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

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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 14.97452 dB 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 8.480769 m. 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 0.628571 m. 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 used in link budget for line of sight (LOS) microwave link [1-5]. Diffraction occurs when wireless signal encounters an 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 strength which is referred 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 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 many 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 transmitter 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: H₀-H₁-H₂ with H₁ as the diffraction edge

ii. Hop2: H₁-H₂-H₃ with H₂ as the diffraction edge

iii. Hop3: H₂-H₃-H₄ 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. Ideally, \( H_j \) takes into account the earth bulge, the elevation and the obstruction height measured from the ground level. Again, \( j = 0 \) refers to the receiver whereas \( j = N+1 \) refers to the transmitter. \( j = 1 \) to \( j = N \) refers 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 \( h \) where [19-21];

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

(1)

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

\[
H_{E(j)} = H_j + \frac{(d_1 + \cdots + d_j)(H_{j+1} - H_j)}{d_{j+1}}
\]

(2)

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

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

(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;

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

(5)

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

\[
A = A_1 + A_2 + \cdots + A_m = \sum_{j=1}^{m} A_j
\]

(6)

\[
A = \sum_{j=1}^{m} \left( 6.9 + 20\log \left( \sqrt{(v_j - 0.1)^2 + 1} + v_j - 0.1 \right) \right)
\]

(7)
The original ITU-R P 526-13 knife edge diffraction loss approximation model is modified by replacing it with an equivalent piecewise model that consists of linear function and log-linear functions without radical terms. The modified ITU knife edge diffraction loss approximation model is given as:

\[
A(0, v) = \begin{cases} 
8.268798105(V) + 6.854646186 & -0.57 < v < 0 \\
7.74337048(V) + 6.989712422 & 0 \leq v < 1.414214 \\
7.21468405[LN(V)] + 14.44900823 & 1.414214 \leq v < 2.828427 \\
8.674978541[LN(V)] + 13.043467 & v \geq 2.828427
\end{cases}
\]

(8)

Where
• \( V \) is diffraction parameter, has no unit
• \( A(0, v) \) is the diffraction loss in dB. \( A(0, v) \) 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 \( A(0, v) \) is zero.

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

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

Where \( U \) and \( W \) are constants and \( A(v) \) is a function of diffraction parameter, \( v \). The values of \( U, W \) and function \( A(v) \) are given in Table 1.

### Table 1. The values of \( U, W \) and function \( A(v) \) 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, \( P \) | \( U \) | \( W \) | \( A(v) \) |
|----------------------------------|----------------------------------|--------|--------|--------|
| \(-0.57 \leq v < 0\) | \(-40\% < P \leq 0\%\) | 8.268798105 | 6.854646186 | \( v \) |
| \(0 \leq v < 1.414214\) | \(0\% < P \leq 100\%\) | 7.74337048 | 6.989712422 | \( v \) |
| \(1.414214 \leq v < 2.828427\) | \(100\% < P \leq 200\%\) | 7.21468405 | 14.44900823 | \( LN(v) \) |
| \(v \geq 2.828427\) | \(P > 200\%\) | 8.674978541 | 13.043467 | \( LN(v) \) |

Again, for Shibuya method the effective multiple knife edge diffraction loss, \( A(0, v) \) is given as:

\[
A(0, v) = A(0, v_1) + A(0, v_2) + \cdots + A(0, v_n) = \sum_{i=1}^{n}(A(0, v_i))
\]

(10)

\[
A(0, v_i) = \begin{cases} 
8.268798105(V_i) + 6.854646186 & -0.57 < v_i < 0 \\
7.74337048(V_i) + 6.989712422 & 0 \leq v_i < 1.414214 \\
7.21468405[LN(V_i)] + 14.44900823 & 1.414214 \leq v_i < 2.828427 \\
8.674978541[LN(V_i)] + 13.043467 & v_i \geq 2.828427
\end{cases}
\]

(11)

Where \( i = 1, 2, 3, \ldots n \) and \( A(0, v_i) \) is given as;

\[
A(0, v_i) = \sum_{j=1}^{n}(U_i[A(v_j)] + W_j)
\]

(12)

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

\[
n_a + n_b + n_c + n_d = n
\]

(13)

For all the \( n_a \) knife edge edge obstructions in the range \(-0.57 < v_i < 0\), the total diffraction loss is denoted as \( A_a(0, v) \) where:

\[
A_a(0, v) = \sum_{j=1}^{n_a}(U_a[A_a(v_j)] + W_a)
\]

(14)

\[
A_a(0, v) = n_a(W_a) + U_a(\sum_{j=1}^{n_a}(A_a(v_j)))
\]

(15)

Similarly, for all the \( n_b \) knife edge edge obstructions in the range \(0 \leq v_i < 1.414214\), the total diffraction loss is denoted as \( A_b(0, v) \)

\[
A_b(0, v) = n_b(W_b) + U_b(\sum_{j=1}^{n_b}(A_b(v_j)))
\]

(16)

For all the \( n_c \) knife edge edge obstructions in the range \(1.414214 \leq v_i < 2.828427\), the total diffraction loss is denoted as \( A_c(0, v) \)

\[
A_c(0, v) = n_c(W_c) + U_c(\sum_{j=1}^{n_c}(A_c(v_j)))
\]

(17)

For all the \( n_d \) knife edge edge obstructions in the range \( v_i \geq 2.828427\), the total diffraction loss is denoted as \( A_d(0, v) \)

\[
A_d(0, v) = n_d(W_d) + U_d(\sum_{j=1}^{n_d}(A_d(v_j)))
\]

(18)

Furthermore, for \( A_a(0, v) \), \( A_a(v_i) = v_i \), then;

\[
A_a(0, v) = n_a(W_a) + U_a(\sum_{j=1}^{n_a}(v_j))
\]
Also, for $A_b(0, v)$, $A_b(v_j) = v_j$, then;

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

However, for $A_d(0, v)$, $A_d(v_j) = \ln(v_j)$. Hence,

$$\sum_{j=1}^{v_{shibuya}(v_j)} A_d(v_j) = \ln(v_1) + \ln(v_2) + \cdots + \ln(v_{nc}) \quad (21)$$

$$\sum_{j=1}^{v_{shibuya}(v_j)} A_d(v_j) = \ln((v_1)(v_2)(v_3) \cdots (v_{nc})) = \ln(\prod_{j=1}^{v_{shibuya}(v_j)}) \quad (22)$$

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

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

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:

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

2. For $j=1$ to $N +1$ obtain the distance $d(j)$ of obstruction from obstruction (j-1).

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

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

5. For $j=1$ to $N$ compute the knife-edge diffraction parameter ($v_j$) for each $h_j$ (Use Eq 3)

6. For all $-0.57 \leq v_j < 0$ compute $A_d(0, v) = n_d(W_d) + U_d \left( \sum_{j=1}^{v_{shibuya}(v_j)} \right)$ (Use Eq 15; $W_d$ and $U_d$ are obtained from Table 1 for $-0.57 \leq v_j < 0$).

7. For all $0 \leq v_j < 1.414214$ compute $A_b(0, v) = n_b(W_b) + U_b \left( \sum_{j=1}^{v_{shibuya}(v_j)} \right)$ (Use Eq 16; $W_b$ and $U_b$ are obtained from Table 1 for $0 \leq v_j < 1.414214$).

8. For all $1.414214 \leq v_j < 2.828427$ compute $A_c(0, v) = n_c(W_c) + U_c \left( \sum_{j=1}^{v_{shibuya}(v_j)} \right)$ (Use Eq 17; $W_c$ and $U_c$ are obtained from Table 1 for $1.414214 \leq v_j < 2.828427$).

9. For all $v_j \geq 2.828427$ compute $A_d(0, v) = n_d(W_d) + U_d \left( \ln(\prod_{j=1}^{v_{shibuya}(v_j)}) \right)$ (Use Eq 18; $W_d$ and $U_d$ are obtained from Table 1 for $v_j \geq 2.828427$). Where $n_d$ is the number of $v_j$ in the range $1.414214 \leq v_j < 2.828427$.

10. For all $v_j \geq 2.828427$ compute $A_d(0, v) = n_d(W_d) + U_d \left( \ln(\prod_{j=1}^{v_{shibuya}(v_j)}) \right)$ (Use Eq 18; $W_d$ and $U_d$ are obtained from Table 1 for $v_j \geq 2.828427$).

11. For all $v_j \geq 2.828427$ compute $A_d(0, v) = n_d(W_d) + U_d \left( \ln(\prod_{j=1}^{v_{shibuya}(v_j)}) \right)$ (Use Eq 18; $W_d$ and $U_d$ are obtained from Table 1 for $v_j \geq 2.828427$).

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 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.

| $j$ | 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          |

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

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

Table 3. The distance $d(j)$ of obstruction from obstruction (j-1) for $j=1$ to $N+1$. 
Table 5. 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 0.628571 m.

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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