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Characterization of Propagation Models in Wireless Communications for 4G Network

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***Abstract*—Estimating the pathloss and signal strength of the transmitted signal at specific distances is one of the main objectives of network designers. This paper aims to provide generalized pathloss models appropriate for urban areas in Muscat the capital city of the Sultanate of Oman environment. The research includes studying different models of pathloss for the 4G cellular network at Muttrah Business District (MBD) at Muscat. Different models (Free Space model, Okumura Hata, Extended Sakagami, Cost231 Hata, ECC-33 Hata – Okumura extended, Ericsson, Egli, and SUI) are used with 800MHz. The results of the prediction models are compared with real measured data by calculating RMSE. The generalized models are created by modified original models to get accepted RMSE values. Different cells at MBD are tested by modified models. The RMSE values are then calculated for verification purposes. To validate the modified pathloss models of 4G, they are also applied at different cells in a different city in the capital. It has approximately the same environment as MBD. The modified pathloss models provided accepted predictions in new locations.**

***Keywords*—pathloss models; prediction; 4G; RMSE**

I. Introduction

SIGNAL propagation prediction is very important for Network designers. It is a significant task before building new network. To ensure the signal quality and subscribers' expectation, the designers need to predict the signal propagation at each distance using accurate method. They should simulate the realistic scenario to understand its performance in particular environment. Transmitted signals are impacted with different propagation mechanisms, for example signal reflection, diffraction and scattering. These mechanisms lead to signal attenuation along its path from transmitter to receiver. The attenuation which happens on signals from surrounding medium is called propagation losses or pathloss [1]. Though different terrains in the Sultanate of Oman environment, buildings and their structure are main obstacles which counteract the signals in cities and urban areas.

Huge usage of data and new life style encourage the service providers to employ the latest technology in cellular network. 4G and 5G networks are demanded widely. They support the implementation of Artificial Intelligence (AI) applications, Smart cities, Internet of Things (IoT), block chain and other smart applications. Their special features request special care in planning and in designing stage. Generally, propagation models assist in pathloss prediction purpose. Consequently, they help network designers fulfill the requirement. There are many types of pathloss models which predict the signal performance and strength versus distance. They were used for different environment. It is impossible to use original models for new specific area [2]. The expected results will include errors. To improve the models' performance in new areas it is better to modify its parameters with new targeted area.

This research introduces different propagation models which will be applied in Muttrah Business District (MBD) city in Muscat Governorate. These models are; Free Space model, Okumura Hata model, Extended Sakagami model, Cost 231 Hata model, ECC-33 Hata – Okumura extended model, Ericsson model, Egli model and SUI model. These models will be applied on 4G networks at 800MHz in urban environment, which were not done before in this area.

Since the prediction results are approximate, this indicates to validate them before any investment. For that, each modified model will be implemented in other cells in MBD. Additional tests are done in Alkhwair, Algubrah and Alkhoud areas. These cities are part of Muscat. For error indication, RMSE is calculated by (1), for each cell pathloss prediction. The RMSE calculation depends on finding the error between measured pathloss and predicted pathloss which should be limited to 6dB [3].

$$RMSE = \sqrt{\frac{\sum(P_m - P_r)^2}{(N-1)}} \quad (1)$$

Where,
P_m: Measured Path Loss [dB]
P_r: Predicted Path Loss [dB]
N: Number of measured values

II. 4G Studies and Research

Internationally, numerous studies were done reviewing the propagation models for different cellular networks. Okumura studied the pathloss in Tokyo in 1968 followed by Hata in 1980 [1, 4, 5]. Jinan city network pathloss measurements in China was done in 1998 by Jianhui Wu and Dongfeng Yuan [3]. These are some examples of the prior studies. They created new pathloss models or modified the existing models. The created or modified models are suitable mostly for the environment where they were earlier implemented. They might not work properly in other areas. Therefore, correction factors were provided in each study. In addition, new models with new names were formed based on old models after modification. They aimed to cover more factors and expanded the models parameters to suit new environments requirements, such as; weather, terrain, antenna type, new technology and country regulation.

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Most of the old models which are developed for old technologies can be implemented with 4G and 5G networks with modification. Here some of the studies will be presented. In Ghana, the research was done in 2019 in 4G network using 800MHz and 2600MHz [6]. The researchers used Free space model, Hata model, Ericsson model, SUI model, and ECC-33 model. Their research results recommended to use Ericsson model in urban area at 800MHz. whereas, ECC-33 was the best model for urban and sub-urban environment at 2600MHz.

The research [7] which done in 2018 in Baghdad, Iraq especially in AL-Habebea (urban area) and AL-Hindea district (rural area) studied Hata Model, ECC-33 Model, Ericsson Model and Coast-231 Model. The researchers tested all models on 800MHz frequency networks. Their research results were Hata model and Ericsson model which suited urban area without model modification, while Hata model was the best in rural area. In [8], the research was done in 2018 for Lagos, Nigeria network. It completed for 4G technology by employing free space model, Ericsson 9999 model, ECC-33 model, COST 231-Hata model and the SUI model. It concludes that the COST 231-Hata model was the best model at 1900MHz in Lagos environment.

In [9], which was done in 2017 for different clutters (urban and suburban) in Kuwait environment. The research concluded with different results. It gave that SUI was performing good with 3.5GHz in urban and suburban environments comparing with Ericsson and Empirical Hata models.

III. PATHLOSS MODELS

A. Free space model

Free space model assumes that there is no obstacles between transmitter and receiver [8]. It considers the signal transmission in LOS (Line of Sight) without any scattering, reflection, etc. [10]. Its calculation is affected by frequency and distance from transmitter to receivers. Friis equation (2), is used to calculate free space pathloss in dB [1, 10].

$$PLFS\ [dB] = 32.44 + 20\text{Log}_{10}(f_c) + 20\text{Log}_{10}(d) \quad (2)$$

Where f_c is frequency in MHz and d is distance between transmitter to receiver in km. The model's results are ideal and usually close to real measured data with very small RMSE.

B. Okumura-Hata model

Most pathloss models are improvement of previous models. Modification of the initial version are carried out by including additional factors or extension of range of limitations. Okumura model was evolved in 1980 by Hata, ended with Okumura-Hata model by implementing Okumura's measurements in Tokyo city [1]. This simplest model is widely used due to its reliability [1]. The Path loss $L_p(dB)$ is measured via Okumura-Hata model as mentioned in (3), for urban environment [11]. Okumura model and developed models from Okumura predict mean pathloss as a function of various parameters [12]. Distance, frequency and antennas heights are main parameters.

$$L_P\ [dB] = 69.55 + 26.16\ \text{Log}_{10}(f_c) - 13.82\ \text{Log}_{10}(h_b) + \left(44.9 - 6.55\ \text{Log}_{10}(h_b)\right)6.55\ \text{Log}_{10}(d) - a(h_m) \quad (3)$$

Where f_c is frequency in MHz, h_b is Base Station (BS) height in meter and d is distance between the Mobile Station (MS) and the BS in km. (ah_m) is MS height correction factor. It can be calculated using (4), for small to medium cities. Where h_m is MS height in meters.

$$a(h_m) = (1.1\ \text{Log}_{10}(f_c) - 0.7)h_m - (1.56\ \text{Log}_{10}(f_c) - 0.8) \quad (4)$$

For a large city, ah_m is calculated by (5):

$$a(h_m) = \begin{Bmatrix} 8.29\left(\text{Log}_{10}(1.54h_m)\right)^2 - 1.1, & f < 300MHz \\ 3.20\left(\text{Log}_{10}(11.75h_m)\right)^2 - 4.97, & f \geq 300MHz \end{Bmatrix} \quad (5)$$

The original Okumura-Hata model is restricted with 1-100 km distance between BS and MS, 150-2000Mhz frequency range, 30-200m BS height and 1-10m MS height [11]. This model is mostly used by latest models as basement. It is widely used with different cellular networks in different terrains (urban, suburban and rural). Okumura-Hata model performance is good with urban clutter [7, 10]. The model is mostly affected by antenna height and distance. As antenna height increases the pathloss decreases. Whereas the pathloss increases with distance incrementals [13].

C. Extended Sakagami model

Extended Sakagami model calculation is affected by city constructions [4]. This is clear in (6). It depends on average street width (W) and average buildings height (H).

$$L_P\ [dB] = 101 - 7.11\text{Log}_{10}(W) + 7.5\ \text{Log}_{10}(H) - \left(24.37 - 3.7\left({}^{H}/_{h_b}\right)^2\right)\ \text{Log}_{10}(h_b) + \left(43.42 - 3.11\ \text{Log}_{10}(h_b)\right)\ \text{Log}_{10}(d) + 20\ \text{Log}_{10}(f_c) - a(h_m) \quad (6)$$

$$a(h_m) = 3.2\left(\text{Log}_{10}(11.75h_m)\right)^2 - 4.97 \quad (7)$$

Where W is average street width, H is average buildings heights, h_b is BS height and h_m is MS height. W, H, h_b and h_m are in meter. d is the distance in km between MS and BS and f_c is frequency in MHz. $a(h_m)$ given by (7), is the received antenna height correction factor [5]. The model limitations as were listed in [4] are for frequency range of 800-6000MHz. The distance between BS and MS is limited to 0.5-3 km. BS antenna height, MS antenna height, average buildings height and average street width are restricted to be (20-150m), (0.5-10m), (5-50m) and (5-50m) respectively.

D. COST 231 Hata model

COST 231 Hata model was extracted from Hata model [14, 15]. It is suitable for urban, suburban and rural terrains [16]. The model can be calculated by (8).

$$L_P\ [dB] = 46.3 + 33.9\ \text{Log}_{10}(f_c) - 13.82\ \text{Log}_{10}(h_b) + \left(44.9 - 6.55\ \text{Log}_{10}(h_b)\right)\ \text{Log}_{10}(d) - a(h_m) + C \quad (8)$$

Where f_c in MHz, h_b BS antenna height in meter, h_m and $a(h_m)$ are mobile antenna height in meter and correction factor for MS respectively. d is BS to MS separation distance in km and C is area correction factor. The factor C is equal to 0 for medium sized city and suburban areas and equal to 3dB for urban areas. $a(h_m)$ is expressed by (9), for small or medium cities [14]:

$$a(h_m) = [1.1\text{Log}_{10}f_c - 0.7]h_m - 1.56\text{Log}_{10}(f_c) - 0.8 \quad (9)$$

As in previous models, Cost-231 Hata model has limitations. The frequencies should be between 500MHz and 2000MHz [7, 16, 17], MS height to be 1–10m and BS height to be 30–200m [15]. The separation distance between BS and MS is limited to 1 km to 20 km [14, 18]. Additionally, Cost 231 Hata model works well when BS is higher than nearby buildings [18].

E. ECC-33 Hata – Okumura Extended model

ECC-33 is also based on Okumura model. Electronic Communication Committee ECC extended Okumura model to cover additional frequency bands up to 3.5Ghz [16]. It calculates urban, suburban and rural environment pathloss by (10), [12, 16].

$$L_p(dB) = A_{fs} + A_{bm} - G_b - G_r \quad (10)$$

Where A_{fs} is free space attenuation, A_{bm} is basic median pathloss, G_b is BS height gain factor and G_r is MS height gain factor for medium city environment. Variables in (10), in dB, is represented in (11) to (14).

$$A_{fs} = 92.4 + 20\text{Log}_{10}(d) + 20\text{Log}_{10}(f_c) \quad (11)$$

$$A_{bm} = 20.4 + 9.8\text{Log}_{10}(d) + 7.9\text{Log}_{10}(f_c) + 9.5[\text{Log}_{10}(f_c)]^2 \quad (12)$$

$$G_b = \text{Log}_{10}\left(\frac{h_b}{200}\right)[13.96+5.8[\text{Log}_{10}(d)]^2] \quad (13)$$

For medium city environment:

$$G_r = [42.57 + 13.57\text{Log}_{10}(f_c)][-0.58 + \text{Log}_{10}(h_m)] \quad (14)$$

For large city environment:

$$G_r = 0.759h_m - 1.862$$

Where, f_c is frequency in GHz, h_b is BS height in meter, h_m is MS height in meter and d is distance in km between BS and MS.

F. Ericsson model

In addition to most of the previously discussed models, Ericsson also modified Hata-Okumura model with new appearance as in (15). Where a_0, a_1, a_2 and a_3 are model parameters recorded in Table I. In this research, the urban environment parameters will be used. $g(f_c)$ can be found from (16), d is in km presenting the distance between BS and MS. h_b and h_m are BS height and MS height in m. f_c is frequency in MHz. Ericsson is modeled to cover frequencies above 3GHz in urban environment [9, 11].

$$L_P\,[dB] = a_0 + a_1\text{Log}_{10}(d) + a_2\text{Log}_{10}(h_b) + a_3\text{Log}_{10}(h_b)\text{Log}_{10}(d) - 3.2[\text{Log}_{10}(11.75h_m)]^2 + g(f_c) \quad (15)$$

$$\therefore g(f_c) = 44.5\text{Log}_{10}(f_c) - 4.78[\text{Log}_{10}(f_c)]^2 \quad (16)$$

TABLE 1
ERICSSON MODEL PARAMETERS

	a_0	a_1	a_2	a_3
urban	36.2	30.2	12	0.1
sub-urban	43.2	68.93	12	0.1

G. Egli model

Egli model is appropriate at frequency from 40MHz to 900MHz. This model is expressed by (17), which suites the case when MS ≤ 10m [19].

$$L_P\,[dB] = 20\text{Log}_{10}(f_c) + 40\text{Log}_{10}(d) - 20\text{Log}_{10}(h_b) - 10\text{Log}_{10}(h_m) + 76.3 \quad (17)$$

Where: f_c is frequency in MHz, d is BS to MS separation distance in meter, h_b is BS antenna height in meter and h_m is MS antenna height in meter. Egli model works well when one antenna is fixed and other one is moving. The measurements of this research are for 800MHz and the MS height equal to 1.5m. So, the parameters are within the limitation of Egli model.

H. SUI (Stanford University Interim) model

SUI model was the research of Stanford University Interim and 802.16 IEEE group. They modified Hata model to create SUI. SUI has many corrections and terrain factors. This model is calculated by (18). Where A, γ, X_f, X_h and S are found by (19) to (23).

$$L_P\,[dB] = A + 10\gamma\text{Log}_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + S \quad (18)$$

$$A = 20\text{Log}_{10}\left(\frac{4\pi d_o}{\lambda}\right) \quad (19)$$

$$\gamma = a - b(h_b) + \frac{c}{h_b} \quad (20)$$

$$X_f = 6\text{Log}_{10}\left(\frac{f_c}{2000}\right) \quad (21)$$

$$X_h = -10.8\text{Log}_{10}\left(\frac{h_m}{2000}\right) \quad \text{for terrain A \& B}$$

$$X_h = -20.8\text{Log}_{10}\left(\frac{h_m}{2000}\right) \quad \text{for terrain C} \quad (22)$$

$$S = 0.65\text{Log}_{10}(f_c)^2 - 1.3\ \text{Log}_{10}(f_c) + a \quad (23)$$

Where d is the distance between MS and BS antenna in meter. d_o is reference distance equal to100m. A is free space pathloss. λ is the wavelength in meter. γ is the pathloss exponent. X_h is the correction of receiving antenna height (h_m). X_f is the frequency correction. S is the shadowing correction in dB. Where S is between, $8.2<S<10.6$ for urban areas, f_c is the frequency in MHz [20]. h_m is MS height in meter. SUI suits paths with frequency between 1900MHz and 11GHz. a, b and c which appear in γ are the terrain dependent constants. They are given in Table II [15]. Including these correction factors in SUI model, allowing the model fitting all environments type (urban, sub-urban and rural) [12].

In this research, SUI will be tested with 800MHz. α is 6.6 dB for urban environment [15]. From SUI model, it is clear that BS heights are not affecting on signal pathloss [16].

TABLE II
SUI TERRAIN DEPENDENT PARAMETERS a, b AND c

Model parameter	Terrain A Urban	Terrain B Sub-urban	Terrain C rural
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

IV. EXPERIMENTAL RESULTS

This research is considering 800MHz for 4G cellular network pathloss prediction in urban areas. Concentrating initially on cell-255,256 and 257 in MBD area, all models were implemented by 4G models equations. The transmitted power of MBD cells was 18.2dBm. The drive test measurements and cells parameters with BS height of 44m and the MS height of 1.5m were employed in pathloss models developed in Matlab. The pathloss models prediction results of the cells- are demonstrated in Fig.1 to Fig.3. These figures present the pathloss in dB as a function of distance in km. They show the pathloss models prediction comparing with blue stars for real measured pathloss. The model's predictions are illustrated in different colored lines. It is clear, the black line for free space model gives perfect results close to real pathloss. This is due to the free space model, considering only frequency and distance and excluding other factors as mentioned previously. It assumes there is no obstacles between transmitter and receiver and the signal transmits in LOS. The other pathloss models are overestimating the measured pathloss. They predicted pathloss higher than real measurements except SUI model.

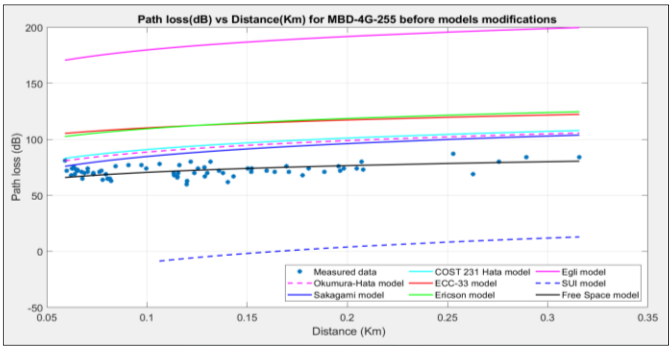

Fig. 1. Path loss(dB) vs Distance (km) for MBD-cell255

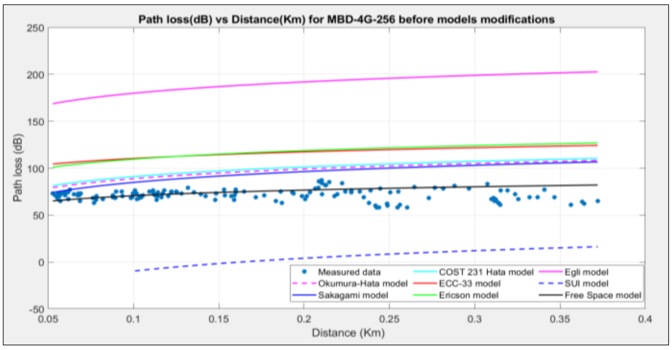

Fig. 2. Path loss(dB) vs Distance (km) for MBD-cell256

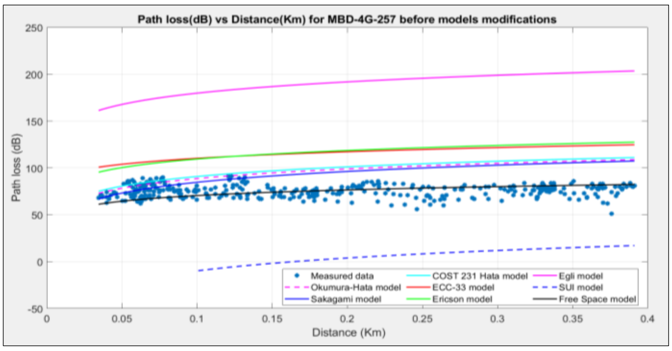

Fig. 3. Path loss(dB) vs Distance (km) for MBD-cell257

To determine the error between measured pathloss and predicted pathloss, the RMSE values were calculated by (1) as error indicator for each cell. Its values are listed in Table III.

TABLE III
RMSE FOR MBD_4G_CELL 255,256 AND 257

Path loss Model	MBD_4G Cell 255	MBD_4G Cell 256	MBD_4G Cell 257	Average RMSE
Free space	5.4256	8.3183	8.4266	7.39
Okumura-Hata	20.0357	25.6167	22.7320	22.7948
Extended Sakagami	16.8301	23.1187	20.6671	20.2053
COST231 Hata	22.1457	27.6622	24.6720	24.826
ECC-33	40.3740	44.0779	40.5017	41.6512
Ericson	40.0645	44.6619	41.1355	41.954
Egli	111.1598	116.3921	112.6139	113.389
SUI	74.6432	69.3544	69.4455	71.148

As cells 255,256 and 257 face different directions in one area, the average RMSE were found from their RMSE values. The averages were used to adjust the pathloss models equations by adding or subtracting ± average RMSE.

Accordingly, the next step was to modify the models taking into account all factors of the environment by utilizing RMSE. As RMSE comprises all factors affected on signals path. This step helped to improve prediction results and reduced errors. Additionally, it helped to generate new versions of each model which suits Muscat environment.

For Okumura-Hata model, the (3) was improved to (25), after considering the averaged RMSE of Okumura-Hata model.

$$L_P\,[dB] = 69.55 + 26.16\,\text{Log}_{10}(f_c) - 13.82\,\text{Log}_{10}(h_b) + \left(44.9 - 6.55\,\text{Log}_{10}(h_b)\right)\text{Log}_{10}(d) - a(h_m) \pm \text{RMSE} \quad (24)$$

$$L_P\,[dB] = 69.55 + 26.16\,\text{Log}_{10}(f_c) - 13.82\,\text{Log}_{10}(h_b) + \left(44.9 - 6.55\,\text{Log}_{10}(h_b)\right)\text{Log}_{10}(d) - a(h_m) \pm 22.80 \quad (25)$$

Same process was implemented for other models including the average RMSE for each model. Equation (26), expresses amended Extended Sakagami model.

$$L_P\,[dB] = 101.0 - 7.11\text{Log}_{10}(W) + 7.5\,\text{Log}_{10}(H) - \left(24.37 - 3.7\left(\frac{H}{h_b}\right)^2\right)\text{Log}_{10}(h_b) + \left(43.42 - 3.11\,\text{Log}_{10}(h_b)\right)\text{Log}_{10}(d) + 20\,\text{Log}_{10}(f_c) - a(h_m) - 20.20 \quad (26)$$

Modified Cost 231 Hata model:

$$L_P\,[dB] = 46.3 + 33.9\text{Log}_{10}(f_c) - 13.82\,\text{Log}_{10}(h_b) - a(h_m) + \left(44.9 - 6.55\,\text{Log}_{10}(h_b)\right)\text{Log}_{10}(d) + 3 - 24.8 \quad (27)$$

Modified ECC-33 Hata – Okumura Extended model:

$$L_p(dB) = A_{fs} + A_{bm} - G_b - G_r - 41.651 \quad (28)$$

Modified Ericson model:

$$L_P\ [dB] = a_0 + a_1 \mathrm{Log}_{10}(d) + a_2 \mathrm{Log}_{10}(h_b) + a_3 \mathrm{Log}_{10}(h_b)\mathrm{Log}_{10}(d) - 3.2[\mathrm{Log}_{10}(11.75 h_m)]^2 + g(f_c) - 41.95 \quad (29)$$

Modified Egli model:

$$L_P\ [dB] = 20\mathrm{Log}_{10}(f_c) + 40\ \mathrm{Log}_{10}(d) - 20\ \mathrm{Log}_{10}(h_b) + -10\ \mathrm{Log}_{10}(h_m) + 76.3 - 113.389 \quad (30)$$

Modified SUI model:

$$L_P\ [dB] = \mathrm{A} + 10\gamma \mathrm{Log}_{10}\left(\frac{d}{d_o}\right) + \mathrm{X}_f + \mathrm{X}_h + S + 71.148 \quad (31)$$

All improved models were applied in same cells coverage in MBD area with same previous parameters. The resulted pathloss model's predictions are shown in Fig.4 to Fig.6. Very clearly the new pathloss predictions are improved. For error indicator, the new RMSEs were calculated for each model. Their values are recorded in Table IV.

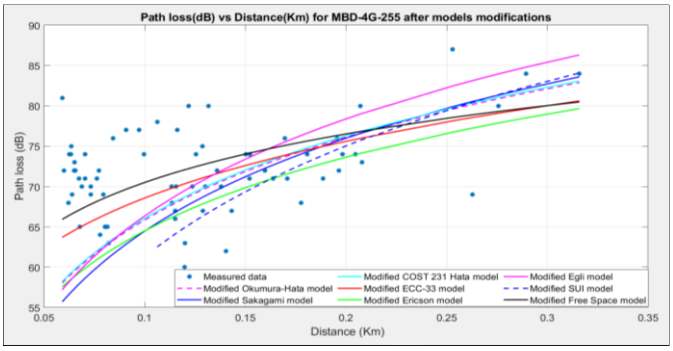

Fig. 4. Path loss(dB) of MBD-cell255 after modification

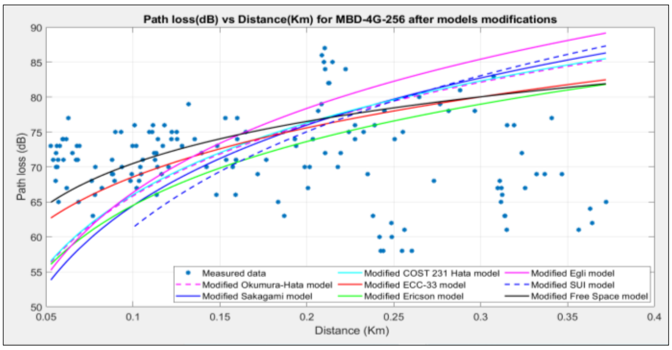

Fig. 5. Path loss(dB) of MBD-cell256 after modification

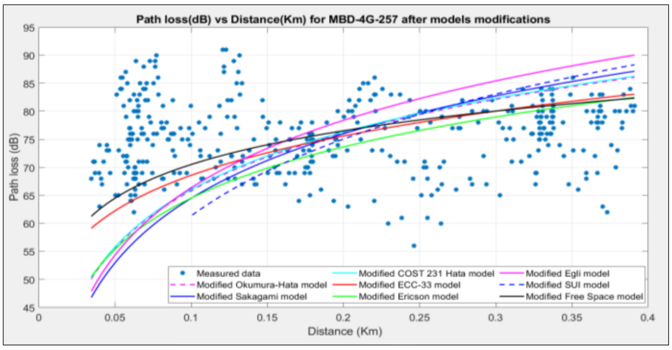

Fig. 6. Path loss(dB) of MBD-cell257 after modification

TABLE IV
RMSE FOR MBD CELL 255,256 AND 257 AFTER MODEL'S MODIFICATION

Modified Path loss Model	MBD Cell 255	MBD Cell 256	MBD Cell 257
Modified Okumura-Hata	8.1235	10.5501	12.0011
Modified Extended Sakagami	9.2436	11.4133	13.1976
Modified COST 231 Hata	8.0274	10.5603	11.9514
Modified ECC-33 Hata–Okumura Extended	5.9390	8.6109	9.2887
Modified Ericson	8.6576	9.8984	11.8641
Modified Egli	8.4916	11.9446	13.1677
Modified SUI	6.0927	11.3813	9.7993

The modified ECC33 model resulted with lowest RMSE in all cells. The best RMSE resulted from cell 255 which is less than 6dB. The smaller RMSE indicates better results. For validation purpose, other cells were tested with modified models. Cell-237 was chosen from MBD area. The resulted pathloss from each model with distance are displayed in Fig.7. It is clear, the red line of ECC33 model crosses the middle of measured data.

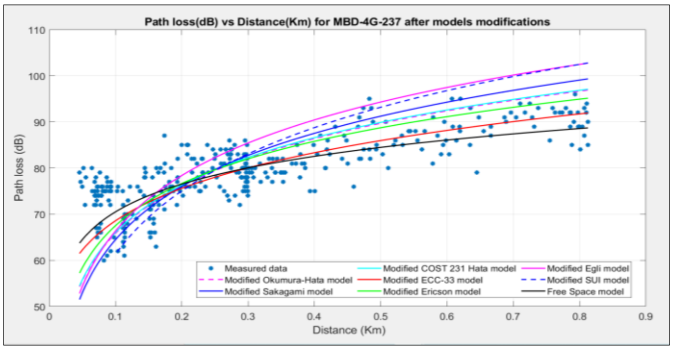

Fig. 7. Path loss(dB) vs Distance (km) for MBD-cell237 after modification

To study the errors of new cell propagation pathloss, the RMSE values were calculated and listed in Table V. The modified ECC33 model produce the smallest RMSE. It matches with the plot descriptions. After observation, the RMSE table of cell 237 confirms the ECC-33 Hata – Okumura Extended is the best model for MBD area. This outcome is similar to cells-255,256 and 257 results.

For more investigation, additional tests were done in Alkhwair, Algubrah and Alkhoud *areas* to prove the modified model's validity.

These locations were selected as they are urban areas. They have many high commercial buildings and residential buildings. The researcher nominated one cell coverage from each. All nominated cells were working with 800MHz. The BS heights of Alkhwair, Algubrah and Akhoud were 38m, 30m and 21m respectively. They are lower than MBD cells heights. Whereas, the MS height was same as before 1.5m. The transmitted power of each cell was 15.2 dBm. Other antenna technical details were identical with what were used in MBD.

TABLE V
RMSE for MBD Cell 237 after model's modification

Path loss Model RMSE for Cell_237	RMSE (dB)
Modified Okumura-Hata	7.0117
Modified Extended Sakagami	8.0584
Modified COST 231 Hata	7.0031
Modified ECC-33	5.1715
Modified Ericson	6.1421
Modified Egli	8.8173
Modified SUI	7.1245

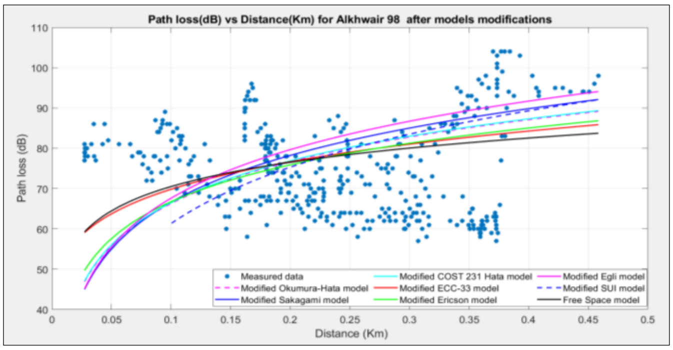

Fig. 8. Path loss(dB) vs Distance (km) Alkhwair-cell98 after modification

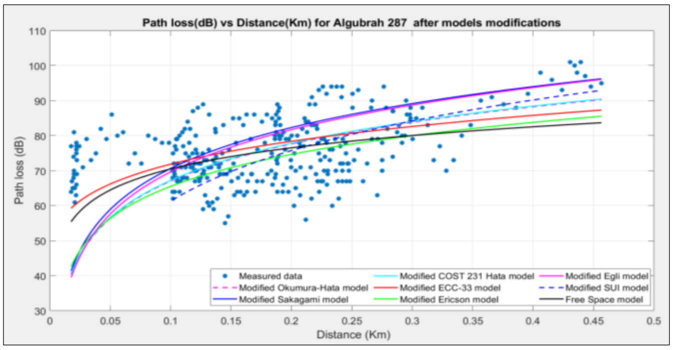

Fig. 9. Path loss(dB) vs Distance (km) for Algubrah-cell287 after modification

After studying the pathloss tests outcomes in Alkhwair, Algubrah and Alkhoud areas and comparison of results with MBD results as in Fig.8 to Fig.10, shows the pathloss models predictions crossing the middle of measured data except prediction of cell 34 in Alkhoud.

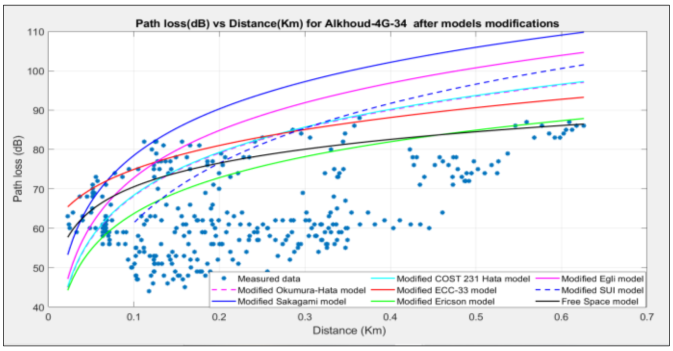

Fig. 10. Path loss(dB) vs Distance (km) for Alkhoud-cell34 after modification

The predicted pathloss models which were modified in MBD gave higher values than measured pathloss in Alkhoud. The possible reasons for this mismatch are the building distribution in two areas which are different. Also, the drive test path differs between them. In Alkhoud, the test was done mostly on the main road which was in LOS with BS. The long street was facing the transmitted antenna without any obstacles. Consequently, the measured pathloss was lower than prediction. On the other hand, the BS height was 21m causing high predicted pathloss. This fact increased the error between measured and predicted pathloss. Normally, with high BS, signal propagation is better than short BS especially in dense urban areas.

The RMSE of these three cells were calculated and listed in Table VI. Alkhwair and Algubrah area followed MBD. The ECC33 Hata – Okumura Extended model gave best results in these two locations with RMSE equal to 13.00dB and 8.90dB respectively. Whereas, Ericsson model performed better in Alkhoud. It gave less errors. Even same frequency 800MHz was used in all sites, there are alternative pathloss results. From the RMSE table, we can conclude that all modified models suit new locations. They produced acceptable RMSE without any additional modification related to each area.

TABLE VI
RMSE FOR ALKHWAIR CELL98, ALGUBRAH CELL287, AND ALKHOUD CELL34

Modified Path loss Models	Alkhwair Cell98 RMSE (dB)	Algubrah Cell 287 RMSE (dB)	Alkhoud Cell 34 RMSE (dB)
Modified Okumura-Hata	14.8384	11.9987	18.3354
Modified Extended Sakagami	15.7735	12.6256	27.7158
Modified COST 231 Hata	14.8620	11.9594	18.4730
Modified ECC-33	13.0066	8.9052	19.3863
Modified Ericson	14.0811	11.8113	13.6991
Modified Egli	16.3996	12.8224	23.1008
Modified SUI	13.9736	8.9098	19.3723

Fig.11 summarizes the RMSE values of each studied location. The red bars which expresses ECC33 model give the best outcomes except for Alkhoud area. ECC-33 is the closest to threshold value of 6dB which appears as horizontal reference black line. ECC-33 Hata – Okumura Extended model is based on Okumura model. It modified Okumura model by taking into account many affected factors appearing in original model (10) to (14). These factors performed perfectly in tested area in Muscat Governorate in addition to RMSE which subtracted from original equations. Generally, employing 4G modified models' was with new cells in new area measurements produce RMSE higher than the MBD cells. As a consequence of collected data, building organizing and drive test path, the time of collecting data in different locations affects also on resulted RMSE.

As a general remark of this study, the measured pathloss increased slowly with distance unlike predicted pathloss. They spread horizontally as distance increased. It means the measured pathloss values reserve their values within fixed range. The measured pathloss range between 60dB to 90dB of cell257 at MBD is an example of this remark. This is due to the tested distance was very short and buildings distribution in the cities. After deep analysis and investigation of the test outcomes in each location, the planner can depend on these models to simulate the pathloss of the new network in design stage. Moreover, the environment factor can be suggested to be used and cover all differences between MBD and other locations. The environment factor will include special areas aspects. It requires additional calculations to fix the suitable factor.

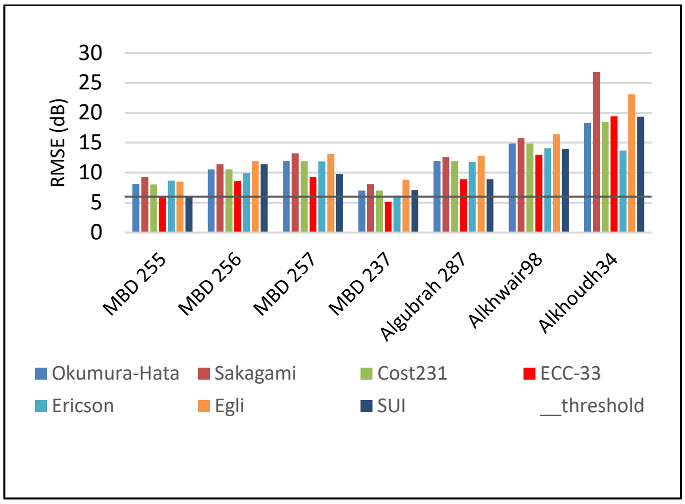

Fig.11. RMSE comparison of 4G network

CONCLUSION

The objective of this research was to identify pathloss models which fits the best for Muscat Governorate region in the Sultanate of Oman for 4G network. The research aim was achieved by employing different pathloss models on 4G network operated at 800MHz in urban areas. This study was the first in the region for 4G networks. From the tested pathloss models and calculated RMSE of 4G network, we can conclude that the modified ECC33 Hata – Okumura Extended model is the best pathloss prediction model in MBD, Alkhwair and Algubrah areas due to the nature of the city. While the modified Ericsson model is performing better in Alkhoud area.

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