Analysis Of Effective Transmission Range Based On Hata Model For Wireless Sensor Networks In The C-Band And Ku-Band

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***Abstract*— In this paper, analysis of effective transmission range or path length based on Hata propagation loss model for wireless sensor networks in the C-band and Ku-band is presented. The effective path length is determine using a form of bisection iterative approach based on link budget expression and rain fade depth. The simulation was conducted for links operating in three different frequencies, namely; Ku-band frequency of 11 GHz, C-band frequency of 7 GHz and C-band frequency of 3.5 GHz. The results show that, for the 3.5 GHz link, it took about 5 cycles for the algorithm to converge to the effective path length of 8.596610809 Km with tolerance error in the order of 10^{-6}. Also, for the 7 GHz link, it took about 3 cycles for the algorithm to converge to the effective path length of 4.360941705 km and, for the 11 GHz link ,it took about 4 cycles for the algorithm to converge to the effective path length of 2.680715363 km with tolerance error in the order of 10^{-5}. Furthermore, among the three frequencies considered, the link at 11 GHz has the lowest path length, the highest value of fade depth (11.95833946 dB) and the lowest propagation loss (134.0416712 dB). On the other hand, the link at 3.5 GHz has the highest path length, the lowest value of fade depth (0.638230094 dB) and the highest propagation loss (145.3617712dB). In essence, higher frequencies face higher rain fade depth and hence have lower effective transmission range.**

Keywords*— Effective Transmission Range , Optimal Path Length, Propagation Loss , Hata Model, Bisection Iteration Method, C-Band, Ku-Band, Microwave Link

I. INTRODUCTION

Wireless sensor networks (WSN) are increasingly being deployed to monitor and control divers systems 1,2,3,4,5]. As such, the demand for such network grows every day, resulting in the congestion of the lower frequencies where they are usually deployed. Accordingly, WSN are being deployed in some higher frequencies due to the higher bandwidth offered by the high frequencies [6,7,8,9,10]. In this wise, the effect of frequencies on the propagation loss and the transmission range of such WSN communication link need to be studies. Among other things, propagation loss models play key role in the determination of the propagation loss and the maximum transmission range of wireless communication link. One of such propagation loss models is the Hata model [11,12,13,14,15,16].

Hata path loss model is one of the most popular empirical propagation loss models that is used to estimate the path loss for different propagation environments [17,18,19,20,21,22]. The model analytically captures the effect of distance, frequency, antenna height and other communication link parameters on the path loss that is experienced by the signal. In this paper, the focus is on the effect of frequency on the propagation loss and more importantly, on the optimal or effective transmission range of a wireless communication link where the path loss is estimated using the Hata model. The actual computation of the optimal link path length is computed using numerical iteration approach implemented in Matlab software. The rest of the paper therefore presents the salient analytical expressions, the requisite flowchart for the iteration method and the simulation data, results and discussion.

II. METHODOLOGY

The effect of frequency on the effective transmission range of line of sight (LOS) microwave link was considered. The Hata model was used to determine the propagation loss and the effective fade margin. The effective transmission range was computed for different frequencies using an iterative procedure developed in this paper and presented in flowchart format.

A. Hata Pathloss Model

The Hata path loss model can be expressed as [23, 24, 25, 26, 27, 28];

$$LP_{HATA} = A + B * \log_{10}(d) - K \quad (1)$$

Where

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (2)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (3)$$

$$K = \begin{cases} 0 & for\ Urban\ Area \\ 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 & for\ Suburban\ \text{Area} \\ 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) & for\ Open\ Area/\text{Rural} \end{cases} \quad (4)$$

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

$$a(h_m) = \begin{cases} [1.1 * \log_{10} f - 0.7] * h_m - [1.56 * \log_{10} f - 0.8] & for\ \text{small city, medium city, open / rural area} \\ 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 & for\ large\ city\ \text{f} \leq 200\text{MHz} \\ 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 & for\ large\ city\ \text{f} \geq 400\text{MHz} \end{cases} \quad (14)$$

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

B. Wireless communication link transmission range and effective fade depth based on Hata path loss model and rain fading

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

$$\text{P}_\text{R} = \text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - LP_{HATA} = fm_s + P_S \quad (7)$$

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

P_s is the receiver sensitivity in dB

fm_s is the specified fade margin in dB

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

$$LP_{HATA} = A + B * \log_{10}(d) - K = \text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - fm_s - P_S \quad (8)$$

$$d_{eHATA} = 10^{\left(\frac{(\text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - fm_S - P_S) - \text{A} + \text{k}}{B}\right)} \quad (9)$$

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

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

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

$$P_{ReHATA} = \text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - LP_{HATA_e} \quad (11)$$

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

$$fm_{eHATA} = (\text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R}) - (A + B * \log_{10}(d_{eHATA}) - K) - P_S \quad (12)$$

The rain fade depth (fd_{meHATA}) at a transmission range (d_{eHATA}) is given as;

$$fd_{meHATA} = \max\left(\left(\text{K}_\text{v}(\text{R}_\text{po})^{\alpha_\text{v}}\right) * d_{eHATA}, \left(\text{K}_\text{h}(\text{R}_\text{po})^{\alpha_\text{h}}\right) * d_{eHATA}\right) \quad (13)$$

C. The flowchart for calculation of the effective transmission range when path loss is based on Hata model

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

$$d_{opHATA} = d_{eHATA} \quad \text{at which} \quad fm_{eHATA} = fd_{meHATA} \quad (15)$$

The flowchart (of Figure 1) used to determine the effective transmission range, d_{opHATA} is based on iterative calculation and adjustment of the transmission range starting with an initial value computed with the specified values of f, h_m, h_b, P_T , G_T, G_R and fm_s.

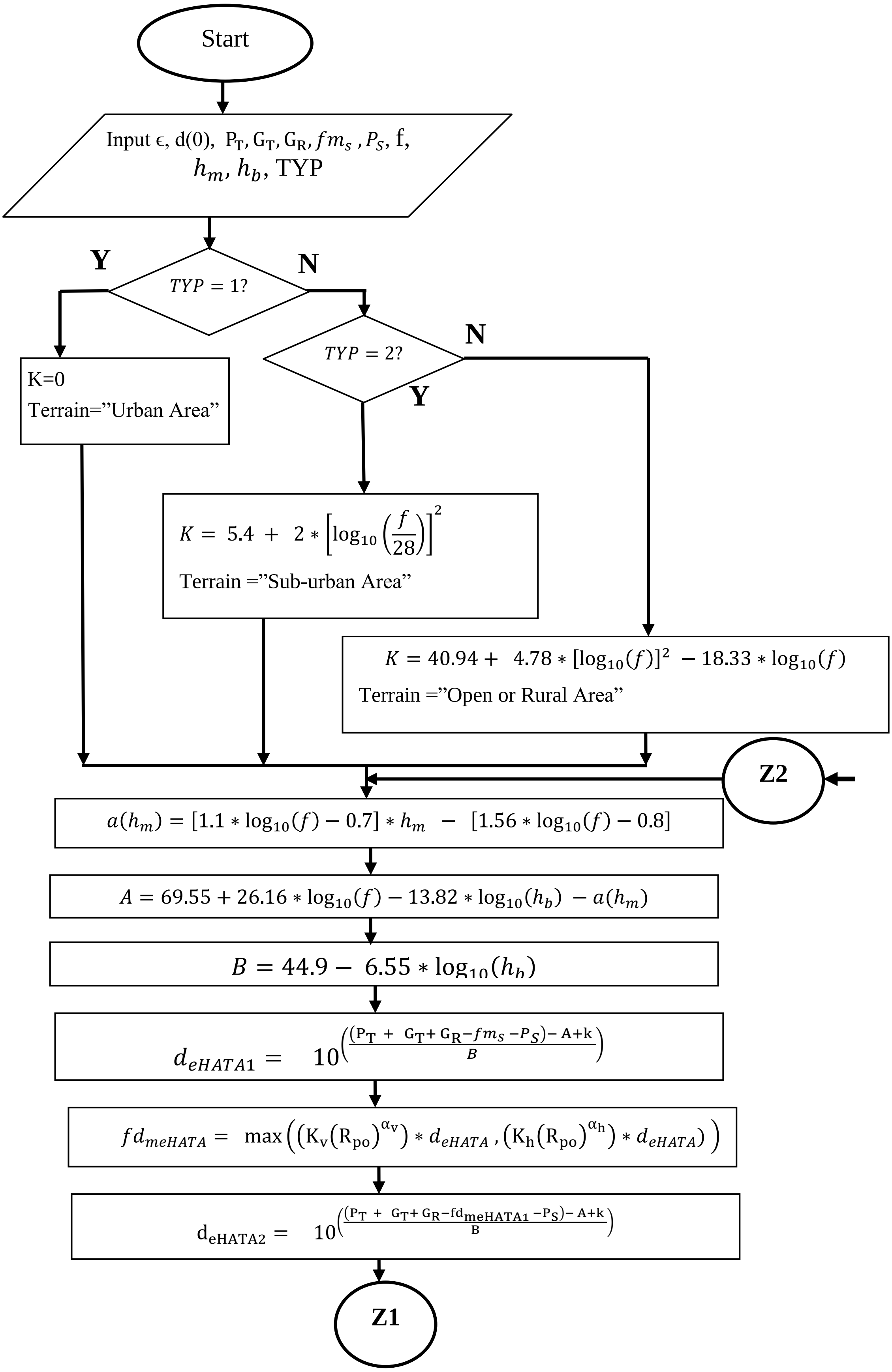


Figure 1(a) Part I of the flowchart for determination of the effective transmission range, d_{eHATA1} based on iterative calculation and adjustment of the transmission range

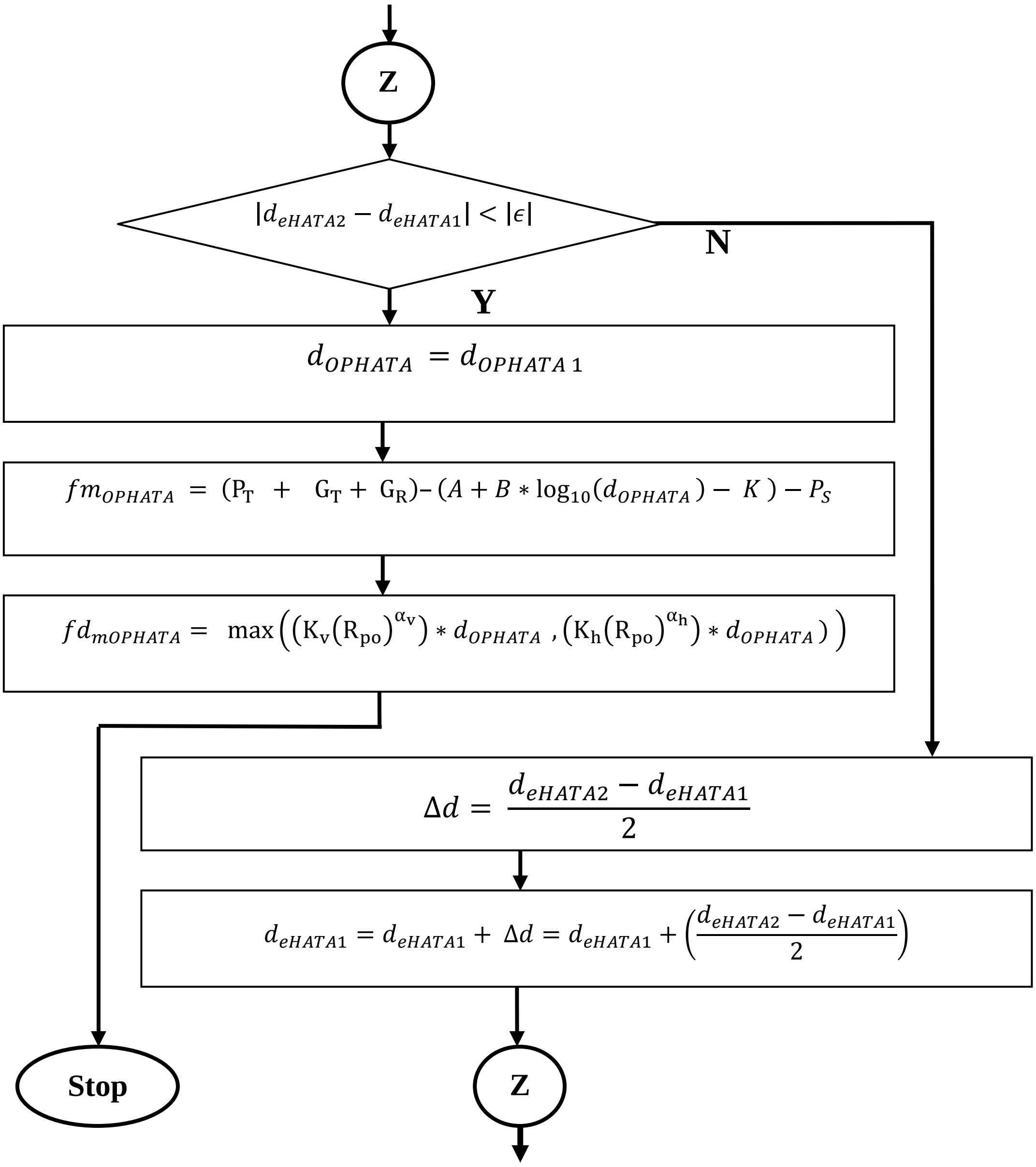


Figure 1(b) Part II of the flowchart for determination of the effective transmission range, d_{eHATA1} based on iterative calculation and adjustment of the transmission range

III. RESULTS AND DISCUSSION

The effect of frequency on the effective transmission range of microwave link was examine using a sample numerical example based on the microwave link parameters presented in Table 1. The simulation was conducted for the same link at three different frequencies of 11 GHz, 7 GHz and 3.5 GHz. The iteration results for the link at frequency of 11 GHz are given in Table 2. Also, the iteration results for the link at frequency of 7 GHz are given in Table 3 and the results for the link at frequency of 3.5 GHz is given in Table 4. The comparison of the path length, the effective rain fade depth and the propagation loss for the link at frequency of 11 GHz, 7 GHz and 3.5 GHz is given in Figure 2.

The results show that, for the 3.5 GHz link (Table 4), it took about 5 cycles for the algorithm to converge to the effective path length of 8.596610809 Km with tolerance error in the order of 10^{-6}. Also, for the 7 GHz link (Table 3), it took about 3 cycles for the algorithm to converge to the effective path length of 4.360941705 km with tolerance error in the order of 10^{-6}. However, for the 11 GHz link (Table 2), it took about 4 cycles for the algorithm to converge to the effective path length of 2.680715363 km with tolerance error in the order of 10^{-5}. Furthermore, among the three frequencies considered, the link at 11 GHz has the lowest path length, the highest value of fade depth (11.95833946 dB) and the lowest propagation loss (134.0416712 dB). On the other hand, the link at 3.5 GHz has the highest path length, the lowest value of fade depth (0.638230094 dB) and the highest propagation loss (145.3617712dB). In essence, higher frequencies face higher rain fade depth and hence have lower effective transmission range.

Table 1 The simulation input data for the microwave link parameters used in the study

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)
11000	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**
0.01772	1.214	0.01731	1.1617	99.99	95

Table 2 The iteration results for the link at frequency of 11 GHz

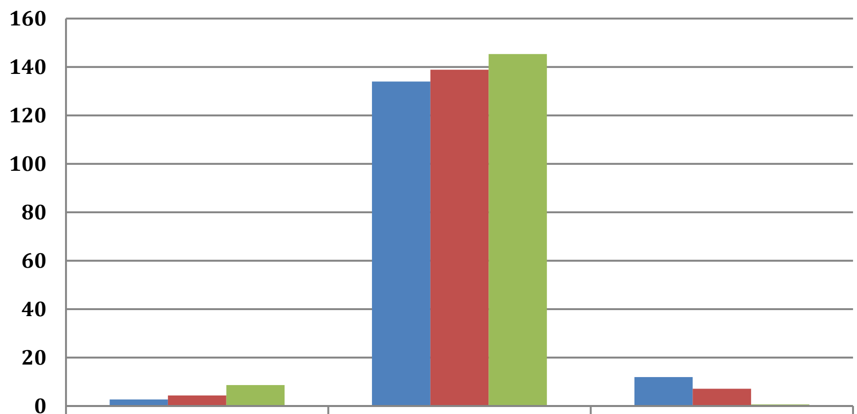
S/N	Path Length	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	4	140.0218417	-80.02184173	5.978158267	17.84350495	1.19E+01
1	2.881057228	135.1186356	-75.11863557	10.88136443	12.85203973	1.97E+00
2	2.658202644	133.9156534	-73.91565336	12.08434664	11.85791301	-2.26E-01
3	2.681169995	134.0442052	-74.04420519	11.95579481	11.96036752	4.57E-03
4	2.680715363	134.0416712	-74.04167124	11.95832876	11.95833946	1.07E-05

Table 3 The iteration results for the link at frequency of 7 GHz

S/N	Path Length	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	4	137.6172323	-77.61723233	8.38276767	6.504852138	-1.88E+00
1	4.382613899	138.9822493	-78.98224927	7.017750732	7.127063848	1.09E-01
2	4.361567143	138.9103173	-78.91031733	7.089682671	7.092837338	3.15E-03
3	4.360941705	138.9081744	-78.90817445	7.09182555	7.091820243	-5.31E-06

Table 4 The iteration results for the link at frequency of 3.5 GHz

S/N	Path Length	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	7	142.2917052	-82.29170522	3.708294779	0.519694419	-3.19E+00
1	11.20699789	149.3240942	-89.32409421	-3.324094212	0.832030608	4.16E+00
2	8.826403938	145.7559505	-85.75595049	0.244049505	0.655290409	4.11E-01
3	8.564981252	145.3066916	-85.30669158	0.693308419	0.635881851	-5.74E-02
4	8.597013788	145.3624716	-85.36247164	0.637528363	0.638260012	7.32E-04
5	8.596610809	145.3617712	-85.3617712	0.638228802	0.638230094	1.29E-06



	Path Length (km)	Propagation Loss by Hata Urban Model	Effective Rain Fade Depth
Frequency of 11 GHz	2.680715	134.0417	11.95834
Frequency of 7 GHz	4.360942	138.9082	7.09182
Frequency of 3.5 GHz	8.596611	145.3618	0.63823

Figure 2 Comparison of the path length, the effective rain fade depth and the propagation loss for the link at frequency of 11 GHz, 7 GHz and 3.5 GHz

IV. CONCLUSION

The effect of frequency on the optimal path length or effective transmission range of microwave link is studied. The path length is determined based on Hata propagation loss model along with rain fade depth computed using the ITU rain fade model. A form of bisection numerical iteration flowchart was developed and used to compute the optimal transmission range of the wireless link in the C-band and in the Ku-band. The computation was implemented in Matlab software. The results showed that communication links operating at higher frequencies face higher rain fade depth and hence have lower effective transmission range.

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