Propagation Measurements and Pertinency of Models for Communications Systems in Oman

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Abstract—**This article discusses the usefulness of Okumura-Hata model and Sakagami model in urban areas for 2G and 3G communication systems. At some places, applicability of the models (Okumura Hata and Extended Sakagami) is studied and extended to a much lower distance from the tower than the specified minimum distance indicated in the model. Authors did an extensive drive test in urban areas and post also processed data and proposed theoretical modified model which is presented and compared for different data sets at different locations in Oman. Higher order interpolating polynomial was also used which helps in reasonable prediction for RF engineers.**

Keywords—Propagation Models, Okumura Hata, Sakagami, Pathloss.

I. Introduction

It is very challenging for wireless network designers to estimate the pathloss of transmitted signals to ensure the quality of service. Generally, the wireless signal is impacted by a variety of propagation mechanisms. These mechanisms include signal reflection, diffraction and scattering. Considering the GSM as the second mobile generation (2G) globally spread RF technology, many propagation models study the pathloss and predict the signal strength at specific distance by predicting the Maximum Permissible Loss (MPL).

This paper is an extension to a paper published recently at IEMTRONICS 2020 of same authors (Rashdi, Nadir, & Lawati, 2020). However, current paper tackles also another model (Sakagami) and additional paths for experimental data in analysis. This paper proposes and focuses on the urban area with its extension in order to have a suitable propagation model for this area or any other urban area. The Okumura-Hata has been practiced before by several researchers and compared to the real measured data. The Root Mean Square Error (RMSE) is to be used as one indicator as an error indicator and results validator. Okumura-Hata model also needs to be studied for 3G frequency spectrum to provide lower RMSE value which are not done before in these areas. Then, the generalized equation has to be obtained by averaging the RMSE values for studied paths in each area. The generalized formulas than is to be tested and verified in different paths of other areas and the obtained results should be within expected range (Jianhui & Dongfeng, 1998).

For several factors, the RF design is a highly challenging. Special efforts are required in order to provide good coverage with sufficient capacity which satisfies the high demands of this populated area. Hence, the path loss variation with respect to distance is investigated and studied in this work. This is very helpful for RF engineers in order to have a special propagation model that can assist the radio network planners to implement high efficient network. In a radio communication system, the pathloss exponent has a solid effect on the quality of signals. Accordingly, it is required to precisely estimate or predict a perfect design of radio communication network.

There are several researchers who working in this area. Several research findings are linked or address modelling of pathloss effects for a very narrowband communication by using diverse techniques starting from analytical models to empirical models. Businesses in this area are having a major issue to get maximum received power. So, for them losses that occur during transmission of signals from the transmitter to the receiver is very critical. This work addresses, the empirical method along with other techniques. It is tedious as it involves the huge data collection, analysis and processing and performing drive test. A fixed distance was initially taken from the base station to the receiver and later drive test was conducted. As a first step, the Centre of Business District (CBD) area has been subdivided into two sub areas. The reason for this is to facilitate the study in terms of data analysis and manipulation. Also, it has to be mentioned that each area differs from each other slightly in terms of buildings pattern arrangement. The buildings of the main area are quite tall and aligned in a uniform pattern. On the other hand, the buildings of the extended area are comparatively shorter and closer to each other. For the purposes of path loss modelling study, a GSM site in each of the two areas has been selected to be used as an RF signal transmitter. The name chosen for the site in the area is ‘Path-1 and Site-1’ and that for the extension area is ‘path-3 and Site-1’.

II. Propagation Models

A. Free Space Propagation Model

As there is an increase in frequency, further to it, rapidly received signal decreases its amplitude when we increase over distance. Due to this reason, some companies like to use 700Mhz for their cell-phones. This can cover a larger distance. WiMAX service, in the 2.5 GHz band loses power more quickly over distance than 700MHz. Similarly, some services in 5800MHz and above lose power even more intensely when distance is increased. This forces the operators to use higher power levels and big high gain antennas which has additional challenges. These figures are not yet in dB which has the effect of reducing the exponential signal deterioration over distance into a straighter graph. The pathloss, which represents signal reduction as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power, and may or may not include the effect of the antenna gains. The free space power received by an antenna separated from a transmitter antenna by a distance d, is given by Frii's free space equation (1):

$$P_R(d) = \frac{P_t G_T G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (1)$$

Pt is the conveyed power, Gt , Gr are the Gain of the source and receiver respectively, λ is the wave length(m), d is the distance between source and receiver and L is the system loss factor (L⩾1). The free-space pathloss denoted by Lp(d) is given by equation (2):

$$L_P(d) = \left(\frac{\lambda}{4\pi d}\right)^2 \Rightarrow L_P(dB) = -20 \log_{10}\left(\frac{\lambda}{4\pi d}\right)$$
$$\because L_P(d) = 20\log_{10} f_C + 20\log_{10} d - 147.56\,[dB]$$
(2)

It can be seen from (2) that the free-space pathloss increases by 6dB when doubling the distance.

B. Urban Propagation Environment

There are several parameters which contribute in the propagation mechanisms. The signal is affected as it moves through an urban environment. There are structures, constructions which cause the signals to be returned or diverted and scattered. These phenomena of propagation of radio signals can be caused by Trees and foliage. The reduction of signals strength, can be measured by taking the difference between the median signal levels in front of the building and inside the building. We can go into depth by taking into account the civil engineering aspects of the buildings, materials used etc. In this case we can be more precise in prediction. Reflection, diffraction, and scattering are the three basic propagation mechanisms which impact propagation in a mobile communication system.

C. Plane Earth Propagation Model

Propagation representations are scientific depiction of results of tests carried on the propagation of wave under several different frequencies, antenna heights and locations over different periods and distances. When the radio wave propagates over the ground, it can be partially absorbed and the rest is reflected back to the medium. Due to the reflection from earth surface, the power of the signal can be higher than predicted by the free space model. Pathloss intended for the plane Earth Model is shown in (3 and 4)

$$P_r = P_t\, 20\left(\frac{h_1 h_2}{d^2}\right) \quad (3)$$

$$L_p = -10 \, Log_{10} \, P_t \, 20\left(\frac{h_1 h_2}{d^2}\right)^2 [dB] \quad (4)$$

Where, (d) = the path length (m)

(h_1) = BS height (m)

(h_2) =MS height (m).

We have to select another model due to its limitations for GSM. Model should also consider, all other aspects also e.g. reflections from buildings, multiple propagation or diffraction effects. Further, due to changes in h_2, everything will change and prediction or measurements will not be accurate.

D. Attenuation Factors

Ideally in free space the signal would be sent and received with no loss but that is not the case in reality. As the signal propagates through the medium, it encounters obstacles that contribute in the attenuation of the signal power. Hence, interpreting their contribution in the pathloss equations is necessary. The weather factors are too many and for simplicity they are often neglected. Due to this neglecting, the calculations will encounter some error. To achieve better accuracy, these factors are inserted into the model as RMSE. Rain is one of the attenuation factors. An area with high rain rate would encounter more attenuation than an area with no rain. This attenuation might be expected due to the nature of the rain drop. The rain drop is the result of a condensed water steam at low temperature. Due to its nature, the rain drop might scatter, absorb or reflect the signal. Humidity is another attenuation factor that contributes to the pathloss. The humidity is the result of the evaporation of water in the atmosphere near earth. Areas like coasts are high humidity areas. The attenuation encountered due to humidity in such areas is expected to be higher than areas with low humidity.

III. Empirical Models

Propagation models are elaborated in this section; between them are Okumura-Hata model which was finally adopted for this article.

A. Okumura Model

Okumura's model is one of the most widely used models for signal prediction in urban areas. This model was the result of intensive propagation tests for mobile systems at different frequencies conducted by a Japanese scientist called Okumura. This model is represented by a set of curves (frequency (MHz) verses attenuation (dB)) assuming mobile antenna height of 3m. This model is appropriate under the following circumstances:

- Frequency range of 150-1920MHz,
- Distance from BTS of 1-100km,
- BTS height of 30-100 m.

B. COST231 Model

This model is a modification of Okumura-Hata model. The extension of this model includes higher frequencies which were not covered by the Okumura-Hata model.

C. Walfisch Model

This model was developed by Walfisch and Bertoni. It considers the impact of rooftops and building height by using diffraction to predict average signal strength at street level.

D. Okumura-Hata Model

Hata's model is the extension of Okumura's. This model can be similar to a mathematical illustration of the Okumura's model. It's in the form of empirical formulas. This model is consistent with the Okumura model for distances greater than 1km. The conditions or basic limitations for this are mentioned as below:

- Frequency range of 150-2000MHz,
- Distance from BTS of 1-100km,
- BTS height of 30-200m,
- MS antenna height 1-10m

The limits on this technique is due to range of test outcomes as illustrated above (Jianhui & Dongfeng, 1998). Hata created several typical Pathloss scientific models for different areas e.g. urban, suburban and open country environments, as mentioned in the following equations, respectively. Model takes urban areas as a reference and applies correction factors as mentioned below: For urban areas generalized Okumura-Hata model is given below:

$$L_{dB} = A + BLog_{10}R - E_{1,2,3} \qquad (5)$$

Where:

$$A = 69.55 + 26.16\,Log_{10} f_c - 13.82\,Log_{10} h_b$$
$$B = 44.9 - 6.55\,Log_{10} h_b$$
$$E_1 = 3.2\left(Log_{10}\left(11.7554 h_m\right)\right)^2 - 4.97 \quad \text{for cities; } f_c \geq 300MHz$$
$$E_2 = 8.29\left(Log_{10}\left(1.544 h_m\right)\right)^2 - 1.1 \quad \text{for cities; } f_c \leq 300MHz$$
$$E_3 = \left(1.1Log_{10} f_c - 0.7\right)h_m - \left(1.56\,Log_{10} f_c - 0.8\right)$$
$$\text{for relatively smaller cities.}$$

Where:

h_m; MS height [m]

d_m; distance between the phone and the building [km]

h_0; height of a building [m]

h_b; BS height [m]

r; circle distance BS and mobile [m]

R=r x 10-3 great circle distance between BS and mobile [km]

f_c= frequency [MHz]

Rest of the parameters are as mentioned above for small and medium cities (Z. Nadir, 2012; Zia Nadir & Ahmad, 2010; Wilson & Scholtz, 2003).

E. Extended Sakagami model

This model is described in (Shalangwa, D. A., & K., 2010) is presented by following equation:

$$\begin{aligned} L_p[dB] = 101.0 - 7.11\log_{10} W \\ + 7.5\log_{10} H \\ - \left(24.37 - 3.7\left(H/h_b\right)^2\right)\log_{10} h_b \\ + (43.42 - 3.11\log_{10} h_b)\ \log_{10} d \\ + 20\log_{10} f_c - a(h_m) \end{aligned}$$

Where a(h_m): correction factor for antenna height (h_m).

$$a(h_m)[dB] = 3.2(\log_{10}(11.75h_m))^2 - 4.97$$

So Pathloss can be calculated using the following equation:

$$L_p(dB) = P_t - P_r \qquad (6)$$

Where Pt is the transmitted power which is equal to 47dB for 2G and 34dB for 3G transmitters and Pr is the received power. The major models used for this study is Okumura-Hata model. Authors contribution is the usage of the model for less than 1km and proposing an interpolated polynomial for RF planners.

IV. RESULTS AND DISCUSSIONS

An intensive drive test was conducted along all pre-identified paths using TEMS. Furthermore, the positioning information is collected via a GPS antenna. The measured data for each path has been recorded in terms of log files and processed using ACTIX. Google Earth program (not shown here in this paper) was also used to plot the received signal strengths. Duplicate data sets were also cleaned before post processing. After that, the data has been worked upon. This area of CBD can be considered as an urban area. After defining, the study was supported to make an evaluation among the tentative and hypothetical data and the outcome is as shown in following Figures. 1-4:

The results of measured path loss have been used as an input for usage with developed MATLAB scripts in order to plot the measured path loss and the predicted path loss curves as a function of distance. MATLAB is an efficient software for mathematical calculation and data analysis. After that, the variation between measured and predicted results has been obtained using RMSE method which was introduced earlier. The RMSE error indication technique has been used to modify each data set to have improved prediction capabilities. RMSE value combined all known and unknown factors and parameters impacting the path loss amount of the propagated signal. These factors include multipath effects, various propagation mechanisms and different weather conditions e.g., temperature and humidity. The RMSE value has been utilized to establish the modified propagation model for each studied path. After that, the RMSE value has been recalculated for the modified equations.

Data-Set-A

f_c=935.4MHz; h_b=25m; h_m=1.5m; H=30; W=20;
RMSE Value for Okumura-Hate Model was 7.3864dB and modified RMSE value after modification of Okumura-Hata model was 5.1321dB which is within acceptable range (Jianhui & Dongfeng, 1998). Following figures (1-4) details the Pathloss and modeling.

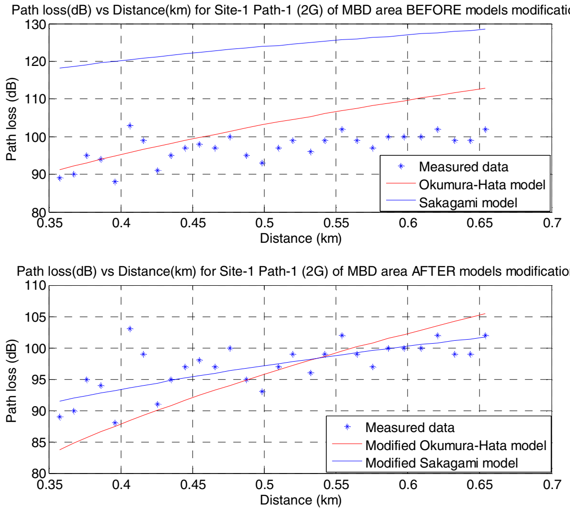

Fig. 1. Experimental and Theoretical Pathloss

RMSE for Okumura-Hata Model is = 7.3864
RMSE for Sakagami Model is = 26.7678
RMSE after modifying Okumura-Hata model is = 5.1321
RMSE after modifying Sakagami model is = 2.9289

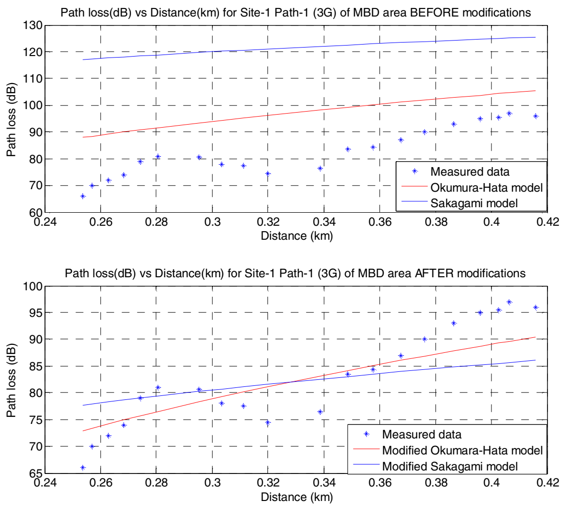

Fig. 2. Experimental and Theoretical Pathloss

RMSE for Okumura-Hata Model is = 15.0821
RMSE for Sakagami Model is = 39.4534
RMSE after modifying Okumura-Hata model is = 4.4799
RMSE after modifying Sakagami model is = 6.7232

Data-set-B
f_c=2130MHz; h_b=28m; h_m=1.5m; H=30; W=20;

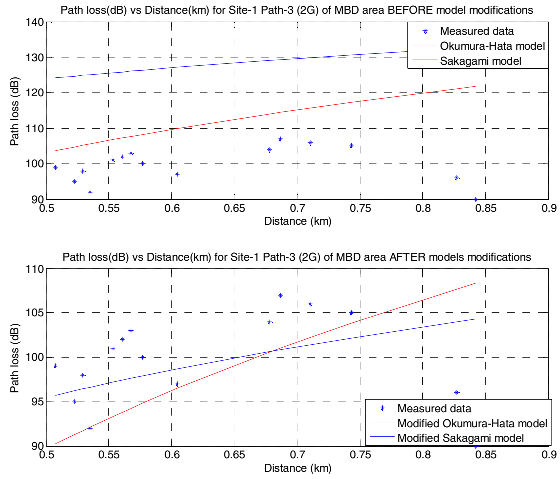

Fig. 3. Experimental and Theoretical Pathloss

RMSE for Okumura-Hata Model is = 13.4640
RMSE for Sakagami Model is = 28.4557
RMSE after modifying Okumura-Hata model is = 7.7247
RMSE after modifying Sakagami model is = 5.5071

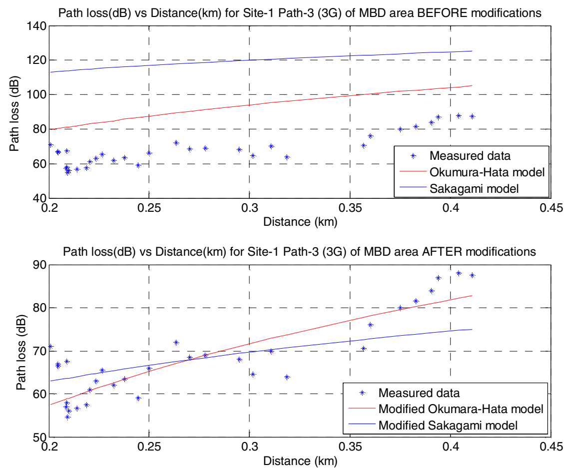

Fig. 4. Experimental and Theoretical Pathloss

RMSE for Okumura-Hata Model is = 22.3003
RMSE for Sakagami Model is = 50.2530
RMSE after modifying Okumura-Hata model is = 5.1666
RMSE after modifying Sakagami model is = 6.3872

Above shown graphs and after comparing with articles (Jianhui & Dongfeng, 1998; Z. Nadir, 2012; Zia Nadir & Ahmad, 2010) the results visibly display that the measured Pathloss is smaller in value than the predicted Pathloss by a variance from 5dB to 20dB. Nevertheless, there are several explanations that may have triggered those substantial modifications. First of all, in Japan there are few zones virtually fulfilling the conditions; and if any, they are narrow. Because of that reason Okumura selected the value for urban area as standard for open areas (Wilson & Scholtz, 2003). Furthermore, the topographical situation of Japan is different from that of our country due to geographical differences. Accordingly, Root Mean Square Error (RMSE) was considered amongst those two different values of pathloss, for Hata model, using following (7) (Jianhui & Dongfeng, 1998) (Shalangwa et al., 2010):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Pmeasured_i - Pcalc_i)^2}{(N-1)}} \qquad (7)$$

N: Measured Data Points

The RMSE acceptable range is up to 6dB so, the RMSE is adjusted with the Hata equation for urban area and the modified Hatas' equation is as given below (8):

$$L_{p\_mod}(urban) = 69.55 + 26.16Log_{10}(f) - 13.82Log_{10}(h_b) + (44.9 - 6.55Log_{10}(h_b))Log_{10}(d) \pm MSE - (1.1Log_{10}(f) - 0.7)h_m - (1.56Log_{10}(f) - 0.8) \qquad (8)$$

The modified result of Hata equation is shown in Fig. 5 and Fig. 6 and the RMSE in this case is less than 6dB, which is acceptable (Jianhui & Dongfeng, 1998) .

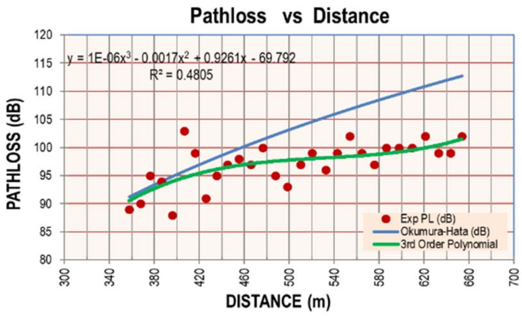

Fig. 5. Theoretical and Exp. Pathloss versus distance for data-set-A

For verification, whether the modified Hata's equation is applicable for some other areas, another data generated from TEMS tool has been used. Based on that practical data, the propagation Pathloss and the distance have been re-verified for (Zia Nadir, Mohamed, & Touati, 2008).

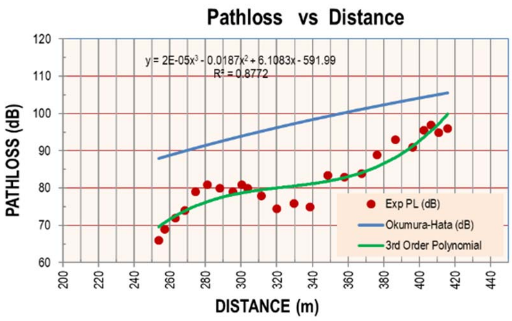

Fig. 6. Theoretical and Exp. Pathloss versus distance for data-set-B

Hypothetical imitation and the found new data are equated and examined further using 3rd order polynomial to interpolate on same experimental data set which provided moderate flexibility. As shown in figures above, higher order polynomial also provides an equally even and effective guess without cumulative computational difficulties, which is expected for these estimates. A decent relationship is detected for the entire series of data set. The decent agreement of the features demonstrate that experimentally replicated numbers is a decent representation of that defined by Hata model.

Additionally, the simulation and the attained tentative data is associated and examined additionally using other models like extended Sakagami model on the set of the new data which gives also satisfactory results. After observation, it can be safely said that the scatter plot of the experimental data on pathloss vs distance reveals a third order polynomial tendency. Fig.5 and Fig. 6 above, show the theoretical, experimental and 3rd order polynomial plots for Okumura-Hata propagation model. As can be seen, results show good agreement between various studies.

Universally, by calculating the RMSE for the second dataset it was also found to be less than 6dB, a satisfactory number. Nevertheless, some experimental values were a bit far from the interpolated points that can be related to the nature of the cell with high rise structures. Though there are many forecasts approaches that are based on deterministic procedures through the availability of improved databases, the Okumura-Hata model is still frequently used (Zia Nadir & Bait-Suwailam, 2014) (Zia Nadir, Bait-Suwailam, & Shafiq, 2014) . We are also aware that the hindrances in the path significantly affect the radio signal propagation (Hrovat, Kandus, & Javornik, 2012). Above all, wireless communication system avoids obstacles such as crossing objects owned by others. There are also many difficulties in establishing a wireless communication system in some applications (L khagvatseren. T & F, 2011). As can be seen from above results, there are some discrepancies between RMSE values for each path compared to the other, although the modified results for each path are within accepted standards. After deep analysis and investigation of the possible reason for this mismatch, it has been noticed that some paths are served by the main lobe of antenna radiation, some are served by side lobes and some are served by a combination of the main lobe and side or back lobes. This conclusion has been obtained by reviewing all paths in Google Earth map with respect to the area of specific serving lobe. The following figure 7 shows general antenna radiation pattern concept and the radiation pattern of another site.

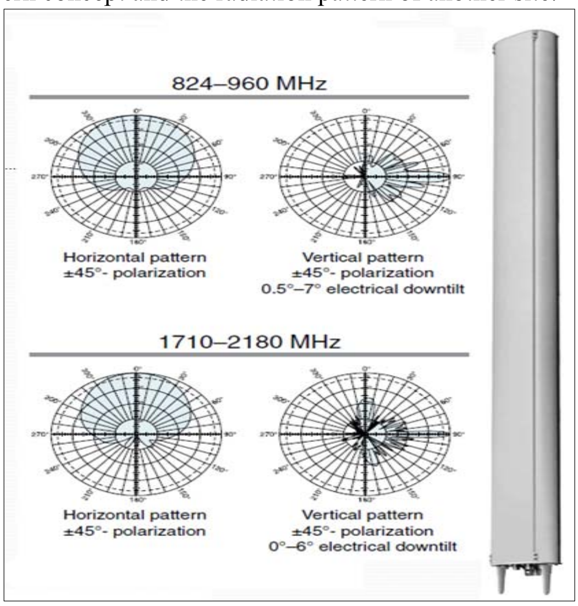

Fig. 7. Radiation pattern of an antenna on one site

In order to produce a generalized model for UMTS path loss prediction use, the average of RMSE for all tested paths was calculated for the model. Then, the same well known process has been applied in to obtain a generalized equation for the propagation model. After that, these equations have been applied for three different paths but not shown here. They are namely: Site-1 Path-1, Site-1 Path-3 respectively. The MATLAB programs for each path was developed and used for generalization and further verification.

This work can be considered as a step forward in establishing generalized propagation models used for path loss prediction in other urban cities of Oman. Further intensive and comprehensive studies and research is recommended to achieve this goal. Also, it is highly recommended to incorporate various modelling techniques in addition to the RMSE method to study their accuracy and impact. Moreover, it is recommended to include more parameters in future prediction models that impact the signal propagation e.g., antenna parameters and patterns.

V. Conclusion

As mentioned earlier, this paper is an extension to a paper published recently at IEMTRONICS 2020 of same authors. However, current paper tackled also another model (Sakagami) and additional paths for experimental data in analysis. This study focused on forecasting the root mean signal strength in diverse areas. As utmost propagation models aim to forecast the median pathloss, existing prediction models vary in terms of their applicability over different terrain and environmental conditions. The effects of terrain situation predicted at 900MHz and 2.1GHz were analyzed. Experimental outcomes of radio signals propagation for an urban area in Oman were related with those predicted based on Okumura-Hata model. The contribution is the prediction by at lower distances than the model is generally used and also validation of experimental data. If precise environmental information was included in the model, better prediction results might be achieved. 3rd order polynomial gave us also the unavailable experimental points showing a good agreement within adequate boundaries.

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