HATA PATH LOSS MODEL-BASED OPTIMAL PATH LENGTH FOR MICROWAVE COMMUNICATION LINK

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***Abstract*— In this paper, Hata path loss model-based optimal path length for microwave communication link is studied. The analytical expression for computing the optimal path length of the link was based on the Hata propagation loss model and rain fade depth. Furthermore, a seeded bisection numerical iteration algorithm was used to compute the effective path length of the link for the three different propagation environments specified in the Hata propagation loss model, namely; urban, suburban and rural environments. The implementation of the algorithm was done in Matlab software. The simulation was for a 12.5 GHz Ku-band link with transmitter power of 12.5 dB, transmitter and receiver antenna gain of 25 dB and receiver sensitivity of -86 dB. The results show that it took at least 4 iterations for the Bisection method to converge with tolerance error that is in the order of 10^{-07}. The effective path length of the link for the urban area is 2.458029795 km, for the suburban area is 4.452334136 km and for the rural area is 7.322759868 km. Also, the propagation loss for the urban area is 133.2087096 dB, for the suburban area is 122.8305168 dB and for the rural area is 107.8931232 dB. Furthermore, the effective rain fade depth for the urban area is 12.79133124 dB, for the suburban area is 23.16948348 dB and for the rural area is 38.10688026 dB. In all, among the three different propagation environments specified in Hata model, the rural area offered the least propagation loss and hence the highest transmission range whereas the urban area presented the highest propagation loss and hence the lowest transmission range. Essential, it will take more network resource to cover a given region in the urban area, especially where multi-hop connection is required.**

***Keywords*— Hata model, microwave communication, path loss , transmission range, path length, Ku-band, communication link**

I. INTRODUCTION

Wireless signals suffer propagation loss along the path and this limits the transmission range or maximum path length of the signals [1,2,3,4,5]. Moreover, propagation loss and hence the maximum path length varies according to the type of environment through which the signal propagates. As such, different propagation loss models include expressions that capture the environmental factors that can impact the propagation loss. In this paper, the Hata propagation loss model is considered in the determination of the optimal path length in three different propagation environments, urban, suburban and rural areas.

Notably, effective or optimal path length is different from the maximum path length [6,7,8,9,10,11]. In this paper, the maximum path length is the path length that can be computed based on the propagation loss model alone. However, the effective or optimal path length considers the path loss and the maximum fade depth that can occur in the worst case fading scenario. Therefore, the effective path length considers both the fade margin computed from the knowledge of the path loss and also the maximum fade depth that can occur in the propagation path for the specified link quality of service.

Meanwhile, given the complexity of the propagation loss models, a close form analytical expressions for computing the effective path length is usually difficult to derive or solve. As such, numerical iteration techniques are applied to determine the effective path length [6,7,8,9,10,11]. In this paper, a seeded bisection numerical iteration algorithm [12,13,14] is used to compute the effective path length of the link for three different propagation environments specified in the Hata propagation loss model. The implementation of the algorithm was done in Matlab software.

II. METHODOLOGY

In this study, the optimal path length of microwave communication link was evaluated for the case where the path loss is based on the Hata model. Particularly, the optimal path length for the various communication terrains, namely, urban, suburban and open area was computed and compared.

A. *Line of Sight (LoS) communication link path length based on Hata path loss model and rain fading*

The general Hata path loss model for all terrain categories can be expressed as;

$$LP_{OK\_HATA(urban)} = A + B * \log_{10}(d) \qquad for\ Urban\ Area \tag{1}$$

$$LP_{OK\_HATA(suburban)} = A + B * \log_{10}(d) - C \quad for\ Suburban\ \text{Area} \quad (2)$$

$$LP_{OK\_HATA(open/rural)} = A + B * \log_{10}(d) - D \quad for\ Open\ Area/\text{Rural} \quad (3)$$

Where

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (4)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (5)$$

$$C = 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 \quad (6)$$

$$D = 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) \quad (7)$$

The an antenna height-gain correction factor, $a(h_m)$ for small city, medium city, open area, rural area and suburban area is give as;

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (8)$$

On the other hand for large city, $a(h_m)$ is give as;

$$a(h_m) = 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \quad for\ large\ city\ \text{f} \leq 200\text{MHz} \quad (9)$$

$$a(h_m) = 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \quad for\ large\ city\ \text{f} \geq 400\text{MHz} \quad (10)$$

Where

- f is frequency in MHz ; d is the link distance in km
- 150 MHz≤ f≤ 1000MHz; 30m $\leq h_b \leq$ 200m ;1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km

The maximum path length of a wireless communication link based on Hata path loss model can be found using the link budget equation;

$$P_R = P_T + G_T + G_R - LP_{HATA} \quad (11)$$

where;

P_R = Received Signal Power (dBm)

P_T = Transmitter Power Output (dBm)

G_T = Transmitter Antenna Gain (dBi)

G_R = Receiver Antenna Gain (dBi)

LP_{HATA} = path loss based on Hata model

Also,

$$fm_s = P_R - P_S \quad (12)$$

Hence,

$$P_R = fm_s + P_S \quad (13)$$

where,

P_s is the receiver sensitivity in dB

fm_s is the specified fade margin in dB

Therefore,

$$P_T + G_T + G_R - LP_{HATA} = fm_s + P_S \quad (14)$$

Consequently, with respect to the Hata model, the effective path length (d_{eHATA}) is given as ;

$$LP_{HATA} = A + B * \log_{10}(d) - K = P_T + G_T + G_R - fm_s - P_S \quad (15)$$

$$d_{eHATA} = 10^{\left(\frac{(P_T + G_T + G_R - fm_s - P_S) - A + k}{B}\right)} \quad (16)$$

With respect to d_{eHATA} the effective Hata model path loss, (LP_{HATA_e}) is given as:

$$LP_{HATA_e} = A + B * \log_{10}(d_{eHATA}) - K \quad (17)$$

Effective Received Power (P_{ReHATA}) is given as:

$$P_{ReHATA} = P_T + G_T + G_R - LP_{HATA_e} \quad (18)$$

Effective Fade Margin (fm_{eHATA}) is given as:

$$fm_{eHATA} = (P_T + G_T + G_R) - (A + B * \log_{10}(d_{eHATA}) - K) - P_S \quad (19)$$

The rain fade depth (fd_{meHATA}) at a path length (d_{eHATA}) is given as [15,16];

$$fd_{meHATA} = \max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d_{eHATA}, \left(K_h(R_{po})^{\alpha_h}\right) * d_{eHATA}\right) \quad (20)$$

B. The algorithm for determination of the optimal path length with path loss based on Hata model

The optimal path length with path loss based on Hata model (denoted as, d_{opHATA}) is the value of d_{eHATA} for which $fm_{eHATA} = fd_{meHATA}$, thus;

$$d_{opHATA} = d_{eHATA} \text{ at which } fm_{eHATA} = fd_{meHATA} \quad (21)$$

The algorithm used to determine d_{opHATA} is based on the adjustment of the path length and it is stated as follows;

Step 1:

Let the error tolerance valueϵ, be $\epsilon = 0.001$

Step 2: Input P_T , G_T, G_R, fm_s, P_S, f, h_m, h_b

Step 3: Select the Type of terrain ,TYP ("1" for urban area ; "2" for sub-urban area; "3" for open or rural area

Input TYP

Step 4:

Step 4.1: If TYP = 1 Then

Step 4.2: K = 0

Step 4.3: Elseif TYP = 2 Then

Step 4.4: $K = C = 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2$

Step 4.5: Else

Step 4.6: $K = D = 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f)$

Step 4.7: Endif

Step 5 Compute path length 1

Step 5.1: $a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8]$

Step 5.2: $A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m)$

Step 5.3: $B = 44.9 - 6.55 * \log_{10}(h_b)$

Step 5.4: $d_{eHATA1} = 10^{\left(\frac{(P_T + G_T + G_R - fm_S - P_S) - A + k}{B}\right)}$

Step 6: Compute rain fade depth

$fd_{meHATA} = \max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d_{eHATA1}, \left(K_h(R_{po})^{\alpha_h}\right) * d_{eHATA1}\right)$

Step 7: Compute path length 2

$d_{eHATA2} = 10^{\left(\frac{(P_T + G_T + G_R - fd_{meHATA1} - P_S) - A + k}{B}\right)}$

Step 8: Check if optimal path length has been obtained

Step 8.1: If $|d_{eHATA2} - d_{eHATA1}| < |\epsilon|$ Then

Step 8.2: $d_{OPHATA} = d_{OPHATA1}$

Step 8.3: $fm_{OPHATA} = (P_T + G_T + G_R) - (A + B * \log_{10}(d_{OPHATA}) - K) - P_S$

Step 8.4: $fd_{mOPHATA} = \max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d_{OPHATA}, \left(K_h(R_{po})^{\alpha_h}\right) * d_{OPHATA}\right)$

Step 8.5: Goto step10

Step 8.7: Endif

Step 9: Compute new path length

Step 9.1: $\Delta d = \frac{d_{eHATA2} - d_{eHATA1}}{2}$

Step 9.2: $d_{eHATA1} = d_{eHATA1} + \Delta d$

$$= d_{eHATA1} + \left(\frac{d_{eHATA2} - d_{eHATA1}}{2}\right)$$

Step 9.4: Repeat the steps from step 3

Goto step 5

Step 10 : Output results

Step 10.1: If TYP = 1 Then

Step 10.2: Output "Terrain Type: Urban Area"

Step 10.3: Elseif TYP = 1 Then

Step 10.4: Output "Terrain Type: Sub-urban Area"

Step 10.5: Else

Step 10.6: Output "Terrain Type: Open Area or Rural Area"

Step 10.7: Endif

Step 11: Output $d_{OPHATA1}$, fm_{OPHATA}, $fd_{mOPHATA}$

Step 12 : End the program

Stop

III. RESULTS AND DISCUSSION

Matlab program was written for the seeded Bisection iteration algorithm in section 2.3. The Matlab program was used to compute the transmission range and other key parameters of the communication link. The input data used by the seeded Bisection iteration algorithm for the computation of the transmission range and other key parameters of the communication link are presented in Table 1. The simulation was for a 12.5 GHz Ku-band link with transmitter power of 12.5 dB, transmitter and receiver antenna power of 25 dB and receiver sensitivity of -86 dB.

The iteration results obtained from the Bisection method for the urban area is given in Table 2. The iteration results for suburban area are given in Table 3 while the results for the rural area are given in Table 4. The comparison of the path length rain, propagation loss and the effective rain fade depth for the urban, suburban and rural environment are given in Figure 2. The results in Table 2, Table 3, and Table 4 show that it took at least 4 iterations for the Bisection method to converge with tolerance error that is in the order of 10^{-07}. The effective path length of the link for the urban area is 2.458029795 km, for the suburban area is 4.452334136 km and for the rural area is 7.322759868 km. Also, the propagation loss for the urban area is 133.2087096 dB, for the suburban area is 122.8305168 dB and for the rural area is 107.8931232 dB. Furthermore, the effective rain fade depth for the urban area is 12.79133124 dB, for the suburban area is 23.16948348 dB and for the rural area is 38.10688026 dB. In all, the among the three different propagation environments specified in Hata model, the rural area offered the least propagation loss and hence the highest transmission range whereas the urban area presented the highest propagation loss and hence the lowest transmission range. Essential, it will take more network resource to cover a given area in the urban area , especially where multi-hop connection is required.

Table 1 The input data used by the modified Bisection iteration algorithm for the computation of the transmission range and other key parameters of the communication link

f(MHz)	**Transmitter power, P_T(dB)**	**Transmitter antenna Gain, G_T(dB)**	**Receiver antenna gain, G_R(dB)**	**Receiver sensitivity, P_s (dB)**	**Fade Margin (dB)**
12000	12.5	25	25	-86	12.5
kh	**ah**	**kv**	**av**	**Percentage Availability, Pa (%)**	**Rain Rate at 0.01 % outage probability, R0.01 mm/hr**
0.02386	1.1825	0.02455	1.1216	99.99	95

Table 2 Iteration Results for Hata Urban Model

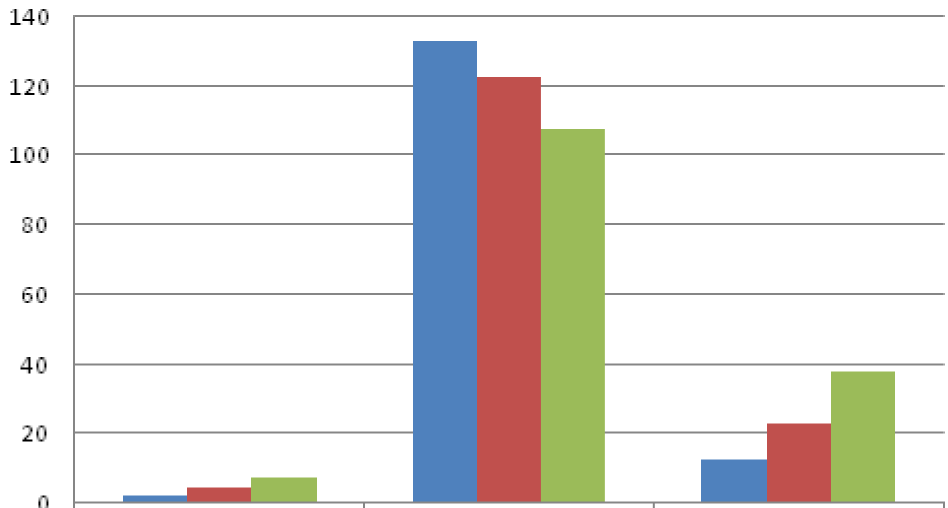
S/N	Path Length Rain	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	4	140.4847516	-80.4847516	5.515248396	20.81558371	1.53E+01
1	2.720066854	134.7223356	-74.72233559	11.27766441	14.15494483	2.88E+00
2	2.423623942	132.9980761	-72.99807605	13.00192395	12.61228676	-3.90E-01
3	2.458979955	133.2144845	-73.21448453	12.78551547	12.79627578	1.08E-02
4	2.458029795	133.2087096	-73.20870955	12.79129045	12.79133124	4.08E-05

Table 3 Hata Sub-urban Model

S/N	Path Length Rain	Propagation Loss by Hata Sub-urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	7	129.5917495	-69.59174954	16.40825046	36.4272715	2.00E+01
1	4.58857529	123.2809019	-63.28090189	22.71909811	23.87846827	1.16E+00
2	4.440336393	122.7901967	-62.79019666	23.20980334	23.10704848	-1.03E-01
3	4.452405141	122.8307551	-62.83075514	23.16924486	23.16985298	6.08E-04
4	4.452334136	122.8305168	-62.83051684	23.16948316	23.16948348	3.22E-07

Table 3 Iteration Results for Hata Open/Rural Model

S/N	Path Length Rain	Propagation Loss by Hata Open/Rural Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	19	122.1401287	-62.14012868	23.85987132	98.87402263	7.50E+01
1	7.766256341	108.7717597	-48.77175975	37.22824025	40.41478975	3.19E+00
2	7.267884137	107.7807241	-47.78072415	38.21927585	37.82131267	-3.98E-01
3	7.323214891	107.8940517	-47.89405171	38.10594829	38.10924815	3.30E-03
4	7.322759868	107.8931232	-47.89312324	38.10687676	38.10688026	3.50E-06



	Path Length	Propagation Loss by Hata Model	Effective Rain Fade Depth
Hata Urban Model	2.4580	133.2087	12.7913
Hata Sub-urban Model	4.4523	122.8305	23.1695
Hata Open/Rural Model	7.3228	107.8931	38.1069

Figure 1 The comparison of the path length rain, propagation loss and the effective rain fade depth for the urban , suburban and rural environment

IV. CONCLUSION

The computation of the effective path length of Ku-band communication link is presented. The analytical expression for the effective path length was derived suing link budget equation and rain fade depth. The computation is conducted using bisection iteration method which was implemented using Matlab program. The study considered the path length; the path loss, the effective fade margin and the effective rain fade depth for the three different propagation environments in Hata model, namely, the urban, the suburban and the rural areas. The results show that the urban area presents the highest propagation loss and hence the lowest effective path length while the rural area presented the lowest propagation loss and hence the highest path length. As such, compared with the other two propagation areas, the urban area will require additional network resources to cover a given area, especially when multi-hop links is involved.

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