ANALYSIS OF OPTIMAL TRANSMISSION RANGE BASED ON WEISSBERGER MODEL FOR PROPAGATION LOSS IN VEGETATION COVERED AREAS

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***Abstract*— In this paper, analysis of optimal transmission range based on Weissberger model for propagation loss in vegetation covered areas is presented. The focus of the paper was to evaluate the impact of frequency on the effective transmission range. Accordingly, the effective transmission range was computed for the C-band (8 GHz) and Ku-band (11 GHz) wireless sensor network (WSN). The computation was performed in Matlab based on a seeded Regular Falsi numerical iteration method. The results for the C-band (8 GHz) show that the iteration converged at the 5th cycle with optimal transmission range of 11.38993935 km, propagation loss of 134.0873275 dB based on Weisberg model and effective rain fade depth of 13.91267259 dB with tolerance error of 5.9876 x 10^{-08}. Also, iteration results for the Ku-band (11 GHz) show that the iteration converged at the 5th cycle with optimal transmission range of 6.293985297 km, propagation loss of 131.9281801 dB and effective rain fade depth of 16.07181999 dB with tolerance error of 5.0351 x 10^{-08}. Notably, the Ku-band WSN has a lower effective transmission range of 6.293985297 km as compared to that of the C-band link with effective transmission range of 11.38993935 km. Essentially, they higher frequency has higher rain fade depth which give rise to lower effective transmission range.**

Keywords*— Transmission Range, Weissberger Model, Propagation Loss, Optimal Path Length, Wireless Sensor Network, C-Band , Ku-Band, Microwave Communiction

I. INTRODUCTION

In this era of precision agriculture, there is high demand for wireless sensor networks (WSN) that can effectively serve vegetation covered areas such as farm lands, forests, plantations, etc [1,2,3,4,5,6,7,8,9]. In this wise, appropriate propagation loss model [10,11,12,13,14,15,16] need to be used in the WSN design so as to ensure that appropriate path loss that will affect the WSN quality of service is taken into account. This paper focuses on the analysis of optimal transmission range [17,18,19] based on Weissberger model [20,21,22,23,24,25,26] for propagation loss in vegetation covered areas. Essentially, in this paper, the Weissberger foliage propagation loss model is used to compute the propagation loss in areas that are covered with vegetation. Then, the effect of frequency on the overall path loss computed with the Weissberger model is examined. Now, the path loss along with the rain fade depth is used to determine the WSN transmission range. As such, as the overall path loss computed with the Weissberger model changes with frequency, the effective transmission range also changes. In essence, in this paper, the effective coverage range of the WSN as a function of frequency is evaluated.

Furthermore, a seeded Regular Falsi numerical iteration method [27,28] is used to determine the optimal transmission range. The flowchart and other mathematical expressions relevant for the analysis are presented along a numerical example. The computations were performed using Mathlab software.

II. METHODOLOGY

A. The Weissberger path loss for vegetation covered area

Weissberger model is a foliage path loss model that can be used to characterise the path loss in vegetation covered areas such as farm lands, plantations, forest etc. According to the Weissberger model, the effective path loss in vegetation covered area is the sum of the free space path loss and the foliage path loss caused by the vegetation cover. The Weissberger path loss is expressed as follows:

$$Pl_{Tl}(dB) = 32.5 + 20 * \log(\mathrm{f}) + 20 * \log(\mathrm{d}) + \begin{cases} 0.45F^{0.284}(d_f) & for \quad 0 \le d_f \le 14\mathrm{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\mathrm{m} \end{cases} \quad (1)$$

Where d_f is the foliage depth along the LOS path and f is the frequency in GHz

B. Determination of the optimal transmission range using seeded Regular Falsi iteration method

The optimal transmission range is determined using seeded Regular Falsi numerical iteration approach. First, the initial transmission range is computed using the free space path loss and link budget equations as follows:

Step 1: the path length, d_0 is determined from link budget and free space path loss as follows:

$$d_0 = 10^{\left(\frac{(\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - fm_S - P_S) - 32.4 - 20\log(\mathrm{f}*1000)}{20}\right)} \quad (2)$$

d=path length (km)

PT = Transmitter Power (dBm)

GT = Transmitter Antenna Gain (dBi)

PR = Received Signal strength (dBm)

GR = Receiver Antenna Gain (dBi)

f =frequency (GHz)

Step 2: Compute path loss using Weissberger model;

$$Pl_{Tl}(dB) = \begin{cases} 32.5 + 20 * \log(\mathrm{f}) + 20 * \log(d_0) + 0.45F^{0.284}(d_f) & for \quad 0 \leq d_f \leq 14\mathrm{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \leq d_f \leq 400\mathrm{m} \end{cases} \quad (3)$$

Step 3: Compute the fade margin, $fm_{(x)}$ [18]

$$fm_{(x)} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - \mathrm{LP_{ERIC}} - P_S \quad (4)$$

Step 4: Compute the rain fade depth, $fd_{(x)}$ [18,29]

$$fd_{(x)} = max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d , \left(\mathrm{k_h}(R_{po})^{\alpha_\mathrm{h}}\right) * d)\right) \quad (5)$$

Step 5: Computes the second initial distance value , d_1

$$d_1 = \left(1 + \left(\frac{fm_{(x)} - fd_{(x)}}{fd_{(x)}}\right)\right) d \quad (6)$$

Step 6: Determine the upper and the lower distances for the Regular Falsi iteration process

$$d_L = minimum(d , d_1) \quad (7)$$

$$d_U = maximum(d , d_1) \quad (8)$$

Step 7: Conduct the Regular Falsi iteration process to determine the optimal transmission range for various frequency, f

The complete flowchart for the determination of the optimal transmission range for various frequency, f based on Weissberger model is given in Figure 1.

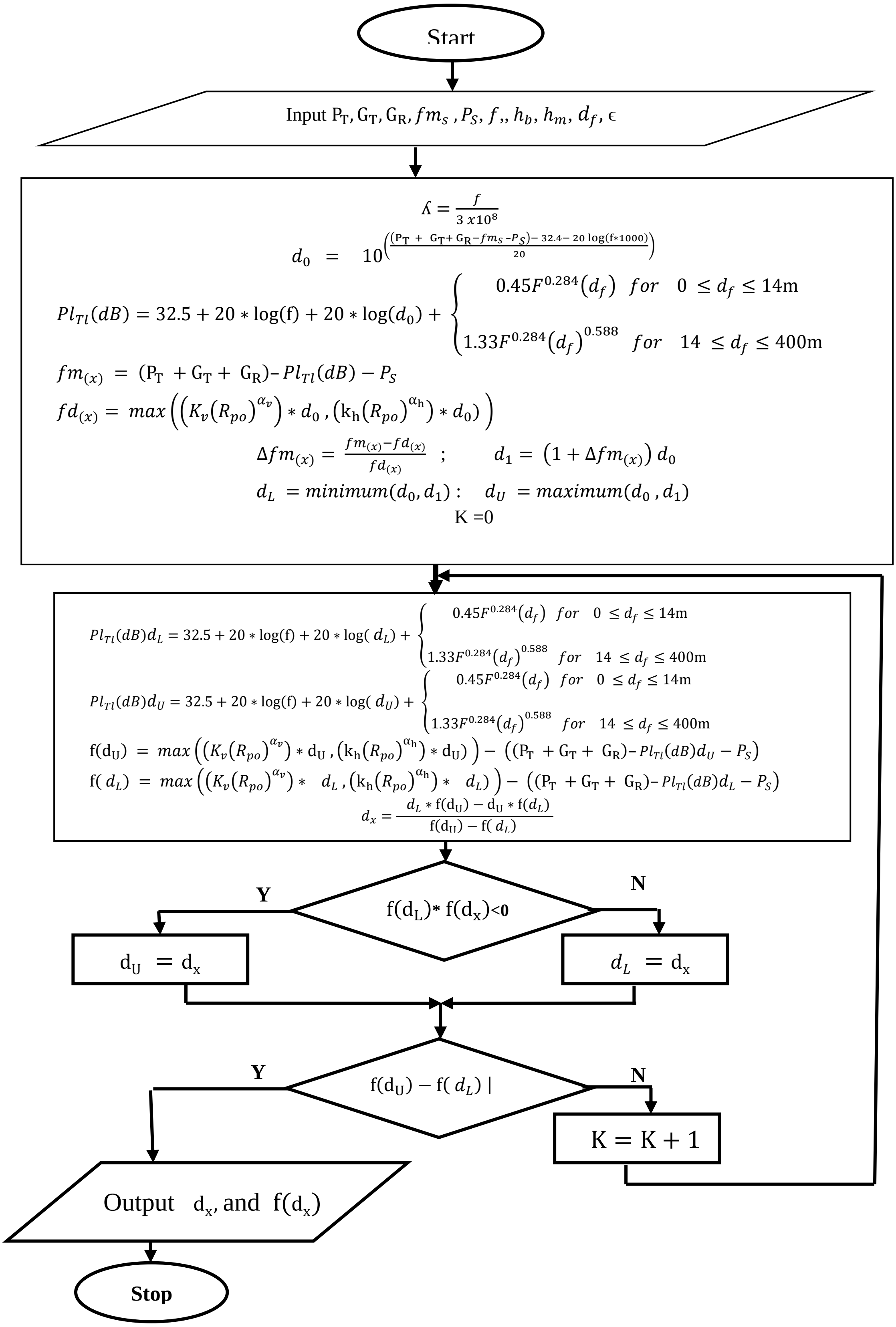

Figure 1 : The complete flowchart for the determination of the optimal transmission range for various frequency, f based on Weissberger model

III. RESULTS AND DISCUSSION

The transmission range of typical WSNs in the Ku-band (11 GHz) and C-band (8 GHz) microwave frequencies are used to analyse the effect of frequency on the optimal transmission range for vegetation covered environment where the transmission range is based on the Weissberger model. The simulation parameters used in the seeded Regular Falsi numerical iteration method for computing the optimal transmission range based on the Weissberger model are shown in Table 1.

The iteration results from the seeded Regular Falsi numerical iteration for the optimal transmission range for the C-band (8 GHz) microwave frequency are shown in Table 2. The results show that the iteration converged at the 5th cycle with optimal transmission range of 11.38993935 km, propagation loss of 134.0873275 dB based on Weisberg model and effective rain fade depth of 13.91267259 dB with tolerance error of 5.9876 x 10^{-08}.

The iteration results from the seeded Regular Falsi numerical iteration for the optimal transmission range for the Ku-band (11 GHz) microwave frequency are shown in Table 3. The results show that the iteration converged at the 5th cycle with optimal transmission range of 6.293985297 km, propagation loss of 131.9281801 dB based on Weisberg model and effective rain fade depth of 16.07181999 dB with tolerance error of 5.0351 x 10^{-08}.

Comparison of the transmission range , propagation loss and effective rain fade depth for the C-band (8 GHz) and the Ku-band (11 GHz) WSN is presented in Figure 1.The results show that the Ku-band WSN has higher effective rain fade depth, 16.0718 dB as compared to that of the C-band with higher effective rain fade depth, 13.9126726 dB. Conversely, the Ku-band WSN has a lower effective transmission range of 6.293985297 km as compared to that of the C-band link with effective transmission range of 11.38993935 km. Essentially, they higher frequency has higher rain fade depth which give rise to lower effective transmission range.

Table 1 The simulation parameters used in the seeded Regular Falsi numerical iteration method for computing the optimal transmission range based on the Weissberger model

S/N	Parameter Name and Unit	Parameter Value	S/N	Parameter Name and Unit	Parameter Value
1	F (MHz)	11000	7	kh	0.01772
2	Transmitter power, PT(dB)	15	8	ah	1.214
3	Transmitter antenna Gain, GT(dB)	25	9	kv	0.01731
4	Receiver antenna gain, GR(dB)	25	10	av	1.1617
5	Receiver sensitivity, Ps (dB)	-83	11	Percentage Availability, Pa (%)	99.99
6	Fade Margin (dB)	12	12	Rain Rate at 0.01 % outage probability, R0.01 mm/hr	60

Table 2 : The iteration results from the seeded Regular Falsi numerical iteration for the optimal transmission range for the C-band (8 GHz) microwave frequency

Frequency (GHz)	Convergence Cycle	Transmission Range (km)	Propagation Loss by Weissberger model (dB)	Received Power (dB)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Error (dB)
8	0	14	135.87946	-70.87945995	12.12054005	17.10082997	**4.98028992**
8	1	11.45228297	134.1347406	-69.13474065	13.86525935	13.98882456	**0.12356521**
8	2	11.39158063	134.088579	-69.08857901	13.91142099	13.91467739	**0.0032564**
8	3	11.38998264	134.0873605	-69.08736048	13.91263952	13.91272546	**8.5947E-05**
8	4	11.38994047	134.0873283	-69.08732832	13.91267168	13.91267395	**2.2685E-06**
8	5	11.38993935	134.0873275	-69.08732747	13.91267253	13.91267259	**5.9876E-08**

Table 3 : The iteration results from the seeded Regular Falsi numerical iteration for the optimal transmission range for the Ku-band (11 GHz) microwave frequency

Frequency (GHz)	Convergence Cycle	Transmission Range (km)	Propagation Loss by Weissberger model (dB)	Received Power (dB)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Error (dB)
11	0	8	134.0114653	-69.01146532	13.98853468	20.42816338	**6.43962869**

11	1	6.330738595	131.9787532	-66.9787532	16.0212468	16.16567029	**0.14442349**
11	2	6.294876252	131.9294095	-66.92940952	16.07059048	16.07409506	**0.00350458**
11	3	6.294006943	131.9282099	-66.92820993	16.07179007	16.07187526	**8.5195E-05**
11	4	6.293985811	131.9281808	-66.92818077	16.07181923	16.0718213	**2.0712E-06**
11	5	6.293985297	131.9281801	-66.92818006	16.07181994	16.07181999	**5.0351E-08**

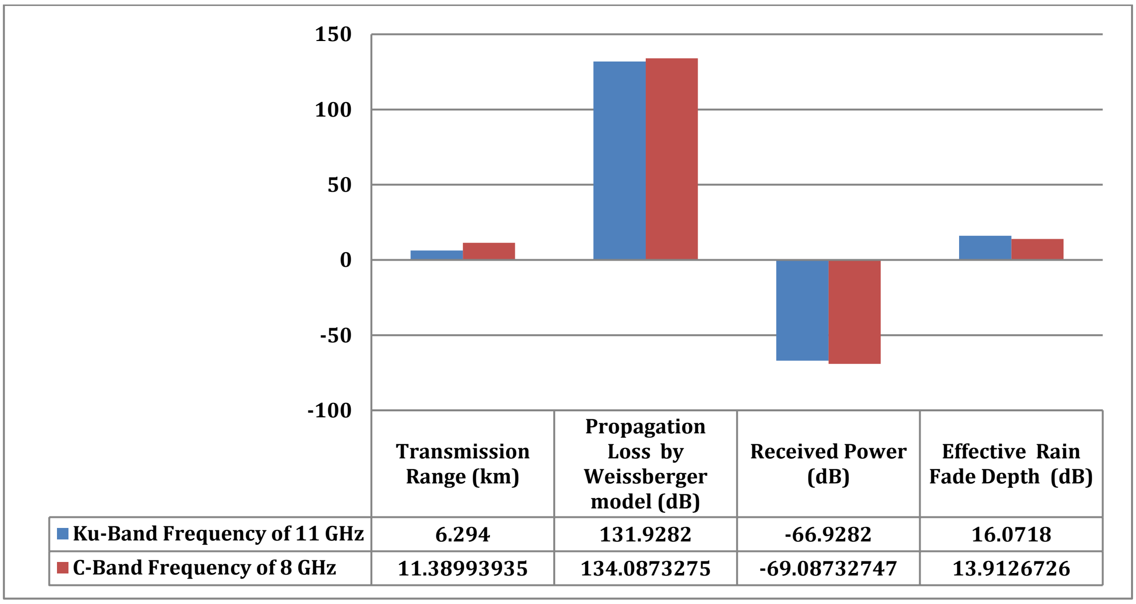

Figure 1 Comparison of the transmission range , propagation loss and effective rain fade depth for the C-band (8 GHz) and the Ku-band (11 GHz) WSN.

IV. CONCLUSION

Effective transmission range of wireless sensor networks in C-band and in the Ku-band frequencies are computed using a seeded Regular Falsi numerical iteration method. The transmission range is computed using link budget equation and rain fade depth. The study is meant to evaluate the impact of frequency on the effective transmission range of the wireless link. In all, the results show that the higher the frequency, the higher the rain fade depth and the lower the effective transmission range. The means that it will take more hops or transmitter power or other means to cover the same transmission range for a Ku-band frequency than it will require for a C-band frequency.

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