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Near Ground Path Loss Prediction for UMTS 2100 MHz Frequency Band Over Propagating Over a Smooth-Earth Terrain

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Abstract: In this paper, path loss prediction for near ground propagation of third generation (3G)-based Universal Mobile Telecommunications System (UMTS) network signal in the 2100 MHz frequency band over a smooth-earth terrain is presented. Particularly, the attenuation due to diffraction is estimated based on ITU-R Recommendation P.526-13 for diffraction over smooth earth. Furthermore, the total pathloss is determined using the Blomquist empirical model which combined free-space loss, plane-earth loss and the diffraction loss over smooth earth. In the study, two drive tests are conducted for the UMTS 2100 MHz frequency band in suburban area of Uyo. The Blomquist empirical model was tuned with respect to the first drive test pathloss dataset. The results show that with the training data (first drive test data), the untuned Blomquist empirical model has RMSE=10.21344 dB, Prediction Accuracy = 89.92%, minimum Prediction error = 9.02 dB and maximum Prediction error = -34.05 dB. Also, with the training data, the optimized Blomquist empirical model has RMSE=1.625388dB, Prediction Accuracy = 98.48%, minimum Prediction error = 5.34 dB and maximum Prediction error = -5.40 dB. Furthermore, with the cross validation data (second drive test data), the optimized Blomquist empirical model has RMSE=1.831368 dB, Prediction Accuracy = 98.24%, minimum Prediction error = 5.25 dB and maximum Prediction error = -6.15 dB. The results show that for the given terrain under study, the tuned or optimized Blomquist empirical model can effectively predict the pathloss for the UMTS network signal in the 2100 MHz frequency band.

Keywords: Blomquist Empirical Model, Plane-Earth Loss, Diffraction Loss, Pathloss, Cross Validation, UMTS Network

1. Introduction

Power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling. Reliable path loss prediction methods are required for efficient planning of wireless communication links. An efficient prediction method minimizes interference levels and also helps to optimize the link parameters [1-3]. Pathloss prediction is the act of estimating the expected pathloss that may be experienced by radio wave as it propagates in a given environment. Pathloss prediction utilizes analytical expressions called pathloss models to estimate the estimate the expected pathloss for any given sign.

The rudimentary concept used in estimating expected path loss in wireless communication links is the free space, which is defined as a region free of all objects that might absorb or reflect radio energy [4]. However, in practice for line-of-sight (LOS) or near LOS communication system, in which the wave is propagated in the atmosphere and near the ground, the free space transmission equivalent is modified through various causes such as atmospheric refraction, reflection, etc [4]. Particularly, when radio wave propagates near the ground with a line of sight (LOS) condition, the path loss can be better described by the plane earth (PE) path loss model rather than the free space model. In addition, when the receiver is obstructed by object like tree, then knife edge diffraction loss need to be considered along with the plane earth (PE) path loss. In practice, due to the effect of obstructions, such receiver close to the ground and below obstruction height are considered non-line-of-sight paths. In that case, Blomquist empirical formula may be used to find the total pathloss over such non-line-of-sight paths with ground reflections [5],[6].

In this paper, path loss prediction for near ground propagation of third generation (3G)-based Universal Mobile Telecommunications System (UMTS) network signal in the 2100 MHz frequency band over a smooth-earth terrain is presented [7-9]. Particularly, the attenuation due to diffraction is estimated based on ITU-R Recommendation P.526-13 for diffraction over smooth earth. Furthermore, the total pathloss is determined using the Blomquist empirical model which combined free-space loss, plane-earth loss and the diffraction loss over smooth earth. In the study, two drive tests are conducted for the UMTS 2100 MHz frequency band in suburban area of Uyo metropolis of Akwa Ibom state. The total loss model was tuned with respect to the first drive test pathloss dataset. The prediction performance of the tuned and the untuned model are compared. The tuned model is then cross validated using the second drive test data.

2. Calculation of the Basic Transmission Loss

In most cases, the basic free-space attenuation model fails to effectively predict the total transmission loss. In such cases, along with the free space pathloss (L_{FSP}), some other attenuation factors are imposed on the radiowave due to medium effects. Consequently, the sum of free-space attenuation (Lfsp) and medium loss (Lm) is defined as basic transmission loss (L_b) given by:

$$L_b(dB) = L_{FSP} + L_m \tag{1}$$

where:

$$L_{FSP}(dB) = 32.4 + 20\log(f) + 20\log(d) \tag{2}$$

where: f is the frequency (MHz) and d is the distance (km). Among others, medium losses include: Atmospheric absorption loss due to gases, vapor, and aerosols; reflection loss, including focusing or defocusing due to curvature of reflecting layer; scattering of radiowave due to irregularities in the atmospheric refractive index or by hydrometeors; diffraction loss due to obstructions; radio precipitation due to rain and snow; temporal climatic effects such as fog and cloud; antenna to medium coupling loss; polarization coupling loss and multipath adverse effects. In most analysis, the value of many of the medium loss components is negligible when compared to others and so they are ignored. In this paper, the medium losses considered include only the ground reflection loss (L_{GRL}) and attenuation due to diffraction (L_{dfl}). In such case, Blomquist empirical method is used to determine the total path loss as follows [5, 6];

$$L_{TL}(dB) = (L_{FSP}) + \sqrt[2]{\left({L_{GRL}}^2 + {L_{dfl}}^2\right)} \tag{3}$$

where all the losses are in dB.

In view of the nature of the terrain considered in the case study area, the ITU-R Recommendation P.526-13 method for estimating attenuation due to diffraction over smooth-earth propagation path is use. According to ITU-R Recommendation P.526-13, the standard method for calculating the transmission loss due to diffraction over a smooth-earth is defined as follows [10], [11]:

$${L_{dl}}^2(dB) = F(X) + G(Y_1) + G(Y_2) \tag{4}$$

where: X is the normalised length of the path;

$$X = 2.2\left(\sqrt[3]{\frac{f}{(a_e)^2}}\right)d \tag{5}$$

Y_1 and Y_2 are the normalised length antenna heights;

$$Y_1 = 0.0096\left(\sqrt[3]{\frac{f^2}{a_e}}\right)h_{tx}\, d \tag{6}$$

$$Y_2 = 0.0096\left(\sqrt[3]{\frac{f^2}{a_e}}\right)h_{rx}\, d \tag{7}$$

a_e is the equivalent Earth radius

$$a_e = K(a)$$

a is the actual Earth radius (6370km);

k is the applicable effective earth radius k-factor. The following k-factors are normally applied:

k = 4/3 under the median link planning "standard atmosphere" criteria (50%);

k = 3 under the long term "annual" interference criteria (20%); and

k = 20 under the short term "worst month3" interference criteria (0.01%)

h_{tx} is the transmitter antenna height (m);

h_{rx} is the receiver antenna height (m);

d is the path length (km);

f is the frequency (MHz).

$$F(X) = 11 + 10\log(X) - 17.6X \tag{8}$$

with the height gain term:

$$G(Y_1) = \begin{cases} 17.6\sqrt[2]{(Y_1 - 1.1)} - 5\text{Log}(Y_1 - 1.1) - 8 \text{ for } Y_1 > 2 \\ 20\text{Log}(Y_1 - 0.1(Y_1)^3) \text{ for } Y_1 \le 2 \end{cases} \tag{9}$$

$$G(Y_2) = \begin{cases} 17.6\sqrt[2]{(Y_2 - 1.1)} - 5\text{Log}(Y_2 - 1.1) - 8 \text{ for } Y_2 > 2 \\ 20\text{Log}(Y_2 - 0.1(Y_2)^3) \text{ for } Y_2 \le 2 \end{cases} \tag{10}$$

When radio wave propagates over ground, direct ray in addition to ground reflected ray are received. The ground reflection loss in dB is given by the plane earth model as;

$$L_{GRL(dB)} = 40\text{Log}(d) - 20\text{Log}(h_{tx}) - 20\text{Log}(h_{rx})$$

Where d is the distance in meters between the transmitter and receiver, h_{tx} is the transmitter antenna height in meters, and h_{rx} is the receiver antenna height in meters.

2.1. Drive Test Measurement Campaign

A handheld Samsung I9500 Galaxy S4 mobile phone was used to take measurement of received signal strength (RSS) from the UMTS 2100 GHz network. The RSS measurements were taken two times along dual lane tarred road in a suburban part of Uyo metropolis. The Samsung I9500 Galaxy S4 has CellMapper Android application installed. The CellMapper captures and displays advanced GSM/CDMA/UMTS/LTE current and neighbouring cells' low level data and can also record and export the data as comma-separated values (CSV) file. Data captured by the CellMapper comprises the current and neighbouring cells RSS in decibels (dB), the current cells cell ID (CID), local area code (LAC). The RSS along with the respective longitudes and latitudes were recorded at each measurement (receiver) point. In addition, the UMTS base station (transmitter) was located, and its longitude and latitude were recorded.

2.2. Calculation of the Measured Pathloss from the Measured RSS

After the measurements, Haversine formula was used to determine the distance between the mast (transmitter) and of the receiver locations.

The RSS value recorded at each of the receiving point is converted to measured pathloss (PL_m) in dB by using the formula:

$$PL_m\ (dB) = (PBTS + GBTS + GMS - LFC - LAB - LCF) - RSS \quad (11)$$

where

PL_m (dB) is the measured pathloss for each measurement location at a distance d (km) from the base station.

PBTS = Base transceiver station power (dBm),

GBTS = Base transceiver station antenna gain (dBi),

GMS = Mobile station antenna gain (dBi),

LFC = Feeder cable and connector loss (dB),

LAB = Antenna body loss (dB) and

LCF = Combiner and filter loss (dB).

The values of these parameters are given by as:

P BTS $= 40\,W = [30 + 10\log_{10} 40] = 46\,dBm$; GBTS = 18.15 dBi,

GMS = 0 dBi, LFC = 3 dB, LAB = 3 dB, LCF = 4.7 dB. The measured path loss value in dB obtained for each of the measurement points is recorded in Table 1. The receiver locations, distance, RSS, measured path loss and Okumura-Hata model predicted Pathloss are also given in Table 1.

2.3. Prediction Perf ormance Analysis of the Model

In order to evaluate the prediction performance of the model, the root mean square error (RMSE), prediction accuracy (PA), the absolute minimum prediction error (AMNPE) and the absolute maximum prediction error (AMXPE) are calculated for the models.

Let $PL_{(measured)(i)}$ be the measured path loss (dB), let $PL_{(predicted)(i)}$ be the predicted path loss (dB) and let $\overline{PL_{(measured)}}$ be the mean of measured path loss and let n be the number of measured data points. The RMSE is estimated as:

$$RMSE = \sqrt{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|^2\right]\right\}} \quad (12)$$

Then, the prediction Accuracy (PA) based on mean absolute percentage error (MAPE) is calculated as:

$$PA = \left\{1 - \frac{1}{n}\left(\sum_{i=1}^{i=n}\left|\frac{\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|}{PL_{(measured)(i)}}\right|\right)\right\} \times 100\% \quad (13)$$

The absolute minimum prediction error (AMNPE) is given for all i as;

$$AMNPE = minimum\left(\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|\right) \quad (14)$$

the absolute maximum prediction error (AMXPE) is given for all i as;

$$AMXPE = maximum\left(\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|\right) \quad (15)$$

3. Results and Discussion

Table 1 and Table 2 as well as figure 1 show the first and the second drive tests datasets of measured received signal strength (RSSI), measured pathloss and the distance (d) of the measurement points from the transmitter base station.

Table 1. *First Dataset Of Measured Received Signal Strength (RSSI), Measured Pathloss and The Distance (d) Of The Measurement Points From The Transmitter Base Station.*

S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)	S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)
1	0.1541	-73	126.45	29	0.3823	-75	128.45
2	0.158	-71	124.45	30	0.396	-73	126.45
4	0.1627	-75	128.45	32	0.4242	-73	126.45
5	0.1633	-71	124.45	34	0.452	-71	124.45
7	0.1643	-73	126.45	35	0.4653	-73	126.45
8	0.166	-65	118.45	37	0.4928	-77	130.45
10	0.1683	-69	122.45	38	0.5068	-73	126.45
12	0.1947	-69	122.45	40	0.5332	-73	126.45
13	0.2082	-71	124.45	41	0.5764	-73	126.45
15	0.2345	-75	128.45	43	0.7016	-73	126.45
16	0.2472	-77	130.45	45	0.7308	-73	126.45
18	0.2717	-73	126.45	46	0.7445	-77	130.45
19	0.2827	-71	124.45	48	0.7716	-77	130.45
21	0.2845	-67	120.45	49	0.7848	-77	130.45
23	0.295	-71	124.45	51	0.812	-75	128.45

S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)	S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)
24	0.311	-73	126.45	52	0.8528	-69	122.45
26	0.338	-71	124.45	54	0.9168	-71	124.45

Table 2. *Second Dataset Of Measured Received Signal Strength (RSSI), Measured Pathloss and The Distance (d) Of The Measurement Points From The Transmitter Base Station.*

S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)	S/N	d (km)	RSSI (dB)	Field Measured Path Loss (dBm)
1	0.1543	-73	126.45	21	0.389	-73	126.45
2	0.1622	-69	122.45	22	0.4172	-73	126.45
3	0.1627	-73	126.45	23	0.4312	-73	126.45
4	0.1634	-73	126.45	24	0.4588	-71	124.45
5	0.1644	-73	126.45	25	0.4723	-75	128.45
6	0.167	-65	118.45	26	0.4864	-75	128.45
7	0.1749	-69	122.45	27	0.4997	-75	128.45
8	0.1877	-69	122.45	28	0.5137	-73	126.45
9	0.2146	-71	124.45	29	0.5401	-73	126.45
10	0.2281	-75	128.45	30	0.5773	-75	128.45
11	0.2538	-75	128.45	31	0.7092	-75	128.45
12	0.2658	-75	128.45	32	0.7238	-75	128.45
13	0.2772	-71	124.45	33	0.7516	-77	130.45
14	0.2843	-69	122.45	34	0.7652	-77	130.45
15	0.2844	-67	120.45	35	0.7914	-75	128.45
16	0.2875	-71	124.45	36	0.8051	-75	128.45
17	0.3033	-71	124.45	37	0.8675	-65	118.45
18	0.3303	-69	122.45	38	0.9166	-71	124.45
19	0.3463	-73	126.45	39	0.9219	-73	126.45
20	0.3753	-75	128.45	40	0.9275	-73	126.45

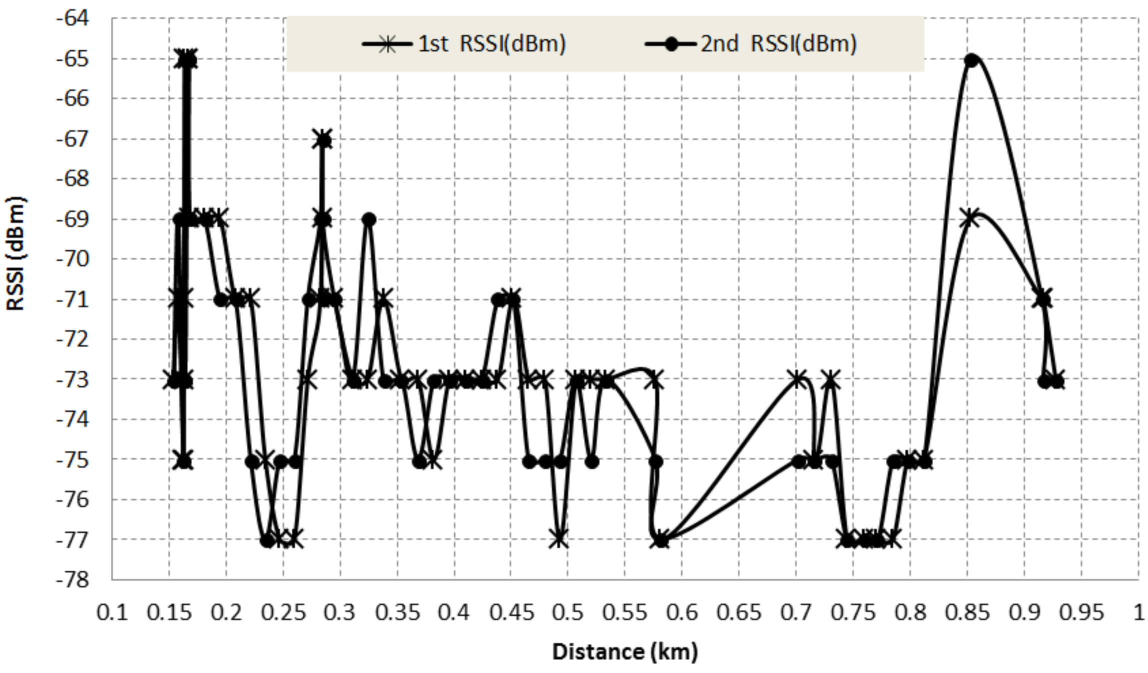

Figure 1. *Measured RSSI (dBm) Versus Distance (km) For The First and The Second Drive Test Dataset In Table 1 and Table 2.*

In the optimization process, the total pathloss in the original Blomquist empirical model is considered as consisting of free space pathloss (L_{FSP}) and excess pathloss due to ground reflection and diffraction $\left(\sqrt[2]{\left({L_{GRL}}^2 + {L_{dfl}}^2\right)}\right)$. Table 3 and figure 2 show the field measured pathloss (dBm) and the pathloss predicted by the untuned Blomquist model versus distance. The Correlation Coefficient (r) between the prediction residual (error) of the untuned Blomquist model and the excess pathloss due to ground reflection and diffraction is -0.97283. In view of the very strong correction, the optimization process is performed by generating a correction factor which is a function of the excess pathloss that minimizes the root mean square error. The correction factor obtained is given as;

$$CF = -1.456862685 \sqrt[2]{\left({L_{GRL}}^2 + {L_{dfl}}^2\right)} + 67.8975822 \quad (16)$$

Hence, the optimized Blomquist empirical model is given as

$$L_{TL}(dB) = (L_{FSP}) + \sqrt[2]{\left(L_{GRL}{}^{2} + L_{dfl}{}^{2}\right)} + CF \quad (17)$$

$$L_{TL}(dB) = L_{FSP} + \sqrt[2]{\left(L_{GRL}{}^{2} + L_{dfl}{}^{2}\right)} + \left(-1.456862685 \left\{\sqrt[2]{\left(L_{GRL}{}^{2} + L_{dfl}{}^{2}\right)}\right\} + 67.8975822\right) \quad (18)$$

The pathloss predicted by the tuned or optimized Blomquist model versus distance is given in table 3.

Table 3. *Measured Pathloss, Pathloss Predicted By Untuned Blomquist Model and Pathloss Predicted By Optimized Blomquist Model Versus Distance.*

S/N	d (km)	Field Measured Pathloss (dBm)	Untuned Blomquist (dBm)	Optimized Blomquist (dBm)	S/N	d (km)	Field Measured Pathloss (dBm)	Untuned Blomquist (dBm)	Optimized Blomquist (dBm)
1	0.1541	126.45	118.4	122.5	19	0.3823	128.45	137.8	125.6
2	0.158	124.45	118.9	122.7	20	0.396	126.45	138.6	125.7
3	0.1627	128.45	119.4	122.7	21	0.4242	126.45	140.2	125.9
4	0.1633	124.45	119.5	122.7	22	0.4384	126.45	141	126
5	0.1643	126.45	119.6	122.8	23	0.4653	126.45	142.4	126.1
6	0.166	118.45	119.8	122.8	24	0.4796	126.45	143.1	126.2
7	0.1683	122.45	120.1	122.9	25	0.5068	126.45	144.3	126.4
8	0.1812	122.45	121.6	123.2	26	0.5202	126.45	145	126.4
9	0.2082	124.45	124.5	123.7	27	0.5764	126.45	147.4	126.7
10	0.2216	124.45	125.8	123.9	28	0.5812	130.45	147.6	126.7
11	0.2472	130.45	128.2	124.3	29	0.7167	128.45	152.6	127.2
12	0.26	130.45	129.2	124.4	30	0.7308	126.45	153	127.2
13	0.2827	124.45	131.1	124.7	31	0.7585	130.45	153.9	127.3
14	0.2844	120.45	131.2	124.7	32	0.7716	130.45	154.3	127.3
15	0.2846	122.45	131.2	124.7	33	0.7979	128.45	155.1	127.4
16	0.295	124.45	132	124.9	34	0.812	128.45	155.6	127.5
17	0.3243	126.45	134.1	125.1	35	0.9156	124.45	158.5	127.8
18	0.338	124.45	135	125.3	36	0.9168	124.45	158.5	127.8

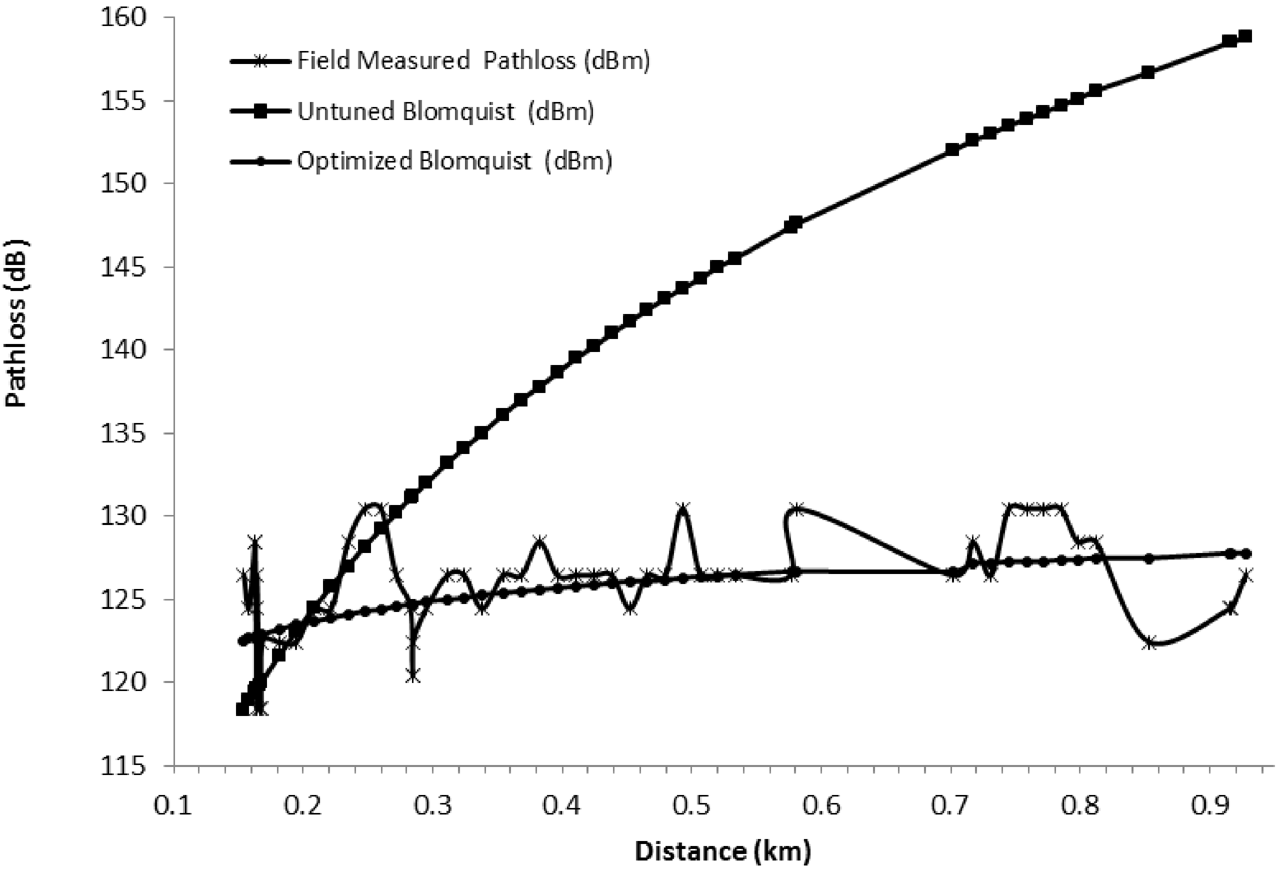

Figure 2. *Measured Pathloss, Pathloss Predicted By Untuned Blomquist Model and Pathloss Predicted By Optimized Blomquist Model Versus Distance.*

The data and pathloss predicted in table 3 are with respect to the training data which is the first drive test field measured data. The second drive test field measured data is used to cross validate the prediction performance of the models. Table 4 and figure 3 show the result of the cross validation process.

Table 4. *Cross Validation Field Measured Pathloss, Pathloss Predicted By Untuned Blomquist Model and Pathloss Predicted By Optimized Blomquist Model Versus Distance.*

S/N	d (km)	Cross Validation Field Measured Pathloss (dBm)	Cross Validation Of Untuned Blomquist (dBm)	Cross Validation Of Optimised Blomquist (dBm)	S/N	d (km)	Cross Validation Field Measured Pathloss (dBm)	Cross Validation Of Untuned Blomquist (dBm)	Cross Validation Of Optimised Blomquist (dBm)
1	0.1543	126.45	118.4	123.6	19	0.389	126.45	138.2	126.2
2	0.1622	122.45	119.4	123.8	20	0.4032	126.45	139.1	126.3
3	0.1627	126.45	119.4	123.8	21	0.4312	126.45	140.6	126.4
4	0.1634	126.45	119.5	123.8	22	0.4455	124.45	141.3	126.5
5	0.1644	126.45	119.6	123.8	23	0.4723	128.45	142.7	126.6
6	0.167	118.45	120	123.9	24	0.4864	128.45	143.4	126.7
7	0.1749	122.45	120.9	124	25	0.5137	126.45	144.7	126.8
8	0.1877	122.45	122.3	124.3	26	0.5267	128.45	145.2	126.9
9	0.2146	124.45	125.1	124.7	27	0.5773	128.45	147.4	127
10	0.2281	128.45	126.4	124.9	28	0.5875	130.45	147.8	127.1
11	0.2538	128.45	128.7	125.2	29	0.7238	128.45	152.8	127.4
12	0.2658	128.45	129.7	125.3	30	0.7378	128.45	153.2	127.5
13	0.2843	122.45	131.2	125.5	31	0.7652	130.45	154.1	127.5
14	0.2844	120.45	131.2	125.5	32	0.7781	130.45	154.5	127.6
15	0.2875	124.45	131.4	125.5	33	0.8051	128.45	155.3	127.6
16	0.3033	124.45	132.6	125.6	34	0.8192	128.45	155.8	127.6
17	0.3463	126.45	135.6	126	35	0.9219	126.45	158.6	127.8
18	0.3753	128.45	137.4	126.1					

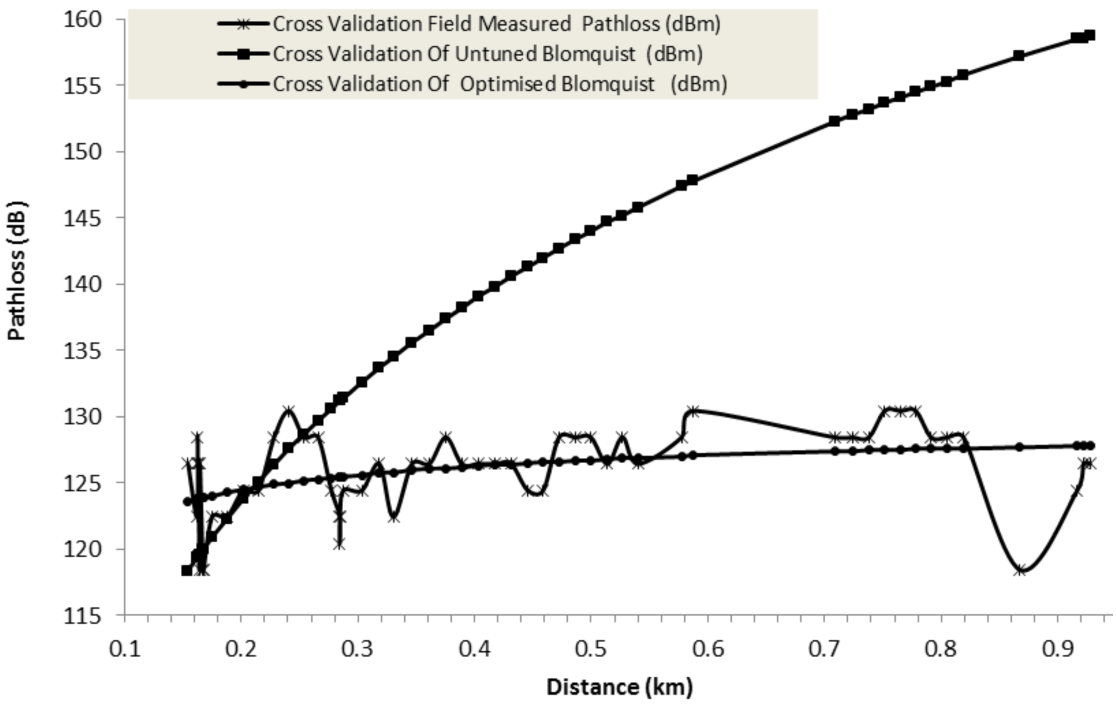

Figure 3. *Cross Validation Field Measured Pathloss, Pathloss Predicted By Untuned Blomquist Model and Pathloss Predicted By Optimized Blomquist Model Versus Distance.*

The prediction performance results in Table 5 show that with the training data (first drive test data), the untuned Blomquist empirical model has RMSE=10.67 dB, Prediction Accuracy = 89.51%, minimum Prediction error = 9.02 dB and maximum Prediction error = -34.29 dB.

Table 5. *The Prediction Performance Of The Models.*

	Performance With Respect To Training Data		Performance With Respect To Cross Validation Data	
	Untuned Blomquist Empirical Model	Tuned Or Optimized Blomquist Empirical Model	Blomquist Empirical Model	Tuned Or Optimized Blomquist Empirical Model
RMSE	10.66742	1.749729	10.75249	1.832906
Prediction Accuracy (%)	89.51575	98.30611	89.43392	98.24335
Maximum Prediction Error	-34.2904	6.33803	-38.7042	-9.27757
Minimum Prediction Error	9.022973	-4.39509	9.022973	5.432986

With the training data, the optimized Blomquist empirical model has RMSE=1.7497dB, Prediction Accuracy = 98.306%, minimum Prediction error = -4.395 dB and maximum Prediction error = 6.338 dB. Furthermore, with the cross validation data (second drive test data), the optimized Blomquist empirical model has RMSE=1.833 dB, Prediction Accuracy = 98.24%, minimum Prediction error = 5.43 dB and maximum Prediction error = -9.278 dB. The results show that for the given terrain under study, the tuned or optimized Blomquist empirical model can effectively predict the pathloss for the UMTS network signal in the 2100 MHz frequency band.

4. Conclusion

Pathloss prediction for near ground propagation of third generation (3G)-based Universal Mobile Telecommunications System (UMTS) network signal in the 2100 MHz frequency band over a smooth-earth terrain is presented. Attenuation due to diffraction is estimated based on ITU-R Recommendation P.526-13 for diffraction over smooth earth. Also, the total pathloss is determined using the Blomquist empirical model which combined free-space loss, plane-earth loss and the diffraction loss over smooth earth. Two drive tests are conducted for the UMTS 2100 MHz frequency band in suburban area. The results show that for the given terrain under study, the tuned or optimized Blomquist empirical model can effectively predict the pathloss for the UMTS network signal in the 2100 MHz frequency band.

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