COMPUTATION OF MICROWAVE COMMUNICATION LINK OPTIMAL TRANSMISSION RANGE BASED ON EXTENDED STANFORD UNIVERSITY INTERIM PROPAGATION LOSS MODEL

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***Abstract*— In this paper, computation of microwave communication link optimal transmission range based on Extended Stanford University Interim (ESUI) propagation loss model is presented. The optimal transmission range is the path length at which the fade margin based on the propagation loss model is equal to the fade depth that can be encountered by the signal in the propagation path. Specifically, the mathematical expressions and modified fixed point numerical iteration algorithm for the computation of optimal transmission range of the microwave communication link is presented. Sample numerical example was presented using a dataset of a typical microwave communication link. The computation was carried out in Matlab software for the three different terrains specified in ESUI model. The microwave link site was in the ITU rain zone N with 95 mm/hr rain rate at 99.99% link availability. The results show that the microwave link in terrain A has the lowest optimal transmission range of 3.055648 km , the highest propagation loss of 150.6083 dB based on ESUI model, the lowest received signal strength of -70.6083 dB and the lowest effective fade margin of 11.39173 dB. On the other hand, the microwave link in terrain C has the highest optimal transmission range of 4.137131 km, the lowest propagation loss of 146.5764 dB based on ESUI model, the highest received signal strength of -66.57637 dB and the highest effective fade margin of 15.42363 dB. Essentially, comparison of the optimal transmission range and the propagation loss for the three different terrains shows that with the ESUI model, the terrain parameters have more impact on the propagation loss than the distance.**

Keywords*— *Propagation Loss , Extended Stanford University Interim (ESUI) , Propagation Loss Model, Transmission Range, Optimal Transmission Range, Numerical Iteration

I. INTRODUCTION

The transmission range of wireless communication link depends on a number of factors which include the transmitter power, antenna gain, propagation loss, and other network and environmental dependent factors [1, 2, 3,4,5,6,7]. Also, the dominant fade mechanism prevalent in the signal propagation environment and applicable to the given signal frequency also need to be considered [8,9,10,11,12,13,14,15,16]. Communication link design is meant to account for the listed factors so as to ensure adequate quality of service is afforded within the network coverage range.

In the line of sight (LoS) microwave communication link, optimal transmission range indicates the link that has just enough fade margin to accommodate the worst case fade depth for the required percentage availability and bit error rate [17,18, 19]. Accordingly, optimal transmission range is in most cases smaller than the maximum possible transmission range. The key criterion for the determination of optimal transmission range is to determine the path length at which the fade margin is equal to the fade depth.

In order to determine the fade margin, the link budget equation is used to compute the received signal strength. At this point, the propagation loss is required. Although in many cases, the free space path loss is used. However, researches have shown that free space path loss underestimates the propagation loss as the transmission range gets longer [20, 21, 22, 23]. As such, in this paper, the Extended Stanford University Interim (ESUI) propagation loss model is used in the link budget equation to determine the received signal strength and by extension the optimal transmission range of a microwave communication link [24,25]. The determination of the optimal transmission range requires iterative algorithm. As such, a modified fixed point numerical iteration algorithm [26, 27, 28, 29] was used in this paper to determine the optimal path length. Sample microwave communication link parameters dataset was used to demonstrate how the ideas presented in this study can be applied.

II. METHODOLOGY

A. THE EXTENDED STANFORD UNIVERSITY INTERIM (ESUI) MODEL

The Extended Stanford University Interim (ESUI) model is a modified version of the Stanford University Interim (SUI) propagation loss model [24,25]. The propagation loss according to ESUI is given as LP_{EXSUI} where;

$$LP_{EXSUI} = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) & for\ d < \acute{\delta}_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\acute{\delta}_o}\right)\right) + X_f + X_h & for\ d > \acute{\delta}_o \end{cases} \quad (1)$$

Where the d is distance in meters between the base station and the mobile device, the frequency in MHz is denoted as f, the reference distance, $d_0 = 100\text{m}$, the modified reference distance, $\acute{\delta}_o$ is given as;

$$\acute{\delta}_o = d_0\left(10^{-\left(\frac{X_h - X_f}{10(\gamma)}\right)}\right) \quad (2)$$

Also, the correction factor for receiving antenna height (in meters) is X_h, the propagation loss exponent is γ, the frequency correction factor is X_f and the shadowing correction factor is S where $8.2 \leq S \leq 10.6$ dB and A is given as:

$$A = 20\left(\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)\right) \quad (3)$$

Also,

$$\gamma = a + b(h_b) + \frac{c}{h_b} \quad (4)$$

Generally, for various terrains , the range of values for the propagation loss exponent, γ are as follows:

$$\begin{cases} \gamma = 2 & \text{for free space} \\ 3 < \gamma < 5 & \text{for urban environment} \\ \gamma > 5 & \text{for indoor situations} \end{cases} \quad (5)$$

In addition, height in meters, h_b for the base station antenna is such that $10 \text{ m} \leq h_b \leq 80$ m. Again, for different terrain type the values of a, b and c as shown in Table 1.

Table 1: The values of the ESUI constants for the different terrains [24,25].

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

The frequency correction factor, X_f is given as;

$$X_f = 6\left(\log_{10}\left(\frac{f}{2000}\right)\right) \quad (6)$$

The receiver antenna height correction factor, X_h is given as;

$$X_h = \begin{cases} -10.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type A and B} \\ -20.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type C} \end{cases} \quad (7)$$

Where, the frequency, f is in MHz, and the receiver antenna height,h_m is in meter.

B. WIRELESS COMMUNICATION LINK EFFECTIVE TRANSMISSION RANGE BASED ON ESUI PROPAGATION LOSS MODEL AND RAIN FADING

The link budget equation for wireless communication link based on ESUI propagation loss model is given as;

$$P_R = P_T + (G_T + G_R) - LP_{EXSUI} \quad (8)$$

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_{EXSUI} = Propagation loss based on ESUI propagation loss model

In this paper, the initial effective transmission range $(d_{eXSUI(o)})$ is set to $\acute{\delta}_o$ where

$$d_{eXSUI(o)} = \acute{\delta}_o = d_0\left(10^{-\left(\frac{X_h - X_f}{10(\gamma)}\right)}\right) \quad (9)$$

With respect to d_{eXSUI} the effective ESUI model propagation loss (LP_{EXSUI_e}) is given as:

$$LP_{EXSUI_e} = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi(d_{eXSUI})}{\lambda}\right)\right) & for\ d_{eXSUI} < \acute{\delta}_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\acute{\delta}_o}\right)\right) + X_f + X_h & for\ d_{eXSUI} > \acute{\delta}_o \end{cases} \quad (10)$$

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

$$P_{ReEXSUI} = P_T + G_T + G_R - LP_{EXSUI_e} \quad (11)$$

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

$$fm_{eEXSUI} = (P_T + G_T + G_R) - LP_{EXSUI_e} - P_S \quad (12)$$

The rain fade depth $(fd_{meEXSUI})$ at a transmission range (d_{eXSUI}) is given as;

$$fd_{meEXSUI} = \max\left(\left(\left(K_v(R_{po})^{\alpha_v}\right) * d_{eXSUI}, \left(K_h(R_{po})^{\alpha_h}\right) * d_{eXSUI}\right)\right) \quad (13)$$

C. DETERMINATION OF THE OPTIMAL TRANSMISSION RANGE BASED ON ESUI PROPAGATION LOSS MODEL AND ENHANCED FIXED POINT ITERATION

The optimal transmission range with propagation loss based on ESUI model (denoted as, d_{OPXSUI}) is the value of d_{eXSUI} for which $fm_{eEXSUI} = fd_{meEXSUI}$.

$$d_{OPXSUI} = d_{eXSUI} \text{ at which } fm_{eEXSUI} = fd_{meEXSUI} \quad (14)$$

Enhanced fixed point iteration is used for the determination of the optimal transmission range. Particularly, a single initial transmission range, $d_{eXSUI(o)}$ is selected, then the fm_{eEXSUI} and $fd_{meEXSUI}$ are computed with respect to $d_{EXSUI(o)}$. Next, the required effective transmission range, $d_{eXSUI(1)}$ is computed as follows;

Step 1:

Set error tolerance value ϵ, where $\epsilon = 0.001$

Step 2:

Set initial value for $d_{eXSUI(o)}$; where $d_{eXSUI(o)} = $ $d_{eXSUI(o)} = \acute{\delta}_o = d_0\left(10^{-\left(\frac{X_h - X_f}{10(\gamma)}\right)}\right)$

Step 3: Compute the propagation loss (LP_{EXSUI_e}) based on ESUI model

$$LP_{EXSUI_e} = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi(d_{eXSUI})}{\lambda}\right)\right) & for\ d_{eXSUI} < \acute{\delta}_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\acute{\delta}_o}\right)\right) + X_f + X_h & for\ d_{eXSUI} > \acute{\delta}_o \end{cases} \quad (9)$$

Step 4: Compute the effective fade margin (fm_{eEXSUI})

$$fm_{eEXSUI} = (P_T + G_T + G_R) - LP_{EXSUI_e} - P_S$$

Step 5: Compute the rain fade depth, $fd_{meEXSUI}$ =

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

Step 6: Check if optimal transmission range has been obtained

If $|fm_{eEXSUI} - fd_{meEXSUI}| < |\epsilon|$ Then

$d_{OPXSUI} = d_{eXSUI(o)}$

"Output Optimal transmission range , d_{OPXSUI} =" , $d_{eXSUI(o)}$

Goto step 10

Endif

Step 7: Compute the next transmission range

IF $fm_{eEXSUI} > fd_{meEXSUI}$

$\Delta F_{eX} = fm_{eEXSUI} - fd_{meEXSUI}$

$d_{eX} = \left(\frac{fd_{meEXSUI}}{\Delta F_{eX}}\right) d_{EXSUI(o)}$

$$d_{EXSUI(1)} = d_{EXSUI(o)} + d_{eX} = d_{EXSUI(o)}\left(1 + \left(\frac{fd_{meEXSUI}}{\Delta F_{eX}}\right)\right)$$

$Esle$IF $fm_{eEXSUI} < fd_{meEXSUI}$

$\Delta F_{eX} = fd_{meEXSUI} - fm_{eEXSUI}$

$d_{eX} = \left(\frac{fm_{eEXSUI}}{\Delta F_{eX}}\right) d_{EXSUI(o)}$

$$d_{EXSUI(1)} = d_{EXSUI(o)} - d_{eX} = d_{EXSUI(o)}\left(1 - \left(\frac{fm_{eEXSUI}}{\Delta F_{eX}}\right)\right)$$

End if

Step 8 : Reset the guess optimal path length

$d_{EXSUI(0)} = d_{EXSUI(1)}$

Step 9 : Repeat the steps from step 3

Goto step 3

Step 10 End the program

Stop

III. RESULTS AND DISCUSSION

A sample microwave communication link data in Table 2 was used for numerical example. The computation of the optimal transmission range for the three different terrains specified by the ESUI model was conducted using Matlab software. Table 2 shows that the microwave link site was in the ITU rain zone N with 95 mm/hr rain rate at 99.99% link availability.

Table 4 shows the numerical iteration results obtained when the data in Table 3 was used to run the iteration algorithm in section 2.3 for ESUI terrain A. According to Table 4, the optimal transmission range for the terrain A is 3.055647795 km while the effective fade margin is 11.39173121 dB. The iteration was run with tolerance error of $1x10^{-5}$.

Similarly, Table 4 shows the numerical iteration results obtained when the data in Table 2 was used to run the iteration algorithm in section 2.3 for ESUI terrain B. According to Table 4, the optimal transmission range for the terrain B is 3.691734 km while the effective fade margin is 13.76311 dB. Also, the iteration was run with tolerance error of $1x10^{-5}$.

Furthermore, Table 5 shows the numerical iteration results obtained when the data in Table 1 was used to run the iteration algorithm in section 2.3 for ESUI terrain C. According to Table 4, the optimal transmission range for the terrain C is 4.1371306 km while the effective fade margin is 15.42363 dB. Also, the iteration was run with tolerance error of $1x10^{-5}$.

The comparison of the numerical iteration results obtained for ESUI terrain A, terrain B and terrain C is presented in Figure 6. The results in Figure 2 shows that the microwave link in terrain A has the lowest optimal transmission range of 3.055648 km, the highest propagation loss of 150.6083 dB based on ESUI model, the lowest received signal strength of -70.6083 dB and the lowest effective fade margin of 11.39173 dB. On the other hand, the microwave link in terrain C has the highest optimal transmission range of 4.137131 km , the lowest propagation loss of 146.5764 dB based on ESUI model, the highest received signal strength of -66.57637 dB and the highest effective fade margin of 15.42363 dB. Essentially, comparison of the optimal transmission range and the propagation loss for the three different terrains shows that with the ESUI model, the terrain parameters have more impact on the propagation loss than the distance.

Table 2: A sample microwave communication link data used for the numerical iteration of optimal for the three terrains specified in ESUI

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)
10000	10	20	20		-82	10
kh	ah	kv	av	Percentage Availability, Pa (%)	Rain Zone	Rain Rate at 0.01 % outage probability, R0.01 mm/hr
0.01	1.26	0.01	1.22	99.99	N	95.00

Table 3: The numerical iteration results obtained when the data in Table 1 was used to run the iteration algorithm in section 2.3 for ESUI terrain A

Iteration Cycle	Transmission Range	Propagation Loss by ESUI Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
1	4.000000000	156.0058203	-76.00582035	5.994179653	14.9123783	8.92E+00
2	3.401960004	152.7600545	-72.76005448	9.239945518	12.6828287	3.44E+00
3	3.102940005	150.9160932	-70.91609317	11.08390683	11.5680538	4.84E-01
4	3.102940005	150.9160932	-70.91609317	11.08390683	11.5680538	4.84E-01
5	3.102940005	150.9160932	-70.91609317	11.08390683	11.5680538	4.84E-01
6	3.065562506	150.6731964	-70.67319635	11.32680365	11.428707	1.02E-01
7	3.065562506	150.6731964	-70.67319635	11.32680365	11.428707	1.02E-01
8	3.056218131	150.6120094	-70.6120094	11.3879906	11.3938703	5.88E-03
9	3.056218131	150.6120094	-70.6120094	11.3879906	11.3938703	5.88E-03
10	3.056218131	150.6120094	-70.6120094	11.3879906	11.3938703	5.88E-03
11	3.056218131	150.6120094	-70.6120094	11.3879906	11.3938703	5.88E-03
12	3.056218131	150.6120094	-70.6120094	11.3879906	11.3938703	5.88E-03
13	3.055926119	150.6100943	-70.61009429	11.38990571	11.3927816	2.88E-03
14	3.055780113	150.6091367	-70.60913667	11.39086333	11.3922373	1.37E-03
15	3.05570711	150.6086578	-70.60865784	11.39134216	11.3919651	6.23E-04
16	3.055670609	150.6084184	-70.60841842	11.39158158	11.3918291	2.47E-04
17	3.055652358	150.6082987	-70.60829871	11.39170129	11.391761	5.97E-05
18	3.055652358	150.6082987	-70.60829871	11.39170129	11.391761	5.97E-05
19	3.055647795	150.6082688	-70.60826879	11.39173121	11.391744	1.28E-05
20	3.055647795	150.6082688	-70.60826879	11.39173121	11.391744	1.28E-05

Table 4: The numerical iteration results obtained when the data in Table 1 was used to run the iteration algorithm in section 2.3 for ESUI terrain B

Iteration Cycle	Transmission Range	Propagation Loss by ESUI Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
1	4	149.6884	-69.6884	12.31158	14.91238	2.60E+00
2	3.825595	148.8815	-68.8815	13.11845	14.26218	1.14E+00
3	3.738392	148.4642	-68.4642	13.53579	13.93708	4.01E-01
4	3.694791	148.2519	-68.2519	13.74813	13.77453	2.64E-02
5	3.694791	148.2519	-68.2519	13.74813	13.77453	2.64E-02
6	3.694791	148.2519	-68.2519	13.74813	13.77453	2.64E-02
7	3.694791	148.2519	-68.2519	13.74813	13.77453	2.64E-02
8	3.692066	148.2385	-68.2385	13.76148	13.76437	2.89E-03

9	3.692066	148.2385	-68.2385	13.76148	13.76437	2.89E-03
10	3.692066	148.2385	-68.2385	13.76148	13.76437	2.89E-03
11	3.692066	148.2385	-68.2385	13.76148	13.76437	2.89E-03
12	3.691896	148.2377	-68.2377	13.76231	13.76374	1.42E-03
13	3.691811	148.2373	-68.2373	13.76273	13.76342	6.87E-04
14	3.691768	148.2371	-68.2371	13.76294	13.76326	3.20E-04
15	3.691747	148.237	-68.237	13.76305	13.76318	1.36E-04
16	3.691736	148.2369	-68.2369	13.7631	13.76314	4.42E-05

Table 5 The numerical iteration results obtained when the data in Table 1 was used to run the iteration algorithm in section 2.3 for ESUI terrain C

Iteration Cycle	Transmission Range	Propagation Loss by ESUI Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
1	4	146.00544	-66.00544	15.99456	14.912378	-1.0821821
2	4.0725694	146.30997	-66.309971	15.690029	15.182924	-0.507105
3	4.1088541	146.46021	-66.460208	15.539792	15.318197	-0.2215955
4	4.1269964	146.53483	-66.534829	15.465171	15.385833	-0.0793375
5	4.1360676	146.57202	-66.572017	15.427983	15.419651	-0.0083314
6	4.1360676	146.57202	-66.572017	15.427983	15.419651	-0.0083314
7	4.1360676	146.57202	-66.572017	15.427983	15.419651	-0.0083314
8	4.1360676	146.57202	-66.572017	15.427983	15.419651	-0.0083314
9	4.1366345	146.57434	-66.574339	15.425661	15.421765	-0.0038963
10	4.136918	146.5755	-66.5755	15.4245	15.422822	-0.0016788
11	4.1370598	146.57608	-66.57608	15.42392	15.42335	-0.0005701
12	4.1371306	146.57637	-66.57637	15.42363	15.423614	-1.574E-05

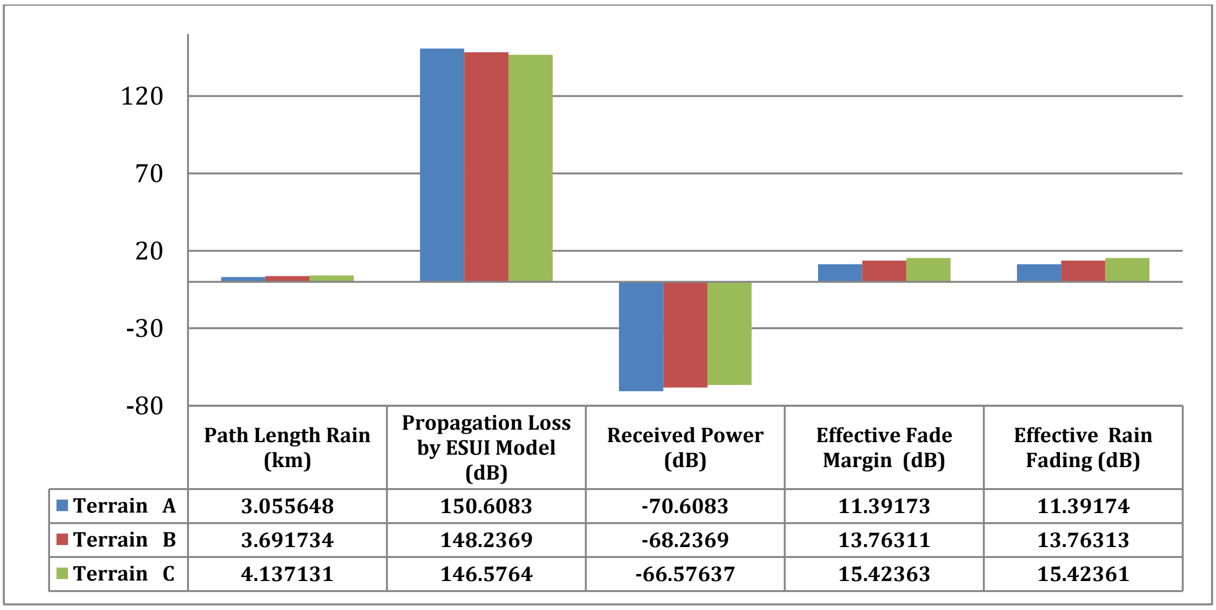

Figure 2. Comparison of the numerical iteration results obtained for ESUI terrain A, terrain B and terrain C

IV. CONCLUSION

The mathematical expressions and algorithm for the computation of optimal transmission range of microwave communication link is presented. The optimal transmission range was based on Extended Stanford University Interim (ESUI) propagation loss model. Sample numerical example was presented using a data set of a typical microwave communication link. The computation was carried out in Matlab software for the three different terrains specified in

ESUI model. The results show that with ESUI model, the terrain parameters have more impact on the value of the propagation loss than the distance. As such, the ESUi terrain A presented the highest propagation loss and the lowest transmission range.

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