SIMULATIONS AND ANALYSIS OF EMPIRICAL PROPAGATION MODELS FOR MOBILE NETWORKS

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Estimating path loss is crucial in the initial deployment of wireless networks and cell planning. Numerous path loss (PL) models are available to predict propagation loss, but they are inclined to be limited to specific parameters. Models for signal attenuation between transceivers include theoretical models, experimentally fitted (usually statistical) models, deterministic ray-optical models, and measurement-directed approaches. This paper presents an analysis of empirical Propagation Models for the mobile network in different environments with different parameters.

Keywords: cellular networks, Predictive Model, signal attenuation, empirical models

1. Introduction

Every business needs one or more communications systems that transmit the varied data required for its survival and growth. These systems are arranged into networks, which are described as collections of equipment and transmission medium that serve the purpose of facilitating information flow. We have entered a period of communication in which the amount and variety of information are increasing [1]. Propagation models are used when designing a radio interface to optimize performance and when deploying systems in the field to determine radio coverage.

The propagation models will be used in engineering tools to anticipate various relevant parameters for the deployment of radio communications systems, as well as the research of radio coverage (site selection, frequency allocation, power definition) and jamming definition. The empirical models rely heavily on geographical datasets incorporating characteristics such as topography and land

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use categories. This is because the way ultra-high frequency (UHF) radio waves propagate in a particular location is highly dependent on the barriers (buildings, tree trunks, mountainsides, and so on) encountered along the propagation channel. As a result, any UHF wave propagation model must include geographic object modeling [2].

The propagation models are then used to provide a mathematical prediction of radio wave propagation between the source and the target service area, allowing a receiver of systems to determine in advance if the proposed radiocommunication system will adequately serve the intended service area. In this research, we will investigate and analyze empirical propagation at four different frequencies to see if those models are still effective with the increase of the frequency, especially since we are at the door of the sixth-generation mobile networks.

The rest of this paper is organized as follows. In Section Two, the definition and parameters of propagation models that are frequently used in path loss prediction are presented. Section Three presents our simulation parameters and the obtained results in different environments. In section Four, an analysis of the simulation results is given. Section Five comparison of our results and some experimental data Section six is the conclusion.

2. Propagation Models

In mobile radio communications, there are two fundamental approaches for predicting the behavior of a transmission channel. The first approach is to model the channel statistically. The second method consists of using a direct analytical resolution of the propagation equations or simulating the signals' paths in the propagation medium.

The type of chosen model depends on the level of estimation desired: approximate or precise. In addition, available field data plays an important role. After the prediction estimation, field measurements must be performed to validate the model. This step generally requires the readjustment of the parameters.

The two main types of models resulting from these approaches are, based on theoretical modeling, and empirical models. Semi-empirical models using the previous approaches are also defined. They take into account the theoretical propagation equations and are parameterized using the results of actual measurements.

Deterministic models give much more precise results but require much information on the area where they will be applied. Moreover, they require a long calculation time. They are generally reserved for places where other models cannot be used. They are based on geometric optics calculations (reflection, diffraction, etc.). This calculation method is called the ray method.

A path loss is considered in this model. The FSPL number represents the amount of signal strength lost during transmission. The frequency f [MHz] and the distance d [m] between the transmitter and receiver affect the FSPL [3]. Due to the implementation of GSM 1800 (Europe) and GSM 1900 (USA), members of the European COST 231 project suggested adapting the Hata model to higher frequencies [4]. When the antenna is positioned on a rooftop but surrounded by taller structures, this model has been used for distances more than 20 m in cells less than 1 km. This model allows for the calculation of attenuation as a function of various variables, including the city's topography. In COST 231, the Walfisch [4] and Ikegami [5] models were integrated. The model improves the calculation of trip losses by analyzing additional data to describe the features of the urban environment.

The Hata-Okumura model [6], based on the Okumura model, is a well-known experimental scattering model for the Ultra High Frequency (UHF) band. With Recommendation ITU-R P.529 [7], the International Telecommunication Union (ITU) recently recommended the future expansion of this idea up to 3.5 GHz. The original Okumura model does not support data speeds beyond 3 GHz. Based on the available information on Okumura's model, an extrapolation approach is utilized to predict the model for frequencies over 3 GHz. The ECC-33 model is the propagation model provisionally proposed by the Hata-Okumura model with a report [7].

The IEEE 802.16 Broadband Wireless Access Working Group suggested the SUI model for the frequency range below 11 GHz [8], [9]. The Stanford University channel model incorporates it. This prediction model was created using a Hata model with a frequency over 1900 MHz. This model may be extended to the 3.5 GHz range using the correction param. This kind is intended for use in the United States Multipoint Microwave Distribution System (MMDS) in the 2.5 to 2.7 GHz frequency band [8]. The SUI model's base station antenna height varies between 10 and 80 meters. The receiver's antenna height changes between 2 and 10 meters. The cell radius ranges from 0.1 to 8 kilometers [9]. The SUI model distinguishes three types of terrain: Terrain A, Terrain B, and Terrain C. There is no mention of a particular environment. Terrain A is best suited to mountainous terrain with light to dense vegetation.

Ericsson's model is based on an updated Okumura-Hata model [9], which allows for parameter changes based on the propagation environment.

3. Simulation parameters and results

Using the MATLAB tool, we conducted many simulations at (800MHz,1900MHz,3.5GHz, and 5.8GHz) with three different mobile station antenna heights (3,6, and10m). As We considered the environment in Algeria, We set a standard building height of 12 meters, a building-to-building spacing of 40 meters, and a street width of 25 meters. We used the Free Space Model (FSL) in all our comparisons as a reference model. The following table summarizes the parameters and the values of each parameter:

Table 1

Parameter values for the simulations.

Parameters	Values
Base station transmitter power	43 dBm
Mobile transmitter power	30 dBm
Transmitter antenna height	30 m in urban and suburban and 20 m in a rural area
Receiver antenna height	3 m, 6 m, and 10 m
Operating frequency	800 MHz,1900MHz,3.5GHz, and 5.8GHz
Distance between Tx-Rx	0.1km - 4.5 km
Building to building distance	40 m
Average building height	12 m
Street width	20 m
Street orientation angle	30 degrees in urban and 40 degrees in suburban
Correction for shadowing	8.2 dB in suburban and rural and10.6 dB in an urban area

The equations that we used to calculate path loss for each model in the MATLAB simulation in the three environments are as below:

- For Walfisch-Ikegami (WI) model:

$L_{\text{wi model}} = L_{fs} + L_{rts} + L_{msd}$ for an urban and suburban environment

$$L_{msd} = -18\log_{10}(1+H_{base}) + 54 + 18\log_{10}(d) + \left(-4+1.5\left(\left(\frac{f}{925}\right)-1\right)\right)\log_{10}(f) - 9\log_{10}(B) \tag{1}$$

$$L_{fs} = 32.45 + 20\log_{10}(d) + 20.\log_{10}(f) \tag{2}$$

$$L_{rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log_{10}(H_{mobile}) + L_{ori} \tag{3}$$

$\mathrm{L_{ori}} = -10+0.354\theta$ for the urban environment (4)

$\mathrm{L_{ori}} = 2.5+0.075(\theta-35)$ for the suburban environment (5)

we consider the Line of sight equation for a rural environment

$PL_{\text{wi model}} = 42.6 + 26\log_{10}(d) + 20\log_{10}(f)$ for a rural environment (6)

- For ECC-33 or extended Hata-Okumura model:

$$PL = A_{fs} + A_{bm} - G_b - G_r \qquad \text{for an urban and suburban environment}$$

$$A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \tag{7}$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56\times 2\log_{10}(f) \tag{8}$$

$$G_r = x \times y \tag{9}$$

$$x = 42.57 + 13.7\log_{10}(f) \tag{10}$$

$$y = \log_{10}(h_r) - 0.585 \tag{11}$$

$$G_b = c\times(b+a) \tag{12}$$

$$a = \begin{bmatrix} 3 & \text{for urban environment} \\ 5.8\times 2\times\log_{10}(d) & \text{for suburban environment} \end{bmatrix} \tag{13}$$

$$b = \begin{bmatrix} 0.005 & \text{for urban environment} \\ 13.958 & \text{for suburban environment} \end{bmatrix} \tag{14}$$

$$c = \begin{bmatrix} 20 & \text{for urban environment} \\ \log_{10}\left(\frac{h_b}{200}\right) & \text{for suburban environment} \end{bmatrix} \tag{15}$$

ECC-33, or the extended Hata-Okumura model, is not applicable in a rural area

- **For COST 231-Hata model:**

$$PL_{\text{costhata model}} = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - a_{hm} + \left(44.9 - 6.55\log_{10}(h_b)\right)\log_{10}(d) + c_m \tag{16}$$

$$a_{hm} = \begin{bmatrix} 3.20\times(\log_{10}(11.75\times h_r))^2 - 4.97 \\ (1.11\times\log_{10}(f) - 0.7)\times h_r - (1.5\times\log_{10}(f) - 0.8) \end{bmatrix} \tag{17}$$

$$c_m = \begin{bmatrix} 3dB & \text{in urban environment} \\ 0dB & \text{in suburban and rural environments} \end{bmatrix} \tag{18}$$

- For Stanford University Interim (SUI) model:

$$PL_{\text{suidelmodel}} = 20\log_{10}\left(\frac{4\times\prod\times d_0}{\lambda}\right) + \left(10\times\gamma\times\log_{10}\left(\frac{d}{d_0}\right)\right) + 6\log_{10}\left(\frac{f}{2000}\right) - 20\log_{10}\left(\frac{h_r}{2000}\right) + s \tag{19}$$

$$\lambda = \frac{3\times 10^{8}}{f} \tag{20}$$

$$\gamma = a - (b \times h_b) + \frac{c}{h_b} \tag{21}$$

$$a = \begin{cases} 3.6 & \text{for urban and rural environments} \\ 4 & \text{for suburban environment} \end{cases} \tag{22}$$

$$b = \begin{cases} 0.005 & \text{for urban and rural environments} \\ 0.0065 & \text{for suburban environment} \end{cases} \tag{23}$$

$$c = \begin{cases} 20 & \text{for urban and rural environments} \\ 17.1 & \text{for suburban environment} \end{cases} \tag{24}$$

$$s = \begin{cases} 10.6 & \text{for urban environment} \\ 8.2 & \text{for suburban and rural environment} \end{cases} \tag{25}$$

$$d_0 = 100m \tag{26}$$

- For Ericson model:

$$PL_{ericson\ model} = 36.2 + 30.2\log_{10}(d) - 12\log_{10}(h_b) + 0.1\log_{10}(h_b)\log_{10}(d) - 6.4\log_{10}(11.75\times h_r) + g(f) \quad \text{for the three environments} \tag{27}$$

$$g(f) = 44.49\log_{10}(f) - 4.78\left(\log_{10}(f)\right)^2 \tag{28}$$

Table 2

Variables of the equations

Parameter	Description
H_{base}, h_b	antenna height of the base station, the height of the roof
H_{mobile}, h_r	height of the roof- antenna height of the mobile station
d	distance between the transmitter and the receiver
f	frequency of signal propagation
B	distance between buildings
W	street width

Parameter	Description
θ	street orientation angel 30 degree
s	fading standard deviation

3.1. Empirical models in the urban areas

In our experiment, we set 3 different antenna heights (i.e., 3 m, 6 m, and 10 m) for the receiver. The distance varies from 100 m to 4.5 km, and the transmitter antenna height is 30 m with frequencies (800MHz,1900MHz,3.5GHz, and 5.8GHz). Table. 4 summarizes the path loss data in the urban environment. The path loss varies according to the changes in receiver antenna height and frequency value.

Table 3

Path loss estimate in an urban environment

The frequency=800MHz	Path loss min			Path loss max		
Models	h_m=3m	h_m=6m	h_m=10m	h_m=3m	h_m=6m	h_m=10m
Walfish Ikegami model	52.82	49.30	39.75	138.52	135.06	125.45
Free space model	58.47	58.47	58.47	103.57	103.57	103.57
Hata extended model	61.10	48.68	39.53	149.90	137.51	128.36
Cost231 Hata model	68.17	64.90	62.12	147.62	144.34	141.56
Stanford university model	67.61	44.38	39.95	160.45	134.23	132.79
Ericson model	61.35	59.43	58.01	129.80	127.87	126.45
The frequency=1900 MHz	**Path loss min**			**Path loss max**		
Models	h_m=3m	h_m=6m	h_m=10m	h_m=3m	h_m=6m	h_m=10m
Walfish Ikegami model	68.36	64.83	55.29	154.06	150.54	140.99
Free space model	65.98	65.98	65.98	111.08	111.08	111.08
Hata extended model	79.31	65.35	55.06	168.14	154.18	143.89
Cost231 Hata model	80.91	77.64	74.86	160.35	157.08	154.30
Stanford university model	60.17	54.15	49.71	153.01	146.99	142.56
Ericson model	74.48	72.55	71.13	142.92	140.99	139.57
The frequency=3.5GHz	**Path loss min**			**Path loss max**		
Models	h_m=3m	h_m=6m	h_m=10m	h_m=3m	h_m=6m	h_m=10m
Walfish Ikegami	84.87	81.35	55.29	170.57	167.05	140.99

model						
Free space model	71.29	71.29	71.29	116.39	116.39	116.39
Hata extended model	92.18	77.12	55.06	181.01	165.95	143.89
Cost231 Hata model	89.90	86.63	74.86	169.34	166.07	154.30
Stanford university model	67.07	61.05	49.71	159.91	153.89	142.56
Ericson model	83.74	81.82	71.13	152.19	150.26	139.57
The frequency=5.8GHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	105.53	102	92.46	191.23	187.70	178.16
Free space model	75.67	75.67	75.67	120.78	120.78	120.78
Hata extended model	102.82	86.85	75.09	191.65	175.68	163.92
Cost231 Hata model	97.34	94.07	91.29	176.78	173.51	170.73
Stanford university model	72.78	66.75	62.32	165.62	159.59	155.16
Ericson model	91.41	89.48	88.06	159.85	157.92	156.50

3.2. Empirical models in suburban areas

The heights of the transmitter and receiving antennas are the same as before. Table. 5 summarizes the path loss data in the suburban environment. The path loss varies according to the changes in receiver antenna height and frequency value.

Table 4

Path loss estimate in a suburban environment.

The frequency=800MHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	93.63	90.11	80.57	141.33	187.81	128.27
Free space model	78.47	78.47	78.47	103.57	103.57	103.57
Hata extended model	100.48	88.07	78.92	149.93	137.51	128.36
Cost231 Hata model	99.08	91.51	81.42	143.29	135.73	125.64
Stanford university model	64.22	60.97	58.57	119.14	115.89	113.49
Ericson model	75.38	73.46	72.04	162.01	160.17	158.75
The frequency=1900MHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami	103.67	100.15	90.61	151.37	147.85	138.31

model						
Free space model	85.98	85.98	85.98	111.08	111.08	111.08
Hata extended model	118.70	104.74	94.45	168.14	154.18	143.89
Cost231 Hata model	111.12	102.31	90.55	155.34	146.52	134.76
Stanford university model	73.99	70.74	68.34	128.90	125.65	125.26
Ericson model	88.51	86.85	85.16	175.22	173.29	171.87
The frequency=3.5GHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	111.02	107.49	97.95	158.72	155.20	145.65
Free space model	91.29	91.29	91.29	116.39	116.39	116.39
Hata extended model	131.57	116.51	105.41	181.01	165.95	154.81
Cost231 Hata model	119.63	109.93	96.99	163.85	154.15	141.21
Stanford university model	80.88	72.33	75.24	135.80	127.25	130.16
Ericson model	97.77	95.85	94.43	184.84	182.56	181.43
The frequency=5.8GHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	105.41	113.90	104.35	154.85	161.60	152.05
Free space model	95.67	95.67	95.67	120.78	120.78	120.78
Hata extended model	105.41	126.24	114.48	156.65	175.68	163.92
Cost231 Hata model	96.99	116.23	102.33	142.82	160.45	146.54
Stanford university model	75.24	83.34	80.94	132.16	138.25	135.86
Ericson model	94.43	103.51	102.09	184.30	190.22	188.80

3.3. Empirical models in the rural areas

The heights of the antennas on mobile stations are the same as before. In this case, the base station antenna height was 20 meters. The extended Hata-Okumura (ECC-33) model is not valid in rural regions. The COST 231 W-I model lacks any rural-specific features for rural areas; we consider the LOS equation provided by this model. Table. 6 summarizes the path loss data in the rural environment. The path loss varies according to the changes in receiver antenna height and frequency value.

Table 5

Path loss estimate in a rural environment

The frequency=800MHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	85.00	85.00	85.00	117.64	117.64	117.64

Free space model	78.47	78.47	78.47	103.57	103.57	103.57
Cost231 Hata model	100.82	93.25	83.16	146.48	138.91	128.82
Stanford university model	90.70	84.68	80.24	147.18	14.16	136.73
Ericson model	61.19	59.26	57.84	187.63	185.71	184.29
The frequency=1900MHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	92.52	92.52	92.52	125.15	125.15	125.15
Free space model	85.98	85.98	85.98	111.08	111.08	111.08
Cost231 Hata model	112.86	104.04	92.29	158.53	149.71	137.95
Stanford university model	100.46	94.44	90.01	156.95	150.93	146.49
Ericson model	74.31	72.39	70.97	200.76	198.83	197.41
The frequency=3.5GHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	97.82	97.82	97.82	130.46	130.46	130.46
Free space model	91.29	91.29	91.29	116.39	116.39	116.39
Cost231 Hata model	121.37	111.67	98.73	167.04	157.33	144.40
Stanford university model	102.06	96.03	91.60	158.54	152.52	148.09
Ericson model	83.58	81.65	80.23	210.02	208.10	206.68
The frequency=5.8GHz	**Path loss min**			**Path loss max**		
Models	**h_m=3m**	**h_m=6m**	**h_m=10m**	**h_m=3m**	**h_m=6m**	**h_m=10m**
Walfish Ikegami model	102.21	102.21	102.21	169.55	134.85	134.85
Free space model	95.67	95.67	95.67	120.78	120.78	120.78
Cost231 Hata model	128.41	117.97	104.06	174.07	163.64	149.73
Stanford university model	113.07	107.04	102.61	134.85	163.53	159.09
Ericson model	91.24	89.32	87.90	217.69	215.76	214.34

4. Simulations analysis

We note in Table 3 that the path loss increases with the increase of the value of frequency and distance. Moreover, it decreases with the increase in the height of the mobile station antenna. The free space model changes according to the value of frequency, and it does not consider the variation of the mobile station antenna height, and it showed the lowest value of path loss in all frequencies. Hata extended (ECC3) model showed the highest path loss at the frequencies (1900MHz, 3.5 GHz, and 5.8 GHz). Stanford university model showed the highest path loss at the frequency of 800 MHz.

We note in Table 4 that the path loss in the free space model is increasing according to the increase of the frequency value, and it does not consider the variation of the mobile station antenna height. It showed the lowest path loss value at all frequencies in the suburban environment. Table 5 shows the highest value at 6m mobile station antenna heights for the six models at frequencies (800 MHz,1900MHz, 3.5 GHz, and 5.8 GHz). The highest value of path loss changes according to mobile station antenna height and frequencies. For example, at the frequency 800 MHz, the Ericson model obtained the highest value at a 3m mobile station antenna height, and the Walfish Ikegami model obtained the highest value at a 6m mobile station antenna height.

Table 5 shows that the lowest path loss value has been recorded in rural environments at the free space model. COST 231 W-I model showed flat results in all changes in receiver antenna heights. There are no specific parameters for rural areas. In our simulation, we considered the LOS equation for this environment because we can expect a line-of-sight signal, if the area is flat enough with less vegetation. The path loss in the free space model increases according to the frequency increase and shows the lowest value of path loss. Ericson model showed the highest path loss at the frequency of 5.8 GHz and 3m mobile station antenna height.

5. Comparison of our results and some experimental data

In this section, we will compare our results with two datasets obtained in an urban environment in Beirut city and a rural environment in Bekaa valley[15]. The path loss was measured with an antenna height of 3m and a signal propagation frequency of 868MHz.

The comparison of our results and the measured data are presented in Figs. 1, 2:

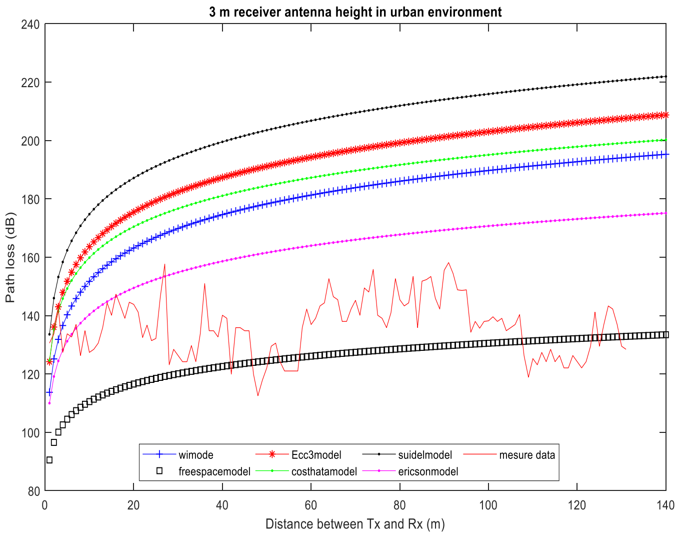

Fig. 1. Comparison between empirical models and measured data in Beirut city at hm=3m, and 800 MHz

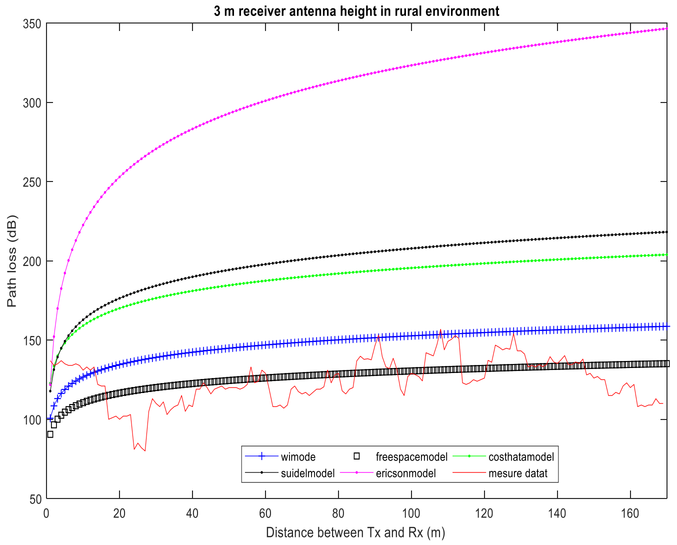

Fig. 2. Comparison between empirical models and measured data in Bekaa valley at hm=3m, and 800 MHz

From the previous figures, we note that most models failed to predict the path loss in the two environments because the models were developed in specific environments with specific parameters. The free space model was the nearest model to the measured data in urban and rural environments. The Walfisch-Ikegami (WI) model was the second-best model after the free space model in the rural environment. At the same time, The Ericson model was the second-best model in the urban environment.

6. Conclusion

The propagation models estimate the mathematical propagation of radio waves between the source and the target service area, giving a receiver of systems a realistic notion of whether the proposed radio communication system will serve the intended service area well.

Due to multipath and NLOS environments, all models demonstrate more significant path losses in metropolitan areas than in suburban and rural areas. We could not find a model that worked in all settings and frequencies. In cities, the free space model exhibited the lowest path loss (103.57 dB at 10 m receiver antenna height). Stanford's model has the highest path loss (160.45 dB in 3 m receiver antenna height). The free space model lowered suburban path loss by 103 dB compared to previous models. Ericson's model showed more significant path loss for 6 m and 10 m reception antenna heights (i.e.190, dB and 188.80 dB, respectively). We may choose from numerous rural models. We may investigate LOS calculations if the site is sufficiently flat and vegetation-free. COST-Hata model demonstrates minor path loss than the Stanford University and Ericsson models if the LOS signal is less likely, particularly at 10 m receiver antenna height. When all receiver antenna heights were evaluated, Stanford showed lower path loss (134.85 dB in 3 m and 163.53 dB in 6 m) than COST-Hata (174.07 dB in 3m and 163.64 dB in 6 m).

In the worst-case scenario for deploying a coverage area, raising transmission power will give maximum coverage but increase interference with nearby regions that utilize the same frequency blocks. If we install a cellular zone with a reduced path loss model, it may not cover the entire region. Fast-moving users may lose signal in the operating cell. Choosing a path loss model for early deployment requires balancing transmission power and frequency block interference.

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