Pathloss Determination Using Okumura-Hata Model And Cubic Regression For Missing Data For Oman

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***Abstract*— In this paper, we aim to adapt a propagation model for Salalah (OMAN) as we examine the applicability of Okumura-Hata model in Oman in GSM frequency band. The study is in continuation to the work by authors which was carried out for urban area due to the data obtained from local operator. We accomplish the modification of model by investigating the variation in pathloss between the measured and predicted values, according to the Okumura-Hata propagation model for a cell in Salalah city and then finding the missing experimental data with cubic regression. We also verify our modified model by applying it for other cells. The mean square error (MSE) was calculated between measured path loss values and those predicated on basis of Okumura-Hata model for an open area. The MSE is up to 6dB, which is an acceptable value for the signal prediction. The model gave a significant difference in an open area that allowed necessary changes to be introduced in the model. That error was minimized by subtracting the calculated MSE from the original equation of open area for Okumura-Hata model. Modified equation was also re-verified for another cell in an open area in Oman and gave acceptable results. Theoretical simulation by Okumura Hata Model and the obtained experimental data is compared and analyzed further using a cubic regression on the set of the experimental data. Scatter plot of the experimental data on path loss verses distance reveals a third order polynomial trend in the experimental data. Therefore the cubic regression model was fitted using method of least squares which estimates the parameters by minimizing sum of squares of the white noise. The coefficient of determination of this regression suggested that about 90% variation in path loss can be explained.**

***Index Terms*— Okumura Hata Model, Pathloss, Propagation models, Cubic Regression.**

I. INTRODUCTION

Mobile communications is growing rapidly due to enabling technologies, which permit wider deployment. Historically, growth in the mobile communications field has now become slow, and has been linked to technological advancements [1,2]. The need for high quality and high capacity networks, estimating coverage accurately has become extremely important. Therefore, for more accurate design coverage of modern cellular networks, signal strength measurements must be taken into consideration in order to provide an efficient and reliable coverage area.

This article addresses the comparisons between the theoretical and the empirical propagation models. It was achieved that, the most extensively used propagation data for mobile communications is Okumura's measurements and this is recognized by the International Telecommunication Union (ITU) [3].

The cellular concept was a major breakthrough in solving the problem of spectral congestion and user's capacity. It offered high capacity with a limited spectrum allocation without any major technological change. The cellular concept is a system level idea in which a single, high power transmitter (large cell) is replaced with many low power transmitters (small cells). The area serviced by a transmitter is called a cell. Each small powered transmitter, also called a base station provides coverage to only a small portion of the service area. The power loss involved in transmission between the base station (BTS) and the mobile station (MS) is known as the path loss and depends particularly on the antenna height, carrier frequency and distance. At higher frequencies the range for a given path loss is reduced, so more cells are required to cover a given area. Base stations close to one another are assigned different groups of channels. So that all the available channels are assigned to a relatively small number of neighboring base stations. Neighboring base stations are assigned different groups of channels so that the interference between base stations or interaction between the cells is minimized. As the demand for service increases, the number of base stations may be increased, thereby providing additional capacity with no increase in radio spectrum. The key idea of modern cellular systems is that it is possible to serve the unlimited number of subscribers, distributed over an unlimited area, using only a limited number of channels, by efficient channel reuse [2].

II. THEORETICAL PROPAGATION MODELS

The propagation models are divided into two basic types; namely: Free space propagation and Plane earth propagation model.

A. *Free Space Propagation Model*

In free space, the wave is not reflected or absorbed. Ideal propagation implies equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation. Spreading the power over greater areas causes the attenuation. Equation (1) illustrates how the power flux is calculated.

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$$P_d = P_t \; / \; 4\pi d^2 \qquad (1)$$

Where P_t is known as transmitted power (W/m^2) and P_d is the power at a distance d from antenna. If the radiating element is generating a fixed power and this power is spread over an ever-expanding sphere, the energy will be spread more thinly as the sphere expands.

By having identified the power flux density at any point of a given distance from the radiator, if a receiver antenna is placed at this point, the power received by the antenna can be calculated. The formulas for calculating the effective antenna aperture and received power are shown in equations (2) and (3) below. The amount of power 'captured' by the antenna at the required distance d, depends upon the 'effective aperture' of the antenna and the power flux density at the receiving element. Actual power received by the antenna depends on the following: (a) The aperture of receiving antenna A_o, (b) the wavelength of received signal λ, (c) and the power flux density at receiving antenna P_d.

Effective area A_e of an isotropic antenna is:

$$A_e = \lambda^2 \; / \; 4\pi \qquad (2)$$

While power received is:

$$P_r = P_d \times A_e = P_t \times \lambda^2 \; / (4\pi d)^2 \qquad (3)$$

While equation (4) illustrates the path loss (L_p):

$$L_p = \mathit{Power\ transmitted}\ (P_t) \; - \; \mathit{Power\ received}\ (P_r) \qquad (4)$$

When substituting equation (3) in equation (4), it yields equation (5):

$$L_p(dB) = 20 \log_{10}(4\pi) + 20 \log_{10}(d) - 20 \log_{10}(\lambda) \qquad (5)$$

Then substituting (λ (in km) = 0.3 / f (in MHz)) and rationalizing the equation produces the generic free space path loss formula, which is stated in equation (6):

$$L_p(dB) = 32.5 + 20 \log_{10}(d) + 20 \log_{10}(f) \qquad (6)$$

B. Plane Earth Propagation Model

The free space propagation model does not consider the effects of propagation over ground. When a radio wave propagates over ground, some of the power will be reflected due to the presence of ground and then received by the receiver. Determining the effect of the reflected power, the free space propagation model is modified and referred to as the 'Plain-Earth' propagation model. This model better represents the true characteristics of radio wave propagation over ground. The plane earth model computes the received signal to be the sum of a direct signal and that reflected from a flat, smooth earth. The relevant input parameters include the antenna heights, the length of the path, the operating frequency and the reflection coefficient of the earth. This coefficient will vary according to the terrain type (e.g. water, desert, wet ground etc). Path Loss Equation for the plane Earth Model is illustrated in equation (7).

$$L_{pe} = 40\log_{10}(d) - 20\log_{10}(h_1) - 20\log_{10}(h_2) \qquad (7)$$

Where d represents the path length in meters and h_1 and h_2 are the antenna heights at the base station and the mobile, respectively. The plane earth model in not appropriate for mobile GSM systems as it does not consider the reflections from buildings, multiple propagation or diffraction effects. Furthermore, if the mobile height changes (as it will in practice) then the predicted path loss will also be changed.

III. EMPIRICAL PROPAGATION MODELS

Empirical propagation models will be discussed in this section; among them are Okumura and Hata models.

A. Cellular Propagation Models

The two basic propagation models (free space loss and plane earth loss) would require detailed knowledge of the location, dimension and constitutive parameters of every tree, building, and terrain feature in the area to be covered. This is far too complex to be practical and would yield an unnecessary amount of detail. One appropriate way of accounting for these complex effects is via an empirical model. There are various empirical prediction models among them are, Okumura – Hata model, Cost 231 – Hata model, Cost 231 Walfisch – Ikegami model, Sakagami- Kuboi model. These models depend on location, frequency range and clutter type such as urban, sub-urban and countryside.

B. Okumura's Measurements

Okumura carried out extensive drive test measurements with range of clutter type, frequency, transmitter height, and transmitter power. It states that, the signal strength decreases at much greater rate with distance than that predicted by free space loss [3-5].

C. Hata's Propagation Model

Hata model was based on Okumura's field test results and predicted various equations for path loss with different types of clutter. The limitations on Hata Model due to range of test results from carrier frequency *150Mhz to 1500Mhz*, the distance from the base station ranges from 1Km to 20Km, the height of base station antenna (h_b) ranges from 30m to 200m and the height of mobile antenna (h_m) ranges from 1m to 10m. Hata created a number of representative path loss mathematical models for each of the urban, suburban and open country environments, as illustrated in equations (8-10), respectively.

Path Loss for urban clutter:

$$L_p(urban) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) \qquad (8)$$

$$a(h_m) = (1.1\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8) \qquad (9)$$

Path loss for suburban clutter:

$$L_p(suburban) = L_p(urban) - 2\{\log_{10}(f/28)\}^2 - 5.4 \qquad (10)$$

Path loss for the open country is :

$$L_p(open\ country) = L_p(urban) - 4.78\{\log_{10}(f)\}^2 + 18.33\log_{10}(f) - 40.94 \qquad (11)$$

Hata model is not suitable for micro-cell planning where antenna is below roof height and its maximum carrier frequency is 1500MHz. It is not valid for 1800 MHz and 1900 MHz systems.

IV. RESULTS AND DISCUSSIONS

To generate measurements of signal strength level for downlink and uplink at coverage areas for a cell in the road of Salalah, OMAN, TEMS tools were used. However, the road of Salalah can be considered as an open area and therefore equations (8), (9) and (11) of Okumura-Hata model were used.

After determining the path loss of the practical measurements for each distance, the study was carried on in order to make a comparison between the experimental and theoretical values and the result is shown in Fig-1.

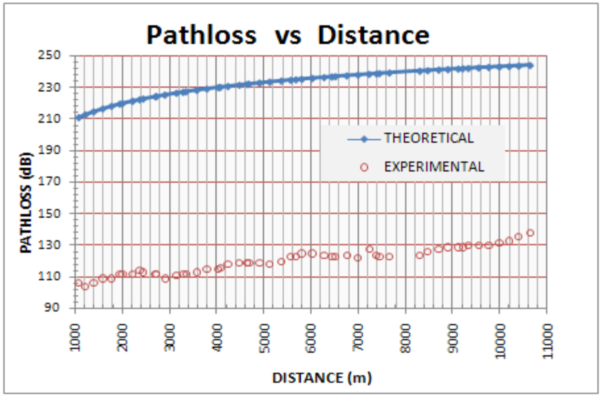

Fig. 1: Theoretical and Experimental path loss versus distance

From the above plot, the results clearly show that the measured path loss is less than the predicted path loss by a difference varying from 4 to 20 dB. However, there are several reasons which may cause those significant differences. First of all, in Japan there are few areas virtually satisfying the open area conditions; and if any, they are narrow. Because of that reason Okumura selected the value for urban area as standard for open area [5]. Moreover, the geographical situation of Japan is different from that in Oman due to geographical differences. Then, mean square error (*MSE*) was calculated between measured path loss value and those predicted by Hata model using the following equation [6]:

$$MSE = \sqrt{\left(\sum (P_m - P_r)^2 / (N-1)\right)} \qquad (12)$$

Where;
P_m: Measured path loss (dB)
P_r: Predicted path loss (dB)
N: Number of Measured Data Points

The *MSE* was found 113.459dB but the acceptable range is up to 6 dB [6]. Therefore, the *MSE* is subtracted from the Hata equation for open area and the modified equation will be as following:

$$L_p Modified(open\ area) = L_p(urban) - 4.78\{\log_{10}(f)\}^2 + 18.33\log_{10}(f) - 40.94 - 113.459 \qquad (13)$$

The modified result of Hata equation in open area is shown in Fig. 2 using modified equation and the *MSE* in this case is less then 6dB, which is acceptable [6].

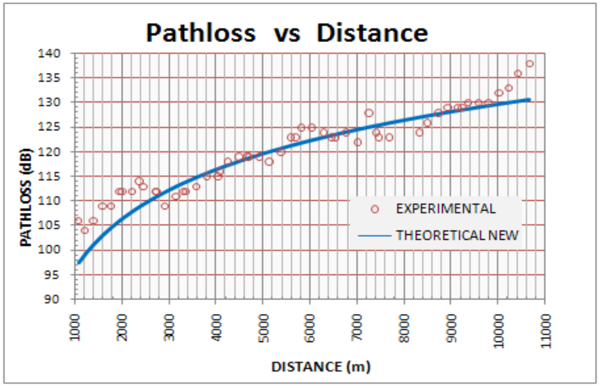

Fig. 2: Modified Hata's open area equation path loss versus distance

In order to verify that the modified Hata's open area equation (13) is applicable for other open areas in Oman, another data generated from TEMS tool for another cell in the road of Salalah has been used. Based on that practical data, the propagation path loss and the distance have been re-verified for another cell.

Theoretical simulation and the obtained experimental data is compared and analyzed further using a cubic regression model on the set of the experimental data which is giving acceptable results. After observation of experimental data, it can be predicted that the scatter plot of the experimental data on path loss verses distance reveals a third order polynomial trend. Therefore the Cubic Regression Model was fitted using method of least squares which estimates the parameters by minimizing sum of squares of the white noise. The estimated model is given as below:

$$P_m = 98.66 + (6.8e^{-3})d + (7.0e^{-7})d^2 + (4.0e^{-11})d^3 \qquad (14)$$

The coefficient of determination of this regression suggested that about 90% variation in path loss can be explained by distance using the above equation (14). The correlation between experimental, theoretical model and fitted by cubic regression were worked out by Pearson Correlation Coefficient. These correlations are presented in Table 1 below. This table shows that the path loss estimated by the equation (14) has highly significant correlation of 0.975 with the experimental data and a correlation of 0.974 with the theoretical model. The correlation between experimental data and theoretical model was 0.948 which is also highly significant at $p<0.01$ value.

Table1. Pearson Correlation Coefficient

	Experimental	Theoretical	Cubic
Experimental	1	0.948**	0.974**
Theoretical	0.948**	1	0.975**
Cubic	0.974**	0.975**	1

** Correlation is significant at 99% level.

Hata propagation model, Fig.3 shows the theoretical, experimental and cubic regression plots showing good agreement.

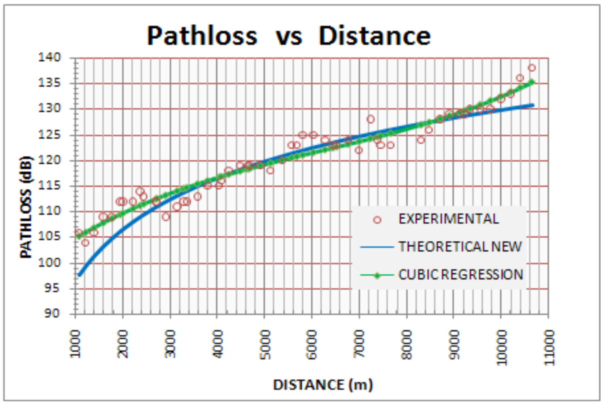

Fig. 3: path loss versus distance for Experimental, Theoretical and Cubic Regression data points

By calculating the *MSE* for the second cell, it was found to be (3.2058dB) which is acceptable [6]. Therefore, the modified Hata's open area equation (13) was re-verified in order to be applicable in other open areas in Oman.

V. CONCLUSION

This work was focused for predicting the mean signal strength in different areas. However, most propagation models aim to predict the median path loss. But, existing predictions models differ in their applicability over different terrain and environmental conditions. Although there are many predictions methods based on deterministic processes through the availability of improved databases, but the Okumura-Hata model is still mostly used [7]. That is because of the ITU-R recommendation for its simplicity and its proven reliability.

The effects of terrain situation predicted at 900MHz were analyzed. Results of radio signals propagation measurements for an open area in Oman were compared to those predicted based on Okumura-Hata model. However, the Okumura-Hata propagation model might not be fully adapted in Oman because there is no rain attenuation impact in Oman environment due to lack of rain. Therefore, further improvement of Okumura-Hata model in the open area has been suggested. This improvement was achieved by using mean square error (*MSE*) between measured and predicted path loss values in order to provide sufficient *MSE* for radio prediction The modified equation (13) was verified for a cell in another open area and the *MSE* was found to be 3.21dB which is accepted value for signal predication [6].

The measured data that provided by OmanMobile just covered the open area. Therefore, measurements for other areas (urban and suburban) should be obtained in order to compare all results (urban, suburban and open areas) with the predicted data based on Okumura-Hata model for Oman. Also, if more detailed environmental information is included in the model, better prediction results might be achieved. Cubic regression gave us also the missing experimental points showing a good agreement with Theoretical model.

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