- Frequency: 1500 MHz to 2000 MHz.
- Mobile Station Antenna Height: 1m up to 10m.
- Base station Antenna Height: 30m to 200m.
- Link Distance: 1km up to 20 km [7].

Median path loss in urban areas is given by:

$$P(db) = 46.3 + 33.9\log_{10}(f) - 13.02\log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log_{10}(h_b)]\log_{10}(d) + C \quad (8)$$

Here, f represents the frequency in MHz and distance between the transmitter and receiver is denoted by d. Correction factors for base station height and receiver height are h_b and h_m, respectively. The parameter c has a value of 3 for urban. It is zero for suburban and rural environments. $a(h_m)$ is the mobile station antenna height correction factor. For urban areas it is given by:

$$a(h_m) = 3.2(\log_{10}(11.75h_m))^2 - 4.97 \quad (9)$$

And for rural area, it is given by:

$$a(h_m) = (1.1\log_{10}(f) - 0.7)h_m - (1.58f - 0.8) \quad (10)$$

And for a large city, the correction factor $a(h_m)$ is defined as :

$$a(h_m) = 8.29(\log_{10}1.54h_m)^2) - 1.1 \quad \text{for } f \leq 300\text{ MHz} \quad (11)$$

$$a(h_m) = 3.2(\log_{10}11.75h_m)^2) - 4.97 \quad \text{for } f \geq 300\text{ MHz} \quad (12)$$

The path losses L_s and L_0 in dB for suburban and open areas are given in equations (13) and (14) respectively.

$$L_S = L\{urbanarea\} - 2\left\{\log_{10}\left(\frac{f}{28}\right)\right\}^2 - 5.4 \qquad (13)$$

$$Lo = L\{urbanarea\} - 4.78\{\log_{10}(f)\}^2 + 18.33\log_{10} f - 40.94 \qquad (14)$$

C. Cost-231 Walfisch-Ikegami Model

COST-231Walfisch-Ikegami model is an extension of COST-231Hata model. It can be used for frequencies above 2000 MHz. Four included parameters are heights of buildings, width of roads, building separation, road orientation with respect to the Line of Sight (LOS) path. This following figure recapitulates these parameters [10].

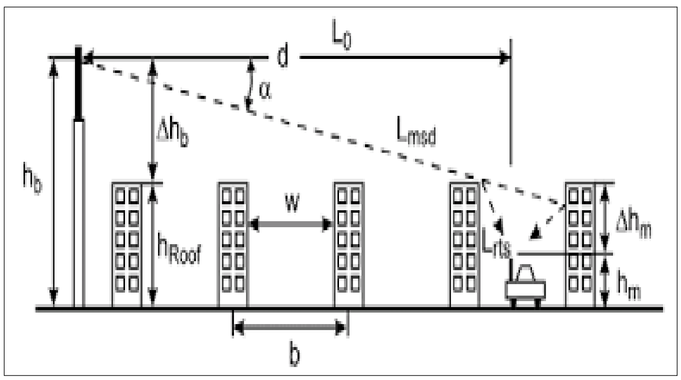

Figure 1. Geometry of Cost-231 Walfisch- Ikegami

For this model we need to consider the following parameters:

- Mobile Station Antenna Height: 1m up to 3 m.
- Base station Antenna Frequency: 800 MHz to 2000 MHz.
- Base Station Height: 4 m to 50 m.
- Distance between the transmitter and the receiver: 0.02 km up to 5 km [1].

If a free Line of Sight (LOS) exists in a street, path loss is defined as:

$$PL = 42.64 + 26\log_{10}(d) + 20\log_{10}(f) \qquad (15)$$

In the Non-LOS case, the basic transmission loss comprises the free space path loss L, the multiple screen diffraction loss L_{msd} and the rooftop to street diffraction and scatter loss L_{rts}. Thus, the path loss PL, in non LOS is defined as:

$$PL = L_0 + L_{RTS} + L_{MSD} \qquad (16)$$

Here L_0 is the attenuation in free space and is defined as:

$$L_0 = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (17)$$

$\mathbf{L_{RTS}}$**,** represents diffraction from rooftop to street and is described as:

$$L_{RTS} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log_{10}(h_b - h_r) + L_{ORI} \qquad (18)$$

Where w, h_b and h_m are width of roads, height of building and height of mobile stations respectively [6].

$$L_{ORI} = \begin{cases} -10 + 0.35\alpha & \text{for } 0^\circ < \alpha < 35^\circ) \\ 2.5 + 0.0755(\alpha - 35) & \text{for } 35^\circ < \alpha < 55 \\ 4 - 0.0114(\alpha - 55) & \text{for } 55^\circ < \alpha < 9 \end{cases} \qquad (19)$$

Where L_{ori} is a factor which has been estimated from only a small number of measurements, α is the street orientation angle. The multiple screen diffraction loss was estimated by Walfisch and Bertoni here for the case when the transmitter is above the rooftops i.e. $h_t > h_b$ [3]. L_{MSD} represents diffraction loss due to multiple obstacles and is specified as:

$$L_{MSD} = L_{BSH} + k_A + k_D\log_{10}(d) + k_F \log_{10}(f) - 9\log_{10}(s_b) \qquad (20)$$

Where:

$$L_{BSH} = \begin{cases} -181\log_{10}(1 + h_t - h_b) & h_t > h_b \\ 0 & h_t \le h_b \end{cases} \qquad (21)$$

$$k_a = \begin{cases} 54 & h_t > h_b \\ 54 - 0.8(h_t - h_b) & h_t < h_b \text{ and } d_{km} \ge 0.5km \\ 54 - 0.8(h_t - h_b)\dfrac{d}{0.5} & h_t \le h_b \text{ and } d_{km} < 0.5km \end{cases} \qquad (22)$$

$$k_d = \begin{cases} 18 & h_t > h_b \\ 18 - 15\dfrac{(h_t - h_b)}{h_b} & h_t \le h_b \end{cases} \qquad (23)$$

$$k_f = -4 + \begin{cases} 0.7\left(\dfrac{f_{MHz}}{925} - 1\right) & \text{for medium sized cities and suburban centers with tree density} \\ 1.5\left(\dfrac{f_{MHz}}{925} - 1\right) & \text{for metropolitan centers} \end{cases} \qquad (24)$$

The term k_a represents the increase in path loss when the base station antenna is below rooftop height. Terms k_d and k_f allow the dependence of the diffraction loss on range and frequency, respectively [3].

III. PATH LOSS ANALYSIS

Simulations were done with Matlab to compare path loss between the SUI model, Cost-231Hata model and Walfish

Ikegami model for frequencies 800 MHz, 1800 MHz and 2000MHz and for different base station antenna heights. The following results were obtained for urban, suburban and rural terrains. Table II shows the values of parameters taken for calculating path loss for the SUI model.

Table II. Simulation Parameters for SUI Model

Parameters	Values
Mobile station antenna height (h_r)	3m
Minimal distance between Tx and Rx (d_0)	100m

Figures 2 shows a comparison of path loss for SUI model for different terrains at 1800 MHz and distance link up to 20 km.

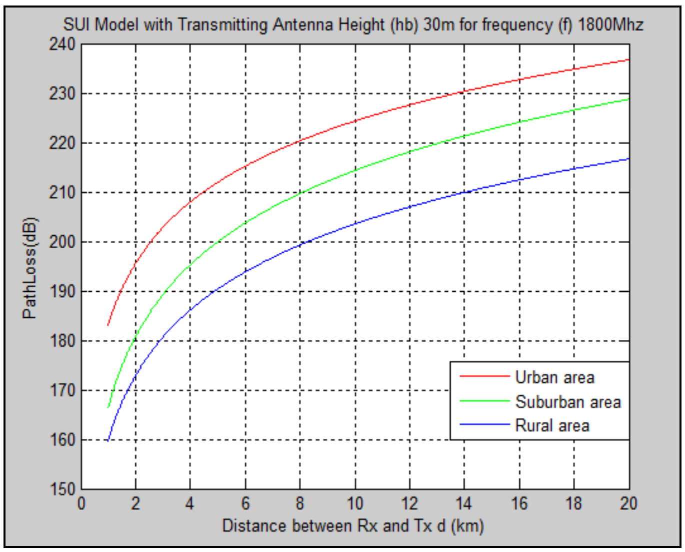

Figure 2 Comparison of path losses for SUI model for different environments

We can observe from figure 2 that path loss in suburban and rural areas is less than that in urban areas. Figure 3 shows that the higher the antenna base station is, the better path loss will be.

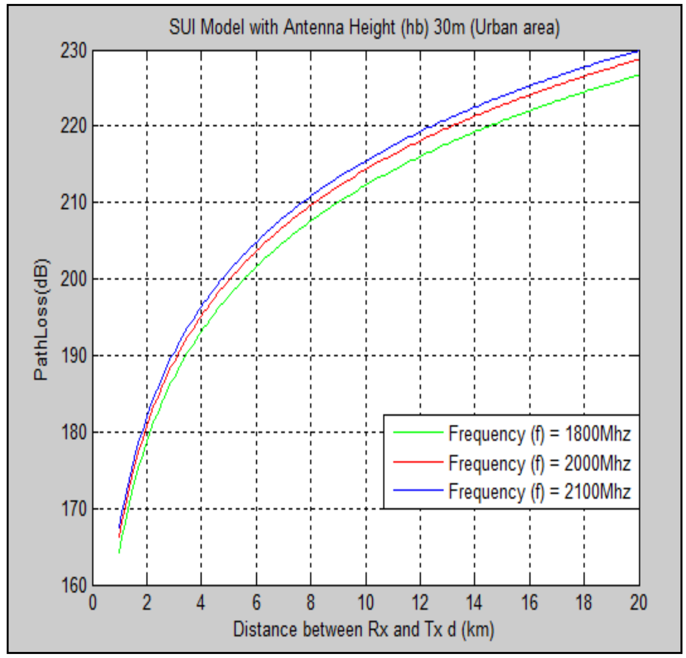

Figure 3. Comparison of path losses for SUI model for different for different frequencies

Figure 3 shows path loss for SUI model for different frequencies in urban area and for base station antenna height 30 m.

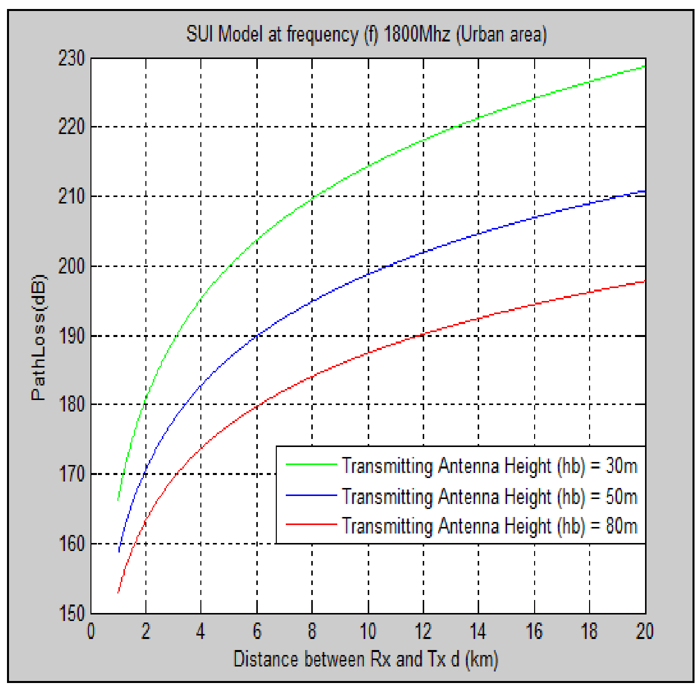

Figure 4. Comparison of path losses for SUI model for different Transmitter Antenna Height

In figure 4, the calculated path losses with three antenna heights are compared to each other at frequency 1800 Mhz in urban terrain. This last figure clearly shows the dependence of path loss on antenna height, in which the higher antenna height provides the smaller path loss.

Table III shows the values of different parameters taken to calculate path loss values for the Cost-231Walfish Ikegami model.

Table III. Simulation Parameters for Cost- 231Walfish Ikegami model

Parameters	Values
Mobile station antenna height (h_r)	3m
Average separation of building (b)	30m
Average street width (w)	15m
Average height of building (hroof)	25m
Street orientation angle (α)	90°

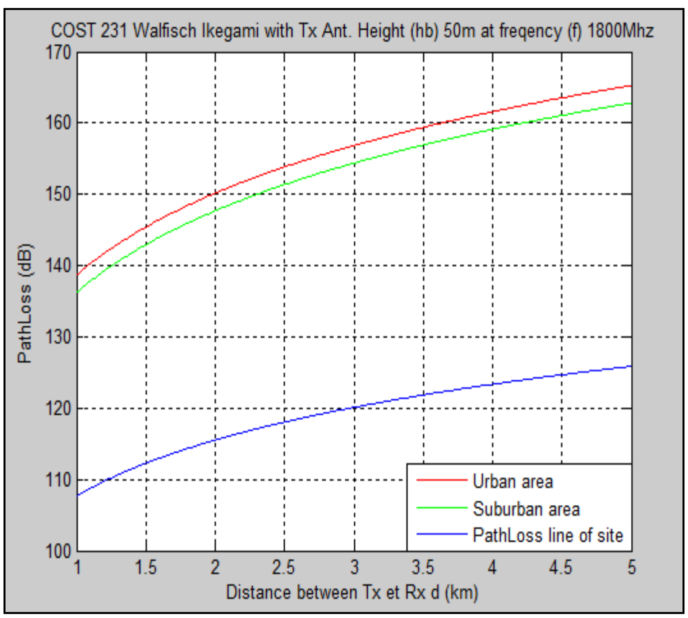

Figure 5. Comparison of path losses for the Cost- 231 Walfish Ikegami model in different areas

Figure 5 illustrates path loss for cost Walifish Ikegami at frequency 1800 Mhz for different types of terrains. This last figure shows that path loss in line of sight is lower than path losses in urban and suburban areas, which is beyond 120dB for 5 km.

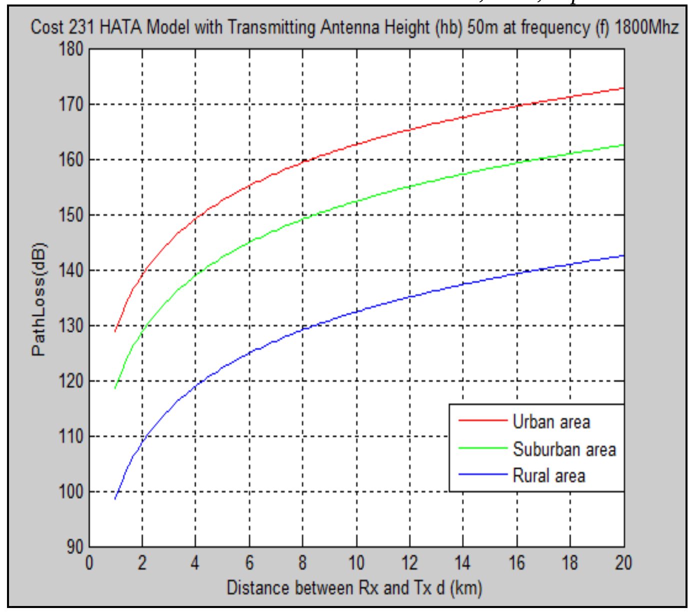

Figure 6. Comparison of path losses for the Cost- 231 Hata model for different terrains

The Cost-231 Hata and the Cost-231 Walfish Ikegami models offer the operator the opportunity to use the 800 MHz band. In Tunisia, we have three operators who use the 800 MHz, 1800 MHz and 2100 MHz bands. Figure 6 illustrates path loss at 1800 MHz for different areas with the Cost-231 Hata Model. We observe that path loss in urban environment is more important than path loss in suburban and rural terrains. It is almost of 172 dB at 20 km for urban area. Based on figure 8, we can conclude that the Cost-231 Hata model provides better performance of path loss for higher base station antenna.

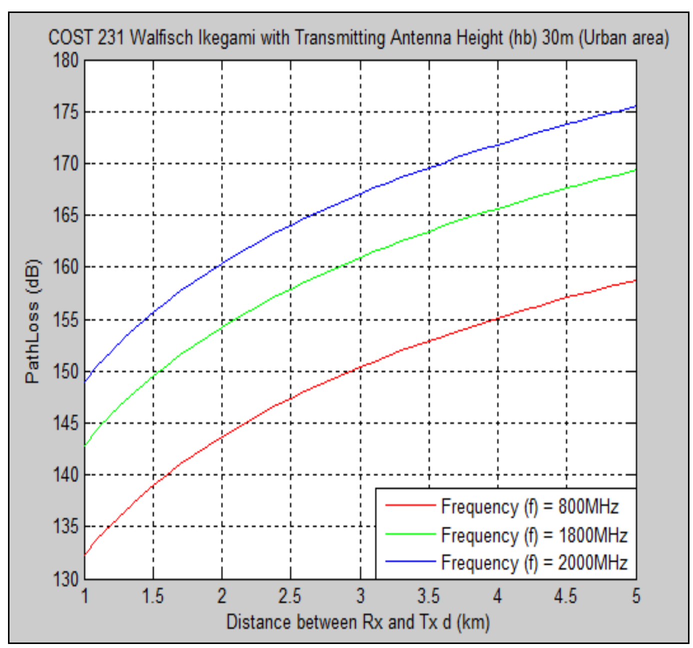

Figure 7 Comparison of path losses for Cost 231 Walfish Ikegami Model for different frequencies

Figure 7 shows that the higher the frequency, the higher the path loss for all distances link

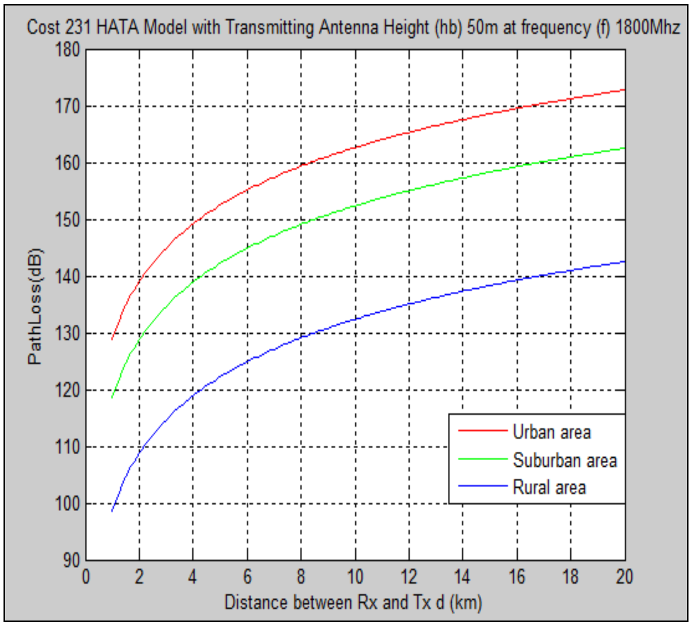

Figure 8. Comparison of path losses for Cost 231 Hata Model for different terrains

It is observed from the Figure 8 that path loss values are less for suburban and open rural areas as compared with urban scenario. Cost 231 Hata model and Cost 231 Walfish Ikegami offer the opportunities for operator to use the 800 MHz band. In Tunisia we have three operators that use 800 MHz, 1800 MHz and 2100 MHz.

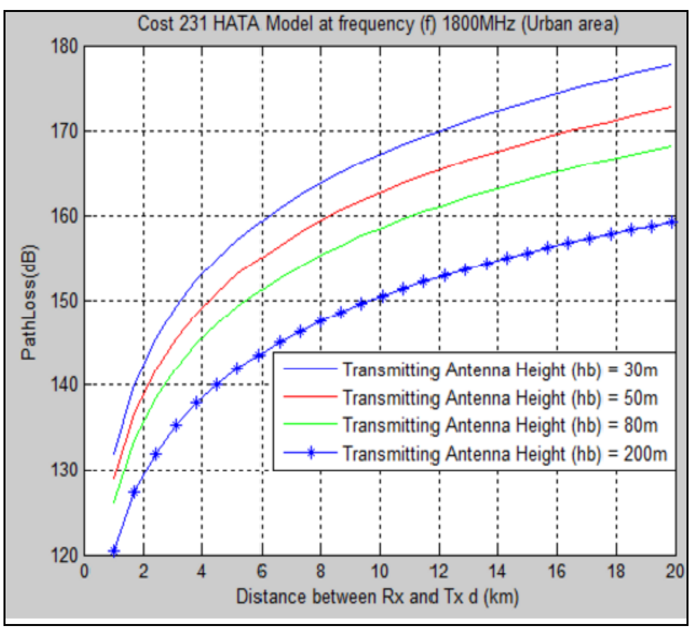

Figure 9. Comparison of path losses for the Cost-231 Hata model for different antenna heights

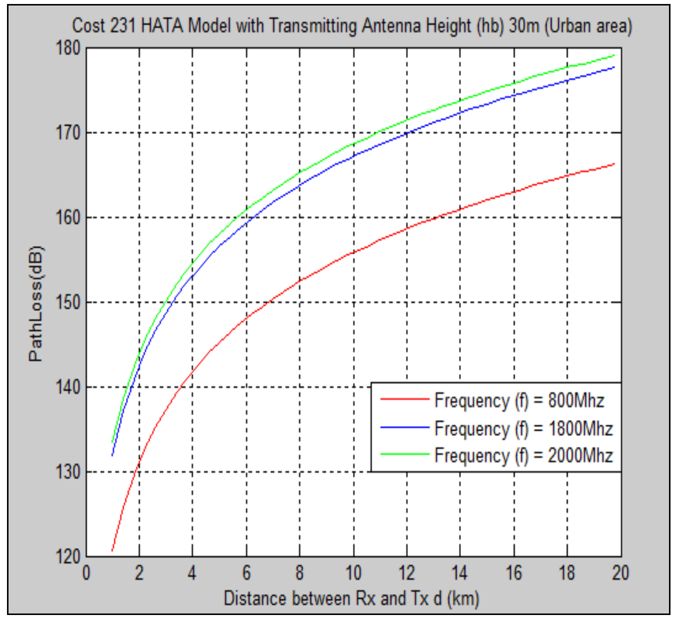

Figure 10. Comparison of path losses for Cost 231 Hata Model at different frequencies

It is observed that as frequency increases path loss values are decreasing in proportion. From this figures, it can be seen that the path loss graphs look similar especially for frequencies 1800 MHz and 2000 MHz.

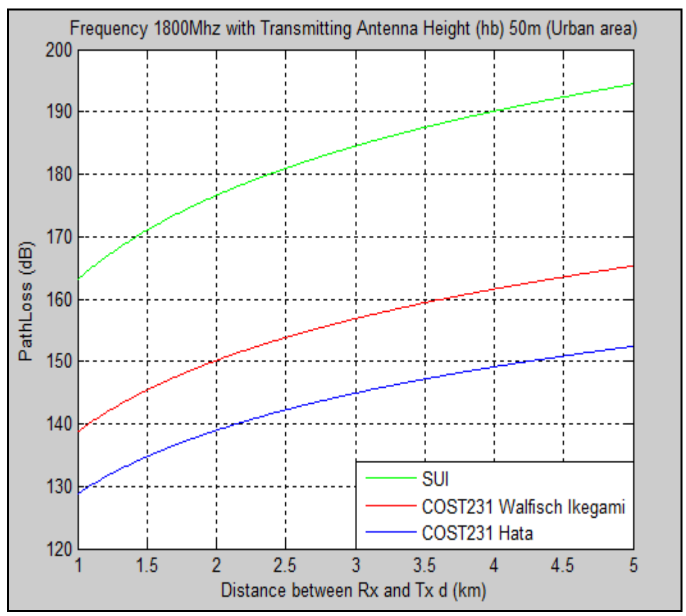

Figure 11. Comparison of path losses for the three propagation models

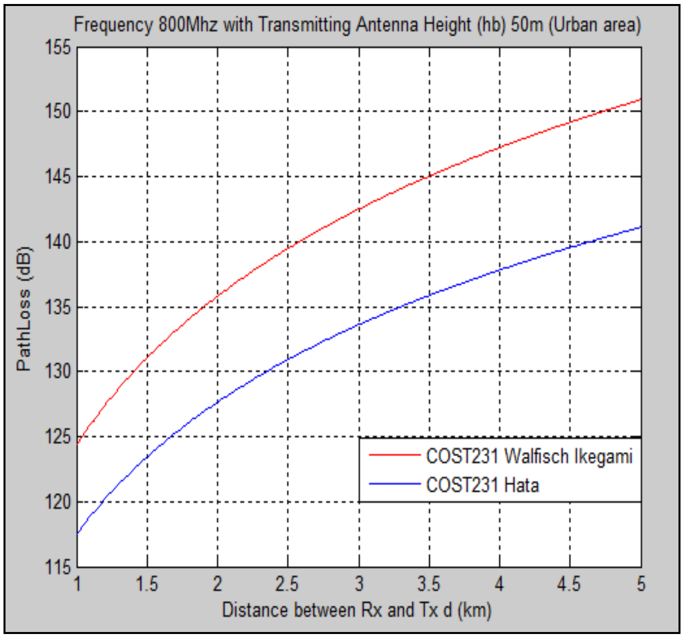

Figure 12. Comparison of path losses for Cost-231 Hata model and Cost-231 Walfish Ikegami model in urban area at 800 MHz

Figure 11 shows the comparison of path loss values for different models at frequencies 1800 MHz for urban area. It can be observed that COST-WI model shows more path loss values as compared to COST-231 Hata model for the same distances. From figure 12, we can deduce that compared to the Cost-231 Walfish Ikegami model and SUI model, the Cost-231Hata model gives better path losses for urban, environment, at both 800 MHz and 1800 MHz. The disadvantage of COST-231 WI model is that it requires detailed knowledge of propagation environment. Besides, its performance becomes poor if the terrain is not flat or the land cover is inhomogeneous [8].
COST-231 WI model defines many parameters and the relation among them. This may make it complex to be applied in certain practical cases, especially for engineering work [8].

IV. CONCLUSION

This paper focuses on radio propagation models with the aim to estimate path loss in both Line of Sight (LOS) and non Line of Sight (NOLS) environments. Simulations were done for 800 MHz, 1800 MHz and 2000 MHz frequencies in urban, suburban and rural areas.

In LTE dimensioning, and for the sake of better performance, high base station antennas should be used. The Cost-231 Hata model should be used as the radio propagation model for LTE networks, since it presents the lowest path loss prediction in different areas for operating frequencies at 800 MHz and 1800MHz.The model gives good results for higher antenna heights. The Stanford University Interim (SUI) model is suitable for a 2100 MHz operating frequency for LTE and LTE advanced standards.

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