Wavelet Based Path Loss Modeling for Global System for Mobile Communication in an Urban Environment

Danladi Ali

Vlada N. Y. Department of Information and Technology, National Metallurgical Academy, Ukraine

Abstract: ***In this paper, we measured GSM signal strength in the Dnepropetrovsk city to predict path loss in study area using one-dimensional multilevel wavelet and used neural network clustering to determine average GSM signal strength received at the study area. The wavelet predicted that the GSM signal fades 5 times the propagation frequency and attenuated with RMSE of 3.428dB; this attenuation value is used to modify the reference model. The neural network clustering revealed that -75dB is received more frequent followed by -85dB. This means that the signal strength received at the study is mostly weak signal.***

Keywords: One-dimensional multilevel wavelets, path loss, GSM signal strength, propagation and urban environment.

1. Introduction

Path loss is a fundamental element for understanding and designing of a radio communication system more especially unguided path like global system for mobile communication (GSM) signal. Usually, better understanding of path loss helps us to choose some important network parameters for example, transmitter power, antenna height, antenna gain, and antenna general location. An ideal propagation means equal propagation in equal directions. Unfortunately, in real situation it is not feasible due to some factors between the base station (BS) and the mobile unit (MU) that attenuates the signal, such factors may be responsible for reflecting, refracting, absorbing, and scattering the GSM signal before reaching the MU. Therefore, in order to receive efficient signal strength it becomes essential to conduct feasibility studies to have almost oran accurate bill of these factors before undertaken a design of radio communication path.

Hata, Okurum-Hata, COST 231-Hata, Sakagami-Kuboi, and Walfisch,-Ikegami have developed different models using different methods[6][7][8][9][10], such as empirical, stochastic or deterministic method. COST 231 Hata or Okumura-Hata model are popularly used, but seems not to have meet up or serve efficiently with all environments around the globe. So, these models are acceptably used as a reference models which need improvements depending on the environmental factors. For example, In [1], path loss prediction model is developed for GSM network planning in suburban and urban environments at 900MHz and 1800MHz, the work adapted the following as reference model; Hata, COST 231, international telecommunication union (ITU-R), Ericson and stanford University interm (SUI). The work revealed that, for suburban environment first Hata is the best fit model, while for urban environment COST 231 is the best fit model.

In this work, we propose to choose Okumura-Hata and COST 231 Hatamodel as our reference model. Our interest is to adopt these models, modify them based on our empirical data collected at the study area. We will use one-dimensional multilevel wavelet to predict the losses in the attenuated signal and determine its root mean square error (RMSE). We will also, use neural network clustering to group the signal according to the signal strength receive at the study area.

1.1 Okumura-Hata Model

This model is developed to study the radio frequency propagation in an urban area with the following parameters; frequency 150 – 1920MHz, MU height 1 -10m, BS height 30 – 200m, and link distance 1 -10km. This model can best examine the behaviors of the propagation in the study area by applying mathematical concept in expression (1).

$$L_{50} = \gamma_0 + a(f,d) - G_B - G_M - G_E \quad (1)$$

Where L_{50} is the 50[th] percentile (the median) value of the propagation path loss, γ_0 is the free space loss, $a(f,d)$ is the median attenuation relative to the free space, G_B is the BS height, G_M is the MU height and G_E is the gain due to the type of environment. The components of the model are as follows

$$\gamma = 20\log f + 20\log d \quad (2)$$

$$G_B = 20\log\left(\frac{h_B}{200}\right) \; 30\text{m} < h_B < 1000\text{m} \quad (3)$$

$$G_M = 10\log\left(\frac{h_M}{3}\right), \; h_M \le 3\text{m} \quad (4)$$

$$G_M = 20\log\left(\frac{h_M}{3}\right), 3\text{m} < h_M < 10\text{m} \quad (5)$$

Okumura–Hata model, change slowly with environment. However, COST 231Hata model stand out to be better reference model for urban areas because of its compatibility ability with new environments.

1.2 Cost 231 Hata Model

The COST-231-Hata is an extension of the Hata model which is developed to address short comings that the first Hata model cannot address. COST 231 model has similar characteristics with Okumura-Hata model, but differs with the following; frequency 1500 MHz to 2000 MHz, and the link distance 1km to 20km [2][3], is given by

$$L_{50} = 46.3 + 33.9\log f_c - 13.82\log h_B - a(h_m) + \log d \, (44.9 - 6.55\log h_m) + C_H \quad (6)$$

Where $a(h_m) = 3.20(\log 11.75 h_m)^2 - 4.97$, for $f > 400$ MHz and C_H is the correction factor usually given by 3dB for urban environments.

2. Study Area and Method of Data collection

The data is collected in a day time with MU in Dnepropetrovsk city, Ukraine at different locations. The city is typically an urban area which consist of; tall buildings, significant number of trees, river Dnepr that divides the city into two and usual human activities like vehicle movements during the time of the day. On the MU, there are 0 to 5bars signifying the signal strength received at the destination. The network bars on the MU that range from 0 to 5 bars, the lowest bar is 0 and is the weakest signal while the signal strength increases as the number of the bars increase, which means the strongest signal is 5 bars. Usually, GSM signal strength is measured in -dBm; that is, the power measured (dB) multiple by the distance between the transmitter and MU receiver. The useful range is from -50dBm to -110dBm in a frequency range of 900MHz to 1800MHz or 1900MHz depending on the environmental requirements. The smaller the number of the dB received by the MU the worse the reception or QoS. Therefore, -50dBm is much better than -110dBm. In this work, we assigned 0 (no bar) to -105dBm, subsequently, 1bar = -95dBm, 2bars = -85dBm, 3bars = -75dBm, 4bars = -65dBm and 5bars = -55dBm. The MU from transmitter is located in different positions. Starting, from; 400m to 4000m.

3. Wavelet Decomposition and Prediction Algorithm

Here, we use wavelet transform to decompose the attenuated signal measured with one-dimensional multilevel wavelet. Full wavelet decomposition of the attenuated signal measured usually provides information about the time and the frequency of the signal at numerous scales. Thus, the signal can be seen in detail and approximated form both on the octave axis (j, J) respectively as shown in the Fig. 1. Where, the approximated signal is situated on the upper scale ranging from $1 \le J \le J_0$ while the details on the lower scale ranging from $1 \le j \le J_0$. The wavelet coefficients $a_x(J,k)$, $d_x(j,k)$ are derived from the relationship below after full decomposition.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (7)$$

Where a is the positive number which defines the scales and b is the real number that defines the shift in (7) sometimes called child wavelets derived from mother wavelet. Full wavelet decomposition (FWD) of (7)is given in (8)

$$y = a_x(J,k)\,\psi_0(J,k) + \sum_{k=1}^{j} d_x(j,k)\,\psi_0(j,k) \quad (8)$$

y is decomposed using Haar at level 5. Haar is chosen for the decomposition because of the following reasons; physical appearance of the experimental data, the wavelet Haar have coefficient of correlation approximately equal to that of experimental data and the wave's energy is almost the same. As earlier mentioned. Ideal propagation means equal radiation in all directions. Perhaps, ideal wavelength (λ) of propagation of the study area may be obtained as $\lambda = C/f$; where C is the speed of the propagated wave and it can be evaluated by $C = d/t$; where d is the distance between the BS and the MU. Haven known the total amount of the power received at the study area using expression (9).

$$\sum_{i=1}^{n} P_i(dBm) \quad (9)$$

Where P is the power received at the study area. Comparing with the approximated power from wavelet after de-noising, shows that the signal suffers attenuation, we then find the average ratio of the signal received to the approximated signal as -81.86dBm/-11.69dBm which is equal to 5:1 respectively, this is evident that the frequency of the signal received fades 5 times [11] and wavelength becomes $\lambda = 5C/f$ greater than the normal wavelength of the propagation due to the obstacles between the BS and the MU. And another factor that may be attributed to the cause of the fast fading is the fact that the study area is close to the river Dnepr. Therefore, to determine the propagation error, we obtained the root mean square error between the approximated signal and the received signal, using expression (10).

$$RMSE = \sum_{i}^{n}\left(\sqrt{\frac{(P-P_a)^2}{n}}\right) \quad (10)$$

where n and P_a is the number of the empirical data and the approximated signal respectively. Fig. 1, shows the wavelet decomposition of the detail and approximated signals.

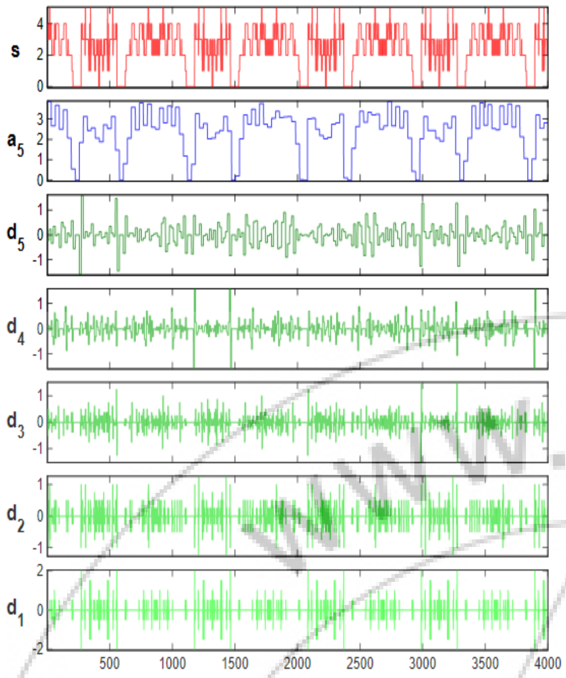

Figure 1: Detail and Approximated signals in octave

4. Clustering of the Variation of signal Strength Received

Clustering simply means grouping elements together based on their properties, appearance, contents and other features. We trained the experimental data collected using neural network clustering, the network learned about the data and produced clusters of the power measured. As we can see clearly the signal is grouped into six different groups, -75dBm appeared more frequent, followed by -85dBm, then -65dBm and -95dBm, -105dBm and -55dBm are the least signals received.

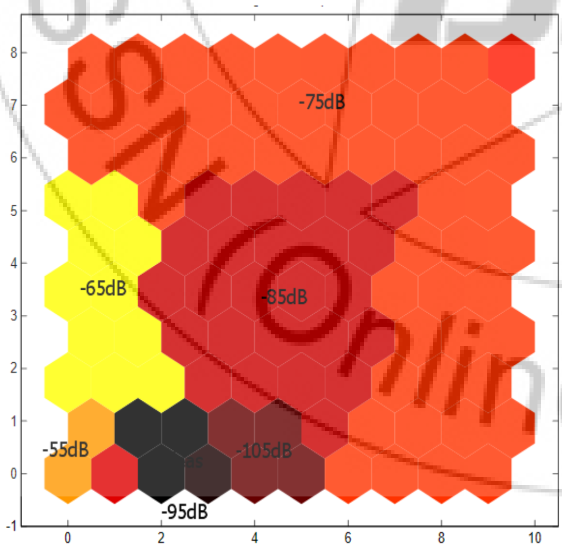

Figure 2: Clusters of the signal strength received

5. Results and Discussion

Using (10), the root mean square error is computed as 3.428dBm. We then modified the two models COST 231 Hata and Okumura – Hata model as given in (11) and (12) respectively.

$$L_{50} = 42.872 + 33.9\log f_c - 13.82\log h_B - a(h_m) + \log d\ (44.9 - 6.55\log h_m) + C_H \quad (11)$$

Fig. 3, shows the COST 231 Hata model and the modified model for Dnepropetrovsk city.

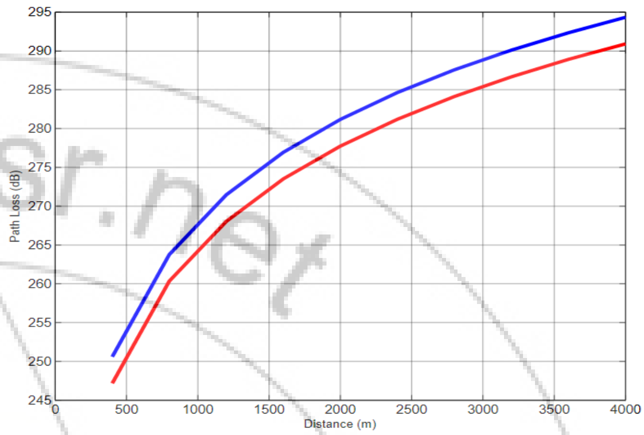

Figure 3.Modified vs COST 231 Hata path loss models

The blue color of the path loss plot represents the COST 231Hata model, while the red color represents the modified COST 231 Hata model. As we can see clearly there is an attenuation difference with RMSE=3.428dB, this falls within the acceptable range of maximum 6dB [4] [5]. This difference may be attributed to the different study areas, while Fig. 4, shows how to evaluate the median attenuation of the Okumura-Hata model.

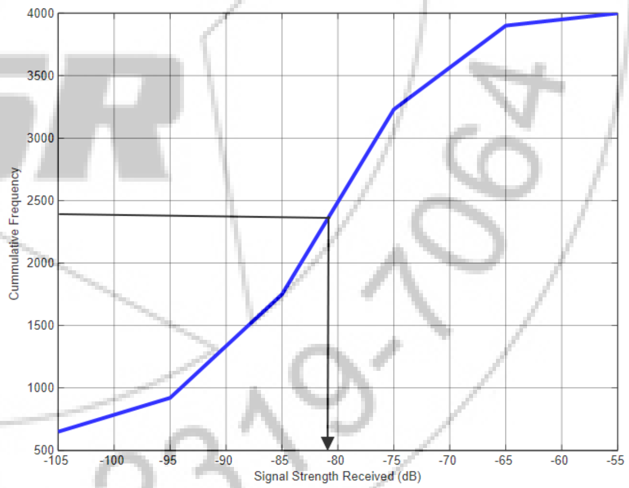

Figure 4: Median attenuation estimation

The median attenuation is estimated as $a(f,d)$=-81dB and outliers is about 15dB, while Fig. 5, shows the Okumura – Hata and the modified model based on the study environment.

$$L_{50} = \gamma_0 - 3.428 + a(f,d) - G_B - G_M - G_E \quad (12)$$

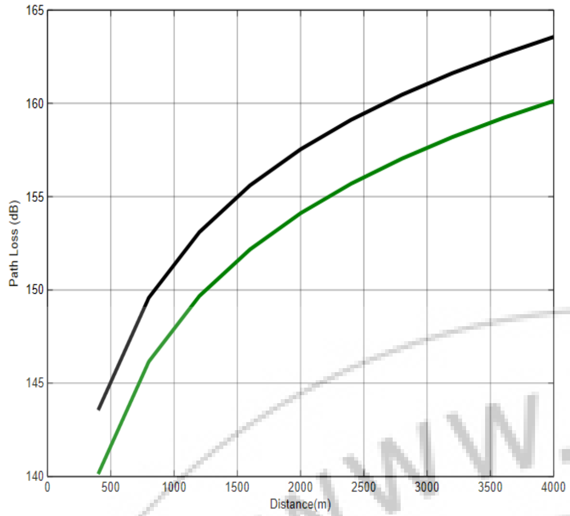

Figure 5: Modified vs Okumura Hata path loss models

The black color of the path loss plot represents the Okumura - Hata model, while the green color represents the modified Okumura – Hata model. We further compared all the models as shown in Fig. 6.

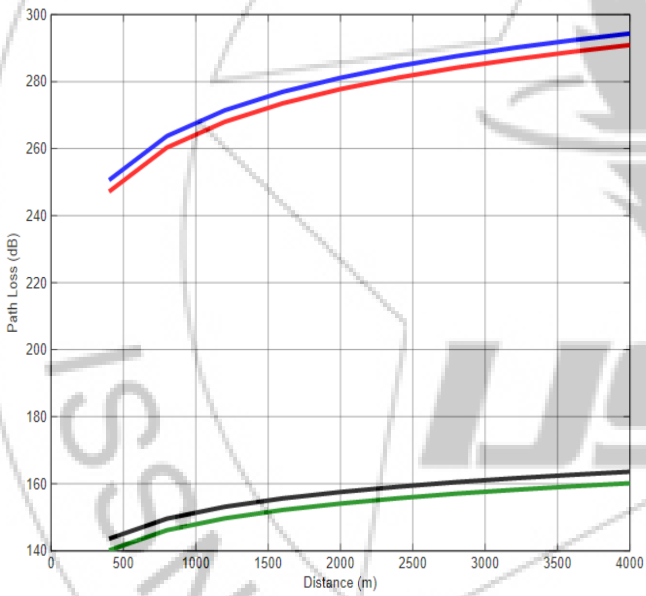

Figure 6: Models comparison

As shown in Fig. 6, COST 231 Hata experience more losses [12], followed by the modified COST 231 Hata, followed by Okumura – Hata then the modified Okumura model.

6. Conclusion

Path loss is an important parameter that one needs to know before undertaking design or improving the existing radio frequency communication path. In this work, we used one-dimensional multilevel wavelet to predict path loss error in the study area. The wavelet predicts that the GSM signal strength is attenuated with RMSE of 3.428dB, the signal strength fades 5times the frequency of the propagation and the signal strength received in the study area is mostly weak signal in order of -75dBm, -85dBm, -95dBm. This work demonstrated that wavelet is a good tool for path loss prediction.

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Author Profile

Danladi Ali, received his B. Eng. (Electrical and Electronic) 2000 at University of Maiduguri Borno State. Nigeria and M. Eng. (Electronic and Telecommunication) 2006 at University of Benin, Nigeria. He is a Ph. D student, department of Information Technology and System at National Metallurgical Academy of Ukraine. He is a Lecturer at the Adamawa State University, Mubi. His area of interest is; Computer networks and Communications with special interest in AD-HOC Wireless Network, Self – Similarity and Fractality of traffic.