PROPAGATION MODELLING OF PATH LOSS MODELS FOR WIRELESS COMMUNICATION IN URBAN AND RURAL ENVIRONMENTS AT 1800 GSM FREQUENCY BAND

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Abstract. *In this research various channel propagation models of wireless communication systems were analysed. There are many types of propagation models that can minutely calculate the path loss in all types of terrain. Performance estimation of different propagation models was analysed using simulations. In the simulations the selected propagation models have been proposed at the operating frequency of 1800 MHz for different receiver antenna heights in urban and rural environments. Simulations were performed using MATLAB R2013b. The propagation models depend on location, frequency range and clutter type such as urban, suburban and countryside. It was noticed from the results of the path loss calculation for 2 m, 7 m and 14 m receiver antenna heights in urban environment that COST 231 (W-I) model showed the lowest path loss results (138 dB) as compared with the other models in urban environment. On the contrary, SUI model showed the highest path loss result (166 dB in 2 m receiver antenna height) as compared with the other models in the same environment.*

Keywords

COST 231 Walfisch-Ikegami (W-I), rural, Stanford University Interim (SUI), urban.

1. Introduction

In wireless communication system, the losses that occurred between transmitter and receiver is known as propagation path loss. Path loss is a major factor in the analysis and design of wireless communication system. Moreover, the electromagnetic waves usually cannot directly reach the receiver due to many obstacles that block the line of sight path. The travelled signal from transmitter to receiver over a lot of reflection path is called multipath propagation which always causes fluctuations in the received signal's phase and amplitude, the description of the main mechanisms that influence the signal propagation are as follows [1]:

- Reflection.
- Diffraction.
- Scattering.
- Doppler Effect.

The propagation models are developed to predict the loss of signal strength or coverage in a particular location. Thus, they are mathematical tools used by engineers and scientists to plan and optimize wireless communication systems.

Moreover, path loss can be defined as the ratio of the transmitted to received power, usually expressed as the following form in decibels [2]:

$$PL(d) = PL(d_0) + 10n\log_{10}(d/d_0), \tag{1}$$

where d is the distance, d_0 is the reference point at 1 km, n is the path loss exponent.

Moreover, path loss normally includes propagation losses caused by the natural expansion of the radio wave propagation in free space. The paper is arranged as follows: In section 2. , the various types of propagation models are described whereas in section 3. , the simulation models and scenarios are presented. In section 4. , the simulation results are analysed, and the conclusions follow in the last section.

2. Types of Propagation Models

Propagation models are mathematical calculations derived to estimate the signal's paths of transmission and the connected losses in a given environment based on varying parameters such as frequency band, distance, and obstacles in the path of transmission. This research focused on COST 231 (W-I), ITU and TRGR propagation models.

2.1. COST 231 Walfisch-Ikegami (W-I) Model

COST 231 (W-I) model is considered as the most appropriate model for rural and suburban environments which have regular building height. Moreover, this model gives more accurate path loss prediction. It identifies various terrains with different parameters. The equation of the model for Non Line Of Sight (NLOS) condition is calculated as [3]:

$$PL_{NLOS} = L_{FSL} + L_{rts} + L_{msd}, \tag{2}$$

for suburban and urban

$$PL_{NLOS} = L_{FSL} \quad \text{when} \quad L_{rts} + L_{msd} > 0, \tag{3}$$

where L_{FSL} is free space loss, L_{rts} is roof top to street diffraction, L_{msd} is multi-screen diffraction loss.

Moreover, the free space loss equation is calculated as [3]:

$$L_{FSL} = 32.45 + 20\log(d) + 20\log(f). \tag{4}$$

The roof top to street diffraction is computed as [3]:

$$\begin{gathered} L_{rts} = -10\log(w) - 16.9+ \\ +10\log(f) + 20\log(H_{mobile}) + L_{ori}. \end{gathered} \tag{5}$$

$$L_{rts} = 0 \quad \text{if} \quad h_{roof} > h_{mobile}, \tag{6}$$

where

$$L_{ori} = 2.5 + 0.075(\varphi - 35) \quad \text{for} \quad 35 \leq \varphi \leq 55, \tag{7}$$
$$L_{ori} = 4 - 0.114(\varphi - 55) \quad \text{for} \quad 55 \leq \varphi \leq 90, \tag{8}$$
$$L_{ori} = -10 + 0.354\varphi \quad \text{for} \quad 0 \leq \varphi \leq 35. \tag{9}$$

We have to observe that:

$$\Delta h_{base} = h_{base} - h_{roof}, \tag{10}$$

$$\Delta h_{mobile} = h_{roof} - h_{mobile}. \tag{11}$$

The L_{msd} (multi screen diffraction loss) is calculated as [3]:

$$\begin{gathered} L_{msd} = k_a + L_{bsh} + k_d \log_{10}(f) - \\ 9\log_{10}(B) - 9\log_{10}(f) \quad \text{for} \quad L_{msd} > 0, \end{gathered} \tag{12}$$

$$L_{msd} = 0 \quad \text{for} \quad L_{msd} < 0, \tag{13}$$

where:

$$L_{bsh} = 0 \quad \text{for} \quad h_{base} \leq h_{roof}, \tag{14}$$
$$L_{bsh} = -18\log_{10}(1 + \Delta h_{base}) \quad \text{for} \quad h_{base} > h_{roof}, \tag{15}$$
$$k_d = 18 + 15\left(\frac{\Delta h_{base}}{h_{roof}}\right) \quad \text{for} \quad h_{base} \leq h_{roof}, \tag{16}$$
$$k_d = 18 \quad \text{for} \quad h_{base} > h_{roof}, \tag{17}$$
$$k_a = 54 - 0.8\Delta h_{base} \quad \text{for} \quad d \geq 0.5 \text{ km} \quad \text{and} \quad h_{base} \leq h_{roof}, \tag{18}$$
$$k_a = 54 - 0.8\Delta h_{base}\left(\frac{d}{0.5}\right) \quad \text{for} \quad d < 0.5 \text{ km} \quad \text{and} \quad h_{base} \leq h_{roof}, \tag{19}$$
$$k_a = 54 \quad \text{for} \quad h_{base} > h_{roof}, \tag{20}$$
$$k_f = -4 + 1.5\left(\frac{f}{925} - 1\right) \quad \text{for urban areas}, \tag{21}$$
$$k_f = -4 + 0.7\left(\frac{f}{925} - 1\right) \quad \text{for suburban areas}, \tag{22}$$

where B is the building to building distance in meters, d is the distance between transmitter and receiver antenna in meters, f is the frequency in GHz, φ is the street orientation angle degree, w is the street width in meters.

The equation for Line Of Sight (LOS) condition is expressed as [3]:

$$PL_{los} = 20\log(f) + 42.6 + 26\log(d). \tag{23}$$

2.2. ITU Terrain Model

The ITU terrain model is good for general planning and coordination. It can be used with the minimum information about the propagation path and can be agreed easily between countries. Therefore, when planning for particular transmitter locations, there are considerable advantages in using deterministic prediction methods [4]. The ITU terrain model is based on diffraction theory and provides a relatively fast means of determining a path loss for a telecommunication link. The path loss calculation of the ITU terrain model is done by using the following equation [5]:

$$A = 10 - 20C_N, \tag{24}$$

where

$$C_N = \frac{h}{F_1}, \tag{25}$$

$$h = h_L - h_O, \tag{26}$$

$$F_1 = 17.3\sqrt{\frac{d_1 d_2}{fd}}, \tag{27}$$

where A is the additional loss (dB), C_N is the normalized terrain clearance, h is the height difference (m), h_L is the height of line of sight link (m), h_O is the height of obstruction (m), F_1 is the radius of the first Fresnel Zone (m), d_1 is the distance of obstruction from one terminal (km), d_2 is the distance of obstruction from other terminal (km), f is the frequency of transmission (GHz) and d is the distance between transmitter and receiver (km).

2.3. Two Ray Ground Reflection (TRGR)

The two-ray ground reflection model considers both the direct path and a ground reflection path. This model is based on two paths. The first path is a direct path between transmitter and receiver and a second path will be with one ground reflection between the same transmitter and receiver [6]. One of the most important parameter in this model is the height of location of receiver and transmitter according to the ground surface. Thus, the received power can be calculated by using the following equation [7], [8]:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}, \tag{28}$$

where P_t is the transmitted signal power, h_t is the height of transmitter, h_r is the height of receiver, d is the distance between transmitter and receiver, L is equal to 1, G_t is the antenna gain of transmitter and G_r is the antenna gain of receiver.

3. Simulation Models and Scenarios

This section provides information about simulation models using MATLAB R2013b software which was used to analyse channel propagation models of wireless communication systems.

3.1. Simulation Models

In this research, COST 231 Walfisch-Ikegami (W-I) model, ITU terrain model and Two Ray Ground Reflection (TRGR) model are analysed in urban and rural environments by applying three various receiver antenna heights which are 4 m, 7 m and 14 m. Also, the operating frequency was fixed at 1800 MHz.

In the simulations, the path loss of channel propagation models is estimated by stratifying different receiver antenna heights 4 m, 7 m and 14 m with fixed transmitter antenna height 29 m. We decided to use the mobile transmitter power equal to the value of 31 dBm based on setting up the simulation parameters.

3.2. Simulation Scenario

In the simulation, the distance between transmitter and receiver is assumed to be 7 km and base station transmitter power equal to 42 dBm. We set the operating frequency at 1800 MHz for all simulation scenarios.

Moreover, Tab. 1 shows values of all parameters which were applied through simulation.

Tab. 1: Parameters of simulation.

Parameters	**Values**
Operating frequency	1800 MHz
Distance between TX and RX	7 km
Transmitter antenna height	29 m
Mobile transmitter power	31 dBm
Base station transmitter power	42 dBm
Receiver antenna height	4 m, 7 m, and 14 m

Simulation scenario was proposed to evaluate the path loss of different channel models. Moreover, simulations were performed in six trials. In each trial, the value of receiver antenna height was changed according to the type of channel model and environment. During each trial, path loss was estimated using all previously described parameters in urban and rural areas.

4. Simulation Results

In this section results achieved in the simulations will be introduced. Related to the results of the propagation models for 4 m, 7 m and 14 m receiver antenna heights, Fig. 1, Fig. 2 and Fig. 3 show it respectively in urban environment.

Results achieved for the mentioned propagation models in rural area are shown in Fig. 4, Fig. 5 and Fig. 6.

By comparing the results in [9] with the results of this research, it has been found that the results of Cost 231 (W-I) model in the mentioned paper stated the highest value (176.22 dB) in urban environment at 4.2 GHz.

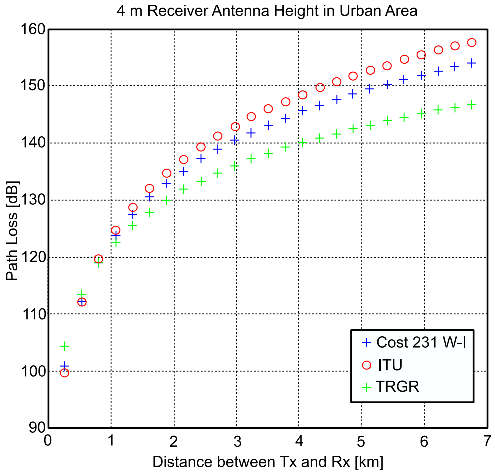

Fig. 1: Path loss for 4 m receiver antenna height in urban environment.

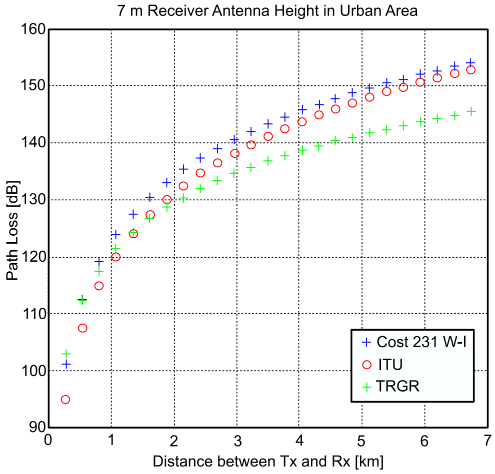

Fig. 2: Path loss for 7 m receiver antenna height in urban environment.

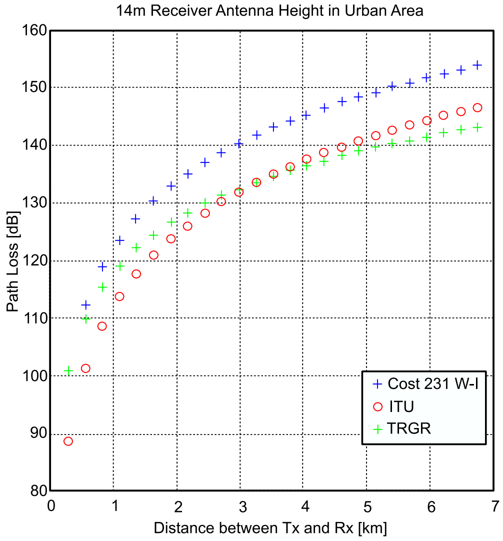

Fig. 3: Path loss for 14 m receiver antenna height in urban environment.

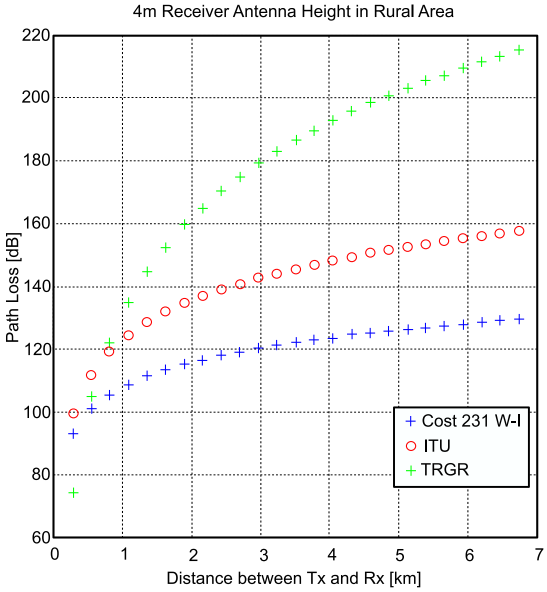

Fig. 4: Path loss for 4 m receiver antenna height in rural environment.

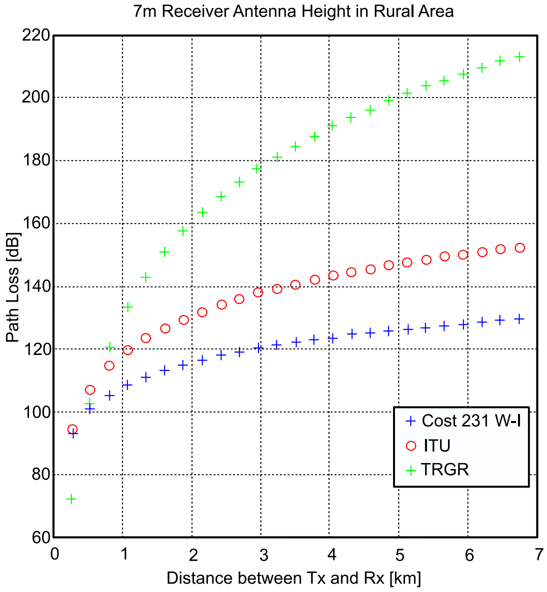

Fig. 5: Path loss for 7 m receiver antenna height in rural environment.

As can be seen from Fig. 5 and Fig. 6, the lowest values of path loss were achieved by COST 231 (W-I) model in urban and rural environments.

By comparing the results in [10] with these results, it has been found that the results of Cost 231 (W-I) model in the mentioned paper stated the lowest value (126 dB) in 3 m, 6 m and 10 m receiver antenna heights in the rural environment at 4.5 GHz.

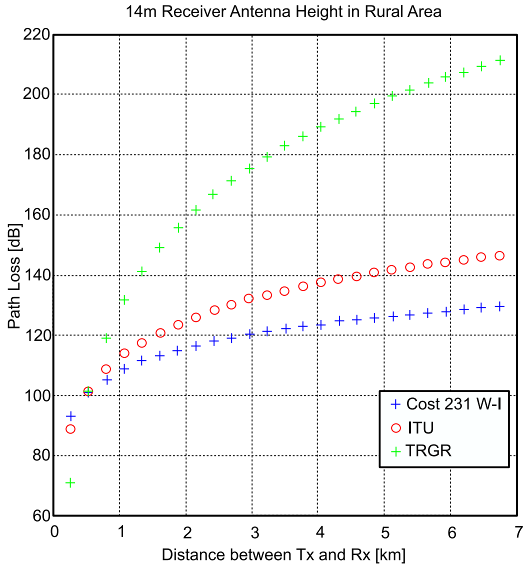

Fig. 6: Path loss for 14 m receiver antenna height in rural environment.

5. Conclusion

Path loss calculation is one of the leading factors that we have to estimate. Network planners rely on the signal propagation path loss models for enhancing the wireless communication systems to achieve an acceptable level of service quality for the users. Therefore, it is very important to find out a suitable propagation model for all types of the environments to provide guidelines for cell planning of wireless communication systems. In this research, the selected models were analysed by using MATLAB R2013b.

It was apparent from the results of the path loss estimation for 4 m, 7 m and 14 m receiver antenna heights in the urban environment that ITU model showed the highest path loss result as compared with the other models in the urban environment.

Finally, it is necessary to point out that finding an accurate propagation model for propagation losses is a leading issue that will give us the best path loss prediction when designing a wireless communication network.

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