Progress In Electromagnetics Research C, Vol. 22, 11–22, 2011

A TERRAIN ROUGHNESS CORRECTION FACTOR FOR HATA PATH LOSS MODEL AT 900 MHZ

M. A. Nisirat [1, *], M. Ismail [1], L. Nissirat [1], and S. Al-Khawaldeh [2]

[1]Department of Electrical, Electronics and System Engineering, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

[2]Department of EE, Faculty of Engineering Tech., Al-Balqa' Applied University, Jordan

Abstract—This paper proposes a new propagation model based on the most widely used Hata model. The proposed model is developed by extrapolating Hata model to be suitable for microcells. The main equation of Hata urban model is modified by substituting the suburban correction factor with a terrain roughness parameter. This parameter uses a quadratic regression estimator of the standard deviation, σ, of the terrain irregularities along the measuring path, in west of Amman, Jordan. It is shown that RMSE between the predicted and measured data for the new proposed model, is improved by up to 3 dB compared to Hata suburban model in most areas under study. Furthermore, the improvement in RMSE increases as σ increases. These results clarify the robustness of the proposed model.

1. INTRODUCTION

Accurate estimation of propagation path loss is a key factor for the good design of mobile systems. Such needs are of a great concern of mobile system designers to optimize system parameters such as number and locations of transmitters, power coverage and interference level. Optimization of these parameters will increase the efficiency of quality of service, reduce undesirable power losses, increase coverage area, and determine best arrangements of base stations.

For free space environment, Friis proposed a propagation model that predicts the strength of the received power [1]. In this model, it is

Received 14 April 2011, Accepted 22 May 2011, Scheduled 30 May 2011
* Corresponding author: Mahdi A. Nisirat (mamnisirat@gmail.com).

obvious that the received power is inversely proportional to the square of distance between the transmitter and the receiver. A drawback of this model is that it is inefficient to predict power loss in other different environments. To overcome this problem, a two-ray propagation model was established for flat areas [1]. It was shown that the received power is inversely proportional to the distance with a power of 4. Unfortunately, this model is not satisfactory for urban areas, and other complicated areas. In 1968, a most widely used model was established by Okumura to predict the path loss in urban areas [2]. This model was based on field measurements in Tokyo, Japan. One disadvantage of this model is that it is not suitable for irregular terrain urban areas [3]. Hata reformulated Okumura model in the form of empirical relations for typical wireless environments such as large, medium, and small, either, urban, suburban, or rural areas [2]. This model was designed for operating frequencies up to 1.5 GHz. COST-231 Hata model is an extension of Hata model for path loss predictions over a frequency range of 800 to 2000 MHz in existence of line-of-sight and non-line-of-sight situations [3]. On the other hand, these statistical models were based on observations and measurements of propagation loss in different areas. These models depend on various parameters such as distance, transmit and receive antenna heights, operating frequency range, particular geographical area or building. Unfortunately, such models usually cover ranges of distances from 1–100 km, and usually represent terrain in category format that barely reflects the morphology of the path of measurements. Terrain data are of at most importance to implement path loss models of high accuracy [4]. Therefore, different deterministic models have introduced terrain roughness in to the overall relation for path loss determination. Terrain loss model ITU [2] is one of such models. ITU uses the deviation in the elevation between base station and receiver to define terrain irregularities. Many literatures argue that this parameter does not reflect the attenuation due to terrain irregularities [2].

Ibrahim and Parsons model [5] was formulated in UK, London. In This model, terrain roughness between the transmitter and the receiver was addressed. The need for detailed and specific terrain and building category data, in addition to the precise implementation of these data, are among reasons for the difficulty of implementing this model [5].

In this paper, a proposed model based on Hata urban relation is considered. The areas under study are microcells and have different terrain irregularities. The use of Hata model in microcellular systems has been addressed in [6]. It is showed that Hata urban, COST-231 Hata, and more specifically Hata suburban models are well suited for predictions in microcells given that transmit Antennas are above roof top.

Terrain roughness data is an important parameter to implement in the model since Amman is considered an area of high terrain roughness [3, 7]. This proposed model has introduced a new factor relating a unique terrain roughness parameter, the standard deviation (σ) of the elevation at the measured points, to the path loss relation. Root mean square error (RMSE) is then calculated between the proposed method and the original received raw data. It is shown that RMSE values calculated by this method are less compared to the RMSE values between Hata suburban model and the actual received raw data. Different statistical and deterministic models are discussed in the following section. In addition to that, recent studies with corrections over Hata model are covered to analyze their effect on the original model. Followed by that, the measurement campaign and modeling validation are discussed.

2. PROPAGATION MODELS

In wireless channels, the path loss prediction is very important factor that enables planning the effective transmitted power, coverage area and quality of service. This section is divided to three subsections. The first one introduces an introduction to the basic models covered by this paper, mainly Hata and Okumura models. The second is a review of some enhancements over Hata model to formulate specific models for a given region. The third is a review of some other models, especially deterministic, found in literature of 900 MHz range.

2.1. Basic Empirical Models

2.1.1. Okumura's Model

This model is well recognized and widely used for urban and suburban environments. It is valid for distance range from 1 km to 100 km. Also, it can be used for frequencies of 150 MHz extended to 3000 MHz. Good results can be obtained for base station antenna heights from 30 m to 1000 m.

For this model, the median value of propagation path loss is expressed as

$$L(\text{dB}) = L_f + A_{mu}(f, d) - G(h_t) - G(h_r) - G_{area} \tag{1}$$

where d is the distance between transmit and receiving antennas, L_f is the free space path loss, A_{mu} is the free space attenuation, $G(h_t)$ is the base station antenna height gain factor, $G(h_r)$ is the mobile antenna height gain factor, and G_{area} is the gain corresponding to specific environment [1, 3].

2.1.2. Hata's Model

Basically, this model has been introduced to urban areas; and with some correction factors it could be extended to suburban and rural areas. For urban area the median path loss equation is given by

$$L_{(urban)}(\text{dB}) = 69.55 + 26.16\log(f_c) - 13.82\log(h_r) - a(h_r) + (44.9 - \log(h_t))\log d \quad (2)$$

For suburban area, it is expressed as

$$L_{(suburban)}(\text{dB}) = L_{(urban)} - 2[\log(f_c/28)]^2 - 5.4 \quad (3)$$

Finally, for open rural area, it is modified as

$$L_{(open)}(\text{dB}) = L_{(urban)} - 4.78(\log(f_c))^2 + 18.33\log(f_c) - 40.94 \quad (4)$$

The correction factor, $(a(h_r))$, in Equation (2), differs as a function of the size of the coverage area.

For small and medium areas, it is

$$a(h_r) = (1.1\log(f_c) - 0.7)h_r - (1.56\log f_c - 0.8)\text{dB} \quad (5)$$

For large area, it is

$$a(h_r) = 8.29(\log 1.54h_r)^2 - 1.1\text{dB} \quad \text{for} \quad f_c < 300\,\text{MHz} \quad (6a)$$

$$a(h_r) = 3.2(\log 11.75h_r)^2 - 4.97\text{dB} \quad \text{for} \quad f_c > 300\,\text{MHz} \quad (6b)$$

In the above equations, d is the transmitter-receiver antenna separation distance and it is valid for 1 km–20 km, f_c represents the operating frequency from 150 MHz to 1500 MHz. The transmit antenna height, h_r, ranges from 30 m to 200 m and the receive antenna height, h_r, ranges from 1 m to 10 m are considered [1, 3].

2.2. Enhancement Over Hata Model

Many site specific models adopted new corrections for the original Hata relations to make it more applicable for different scenarios. Medeisis and Kajackas [8] have studied Hata-Okumura model for the region of Lithuania. The study divided the main equation of Hata urban model into three parts. One is considered as offset value, while the second is a factor related to system variables as transmitter and receiver heights. The third is a slope of $(\log d)$ factor. The paper has covered urban, suburban, and rural areas in different frequencies at 160 MHz, 450 MHz, and 900 MHz. In the 900 MHz range, the authors found that for urban area assumption the offset value and the slope have not been changed from the original relation of Hata model. Other new suggested values were found for both the offset and the slope, for suburban and rural areas. The conclusion of this study emphasizes that site specific relations are needed for different locations. Similar study also carried out for the city of Ladang Jugra land and Carey area, Malaysia by Kandasamy et al. [9]. In this study, authors have applied Genetic Algorithm to optimize and compare the three different models, Okumura Hata, Walfisch-Ikegami and free space, for the 900 MHz frequency range. Optimization is made possible through adding offset constants to the models. Results conclude that optimized models have negligible error compared to the measured data, and that Hata-Okumura model has the least standard deviation error. Other authors such as Mardeni and Kwan [10] have compared Hata suburban, Egli, and COST 231 Walfisch-Ikegami model to the measured path loss data. It was concluded that Hata suburban model is the best fitting model among the others. Both the offset dc value and the slope of Hata suburban model where optimized to suit different areas at different frequencies in Malaysia. Panda et al. [11] have applied Hata model for Tokyo region in the frequency range of 1300 MHz. An Adaptive Knowledge Guided Neural Network (AGNN) scheme is applied for fast and reliable convergence to the collected data. This scheme is compared to the Adaptive Neural Network (ANN) method and showed better and more reliable results. The conclusion argued that empirical formulas suffer from lack of adaptation for various terrain irregularities.

Many literatures have applied Hata for microcell areas and with transmit antenna heights below 30 meter. Mansour [6] has applied Hata model for distance ranges below 600 meter with different transmit antenna heights in the vicinity of roof top, at 1800 MHz. It was concluded that Hata suburban model predicts the data very will in the given range. Mognesen et al. [12] have applied Hata model for micro and small cells, at 900 and 1800 MHz. Results conclude that Hata model predicts the path loss very closely down to tenths of meters.

2.3. Deterministic Models

Terrain Loss model (ITU) [2] computes path loss by accounting for the roughness of the terrain, by inserting a factor Δh to define terrain irregularity. Δh is defined as 10 %–90 % deviation over the propagation path of length 10 km–50 km. Many literatures find that Δh is not suitable for precise determination of the attenuation correction factor. In addition to that, the irregularity in the vicinity of the receiver is not accounted for in this model which will affect the accuracy in determining the exact path loss [2]. The clearance angle method has overcome this weakness and corrected for the terrain irregularity by computing the angle θ of the clearance between the transmitter and the receiver. This model has been adopted by CCIR. Ibrahim and Parsons [5] have extensive data collected in London area, UK. Their model accounted for different terrain roughness found in London and covers the range of area from the transmitter to the receiver. This model simply introduces a factor H accounting for the difference between the heights of the transmitter and the receiver surrounding areas.

3. PROPAGATION MEASUREMENT AND MODELING

3.1. Propagation Measurement

The propagation models presented in the previous section were developed for large cell areas where the roughness of the terrain has not been considered explicitly. In this section, an extension of Hata urban model is proposed for microcells [3]. The data has been collected by TEMS tool with an antenna mounted on a moving vehicle, average speed of 20 km/h, 1.5 meter above ground level. Average height of transmit antenna is about 30–40 meter above ground level. The data are offered in excel sheet and contains time of recording measurement, type of message, sector number, latitude, longitude, altitude, and received power level. The data has been collected in a regular road test on quasi-regular path at the range of 900 MHz offered by different mobile service providers in west of Amman, Jordan. The average sample rate of the collected data is about 4 samples per second. A sketch of the experimental setup is shown in Fig. 1.

West of Amman can be considered as a suburban area mostly of high terrain roughness and with building heights ranging from two to three levels approximately 7–10 m in most parts [1, 3]. The path loss data of each area has been filtered by a moving window mean filter to filter out any small scale variation of the received signal [13]. The large scale variation has been used to represent the received power from the transmitter.

3.2. Model Derivation and Verification

In this model, the standard deviation (σ) of the elevation, at the measured points, of each area has been calculated. The (σ) values, of the areas under consideration, ranged from 0.466 up to 9.21. It is worth saying that standard deviation of the elevation reflects terrain roughness level [14]. It reveals the roughness of the given path clearly. In this paper, the standard deviation of the elevation (σ) is calculated

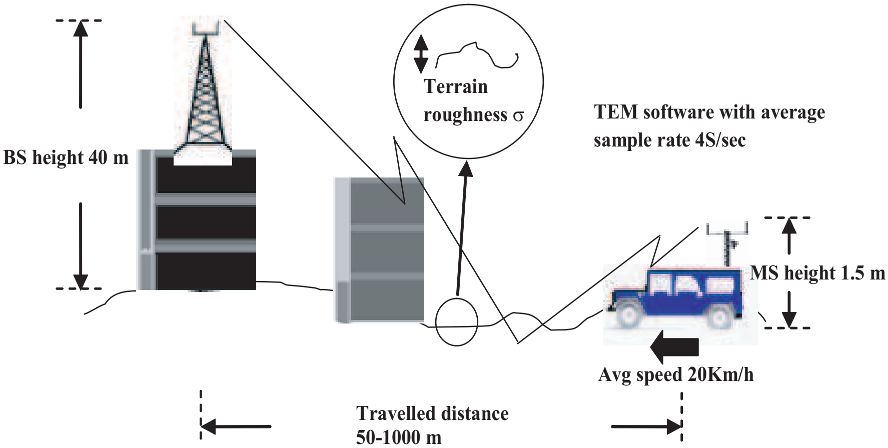

Figure 1. A sketch of the experimental campaign.

to measure global (coarse) terrain roughness [14]. The difference between the received power and the predicted power by Hata urban model, μ_d, is then calculated for a given measured path, for each area. This difference, μ_d, is correlated with ($\log\sigma$). This correlation factor is found to be about 0.92, which reflects a high correlation between μ_d and ($\log\sigma$). A quadratic regression is then applied to derive the parametric relation between μ_d and $\log(\sigma)$. This can be achieved according to the quadratic relation:

$$\hat{\mu_d}(\sigma) = a_0 + a_1 \log(\sigma) + a_2(\log(\sigma))^2 \tag{7}$$

where $0.466 \leq \sigma \leq 9.21$.

The values of a_0, a_1, a_2 are found to be 10.7463, −1.1401, −2.7183, respectively. Then Equation (7) would become of the form

$$\hat{\mu_d}(\sigma) = 10.7463 - 1.1401 \log(\sigma) - 2.7183(\log(\sigma))^2 \tag{8}$$

The proposed path loss based on Hata urban model is then written in the form

$$L_{(\text{proposed})}(\text{dB}) = L_{(\text{Hata urban, small area})}(\text{dB}) + \hat{\mu_d}(\sigma) \tag{9}$$

or

$$\begin{aligned} L_{(\text{proposed})}(\text{dB}) = & \, 69.55 + 26.16 \log f_c - 13.82 \log h_r - a(h_r) \\ & + (44.9 - \log h_t) \log d + \hat{\mu_d}(\sigma) \end{aligned} \tag{10}$$

where $\hat{\mu_d}(\sigma)$ is the parametric regression relation given in (8) at the measured points and f_c, h_r, h_t, d, and $a(h_r)$ are given in (2), and (5).

To validate the effectiveness of this proposed model, Root Mean Square Error (RMSE) is calculated between the results of the proposed model and the measured path loss data of each area. These values are compared with RMSE values calculated between Hata suburban model, where the correction factor given in (3) is used for Hata model, and the measured path loss data. Some samples of calculated RMSE for some areas are given in Table 1.

RMSE is introduced according to the following equation

$$\mathrm{RMSE} = \sqrt{\frac{\sum(d_m - d_{p,H})^2}{N-1}} \tag{11}$$

where d_m is the measured data path loss, d_p is the path loss by the proposed model, d_H is the path loss by Hata model (suburban area assumed), and N represents the number of points.

4. RESULTS AND DISCUSSION

To prove the efficiency of the presented model, a location of one site by the name Abdoun area have been selected and shown in Fig. 2. The path where the data has been collected is shown by black colored line. The standard deviation of the area is $\sigma = 8.98$.

Figure 3 represents the path loss in dB of the measured values, the median filtered data of the measured values, the path loss predicted by the proposed model, and the path loss applying Hata suburban model.

Comparing the results of RMSE's, given in Table 1, it can be deduced that the new proposed model is more accurate in predicting the actual calculated path loss. Hata suburban model actually underestimates the real measured data in the given area. This may be argued due to the fact that measurements are collected in more dry regions than the original Hata-Okumura model. In addition to

Table 1. Different terrain roughness values, and comparison of RMSE values between Hata suburban, proposed model, with the real measured path loss.

Area Name	RMSE compared to Hata Suburban (dB)	RMSE compared to proposed Model (dB)
Galaria Cinema area with $\sigma = 2.89$	17.70	17.04
Kabarity area with $\sigma = 7.77$	8.69	7.38
Abdoun area with $\sigma = 8.98$	18.46	15.79

Figure 2. The location of Abdoun area (1 km^2) with terrain roughness $\sigma = 8.98$ [Google earth].

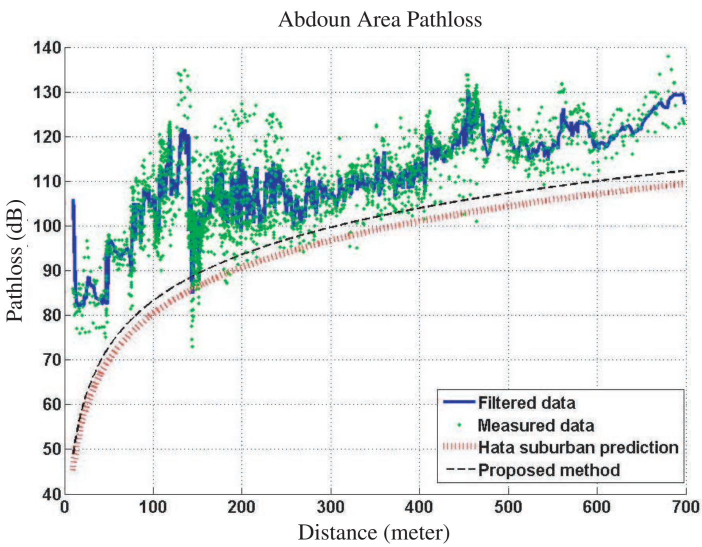

Figure 3. Path loss of measured values and predicted values by the proposed scheme for Abdoun area with terrain roughness $\sigma = 8.98$.

that, terrain irregularities have been implicitly used by the original Hata model. Furthermore, it is shown from Table 1 that as σ increases the difference in the value of RMSE between Hata suburban and the proposed model increase. This result would emphasize the impact of any correction based on the topology. For better path loss prediction, this difference in RMSE values would be considered not negligible. Regular mobile companies in Jordan work in the 900 MHz and 1800 MHz band of frequencies. Further studies to analyze the behavior of the proposed model at different frequency bands are suggested. On the other hand, path loss prediction in the 1800 MHz is highly correlated to the 900 MHz, therefore, the 1800 MHz band path loss prediction is expected to behave as the 900 MHz band path loss prediction by adding only an offset shift according to [12].

5. CONCLUSION

In this paper, an effective and vigorous propagation model is proposed for microcell areas with different terrain roughness. The standard deviation (σ) of the elevations of the path taken at the measuring points is used as a single parametric index representing area roughness. A correction mathematical relation using this calculated roughness parameter (σ) has been introduced into Hata urban model. By this proposed model, improved path loss results are calculated with no need to categorize areas undertaken in the study. This model was tested and applied on many areas with different scale of terrain roughness. The proposed model in all the cases has given a comparable or better RMSE values over Hata suburban model, where Hata suburban model has been used in the sites under test in West of Amman. Difference in RMSE values between the proposed and Hata suburban models, are ranged from 0 dB up to 3 dB. It is noticed that in all cases under study, Hata suburban model has under estimated the real measured path loss data. This would be explained due to the fact that measurements were collected in less precipitation regions than the original Hata model. In addition to that, terrain irregularities have been weighed down by the original Hata model. In the areas under study, it is noted that more improvement in RMSE values is achieved, compared to Hata suburban, as the terrain roughness increases. This result would suggest the importance of any correction based on terrain roughness parameters. Further study on other terrain parameters that would affect propagation is needed. Such parameters are to be optimized for best fitting. Furthermore, the impact of different frequency bands on the proposed model is to be analyzed.

REFERENCES

1. Sarkar, T. K., Z. Ji, K. J. Kim, A. Medour, and M. Salazar-Palma, "A survey of various propagation models for mobile

communication," *IEEE Antennas and Propagation Magazine*, Vol. 45, No. 3, 51–82, June 2003.

2. Neskovic, A., N. Neskovic, and G. Paunovic, "Modern approaches in modeling of mobile radio systems propagation environment," *IEEE Communications Surveys*, 2–12, Third Quarter, 2000.
3. Nisirat, M. A., M. Ismail, S. Alkhawaldeh, and L. Nissirat, "Expectation of power propagation at 900 MHz in Amman, Jordan," *WSEAS, EHAC'10 Proceedings of the 9th WSEAS International Conference on Electronics, Hardware, Wireless and Optical Communications*, 76–79, 2010.
4. Tunc, C. A., A. Altintas, and V. B. Ertürk, "Examination of existent propagation models over large inhomogeneous terrain profiles using fast integral equation solution," *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 9, 3080–3083, September 2005.
5. Cruzl, R. M. S., F. C. Da Costal, P. F. Bragal, G. Fontgalland, M. A. Barbosa Demelo, and R. R. M. Do Valle, "A comparison between theoretical propagation models and measurement data to distinguish urban, suburban and open areas in Jodo Pessoa, Brazil," *IEEE Microwave and Optoelectronics*, 287–291, July 2005.
6. Mansour, N. A., "RF predictions and modeling for microcells and PCS cell design," *IEEE Vehicular Technology Conference*, 1745–1749, 1994.
7. Fadda, E. H., A. A. Aldosari, and N. N. Al-Hanbali, "Building geospatial information system using IKONOS and SPOT images; creation three dimensional model for higher council for youth, Amman area, Jordan," *4th National GIS Symposium*, 1–12, Saudi Arabia, 2009.
8. Medeisis, A. and A. Kajackas, "On the use of the universal okumura-hata propagation prediction model in rural areas," *IEEE, Vehicular Technology Conference Proceedings*, 1815–1818, 2000.
9. Kandasamy, S. K., M. Ismail, and S. K. Tiong, "Application of genetic algorithm for large scale coverage prediction in gsm cellular mobile system," *MMU International Symposium on Information and Communications Technologies (M2USIC)*, 9–12, Putrajaya, Malaysia, 2004.
10. Mardeni, R. and K. F. Kwan, "Optimization of hata propagation prediction model in suburban area in Malaysia," *Progress In Electromagnetics Research C*, Vol. 13, 91–106, 2010.
11. Panda, G., R. K. Mishra, and S. S. Palai, "A novel site adaptive

propagation model," *IEEE, Antennas and Wireless Propagation Letters*, 447–448, 2005.

12. Magensen, P. E., P. Eggers, C. Jensen, and J. B. Andersen, "Urban area radio propagation measurements at 955 and 1845 MHz for small and micro cells," *IEEE GLOBECOM'91*, 1297–1302, 1991.
13. Fontan, F. P. and P. M. Espineira, *Modeling the Wireless Propagation Channel a Simulation Approach with MATLAB*, 1–27, John Wily and Sons, 2008.
14. Wilson, J. P. and J. C. Gallant, *Terrain Analysis: Principles and Applications*, 51–86, John Wily and Sons, 2000.