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Shibuya Method and Modified ITU Knife Edge Diffraction Loss Model for Computing N Knife Edge Diffraction Loss

Kalu Okore Ama, Constance Kalu, Aneke Chikezie

Department of Electrical/Electronic and Computer Engineering, University of Uyo, Uyo, Nigeria

Email address:

constance.kalu@yahoo.com (C. Kalu)

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Abstract: In this paper, algorithm for applying Shibuya multiple knife edge diffraction method and modified ITU-R P 526-13 knife edge diffraction loss approximation model are presented. Particularly, in this paper, algorithm for using the two models for computing N knife edge diffraction loss is presented. Requisite mathematical expressions for the computations are first presented before the algorithm is presented. Then sample 10 knife edge obstructions are used to demonstrate the application of the algorithm for C-band 6 GHz microwave link. The results showed that for the 10 knife edge obstructions spread over a path the maximum virtual hop single knife edge diffraction loss is 14.97452dB and it occurred in virtual hop j =6 which has the highest diffraction parameter of 1.027072 and the highest line of site (LOS) clearance height of 8.480769m. The minimum virtual hop single knife edge diffraction loss is 7.881902 dB and it occurred in virtual hop j =9 which has the lowest diffraction parameter of 0.114761 as well as the lowest LOS clearance height of 0.628571m. The algorithm is useful for development of automated multiple knife edge diffraction loss system based on Shibuya method and the modified ITU-R P 526-13 knife edge diffraction loss approximation model.

Keywords: Single Knife Edge Diffraction, Diffraction Loss, ITU-R P 526-13 Model, Diffracting Parameter, Knife Edge Obstruction, Multiple Knife Edge Diffraction, Shibuya Diffracting Method

1. Introduction

Diffraction loss is one of the key components of pathloss that is udsed in link budget for line of sight (LOS) microwave link [1-5]. Diffraction occurs when wireless signal encouter obstacle in its path [7-11]. In such case, the signal bend and hence move round the obstacle to the receiver. The diffracted signal experiences loss in signal strenght which is reffered to as diffraction loss.

Huygens-Fresnel principle is used to explain the diffraction concept [11-13]. Particularly, in order to simplify the analysis of diffraction loss, an isolated obstruction like hill or building can be considered as a knife edge obstruction [14-16]. When there are two or more of such knife edge obstructions, then multiple knife edge diffraction loss methods can be employed to determine the effective diffraction loss of all the knife edge obstructions [17].

Available studies show that computation of multiple knife edge diffraction is quite complex [18-20]. The complexity increases with increasing number of obstructions considered. As such, most studies limit the multiple knife edge computation to three obstructions. In this paper, algorithm is presented which can be used to compute diffraction loss for any number of knife edge obstructions. The algorithm is based on the use of Shibuya multiple knife edge diffraction method and the modified ITU-R P 526-13 knife edge diffraction loss approximation model are presented. Sample 10 knife edge obstructions are used to demonstrate the applicability of the algorithm.

2. Methodology

Present studies on multiple knife edge diffraction loss computation limit the number of obstructions considered to a maximum of three. This is due to the fact that complexity of the computation increases so much as the number of obstructions increases. This paper focuses on presenting a method computing multiple knife edge diffraction loss where as muany as ten obstructions are considered. The computation is based on the Shibuya Multiple knife edge diffraction loss method. The mathematical expressions are presented for N-knife edge obstruction. The N knife edge obstructions with n =1,2,3,…,N-1,N is shown in Figure 1. The transmiter is denoted with N = 0 and the receiver is designated as N+1. In the computation, each of the N obstructions gave rise to a virtual hop which resulted in a knife edge diffraction loss. The overall diffraction loss, according to the Shibuya method is the sum of the diffraction loss computed for each of the N virtual hops. Accordingly, in figure 1 with the N knife edge obstructions there are N virtual hops. The first three virtual hops are;

i. Hop1: H_0-H_1-H_2 with H1 as the diffraction edge
ii. Hop2: H_1-H_2 -H_3 with H2 as the diffraction edge
iii. Hop3: H_2 -H_3 -H_4 with H3 as the diffraction edge

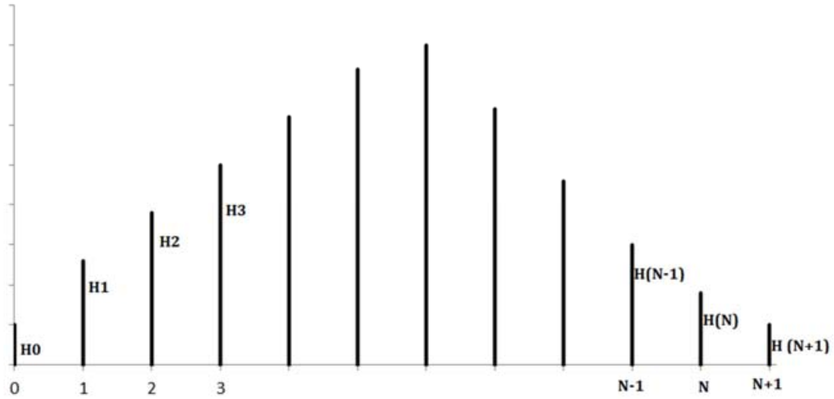

Figure 1. *Link With N Knife Edge Obstructions.*

In figure 1, H_j is the height of the obstruction from the sea level. Idealy, H_j takes into account the earth bulge, the elevation and the obstruction height measured from the ground level. Again, j =0 referes to the receiver whereas j =N+1 referes to the transmitter. J = 1 to J = N referes to the obstructions 1,2,3,…N respectively.

Shibuya method relies on the assumption that the ray grazing the obstacles at edge H_j and H_{j+1} generates a fictitious transmitter E_j [19-21]. The procedure for determination of the attenuation due to the diffraction by multiple knife edges is the same as in the Epstein-Peterson method with the difference however that the transmitter E is replaced here by a fictitious transmitter (Shibuya 1983). According to Shibuya multiple knife edge diffraction loss method, for any given hop j, the clearance height to its LOS is given as h_j where [19-21];

$$h_{shibuya(j)} = \left(H_j - H_{E(j-1)}\right) - \left(\frac{(d_1+\cdots+d_j)(H_{j+1} - H_{E(j-1)})}{d_1+\cdots+d_{j+1}}\right) \quad (1)$$

The transmitter height in hop j can be denoted $H_{E(j)}$, where;

$$H_{E(j)} = H_j + \frac{(d_1+\cdots+d_j)(H_j - H_{j+1})}{d_{j+1}} \quad (2)$$

The knife-edge diffraction parameter for any hop j is given as v_j where [19-21];;

$$v_j = h_{shibuya(j)}\sqrt{\frac{2(d_j+d_{j+1})}{\lambda(d_j)(d_{j+1})}} \quad (3)$$

For any given diffraction parameter, v the knife-edge diffraction loss, A according to ITU-R P 526-13 model is given as [22];

$$A = 6.9 + 20\text{Log}\left(\left(\sqrt{(v-0.1)^2+1}\right) + v - 0.1\right) \text{ where A is in dB} \quad (4)$$

Then, in respect of knife-edge diffraction loss for any hop j with diffraction parameter, v_j, the knife-edge diffraction loss is denoted as A_j, where ITU approximation model for A_j is given as;

$$A_j = 6.9 + 20\text{Log}\left(\left(\sqrt{(v_j-0.1)^2+1}\right) + v_j - 0.1\right) \text{ where } A_j \text{ is in dB} \quad (5)$$

According to the Shibuya multiple diffraction loss method, the effective diffraction loss for all the m hops is given as;

$$A = A_1 + A_2 + \cdots + A_m = \sum_{j=1}^{j=m}(A_j) \quad (6)$$

$$A = \sum_{j=1}^{j=m}\left(6.9 + 20\text{Log}\left(\left(\sqrt{(v_j-0.1)^2+1}\right) + v_j - 0.1\right)\right) \quad (7)$$

The original ITU-R P 526-13 knife edge diffraction loss approximation model is modified by replacing it with equivalent piecewise model that consists of linear function and linear –log functions without radical terms. The modified ITU knife edge diffraction loss approximation model is given as;

$$\mathrm{A}(0,v)=\begin{cases} 8.268798105(V)\ +\ 6.854646186 & -0.57<v<0 \\ 7.774337048(V)\ +\ 6.989712422 & 0\le v<1.414214 \\ 7.21468405[LN(V)]\ +\ 14.44900823\ ; & 1.414214\le v<2.828427 \\ 8.674978541\ [LN(V)]\ +\ 13.043467 & v\ge 2.828427 \end{cases} \tag{8}$$

Where

- V is diffraction parameter, has no unit
- $\mathrm{A}(0,v)$ is the diffraction loss in dB. $\mathrm{A}(0,v)$ means that the diffraction loss is given by the piecewise functions of v in the specified ranges of values of v. Beyond the specified range of values of v the value of $\mathrm{A}(0,v)$ is zero.

The modified ITU knife edge diffraction loss approximation model can further be simplified as;

$$\mathrm{A}(0,v)=U[\mathrm{A}(v)]+W \tag{9}$$

Where

U and W are constants and $\mathrm{A}(v)$ is a function of diffraction parameter, v. The values of U, W and function $\mathrm{A}(v)$ are given in 1.

Table 1. *The values of U, W and function $\mathrm{A}(v)$ for the modified ITU knife edge diffraction loss approximation model.*

Range of Values of the Diffraction Parameter, V	**Range of Values of the LOS Percentage Clearance of the First Fresnel Zone, P**	**U**	**W**	**$\mathrm{A}(v)$**
$-0.57\le v<0$	-40%<P≤0%	8.268798105	6.854646186	v
$0\le v<1.414214$	0%<p≤100%	7.774337048	6.989712422	v
$1.414214\le v<2.828427$	100%<P≤200%	7.21468405	14.44900823	LN(v)
$v\ge 2.828427$	P>200%	8.674978541	13.043467	LN(v)

Again, for Shibuya method the effective multiple knife edge diffraction loss, $\mathrm{A}(0,v)$ is given as;

$$\mathrm{A}(0,v)\ =\ \mathrm{A}(0,v_1)+\mathrm{A}(0,v_2)+\cdots+\mathrm{A}(0,v_n)\ =\ \textstyle\sum_{i=1}^{i=n}\big(\mathrm{A}(0,v_i)\big) \tag{10}$$

$$\mathrm{A}(0,v)=\textstyle\sum_{i=1}^{i=n}(U_i[\mathrm{A}(v_i)]+W_i) \tag{11}$$

Where i = 1,2,3,…n and $\mathrm{A}(0,v_i)$ is given as;

$$\mathrm{A}(0,v_i)=\begin{cases} 8.268798105(v_i)\ +\ 6.854646186 & -0.57<v_i<0 \\ 7.774337048(v_i)\ +\ 6.989712422 & 0\le v_i<1.414214 \\ 7.21468405[LN(v_i)]\ +\ 14.44900823 & 1.414214\le v_i<2.828427 \\ 8.674978541\ [LN(v_i)]\ +\ 13.043467 & v_i\ge 2.828427 \end{cases} \tag{12}$$

Let n_a be the number of knife edges with diffraction parameter (v_i) values in the range $-0.57<v_i<0$. Let n_b be the number of knife edges with diffraction parameter (v_i) values in the range $0\le v_i<1.414214$. Let n_c be the number of knife edges with diffraction parameter (v_i) values in the range $1.414214\le v_i<2.828427$. Let n_d be the number of knife edges with diffraction parameter (v_i) values in the range $v_i\ge 2.828427$

Where

$$n_a+n_b+n_c+n_d=n \tag{13}$$

For all the n_a knife edge obstructions in the range $-0.57<v_i<0$, the total diffraction loss is denoted as $\mathrm{A}_a(0,v)$ where;

$$\mathrm{A}_a(0,v)=\textstyle\sum_{j=1}^{j=na}(U_a[\mathrm{A}_a(v_i)]+W_a) \tag{14}$$

$$\mathrm{A}_a(0,v)=n_a(W_a)+U_a\left(\textstyle\sum_{j=1}^{j=na}\left(\mathrm{A}_a(v_j)\right)\right) \tag{15}$$

Similarly, for all the n_b knife edge obstructions in the range $0\le v_i<1.414214$, the total diffraction loss is denoted as $\mathrm{A}_b(0,v)$

$$\mathrm{A}_b(0,v)=n_b(W_b)+U_b\left(\textstyle\sum_{j=1}^{j=nb}\left(\mathrm{A}_b(v_j)\right)\right) \tag{16}$$

For all the n_c knife edge obstructions in the range $1.414214\le v_i<2.828427$, the total diffraction loss is denoted as $\mathrm{A}_c(0,v)$

$$\mathrm{A}_c(0,v)=n_c(W_c)+U_c\left(\textstyle\sum_{j=1}^{j=nc}\left(\mathrm{A}_c(v_j)\right)\right) \tag{17}$$

For all the n_d knife edge obstructions in the range $v_i\ge 2.828427$, the total diffraction loss is denoted as $\mathrm{A}_d(0,v)$

$$\mathrm{A}_d(0,v)=n_d(W_d)+U_d\left(\textstyle\sum_{j=1}^{j=nd}\left(\mathrm{A}_d(v_j)\right)\right) \tag{18}$$

Furthermore, for $\mathrm{A_a(0,v)}$, $\mathrm{A_a(v_i)=v_i}$, then;

$$\mathrm{A}_a(0,v)=n_a(W_a)+U_a\big(\textstyle\sum_{j=1}^{j=na}(v_j)\big) \tag{19}$$

Also, for $A_b(0, v)$, $A_b(v_i) = v_i$, then;

$$A_b(0, v) = n_b(W_b) + U_b\left(\sum_{j=1}^{j=nb}(v_j)\right) \quad (20)$$

However, for $A_c(0, v)$, $A_c(v_i) = LN(v_i)$. Hence,

$$\sum_{j=1}^{j=nc}\left(A_c(v_j)\right) = LN(v_1) + LN(v_2) + \cdots + LN(v_{nc}) \quad (21)$$

$$\sum_{j=1}^{j=nd}(A_c(v_i)) = LN((v_1)(v_2)(v_3)\ldots(v_{nd})) = LN\left(\prod_{j=1}^{j=nc}(v_j)\right) \quad (22)$$

$$A_c(0, v) = n_c(W_c) + U_c\left[LN\left(\prod_{j=1}^{j=nc}(v_j)\right)\right] \quad (23)$$

Likewise, for $A_d(0, v)$, $A_d(v_i) = LN(v_i)$

$$A_d(0, v) = n_d(W_d) + U_d\left[LN\left(\prod_{j=1}^{j=nd}(v_j)\right)\right] \quad (24)$$

Therefore, the effective diffraction loss by the multiple knife edeg diffracting obstructions is given as;

$$A(0, v) = A_a(0, v) + A_b(0, v) + A_c(0, v) + A_d(0, v) \quad (25)$$

$$A(0, v) = \{n_a(W_a) + U_a(\sum_{j=1}^{j=na}(v_j))\} + \{n_b(W_b) + U_b(\sum_{j=1}^{j=nb}(v_j))\} + \{n_c(W_c) + U_c[LN(\prod_{j=1}^{j=nc}(v_j))]\} + \{n_d(W_d) + U_d[LN(\prod_{j=1}^{j=nd}(v_j))]\} \quad (26)$$

$$A(0, v) = n_a(W_a) + n_b(W_b) + n_c(W_c) + n_d(W_d) + U_a(\sum_{j=1}^{j=na}(v_j)) + U_b(\sum_{j=1}^{j=nb}(v_j)) + U_c[LN(\prod_{j=1}^{j=nc}(v_j))] + U_d[LN(\prod_{j=1}^{j=nd}(v_j))] \quad (27)$$

3. The Procedure for Computing N Knife Edge Diffraction Loss Using Epstein-Peterson Method

The Procedure for computing N knife edge diffraction loss using Epstein-Peterson method and the modified ITU knife edge diffraction loss approximation model is as follows:

Step 1: For j = 0 to N +1 obtain height H(j) of obstruction, where j includes the transmitter with j=0, the receiver with j =N +1and the N obstructions with j =1 to N.

Step 2: For j=1 To N +1 obtain the distance d(j) of obstruction (j) from obstruction (j-1)

Step 3: For j = 1 to N compute the virtual transmitter height in hop j denoted as $H_{E(j)}$ (Use Eq 2)

Step 4: For j = 1 to N compute the LOS clearance heights $h_j = h_{shibuya(j)}$ (Use Eq 1)

Step 4: For j = 1 to N compute the knife-edge diffraction parameter (v_j) for each h_j (Use 3)

Step 5: For all $-0.57 \le v_j < 0$ compute $A_a(0, v) = n_a(W_a) + U_a\left(\sum_{j=1}^{j=na}(v_j)\right)$ (Use Eq 15; W_a and U_a are obtained from Table 1 for -0.57≤v<0. Where n_a is the number of v_j in the range $-0.57 \le v_j < 0$.

Step 5: For all $0 \le v_j < 1.414214$ compute $A_b(0, v) = n_b(W_b) + U_b\left(\sum_{j=1}^{j=nb}(v_j)\right)$ (Use Eq 16; W_b and U_b are obtained from Table 1 for $0 \le v < 1.414214$. Where n_b is the number of v_j in the range $0 \le v_j < 1.414214$.

Step 6: For all $1.414214 \le v_j < 2.828427$ compute $A_c(0, v) = n_c(W_c) + U_c\left[LN\left(\prod_{j=1}^{j=nc}(v_j)\right)\right]$ (Use Eq 17; W_c and U_c are obtained from Table 1 for $1.414214 \le v < 2.828427$. Where n_c is the number of v_j in the range $1.414214 \le v_j$ 2.828427.

Step 7: For all $v_j \ge 2.828427$ compute $A_d(0, v) = n_d(W_d) + U_d\left[LN\left(\prod_{j=1}^{j=nd}(v_j)\right)\right]$ (Use Eq 18; W_d and U_d are obtained from Table 1 $v \ge 2.828427$. Where n_d is the number of v_j in the range $v_j > 2.828427$.

Step 8: $A(0, v) = A_a(0, v) + A_b(0, v) + A_c(0, v) + A_d(0, v)$ (Use Eq 25)

4. Numerical Example and Discussion of Results

Ten (10) knife edge obstructions located in a 6 GHz C-band microwave link is used for the numerical example. In this case, N = 10. The height, H(j) of the obstructions for j = 0 to j = N +1 are given in Table 2 while Table 3 shows the distance d(j) of obstruction (j) from obstruction (j-1) for j=1 to j= N+1. The results of the computations are presented according to the steps given in the algorithm. In all, for the given 10 obstructions, the total diffraction loss is 92.15261 dB.

Result for Step 1: The height H(j) of obstruction for j = 0 to N +1, where j includes the transmitter with j=0, the receiver with j =N +1and the N obstructions with j =1 to N.

Table 2. *Height H(j) of obstruction for j = 0 to N, where j includes the transmitter with j=0, the receiver with j =N and the N obstructions with j =1 to N.*

j	Height H(j)	Height in m
0	H0	10
1	H1	18
2	H2	24
3	H3	30
4	H4	36
5	H5	42
6	H6	45
7	H7	37
8	H8	28
9	H9	20
10	H10	14
11	H11	10

Result for Step 2: The distance d(j) of obstruction (j) from obstruction (j-1) for j=1 to N+1.

Table 3. *The distance d(j) of obstruction (j) from obstruction (j-1) for j=1 to N+1.*

j	d(j)	Distance in km
1	d1	1
2	d2	2
3	d3	3
4	d4	4
5	d5	5

j	d(j)	Distance in km
6	d6	6
7	d7	5
8	d8	4
9	d9	3
10	d10	2
11	d11	1
	d	36

Result for Step 3: The LOS clearance heights $h_j = h_{Epstein(j)}$ for 1 to N. The results are given in Table 4.

Table 4. *LOS clearance heights* $h_j = h_{Epstein(j)}$ *for 1 to N.*

j	h_j	LOS clearance heights in m
1	h1	3.333333
2	h2	1.5
3	h3	1.2
4	h4	1
5	h5	3
6	h6	8.480769
7	h7	2.253333
8	h8	1.136364
9	h9	0.628571
10	h10	0.972222

Result for Step 4: For j = 1 to N compute the knife-edge diffraction parameter (v_j) for each h_j.The results are given in Table 5.

Table 5. *the knife-edge diffraction parameter* (v_j) *for j = 1 to N.*

j	v_j	Diffraction Parameter
1	v1	0.816497
2	v2	0.273861
3	v3	0.183303
4	v4	0.134164
5	v5	0.363318
6	v6	1.027072
7	v7	0.302316
8	v8	0.173582
9	v9	0.114761
10	v10	0.238145

Result for Step 5: For j = 1 to N compute the knife-edge diffraction loss (A_j) for each v_j.The results are given in Table 6.

Table 6. *The knife-edge diffraction loss* (A_j) *for j = 1 to N.*

	A_j	The knife-edge diffraction loss in dB
1	A1	13.33743
2	A2	9.118802
3	A3	8.414772
4	A4	8.032749
5	A5	9.814269
6	A6	14.97452
7	A7	9.340022
8	A8	8.339201
9	A9	7.881902
10	A10	8.841131

Result for Step 8: $A = A_1 + A_2 + A_3 + \cdots + A_{N-1} + A_N$ = 92.15261 dB

From the results, the maximum virtual hop single knife edge diffraction loss is 14.97452dB and it occurred in virtual hop j =6 which has the highest diffraction parameter of 1.027072 and the highest LOS clearance height of 8.480769m. The minimum virtual hop single knife edge diffraction loss is 7.881902 dB and it occurred in virtual hop j =9 which has the lowest diffraction parameter of 0.114761 as well as the lowest LOS clearance height of 0.628571m.

5. Conclusion

Algorithm for computing N knife edge diffraction loss using Shibuya method and modified ITU-R P 526-13 knife edge diffraction loss approximation model is presented. The mathematical expressions required for the computations are first presented before the algorithm. Then 10 knife edge obstructions located in a 6 GHz C-band microwave link is used to demonstrate the application of the algorithm.

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