

## Pathloss Measurements and Prediction using Statistical Models

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**Abstract.** There is a major expansion in the market of wireless communications services in urban areas. New regulatory environments as well as rivalry in the communications industry necessitate that these systems be arranged quickly and at low cost. Computer-based radio propagation prediction tools are strong candidates for this goal. This paper provides an extension of pathloss analysis in urban environments in Oman. The paper addresses the applicability of Okumura-Hata model in an area in Oman in GSM frequency band. Trigonometric Regression Model is used for data prediction at unknown nodes. These can be used to make desired forecasts. The results are acceptable, can be used primarily for OMAN, and can be extended for other regions.

### 1. Introduction

Mobile communications is currently at its fastest growth-period in history; 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. The need for high quality and high capacity networks, estimating coverage accurately has become extremely important. The fundamental task is to predict the coverage of the proposed system. Propagation models are useful for predicting signal attenuation or path loss which may be used as a controlling factor for system performance or coverage so as to achieve perfect reception [1]. It has been found that the mechanisms behind electromagnetic wave propagation are diverse and characterized by certain phenomena such as reflection, refraction and diffraction of waves. These phenomena induces signal scattering, fading and shadowing along the signal path and their effects can best be described (in a large scale) by the path loss exponent which defines the rate of change of attenuation that the signals suffers as it propagates from the transmitter to the receiver. Growth in the mobile communications field has now become slow, and has been linked to technological advancements. 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 evaluations between the statistical and the experimental analysis at GSM frequency of 900 MHz using Okumara model which is most widely used. 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. Empirical Propagation Models

#### 2.1 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 [2-4].

#### 2.2 Hata's Propagation Model

Hata model was based on Okumura's field test results and predicted various equations for Pathloss with different types of clutter. It is well suited model for the Ultra High Frequency (UHF) band [5]. The limitations on Hata Model due to range of test results from carrier frequency 150 MHz to 1500 MHz, the distance from the base station ranges from 1 km to 20 km, the height of base station antenna ( $h_b$ ) ranges from 30 m to 200 m and the height of mobile antenna ( $h_m$ ) ranges from 1 m to 10 m. It was also observed that the signal strength is a function of distance and antenna height, as we can see in this work the highest antenna has less propagation path loss and as the distance increases the path loss also increases [6]. Hata created a number of representative Pathloss mathematical models, as illustrated in following Eq. 1. Okumura takes urban areas as a reference and applies correction factors as following. For urban areas:

$$L_{dB} = A + B \log_{10} R - E_{1,2,3} \quad (1)$$

Where

$$A = 69.55 + 26.16 \text{Log}_{10} f_c - 13.82 \text{Log}_{10} h_b$$

$$B = 44.9 - 6.55 \text{Log}_{10} h_b$$

$$E_1 = 3.2 (\text{Log}_{10} (11.7554 h_m))^2 - 4.97 \quad \text{for cities; } f_c \geq 300 \text{MHz}$$

$$E_2 = 8.29 (\text{Log}_{10} (1.544 h_m))^2 - 1.1 \quad \text{for cities; } f_c \leq 300 \text{MHz}$$

$$E_3 = (1.1 \text{Log}_{10} f_c - 0.7) h_m - (1.56 \text{Log}_{10} f_c - 0.8)$$

for relatively smaller cities.

$h_m$  ;MS antenna height [m];  $d_m$  ;distance between the mobile and the building [km];  $h_0$  ; typical height of a building [m];  $h_b$  ;BS height [m];  $r$ ; great circle distance between BS and mobile [m];  $f_c=f \times 10^{-6}$  carrier frequency [MHz];  $\lambda$  ; free space wavelength [m].

The practical Pathloss can be calculated using the Eq. (2):

$$L_p(\text{dB}) = P_t - P_r \quad (2)$$

Where  $P_t$  is the transmitted power which is equal to 47 dB and  $P_r$  is the received power. ‘A’ and ‘E<sub>3</sub>’ are as mentioned above for small and medium cities [7-9]. The generation of such predictions is based on the assumption that the power of a signal decreases monotonically with the increase of the distance traveled by the signal [10].

### 3. Results and Discussions

#### Data Collection

An intensive drive test has been conducted along all pre-identified paths. GSM sample every 450 ms. This sampling rate is adequate to determine representative signal levels. The drive test process was conducted using TEst Mobile System, (TEMS) Investigation Data Collection V13.0 tool. The measurement reports of radio signal strength and many other RF parameters are collected by a special purpose mobile handset connected to the PC in which the TEMS program is installed. Furthermore, the positioning information is collected via GPS antenna terminal which have direct communication with GPS satellite

#### Data Processing

The measured data for each path has been recorded in terms of log files. These log files have been exported to a post processing tool called ACTIX for further processing and extraction of the required data. ACTIX Analyzer is a tool used for drive test post-processing, supporting network optimization and network troubleshooting. It is capable of troubleshooting RF problems automatically for GSM, Wi-MAX, WCDMA and LTE technologies. The data files collected from TEMS Investigation is post-processed from this tool. Also, it has been used to convert the recorded log files into graphical format for map viewing via Google Earth program (not shown). Moreover, it has been utilized to export coverage log files into Excel worksheets format

for further manipulation. After that, the required data has been manipulated as the main aim of the conversion was to obtain the path loss and the link distance. After determining the Pathloss of the practical measurements for each distance, the study was carried in order to make a comparison between the experimental and theoretical data. Results (Fig. 1) show that the measured Pathloss is less than the predicted Pathloss by a major difference. However, there are several reasons that may have caused those significant differences. First of all, in Japan there are few areas virtually satisfying the conditions; and if any, they are narrow. Because of that reason Okumura selected the value for urban area as standard for open areas [8]. Moreover, the geographical situation of Japan is different from that in Oman due to geographical differences. As such, Root Mean Square Error (RMSE) was calculated between measured Pathloss value and those predicted by Hata model using the Eq. (3) [11-12]:

$$RMSE = \sqrt{\left( \frac{\sum (P_m - P_r)}{N - 1} \right)} \quad (3)$$

where;

$P_m$ : Measured Pathloss (dB);  $P_r$ : Predicted Pathloss (dB); N: Number of Measured Data Points

The RMSE was found 113.459 dB but the acceptable range is up to 6 dB. Therefore, the RMSE is adjusted with the Hata equation for urban area. The modified result of Hata equation is shown in Fig. 2 and the RMSE in this case is less than 6dB, which is acceptable.

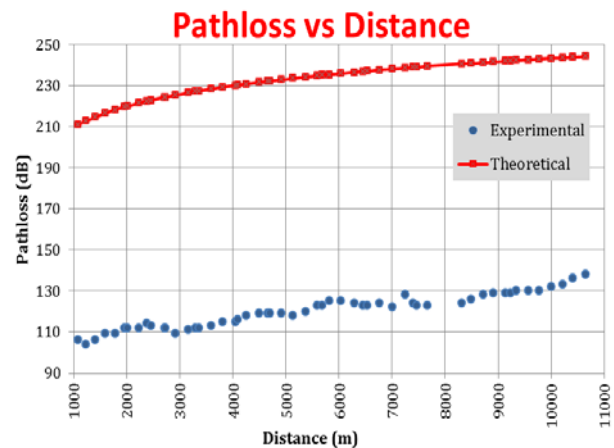


Fig. 1: Theoretical and Experimental Pathloss

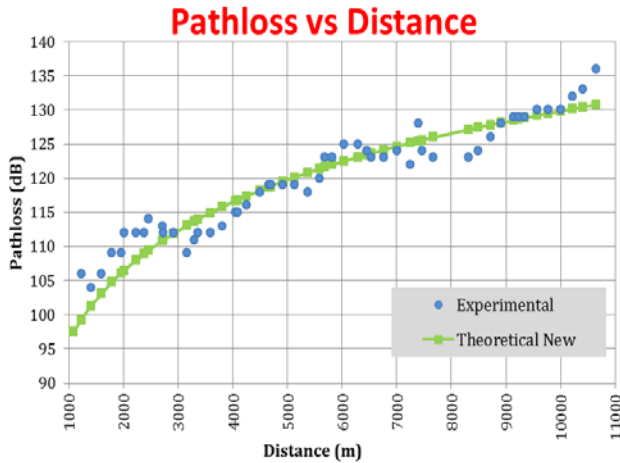


Fig. 2: Pathloss on experimental data set B.

Based on that practical data, the propagation Pathloss and the distance has been re-verified for another cell [7]. Theoretical simulation and the obtained experimental data is compared and analyzed further using a Trigonometric Regression model as in Eq. 4.

$$L_d = \beta_o + \beta_1 d + \beta_2 \sin\left(\frac{\pi L}{\sqrt{d}}\right) + \beta_3 \cos\left(\frac{\pi L}{\sqrt{d}}\right) + \varepsilon_d \quad (4)$$

The following regression model with trigonometric terms as in Eq. 7 was specified for estimation and prediction of Path Losses because the area under study has a pattern of obstacles such as high-rise buildings and towers, which could interrupt the signals in an irregular cyclical manner. The model has the form:

Where

$d$  is the distance in meters from an antenna;  $L_d$  is the Path loss at distance  $d$ ;  $L$  is the overall expected Path loss;  $\varepsilon_d$  is the random noise at distance  $d$ . The  $\varepsilon_d$  is assumed to be independently and identically distributed. The  $\beta_0, \beta_1, \dots, \beta_5$  are the parameters of the model. These parameters were estimated by Ordinary Least Squares (OLS) method. The assumption of independence of  $\varepsilon_d$  was checked by Durbin Watson (DW) test as given below.

$$DW = \frac{\sum (E_d - E_b)^2}{(E_b)^2}$$

Where  $E_d$  is the estimate of the random noise at distance  $d$ . and  $E_b$  is the estimate of the random noise distance  $b$  which is distance just before  $d$ . The estimates of all these parameters along with their standard errors (SE), t-values and p-values as well as R are presented in Table. 1. This table shows that most of the distance significantly affects the Path loss but the Durbin Watson (DW) test value should be close to 2 to satisfy the assumption of independence of noise at successive distances. The DW value of 1.36 is significantly below the significant points at 1% and 5%

levels which means there is at least first order autocorrelation in Path loss at successive spatial points.

Table: 1 Estimates of the parameters

Parameters	Parameters Estimates	SE	T	P
$\beta_0$	103.846	4.251	24.43	0.000
$\beta_1$	0.046497	0.008669	5.36	0.000
$\beta_2$	1.0072	0.8852	1.14	0.260
$\beta_3$	1.6997	0.7908	2.15	0.036

DW=1.36 and R2 = 54.6

Table: 2 Estimates of the parameters with an additional term

Parameters	Parameters Estimates	SE	T	P
$\beta_0$	71.87	14.48	4.96	0.000
$\beta_1$	0.02941	0.01106	2.66	0.010
$\beta_2$	0.3195	0.1346	2.37	0.022
$\beta_3$	0.6000	0.8754	0.69	0.496
$\beta_4$	0.9330	0.8567	1.09	0.281

DW=1.93 and R<sup>2</sup> = 56.2

Therefore, it is decided to include an autoregressive term  $L_b$  in the model to accommodate the serial correlation. The model Eq. 4, thus takes the form as presented in Eq. 5 as below with usual OLS assumptions. The DW value of 1.93 in this table is very close to 2 hence the model assumption of noise term is satisfied.

$$L_d = \beta_o + \beta_1 d + \beta_2 L_b + \beta_3 \sin\left(\frac{\pi L}{\sqrt{d}}\right) + \beta_4 \cos\left(\frac{\pi L}{\sqrt{d}}\right) + \varepsilon_d \quad (5)$$

The estimates of the parameters presented in table 2 were used to predict the Path loss at each given distance. Fig. 3 clearly reveals the adequacy of the proposed model.

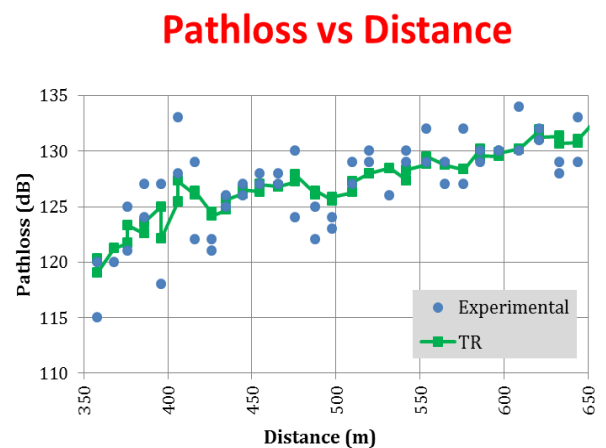


Fig. 3: Pathloss versus distance for Experimental, and Trigonometric regression modeling

Overall, by calculating the RMSE for the second cell and for most of the data sets it was found to be 3.2058 dB, which is an acceptable figure. However, few data points were a bit far from the interpolated values which are

attributed to the nature of the cell with high rise buildings. Although there are many prediction methods that are based on deterministic processes through the availability of improved databases, the Okumura-Hata model is still mostly used [13-14]. That is because of the ITU-R recommendation for its simplicity and its proven reliability.

We also know that the obstacles in the path significantly influence the radio signal propagation [14]. Above all, wireless communication system avoids obstacles such as crossing objects owned by others. There are also many problems in a realization of wireless communication system in some applications. However, the current study of neural network and other methods might explain these that have influence in our data acquisition in business district area with high-rise buildings and curved roads.

#### 4. Conclusion

This work focused on predicting the root mean signal strength in different areas. As most propagation models aim to predict the median Pathloss, existing prediction models differ in their applicability over different terrain and environmental conditions. The effects of terrain situation predicted at 900 MHz were analyzed. Experimental results of radio signals propagation for an urban area in Oman were compared with those predicted based on Okumura-Hata model. The contribution is the prediction by trigonometric regression and validation of experimental data. If environmental information is included in the model, better prediction results might be achieved. Trigonometric regression gave us also the missing experimental points showing a good agreement within acceptable limits.

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