Analysis Of The Effect Of Frequency On The Optimal Transmission Range Based On Ericsson Model

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***Abstract*— The classical Ericsson model has analytical expression that captures the effect of frequency on the effective transmission range of a wireless network. Hence, in this paper, the analysis of the effect of frequency on the wireless communication link optimal transmission range based on Ericsson model is presented. The relevant mathematical models and flowcharts are presented. Also, the effective transmission range is determined using a seeded Bisection numerical iteration approach. Specifically, communication link at Ku-band frequency of 11 GHz and another communication link at C-band frequency of 5.5 GHz were used to examine how frequency affect the effective transmission range of wireless links. The results show that the C-band frequency has lower rain fade depth of 25.96737719 dB and higher effective transmission range of 18.03890876 km when compared to the Ku-band which has rain fade depth of 41.47501848 dB and higher effective transmission range of 5.564448355 km. Also, the Ku-band frequency has lower propagation loss of 83.02496985 dB when compared with that of the C-band which is 98.53260318 dB.**

Keywords — Ericsson model, transmission range, wireless network, communication link, optimal transmission range, seeded Bisection method, numerical iteration

I. INTRODUCTION

At design time, network experts set the desired quality of service and determine the propagation loss [1, 2, 3, 4, 5, 6, 7, 8, 9], the fade margin to be accommodated in the link [15, 16, 17], the transmission range [10, 11, 12, 13, 14] and other issues that may affect the quality of service. In most cases, the propagation loss is estimated using propagation loss model. Ericsson propagation loss model is an empirical model for predicting the attenuation wireless signal will encounter as it propagates from the source to the destination over a distance [18,19,20,21,22,23,24,25,26,27]. The model accounts for the effect of transmitter and receiver antenna height, the distance and terrain or environmental factors. More importantly, Ericsson propagation loss model also provides analytical expression for modeling the effect of frequency on the propagation loss the wireless signal will encounter in the propagation environment.

Moreover, usually, when terrestrial communication link is designed, it is important to determine the appropriate maximum distance (transmission range) between the transmitter and the receiver [10,11,12,13,14]. Several factors are considered in the determination of the appropriate maximum distance. One of such factors is the propagation loss [1,2,3,4,5,6,7,8,9] and also the frequency, among others. There are several propagation loss models each of which will give different mean propagation loss and hence different effective maximum transmission range. Also, for a given propagation loss model, in most cases, the mean propagation over a given distance is a function of frequency. Particularly, the Ericsson propagation loss model considered in this study has explicit analytical expression that models the effect of frequency on the propagation loss. Accordingly, in this paper, the effect of frequency on the effective transmission range of a wireless network where the propagation model is based on the Ericsson model is studied. The effective transmission range in this paper is determined using numerical iteration approach. The relevant mathematical models and flowcharts are presented.

II. METHODOLOGY

A. ERICSSON PROPAGATION LOSS MODEL

The attenuation wireless signal will encounter as it propagates from the source to the destination over a distance (d) is expressed in Ericsson model is as follows [18,19,20,21,22,23,24,25,26,27];

$$\mathrm{LP_E} = \mathrm{a_0} + \mathrm{a_1}(\log_{10}(\mathrm{d})) + \mathrm{a_2}(\log_{10}(\mathrm{h_b})) + \mathrm{a_3}\{\log_{10}(\mathrm{h_b})(\log_{10}(\mathrm{d}))\} - 3.2\log_{10}(11.75\mathrm{h_m})^2 + \mathrm{g(f)} \quad (1)$$

Where frequency, f is in MHz; the, $\mathrm{h_m}$ is in meters; transmitter antenna height, $\mathrm{h_b}$ is in . According to the Ericsson model, the effect of frequency on the effective transmission range of a wireless network is expressed as g(f) where;

$$g(f) = 44.49(\log_{10}(f)) - [4.78(\log_{10}(f))^2] \quad (2)$$

Also, Ericsson model provided values of the parameters ($\mathrm{a_0}$,$\mathrm{a_1}$,$\mathrm{a_2}$ and $\mathrm{a_3}$, as given in Table 1) to account for the differences in propagation loss is different types of terrains.

Table 1: Ericsson model parameter values for different types of terrains l (Source :[18,19,20,21,22,23,24,25,26,27])

Environment	a_0	a_1	a_2	a_3
Rural	45.95	100.6	12	0.1
Suburban	43.20	68.63	12	0.1

Urban	36.20	30.20	12	0.1

B. *DETERMINATION OF THE OPTIMAL TRANSMISSION RANGE BASED ON ERICSSON MODEL*

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

$$d = 10^{\left(\frac{(P_T + G_T + G_R - fm_S - P_S) - 32.4 - 20\log(f*1000)}{20}\right)} \quad (3)$$

f =frequency in GHz

d=length of the link in km

PR = Received Signal Power in dBm

PT = Transmitter Power Output in dBm

GT = Transmitter Antenna Gain in dBi

GR = Receiver Antenna Gain in dBi

Next, the initial transmission range, d is used in to compute the propagation loss based on Ericsson model, as follows;

$$GF = 44.49(\log_{10}(f)) - [4.78(\log_{10}(f))^2] \quad (4)$$

$$LP_{ERIC} = a_0 + a_1(\log_{10}(d)) + a_2(\log_{10}(h_b)) + a_3\{\log_{10}(h_b)(\log_{10}(d))\} - 3.2\log_{10}(11.75h_m)^2 + GF \quad (5)$$

Then, the fade margin, $fm_{(x)}$ and the rain fade depth, $fd_{(x)}$ are computed and the two fade parameters are used to determine the second initial distance , d_1 required in the Bisection iteration method used to determine the optimal transmission range. In all, d_L and d_U are used in the Bisection method of Figure 1 to determine the optimal transmission range for various frequencies. The requisite tables and graph plots are presented and discussed in the result section of this paper.

$$fm_{(x)} = (P_T + G_T + G_R) - LP_{ERIC} - P_S \quad (6)$$

$$fd_{(x)} = max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d, \left(k_h(R_{po})^{\alpha_h}\right) * d\right) \quad (7)$$

$$d_1 = \left(1 + \left(\frac{fm_{(x)} - fd_{(x)}}{fd_{(x)}}\right)\right) d \quad (8)$$

$$d_L = minimum(d, d_1) \quad (9)$$

$$d_U = maximum(d, d_1) \quad (10)$$

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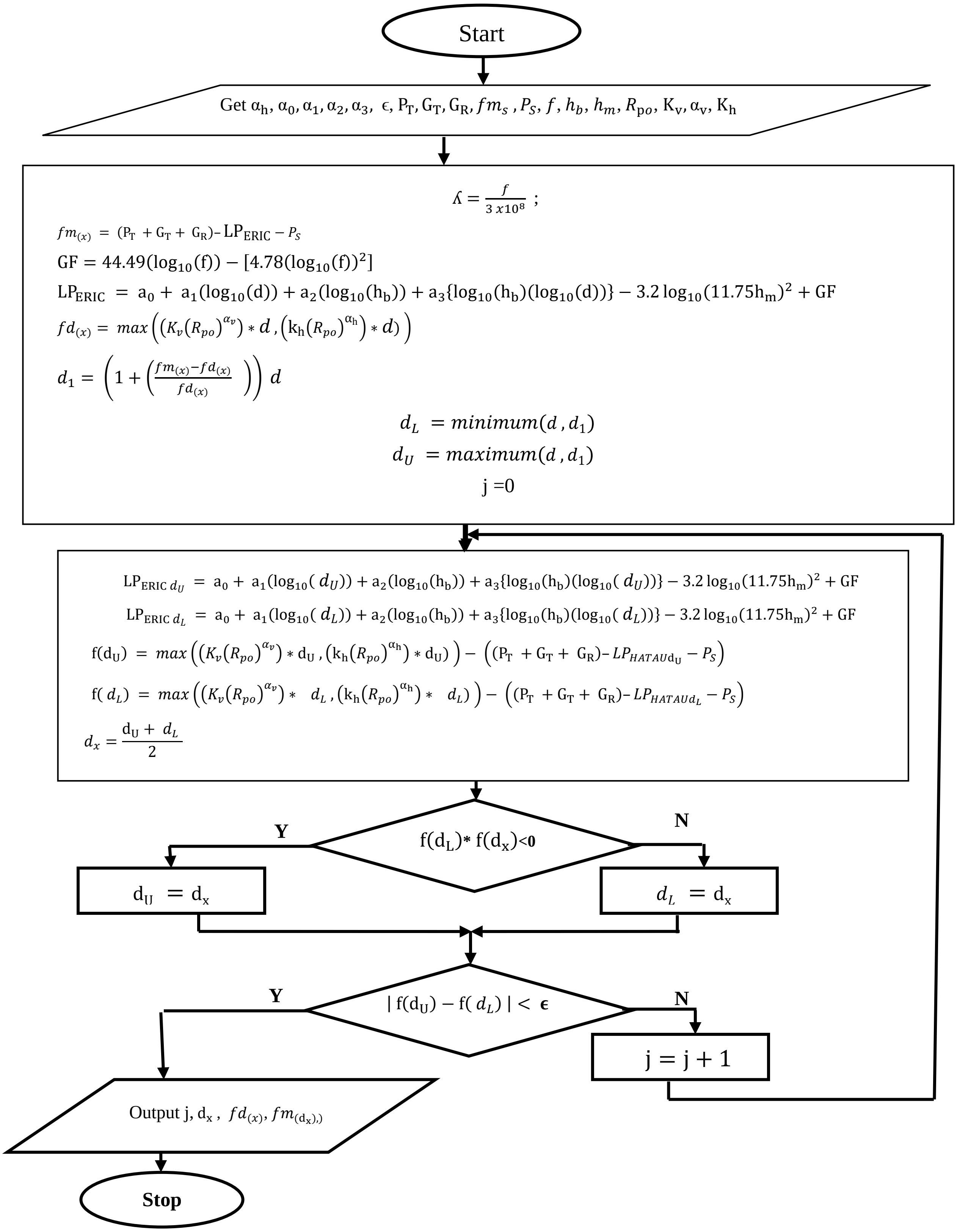

Figure 1 : The flowchart of the Bisection iteration method used to determine the optimal transmission range for various frequencies based on Ericsson propagation loss model

III. RESULTS AND DISCUSSION

The effect of frequency on the effective transmission range is well captured in the Ericsson propagation loss model. In this paper, communication link at Ku-band frequency of 11 GHz and another communication link at C-band frequency of 5.5 GHz were used to examine how frequency affect the effective transmission range of wireless links. The link parameters for the two case study communication links are given in Table 2. Specifically, the simulation used the Ericsson propagation loss model for urban environment.

The simulation results for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5

GHz are given in Table 3. The comparison of the transmission range for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz is given in Figure 2. Also, the comparison of the propagation loss, the received power and the effective rain fade depth for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz is given in Figure 3. The results show that the C-band frequency has lower rain fade depth of 25.96737719 dB and higher effective transmission range of 18.03890876 km when compared to the Ku-band which has rain fade depth of 41.47501848 dB and higher effective transmission range of 5.564448355 km.

However, the Ku-band has lower propagation loss of 83.02496985 dB when compared with that of the C-band which is 98.53260318 dB. The reason is because the Ericsson propagation loss is highly dependent on the propagation path length. Hence, the Ku-band with lower effective transmission range of 5.564448355 km has a lower propagation loss of 83.02496985 dB when compared with that of the C-band which has a higher effective transmission range of 18.03890876 km and higher propagation loss of 98.53260318 dB.

Table 2 The input parameters for the simulation for urban environment at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz

S/N	Parameter Name and Unit	Parameter Value at Ku-Band Frequency of 11GHz	Parameter Value at C-Band Frequency of 5.5 GHz
1	f (MHz)	11000	5500
2	Transmitter power, PT(dB)	12.5	12.5
3	Transmitter antenna Gain, GT(dB)	12.5	12.5
4	Receiver antenna gain, GR (dB)	12.5	12.5
5	Receiver sensitivity, Ps (dB)	-87	-87
6	Fade Margin (dB)	8	8
7	kh	0.01772	0.000391
8	ah	1.214	1.6499
9	kv	0.01731	0.000312
10	av	1.1617	1.5882
11	Rain Zone	P	P
12	Rain Rate at 0.01 % outage probability, R0.01 mm/hr	145	145

Table 3 The simulation results for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz

S/N	Parameter Name and Unit	Parameter Value at Ku-Band Frequency of 11GHz	Parameter Value at C-Band Frequency of 5.5 GHz
1	Frequency (MHz)	11000	5500
2	Convergence Cycle	3	3
3	Transmission Range (km)	5.564448355	18.03890876
4	Propagation Loss by Ericsson Urban Model (dB)	83.02496985	98.53260318
5	Received Power (dB)	-45.52496985	-61.03260318
6	Effective Fade Margin (dB)	41.47503015	25.96739682
7	Effective Rain Fade Depth(dB)	41.47501848	25.96737719
8	Error (dB)	-1.17E-05	-1.96E-05

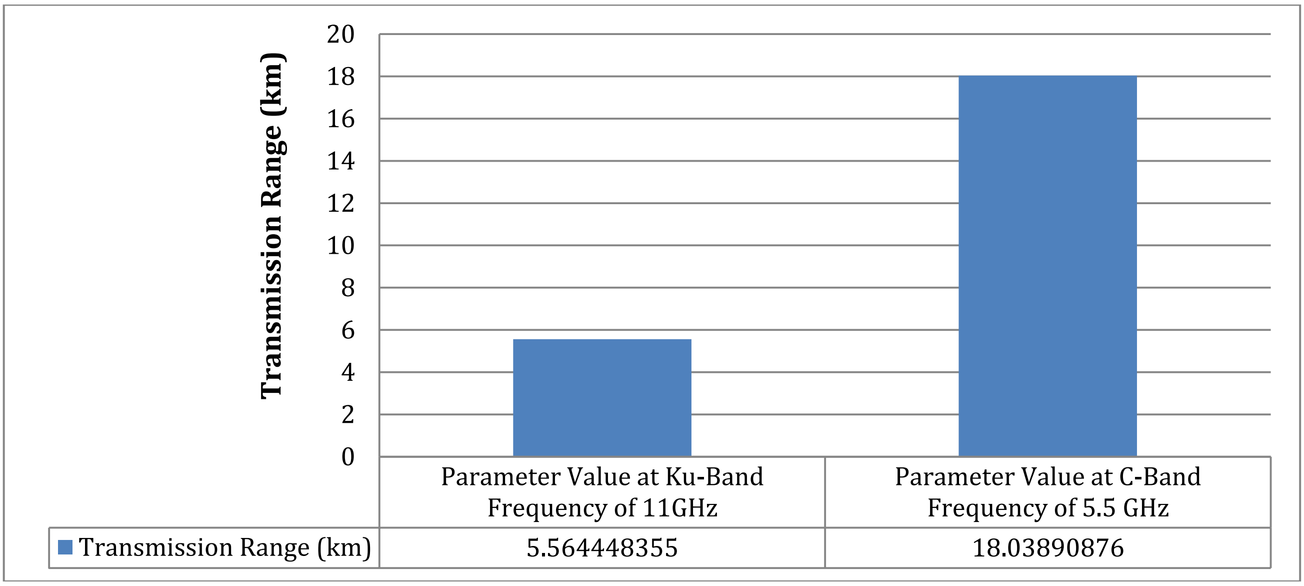

Figure 2 Comparison of the transmission range for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz

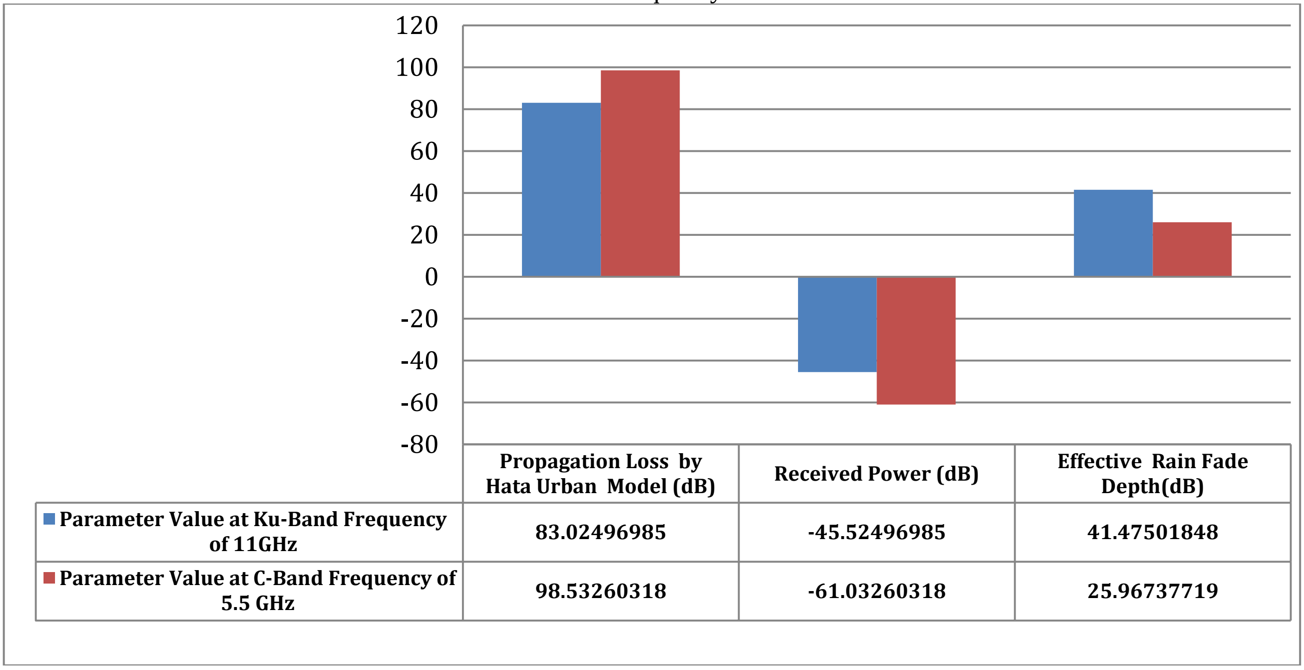

Figure 3 Comparison of the propagation loss, the received power and the effective rain fade depth for the communication links at Ku-Band Frequency of 11GHz and at C-Band Frequency of 5.5 GHz

IV. CONCLUSION

The effect of frequency on the transmission range of wireless communication link is studied. The Ericsson propagation loss model for urban area is used along with rain fading to determine the effective transmission range at which the effective fading is equal to the maximum fade depth available in the link at the specified system availability and other quality of service specifications. The effective transmission path length is computed for both a C-band and a Ku-band link. The results showed that the Ku-band link with higher frequency has higher rain fade depth, lower effective transmission range and lower path loss when compared to those of the C-band link.

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