ANALYSIS OF PATH LOSS EXPONENT IMPACT ON THE EFFECTIVE PATH LENGTH OF MICROWAVE LINK BASED ON STANFORD UNIVERSITY INTERIM PATH LOSS MODEL

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***Abstract*— In this paper, analysis of path loss exponent impact on the effective path length of microwave link based on Stanford University Interim (SUI) path loss model is presented. In wireless communication link design, the effective path length is different from the maximum transmission range computed based on pathloss model alone. As such, the effective path length is defined as the path length at which the fade margin is equal to the fade depth at the required link percentage availability and bit error rate performance. The computation of the effective path length in this paper is conducted using numerical iteration approach. Mathlab program was written and used to compute the effective path length for a case study 10 GHz microwave link located in the ITU rain zone N region with rain rate, $R_{0.01}$ of 95 mm/hr. The computation was conducted for six (6) different path loss exponents. The results showed that the indoor environment has the highest path loss exponent value of 5, the lowest effective path length of 3.03423865 km and the highest propagation loss of 156.6880812 dB based on SUI model. Conversely, the free space region in urban area has the lowest path loss exponent value of 2, the highest effective path length of 11.79669587 km and the lowest propagation loss of 124.0208021 dB based on SUI model. In essence, the path loss exponent in SUI model has greater impact than the distance given that the link with the lowest path loss exponent has the lowest propagation loss but the highest effective path length. In all, the effective path length is inversely proportional to the path loss exponent while the propagation loss is directly proportional to the path loss exponent.**

Keywords*— *Path Loss Model, Stanford University Interim (SUI) Model, Path Loss Exponent, Effective Path Length, Propagation Loss

I. INTRODUCTION

In wireless communication links, due to different factors, signals suffer diverse losses as they propagate from the source device to the destination device [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16]. The extent of propagation losses that is suffered by the signals depend among other things on the environmental factors and network related issues. Accordingly, different environments present different degree of propagation losses to the signals [17,18,19,20]. The differences in the environmental factors that determine the extent of propagation losses signal can experience in those environments are captured as pathloss exponents in some pathloss models. One of such models with pathloss exponent is the Stanford University Interim (SUI) model which was the product of collaborative research conducted by Stanford University and 802.16 IEEE group [21,22,23,24,25,26,27,28].

In this paper, the focus is on the study of the impact of pathloss exponent on the effective transmission range of microwave link based on SUI path loss model. The effective path length is different from the maximum transmission range based on the pathloss model. Rather , the effective path length is the path length at which the fade margin is equal to the fade depth at the required link percentage availability and bit error rate performance. The computation of the effective path length in this paper is conducted using numerical iteration approach. The computation was done using Mathlab software. Also, the computation was done for various values of pathloss exponents and the resulting tables and graph plots were used to determine the impact of the pathloss exponent on the effective transmission range of microwave link based on SUI path loss model.

II. METHODOLOGY

A. PATH LOSS BASED ON THE STANFORD UNIVERSITY INTERIM MODEL

Stanford University Interim (SUI) model was the product of collaborative research conducted by Stanford University and 802.16 IEEE group. The path loss, $LP_{SUI(dB)}$ estimated by SUI model is given is given by the following expressions [21,22,23,24,25,26,27,28]:

$$LP_{SUI(dB)} = A + 10\gamma\left(\log_{10}\left(\frac{d}{d_0}\right)\right) + X_f + X_h + S \; for \; d > d_0 \quad (1)$$

Where,

d is the distance in meters between mobile device and the base station antennas

f is the frequency in MHz

d_0=100m

$X_h$is the correction for receiving the antenna height in meters

γ is the path loss exponent

X_f is the correction for frequency in MHz

S is the correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of trees and other clutters on the path

The parameter A is defined as:

$$A = 20\left(\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)\right) \quad (2)$$

and the path loss exponent, γ is given by:

$$\gamma = a + b(h_b) + \frac{c}{h_b} \quad (3)$$

Although it is more suitable for suburban areas, however, there is path loss exponent, γ that is used to adjust the pathloss for other types of areas where for free space Path in an urban area , $\gamma = 2$; for non line of sight environment in an urban area 3 <γ< 5, and for indoor Path , γ> 5. Also, h_b = base station antenna height in meters and 10 m <h_b< 80 m .

The SUI correction factor for frequency is X_f and the SUI receiver antenna height correction factor X_h are given as;

$$X_f = 6\left(\log_{10}\left(\frac{f}{2000}\right)\right) \quad (4)$$

$$X_h = \begin{cases} -10.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type A and B} \\ -20.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type C} \end{cases} \quad (5)$$

Where, f is in MHz, and h_m (receiver antenna height) is in meter. Furthermore, the terrain dependent constants a, b and c are given in Table 1.

Table 1 The values for SUI terrain dependent parameter a, b and c

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

Type A terrain is for hilly terrain that has moderate to heavy foliage densities. Type B is suitable for flat terrains where there is moderate to heavy tree densities. It is also applicable to hilly terrains where there are light tree densities. Type C terrain is the terrain with the minimum path loss and it is for flat terrain where there are light tree densities.

B. COMPUTATION OF THE EFFECTIVE PATH LENGTH BASED ON SUI PATH LOSS MODEL

If the path length is denoted as d_{SUI} then, the path loss by **SUI** model is LP_{SUI_e} where :

$$LP_{SUI(dB)} = A + 10\gamma\left(\log_{10}\left(\frac{d_{SUI}}{d_0}\right)\right) + X_f + X_h + S \text{ for } d_{SUI} > d_0 \quad (6)$$

Based on link budget equation, the received power (P_{RSUI}) is:

$$P_{RSUI} = P_T + G_T + G_R - LP_{SUI(dB)} \quad (7)$$

Accordingly, the fade margin (fm_{SUI}) is:

$$fm_{SUI} = (P_T + G_T + G_R) - LP_{SUI(dB)} - P_S \quad (8)$$

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)

$LP_{SUI(dB)}$ = Path loss based on SUI Path loss model

The rain fade depth (fd_{mSUI}) is [29,30,31,32];

$$fd_{mSUI} = \max\left(\left(K_v\left(R_{po}\right)^{\alpha_v}\right) * d_{SUI}, \left(K_h\left(R_{po}\right)^{\alpha_h}\right) * d_{SUI}\right) \quad (9)$$

The effective path length with path loss based on SUI model is denoted as, d_{eSUI} where d_{eSUI} is the value of d_{SUI} for which $fd_{mSUI} = fm_{SUI}$.

$$d_{eSUI} = d_{SUI} \text{ when } fd_{mSUI} = fm_{SUI} \quad (10)$$

C. THE FLOWCHART FOR THE COMPUTATION OF THE EFFECTIVE PATH LENGTH BASED ON SUI PATH LOSS MODEL

The value of d_{eSUI} for any given set of link parameters can be found suing numerical iteration method. In this paper, for the SUI model, the initial Path length (d_0) is 100 m. The flowchart used to compute the effective path length based on SUI path loss model is given in Figure 1.

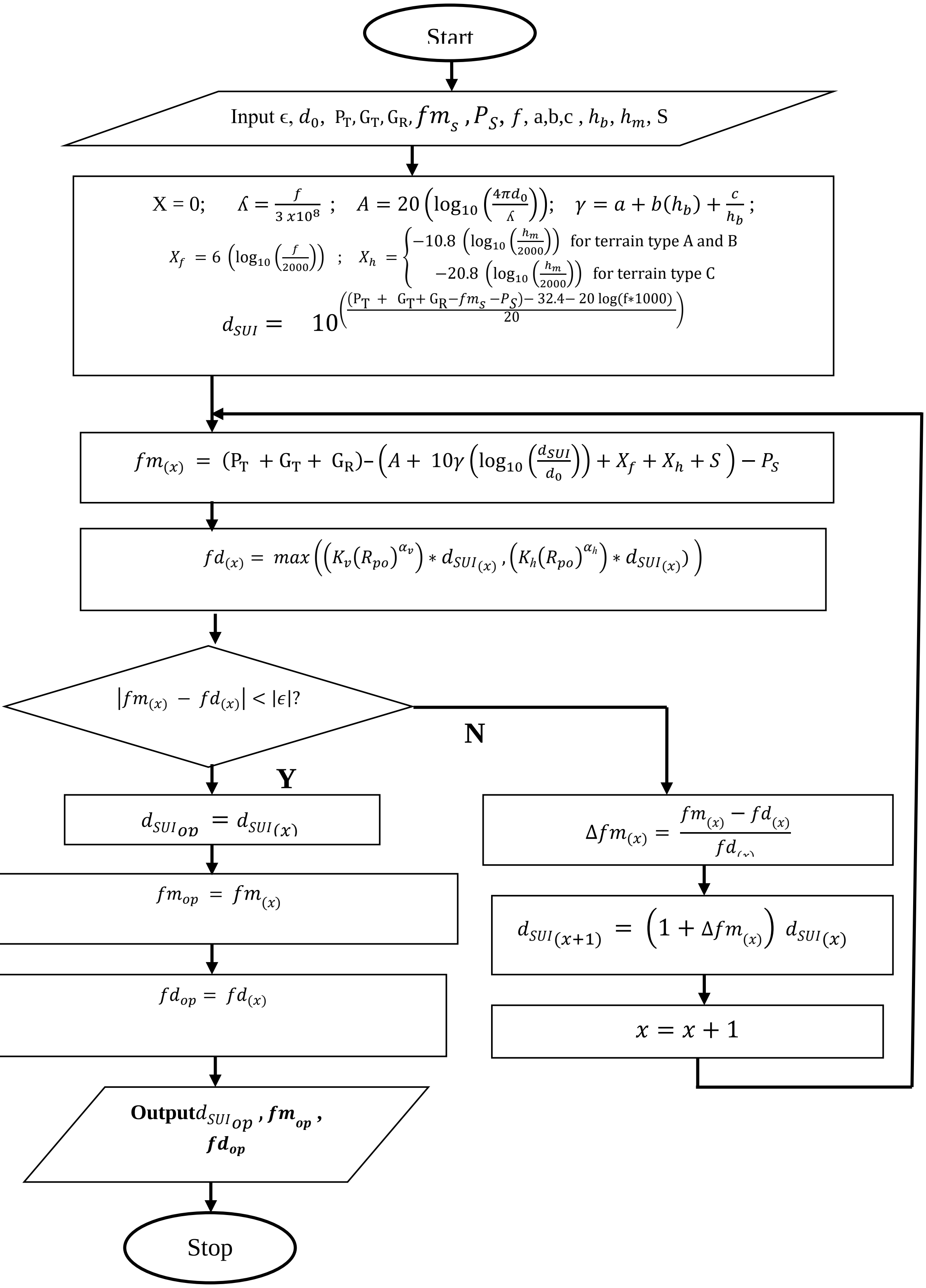

Figure 1 The flowchart used to compute the effective path length based on SUI path loss model

III. RESULTS AND DISCUSSION

A program for the numerical iteration flowchart in Figure 1 was used in Mathlab to compute the effective path length for a 10 GHz microwave link located in the ITU rain zone N region with rain rate, $R_{0.01}$ of 95 mm/hr (as shown in Table 2) . The computation was conducted for six (6) different path loss exponents and the results are shown in Table 3. Also, the comparison of the effective path length for the six (6) different path loss exponent cases is shown in Figure 2 while the comparison of the effective propagation loss for the six (6) different path loss exponent cases is shown in Figure 3.

According to the results in Table 3, figure 2 and Figure 3, the indoor environment has the highest path loss exponent value of 5, the lowest effective path length of 3.03423865 km and the highest propagation of 156.6880812 dB based on SUI model. Conversely, the free space region in urban area has the lowest path loss exponent value of 2, the highest effective path length of 11.79669587 km and the lowest propagation of 124.0208021 dB based on SUI model. The results show that the path loss exponent in SUI model has greater impact than the distance given that the link with the lowest path loss exponent has the lowest propagation loss but the highest effective path length. Similar results are observed with the link with the highest path loss exponent. In all, the effective path length is inversely proportional to the path loss exponent while the propagation loss is directly proportional to the path loss exponent.

Table 2 The microwave link parameter values used in the Mathlab-based iteration process

S/N	Parameter Name and Unit	Parameter Value	S/N	Parameter Name and Unit	Parameter Value
1	F (MHz)	10000	7	kh	0.01217
2	Transmitter power, PT(dB)	10	8	ah	1.2571
3	Transmitter antenna Gain, GT(dB)	20	9	kv	0.01129
4	Receiver antenna gain, GR (dB)	20	10	av	1.2156
5	Receiver sensitivity, Ps (dB)	-88	11	Rain Zone	N
6	Fade Margin (dB)	10	12	Rain Rate at 0.01 % outage probability, R0.01 mm/hr	95

Table 3 The iteration results for six (6) different path loss exponent.

S/N	Parameter Name And Unit	Free Space Region In Urban Area	Non Line Of Sight Environment In An Urban Area	Terrain C : Terrain Is The Terrain With The Minimum Path Loss And It Is For Flat Terrain Where There Are Light Tree Densities	Terrain B : Flat Terrains Where There Is Moderate To Heavy Tree Densities Or Hilly Terrains Where There Are Light Tree Densities.	Terrain A : Hilly Terrain That Has Moderate To Heavy Foliage Densities	Indoor Environment
		γ(1)	**γ(2)**	**γ(3)**	**γ(4)**	**γ(5)**	**γ(6)**
1	**Path Loss Exponents (γ)**	**2**	**3.5**	**3.9000**	**4.1675**	**4.6150**	**5**
2	**Convergence Cycle**	**5**	**4**	**4**	**5**	**5**	**2**
3	**Transmission Range (km)**	**11.79669587**	**6.130011836**	**6.8911**	**4.4666**	**3.6183**	**3.03423865**
4	**Propagation Loss by SUI Urban Model (dB)**	**124.0208021**	**145.1467404**	**142.3094**	**151.3482**	**154.5106**	**156.6880812**
5	**Received Power (dB)**	**-44.02080208**	**-65.14674038**	**-62.3094**	**-71.3482**	**-74.5106**	**-76.68808122**
6	**Effective Fade Margin**	**43.97926555**	**22.85325962**	**25.6906**	**16.6518**	**13.4894**	**11.31191878**

	(dB)						
7	Effective Rain Fade Depth(dB)	43.97919803	22.85326394	25.6959	16.6585	13.4894	11.31192868
8	Error (dB)	-6.75E-05	4.32E-06	5.23E-03	6.67E-03	-4.39E-05	9.90E-06

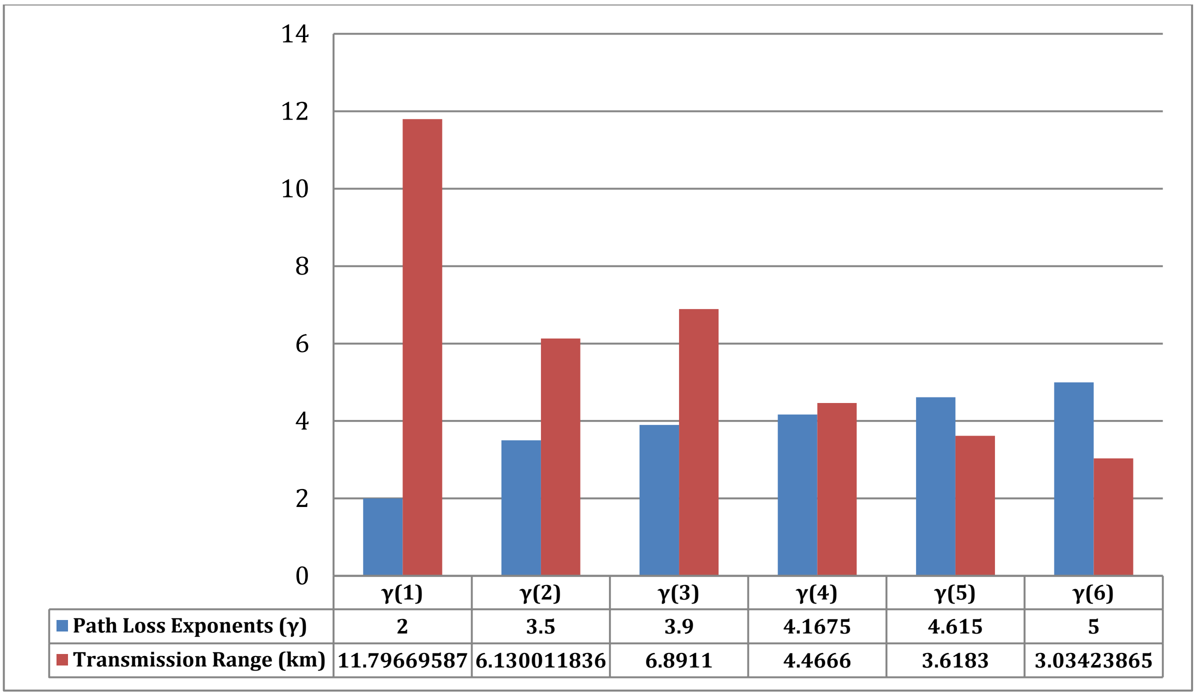

Figure 2 Comparison of the effective path length for the six (6) different path loss exponents

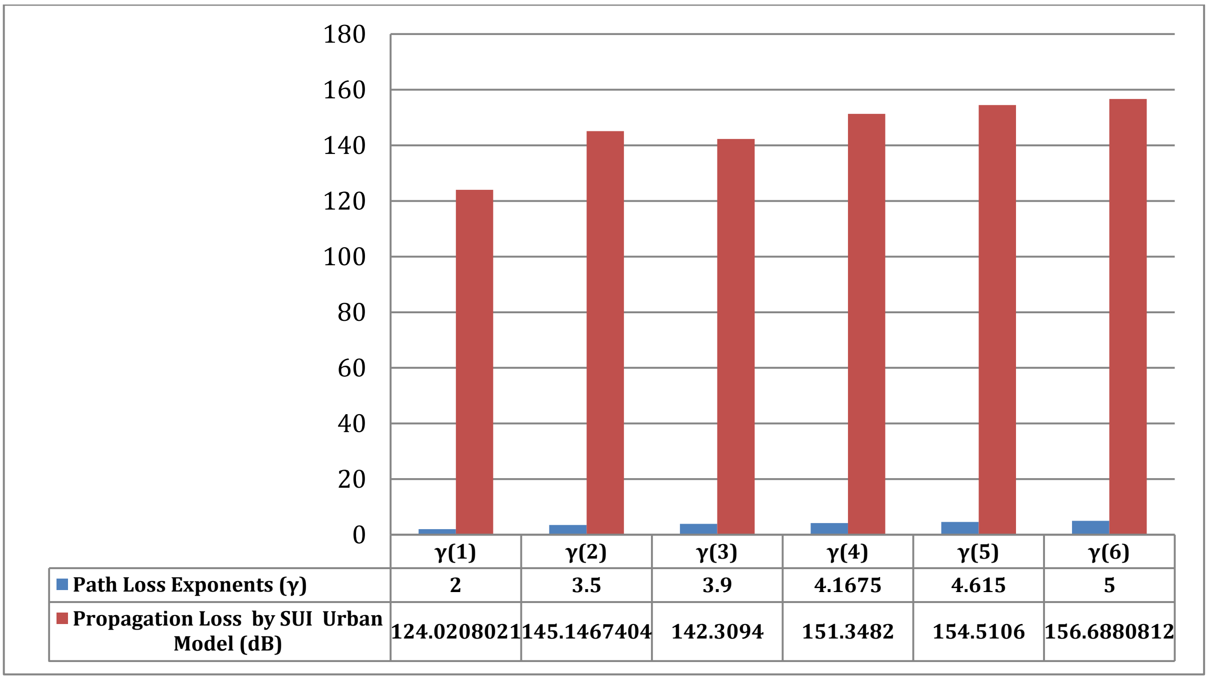

Figure 3 Comparison of the effective propagation loss for the six (6) different path loss exponents

IV. CONCLUSION

Stanford University Interim (SUI) propagation loss model was used in link budget equation to compute the path length of a microwave link. The link budget expression was used along with rain fade depth to determine the optimal or effective path length of the link. A Mathlab program written for a numerical iteration flowchart was used for the computation of the effective path length for a sample Ku-band microwave link. The computation was conducted for six (6) different path loss exponents. The results showed that the indoor environment with the highest path loss exponent had the lowest effective path length whereas the free space environment with the lowest path loss exponent had the highest effective path length. In all, it was deduced from the results that the effective path length is inversely proportional to the path loss exponent while the propagation loss is directly proportional to the path loss exponent.

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