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Evaluation Of Optimal Transmission Range Of Wireless Signal On Different Terrains Based On Ericsson Path Loss Model

Ozuomba Simeon
Department of Electrical/Electronic and Computer Engineering,
University of Uyo, Akwa Ibom, Nigeria
simeonozuomba@uniuyo.edu.ng
simeonoz@yahoo.com

***Abstract*— In this paper, the evaluation of optimal transmission range of wireless signal on different terrains based on Ericsson path loss model is presented. The Ericson propagation loss model is used along with rain fading to determine the effective transmission range of Ku-band microwave links located in the three different propagation environments specified in Ericson model. The relevant mathematical expressions, numerical iteration algorithm and communication link data used in the study are also presented. Mathlab program was written and used to perform the iterative computation of the effective transmission range for a case study Ku-band wireless link with operating frequency of 10 GHz, power of the transmitter (13 dB), gain of the transmitter and the receiver antennas (17 dBi) and the sensitivity of the receiver (-83 dB). The case study link was located in ITU rain zone N with operating rain rate of 95 mm/hr. The simulation results show that the urban propagation environment has the lowest transmission range of 10.3913 km, the lowest propagation loss of 91.2601 dB and the highest effective rain fade depth of 38.7398 dB. Conversely, the rural propagation environment has the lowest transmission range of 3.0328 km, the lowest propagation loss of 118.6939 dB and the highest effective rain fade depth of 11.3063 dB. Essentially, the propagation loss based on Ericsson model is such that the urban area offered the least propagation loss when compared to the other two terrains specified in the Ericsson model. The lower propagation loss in the urban area means that the communication links located in such area enjoy greater transmission range when compared to the links located in the other two propagation terrains.**

Keywords*— *Wireless Communication, Transmission Range , Propagation Loss, Ericson Model , Empirical Models, Numerical Iteration Algorithm, Communication Link

I. INTRODUCTION

In the wireless communication industry, propagation loss and transmission range are among the key parameters needed to determine or specify the required quality of service [1,2,3,4,5,6,7,8,9,10,11]. Basically, the propagation loss is a function of the transmission range and environmental factors. As such, most of the available empirical propagation loss models include distance and other parameters to capture the differences in the propagation loss for different environments. Ericson model is one of such empirical models that has elaborate specification for three different propagation environments, namely; rural area, suburban area and urban area [12, 13, 14, 15, 16, 17]. As such, during the wireless communication link design, the maximum transmission range can be determined for each of the three different propagation environments.

While the maximum transmission range is important, it may not be applied in real life situation. Instead, effective or optimal transmission range is preferred [18,19,20,21,22,23,24]. The effective transmission range is determined by considering the maximum fade depth that will occur in the link at the specified quality of service and transmission range. So, the maximum transmission range is adjusted iteratively until an effective transmission range is reach at which the fade margin obtained from the link budget analysis is equal to the maximum fade depth that can be experienced by the signal.

In this paper, the Ericson propagation loss model is used along with the rain fading to determine the effective transmission range of Ku-band microwave links located in the three different propagation environments specified in the Ericson model. Mathlab program was written and used to perform the iterative computation of the effective transmission range. The relevant mathematical expressions, numerical iteration algorithm and communication link data used in the study are also presented.

II. METHODOLOGY

A. *ERICSSON PATH LOSS MODEL*

The mathematical expressions for computing propagation loss of wireless signal based on Ericsson model is as follows [12,13,14,15,16,17];

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

Where frequency, f is in MHz; the, h_m is in meters; transmitter antenna height, h_b is in meters and *g(f)* is given as;

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

The model has provision for the path loss in different terrains, such as, the urban, the suburban and the rural environments. The values of the parameters (a_0,a_1,a_2,a_3) for the different types of terrains are given in Table 1.

Table 1: Parameter Values For Ericsson Model (Source : [12, 13, 14, 15, 16, 17])

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. WIRELESS COMMUNICATION LINK TRANSMISSION RANGE

By using the link budget equation based on Ericsson path loss model, the received power, P_R is given as ;

$$P_R = P_T + (G_T + G_R) - LP_{\mathbf{ERIC}} = fm_s + P_S \quad (3)$$

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)

fms = fade margin (dB)

Ps = receiver sensitivity (dB) ;

$LP_{\mathbf{ERIC}}$ = Propagation loss based on Ericsson path loss model

Let $d_{e\mathbf{ERIC}}$ be the transmission range when Ericsson model is used, then the $(LP_{\mathbf{ERIC}_e})$ is given as:

$$LP_{\mathbf{ERIC}_e} = a_0 + a_1(\log_{10} d_{e\mathbf{ERIC}}) + a_2(\log_{10} h_b) + a_3\{\log_{10} h_b(\log_{10} d_{e\mathbf{ERIC}})\} - 3.2\log_{10}(11.75h_m)^2 + g(f) \quad (4)$$

Effective Received Power $(P_{Re\mathbf{ERIC}})$ is given as:

$$P_{ReEXSUI} = P_T + G_T + G_R - LP_{\mathbf{ERIC}_e} = fm_{e\mathbf{ERIC}} - P_S \quad (5)$$

Effective Fade Margin $(fm_{e\mathbf{ERIC}})$ is given as:

$$fm_{e\mathbf{ERIC}} = (P_T + G_T + G_R) - LP_{\mathbf{ERIC}_e} - P_S \quad (11)$$

The rain fade depth $(fd_{me\mathbf{ERIC}})$ at a transmission range $(d_{e\mathbf{ERIC}})$ is given as;

$$fd_{me\mathbf{ERIC}} = \max\left(\left(K_v(R_{po})^{\alpha_v}\right) * d_{e\mathbf{ERIC}}, \left(K_h(R_{po})^{\alpha_h}\right) * d_{e\mathbf{ERIC}}\right) \quad (12)$$

C. ALGORITHM FOR OPTIMAL TRANSMISSION RANGE BASED ON ERICSSON PROPAGATION LOSS MODEL

The optimal transmission range with propagation loss based on Ericsson model (denoted as, $d_{opEricsson}$) is the value of $d_{eEricsson}$ for which $fm_{eEricsson} = fd_{meEricsson}$, thus;

$$d_{opEricsson} = d_{eEricsson} \text{ at which } fm_{eEricsson} = fd_{meEricsson} \quad (27)$$

The algorithm used is the modified fixed point iteration method which is based on the adjustment of the transmission range as stated below;

Step 1:

Set the tolerance error valueϵ, $\epsilon = 0.001$

Step 2: Input P_T , G_T, G_R, fm_s , P_S, f, h_m, h_b, $d_{eEricsson(0)}$

Step 3: Input the terrain type ,TP (where "1" represent urban area ; "2" represent suburban area; "3" represent rural area

Input Tp

Step 4:

Step 4.1: If TP = 1 Then

Step 4.2: $a_0 = 45.95$

Step 4.3: $a_1 = 100.6$

Step 4.4: $a_2 = 12$

Step 4.5: $a_3 = 0.1$

Step 4.6: Elseif TP = 2 Then

Step 4.7: $a_0 = 43.20$

Step 4.8: $a_1 = 68.63$

Step 4.9: $a_2 = 12$

Step 4.10: $a_3 = 0.1$

Step 4.11: Else

Step 4.12: $a_0 = 36.20$

Step 4.13: $a_1 = 30.20$

Step 4.14: $a_2 = 12$

Step 4.15: $a_3 = 0.1$

Step 4.16: Endif

Step 5: x = 0

Step 6 Compute transmission range 1

Step 6.1: $g(f) = 44.49(\log_{10}(f)) - [4.78(\log_{10}(f))^2]$

Step 6.2: $LP_{Ericsson} = a_0 + a_1\left(\log_{10}\left(d_{eEricsson(x)}\right)\right) + a_2(\log_{10}(h_b)) + a_3\{\log_{10}(h_b)\left(\log_{10}\left(d_{eEricsson(x)}\right)\right)\} - 3.2\log_{10}(11.75h_m)^2 + g(f)$

Step 6.3:
$fm_{OPEricsson(x)} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - LP_{Ericsson} - P_S$

Step 6.4: $fd_{mOPEricsson(x)} \max\left(\left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_v}\right) * d_{eEricsson(x)}, \left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_h}\right) * d_{eEricsson(x)}\right)$

Step 7: Check if optimal path length has been obtained

Step 7.1: If $|fm_{OPEricsson(x)} - fd_{mOPEricsson(x)}| < |\epsilon|$ Then

Step 7.2: $d_{OPEricsson} = d_{eEricsson(x)}$

Step 7.3: $fm_{OPEricsson} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - LP_{Ericsson} - P_S$

Step 7.4: $fd_{mOPEricsson} = \max\left(\left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_v}\right) * d_{OPEricsson}, \left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_h}\right) * d_{OPEricsson}\right)$

Step 7.5: Goto step 9

Step 7.6: Endif

Step 8: Compute the next path length

Step 8.1: $\Delta fm_{(x)} = \frac{fm_{OPEricsson(x)} - fd_{mOPEricsson(x)}}{fd_{mOPEricsson(x)}}$

Step 8.2: $d_{eEricsson(x+1)} = \left(1 + \Delta fm_{(x)}\right) d_{eEricsson(x)}$

Step 8.3: $\mathbf{x = x + 1}$

Step 8.4: Goto step 6

Step 9 : Output results

Step 9.1: If TYP = 1 Then

Step 9.2: Output "Terrain Type: Rural Area"

Step 9.3: Elseif TYP = 1 Then

Step 9.4: Output "Terrain Type: Sub-urban Area"

Step 9.5: Else

Step 9.6: Output "Terrain Type: Urban Area"

Step 9.7: Endif

Step 10: Output $d_{OPEricsson1}$, $fm_{OPEricsson}$, $fd_{mOPEricsson}$

Step 11 : End the program

Stop

III. RESULTS AND DISCUSSION

A Malab program written for the numerical iteration algorithm for optimal transmission range based on the Ericsson path loss model was used along with the case study communication link data in Table 2 to compute the effective transmission range and other pertinent communication link parameters. The Ku-band wireless link has operating frequency of 10 GHz, power of the transmitter (13 dB), gain of the transmitter and the receiver antenna (17 dB) and the sensitivity of the receiver (-83 dB). The link is in ITU rain zone N with operating rain rate of 95 mm/hr.

The modified fixed point iteration method results for the urban environment are given in Table 3 and Figure 1. The iteration ran for about 18 cycle before the algorithm converged to the optimal transmission range of 10.3913 Km with error tolerance of 10^{-5}. At the convergence point, the effective propagation loss based on the Ericsson model is 91.2602 dB and the effective rain fade depth is 38.7398 dB.

The comparison of the simulation results for the three propagation environments; the urban, the suburban and the rural areas are given in Table 4 and Figure 2. The results in Table 4 and Figure 2 show that the urban propagation environment has the lowest transmission range of 10.3913 km, the lowest propagation loss of 91.2601 dB and the highest effective rain fade depth of 38.7398 dB. Conversely, the rural propagation environment has the lowest transmission range of 3.0328 km, the lowest propagation loss of 118.6939 dB and the highest effective rain fade depth of 11.3063 dB. Essentially, the propagation loss based on Ericsson model is such that the urban area offers the least propagation loss when compared to the other two terrains specified in the Ericsson model. The lower propagation loss in the urban area makes the links located in such to enjoy maximum transmission range when compared to the links located in the other two propagation terrains.

Table 2 The case study communication link data used for the simulation

S/N	Parameter Name and Unit	Parameter Value
1	f (MHz)	10000
2	Transmitter power, PT(dB)	13
3	Transmitter antenna Gain, GT(dB)	17
4	Receiver antenna gain, GR (dB)	17
5	Receiver sensitivity, Ps (dB)	-83
6	Fade Margin (dB)	5
7	kh	0.01217
8	ah	1.2571
9	kv	0.01129
10	av	1.2156
11	Rain Zone	N
12	Rain Rate at 0.01 % outage probability, R0.01 mm/hr	95

Table 3 The modified fixed point iteration method results for the urban environment

Cycle	Transmission Range (km)	Propagation Loss by Ericsson Model (dB)	Effective Fade Margin (dB)	Effective Rain Fade Depth(dB)	ϵ
0	14	95.1905	34.8095	34.8095	1.74E+01
1	11.6685	92.7886	37.2114	34.8095	6.29E+00
2	10.5028	91.4008	38.5992	34.8095	5.56E-01
3	10.5028	91.4008	38.5992	36.9825	5.56E-01
4	10.5028	91.4008	38.5992	38.0690	5.56E-01
5	10.5028	91.4008	38.5992	38.6122	5.56E-01
6	10.4300	91.3091	38.6909	38.6122	1.93E-01
7	10.3935	91.2629	38.7371	38.6122	1.10E-02
8	10.3935	91.2629	38.7371	38.6801	1.10E-02
9	10.3935	91.2629	38.7371	38.7141	1.10E-02
10	10.3935	91.2629	38.7371	38.7311	1.10E-02
11	10.3935	91.2629	38.7371	38.7395	1.10E-02
12	10.3924	91.2615	38.7385	38.7395	5.27E-03
13	10.3918	91.2608	38.7392	38.7395	2.43E-03
14	10.3915	91.2604	38.7396	38.7395	1.01E-03
15	10.3914	91.2602	38.7398	38.7395	2.97E-04
16	10.3914	91.2602	38.7398	38.7398	2.97E-04
17	10.3914	91.2602	38.7398	38.7398	1.19E-04
18	10.3913	91.2602	38.7398	38.7398	3.02E-05

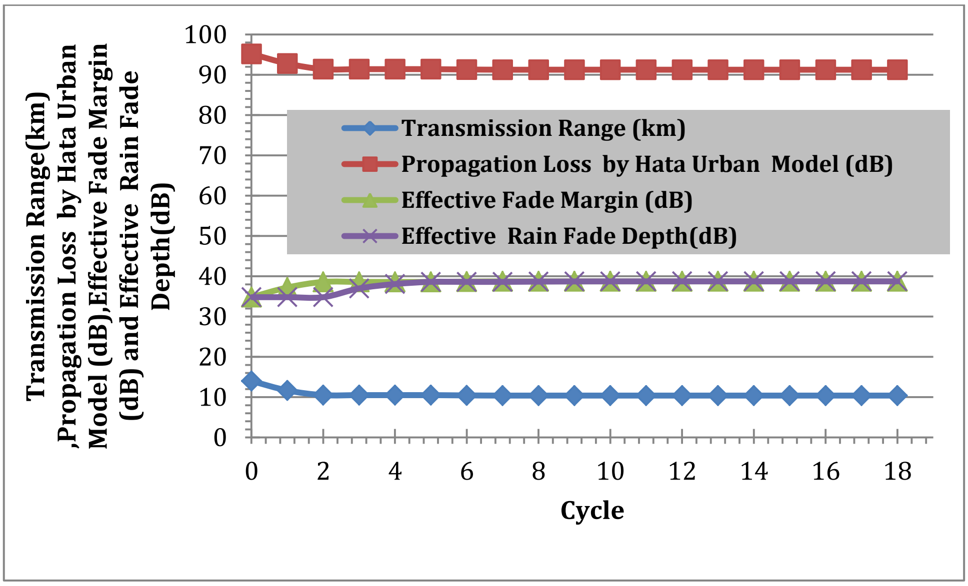

Figure 1 The plots of the modified fixed point iteration method results for the urban environment

Table 4 Comparison of the simulation results for the three propagation environments; the urban, the suburban and the rural areas

S/N	Parameter Name and Unit	Urban	Suburban	Rural
1	Convergence Cycle	18	18	18
2	Transmission Range (km)	10.3913	4.5869	3.0328
3	Propagation Loss by Ericsson Model (dB)	91.2601	112.8996	118.6939
4	Received Power (dB)	-44.2601	-65.8996	-71.6939
5	Effective Fade Margin (dB)	38.7399	17.1004	11.3064
6	Effective Rain Fade Depth(dB)	38.7398	17.1003	11.3063
7	Error (dB)	-3.8573E-05	-8.38151E-05	-1.85E-05

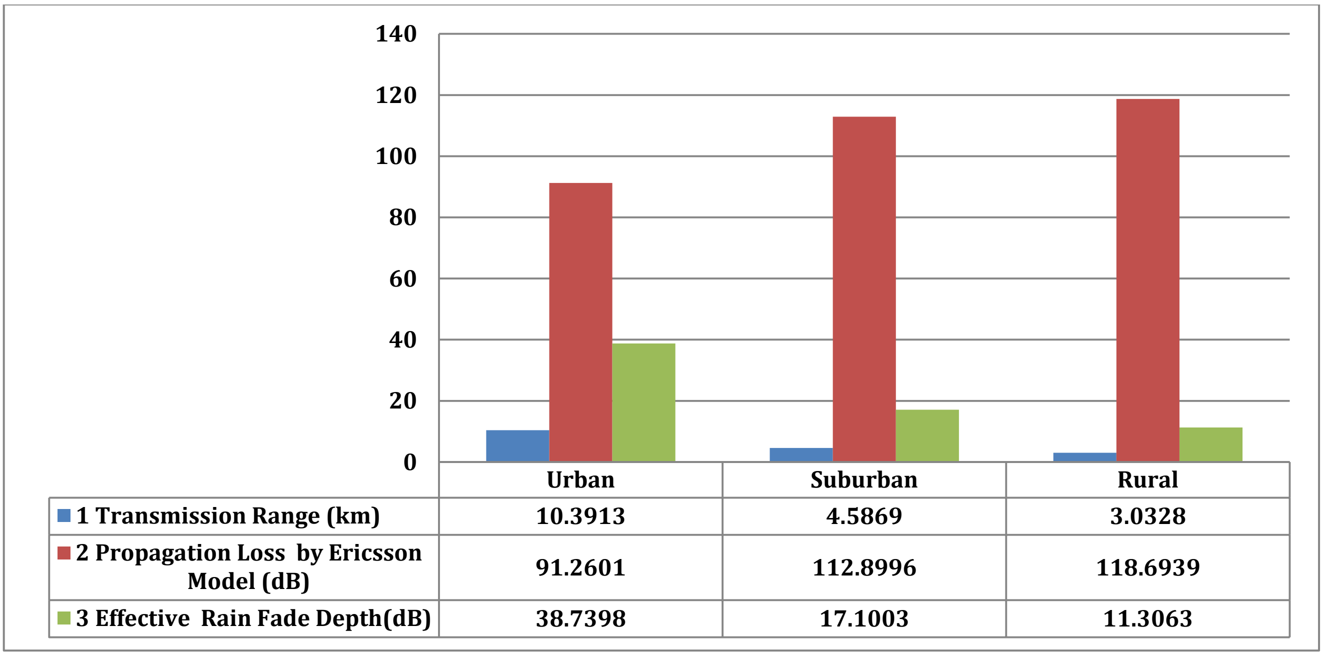

Figure 2 Comparison of the simulation results for the three propagation environments; the urban, the suburban and the rural areas

IV. CONCLUSION

Analysis of the optimal transmission range of wireless link for the three different propagation terrains specified in Ericsson path loss model is presented. The analysis was done using link budget equation with path loss based on Ericsson path loss model, rain fade depth based on ITU rain fade model and modified fixed point iteration algorithm. Numerical example was presented using Ku-band communication links located in each of the three terrains. The results showed that the propagation loss based on Ericsson model is such that the urban area offered the least propagation loss when compared to the other two terrains specified in the Ericsson model. Hence, the optimal transmission range in the urban area is higher than what is obtainable in the other two terrains.

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