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Shibuya Method for Computing Ten Knife Edge Diffraction Loss

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Abstract: Shibuya multiple knife edge diffraction loss method is presented in this paper. The Shibuya method is used to compute the effective diffraction loss of ten multiple knife edge obstructions for a 900 MHz GSM network. Each of the ten obstructions gave rise to a virtual hop which resulted in a knife edge diffraction loss while the overall diffraction loss, according to the Shibuya method is the sum of the diffraction loss computed for each of the ten virtual hops. According to the results, the highest line of sight (LOS) clearance height of 8.480769 m and the highest diffraction parameter of 0.397783 occurred in virtual hop 6. On the other hand, the lowest line of sight (LOS) clearance height of 0.628571 m and the lowest diffraction parameter of 0.044447 occurred in virtual hop 9. Furthermore, the highest virtual hop diffraction loss of 9.30294 dB occurred in virtual hop 6 whereas the lowest virtual hop diffraction loss of 6.38736 dB occurred in virtual hop 9. In all, the overall effective diffraction loss for the 10 knife edge obstructions as computed by the Shibuya is 71.7973 dB.

Keywords: Multiple Knife Edge, Diffraction Loss, Diffraction Parameter, Line of Sight, Clearance Height, Virtual Hop, Shibuya Method

1. Introduction

Diffraction phenomenon is described as the apparent bending of waves around obstacles and the spreading out of waves past small openings [1-7]. In respect of the diffraction phenomenon, obstructions in the path of wireless signal cause reduction in the signal strength. This reduction in received signal power due to diffracting obstructions is referred to as diffraction loss [1-11].

The Huygens-Fresnel principle is used to explain the diffraction concept [12, 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]. In this paper, Shibuya method is considered [18], [19]. Like every other multiple knife edge diffraction loss methods, the complexity of the computation increases as the number of knife edge increases. Consequently, most analysis are limited to two or three knife edges. However, in this paper, 10 (ten) knife edge obstructions are considered and Shibuya method is used to determine the overall diffraction loss that can be caused by the ten knife edge obstruction. The study is conducted for 900 MHz GSM frequency band.

2. Shibuya Multiple Knife Edge Diffraction Loss Method

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 [18], [19]. 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 [18], [19].

In figure 1 there are three vitual hop and each virtual hop has one edge that causes diffraction. The three virual 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

However, for Shibuya method, in figure 1, E_0 is the actual transmitter for hop 1 whereas E_1 and E_2 are the ficticious or virtual transmitters used in Shibuya diffraction computation for hop 2 and hop 3 respectively. Let the height of the transmitters E_0, E_1 and E_2 be represented as H_{E0}, H_{E1} and H_{E2} respetively. Also, from figure 1, it can be seen that, $H_{E0} = H_0$. Furthermore, by similar traingle principle, H_{E1} is given from triangle $E_1 H_2 H_3$ as follows [18], [19];

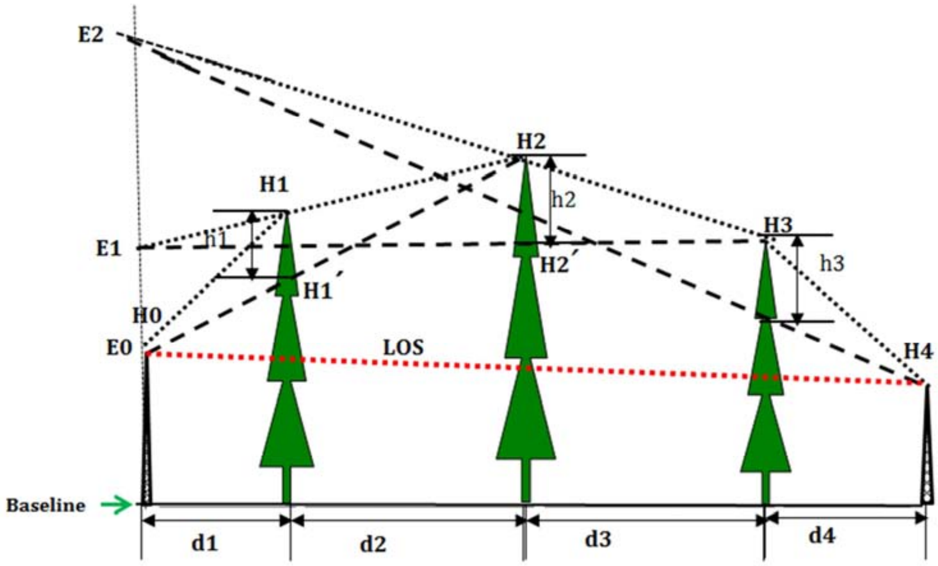


Figure 1. *None Line –Of Sight Link With Three Obstructions For The Shibuya Method [18], [19].*

$$\frac{H_1 - H_{E1}}{d_1} = \frac{H_2 - H_{E1}}{d_1 + d_2} \quad (1)$$

$$H_1(d_1) + H_1(d_2) - H_{E1}(d_1) - H_{E1}(d_2) = H_2(d_1) - H_{E1}(d_1) \quad (2)$$

$$H_1(d_1) + H_1(d_2) - H_2(d_1) = H_{E1}(d_2) \quad (3)$$

$$H_{E1} = H_1 + \frac{d_1(H_1 - H_2)}{d_2} \quad (4)$$

Similarly, h_2 is given from trangle $E_1 H_2 H_3$ by similar traingle principle as follows;

$$h_1 = H_2 - H_2' \quad (5)$$

Where H_2' is the hop 2 line of sight (H_{E1} To H_3) height at a distance of d_1 from the virtual transmitter E_1 at H_{E1}. H_2' is given by similar traingle as;

$$\frac{H_2' - H_{E1}}{d_1 + d_2} = \frac{H_3 - H_{E1}}{d_1 + d_2 + d_3} \quad (6)$$

$$H_2' = \frac{(d_1 + d_2)(H_3 - H_{E1})}{d_1 + d_2 + d_3} + H_{E1} \quad (7)$$

$$h_1 = H_2 - \left(\frac{(d_1 + d_2)(H_3 - H_{E1})}{d_1 + d_2 + d_3}\right) - H_{E1} \quad (8)$$

$$h_1 = (H_2 - H_{E1}) - \left(\frac{(d_1 + d_2)(H_3 - H_{E1})}{d_1 + d_2 + d_3}\right) \quad (9)$$

Similarly,

$$h_3 = (H_3 - H_{E2}) - \left(\frac{(d_1 + d_2 + d_3)(H_4 - H_{E2})}{d_1 + d_2 + d_3 + d_4}\right) \quad (10)$$

Generally, for any given hop j, the clearance height to its LOS is given as h_j where [18];

$$h_j = \left(H_j - H_{E\,(j-1)}\right) - \left(\frac{(d_1 + \cdots + d_j)(H_{j+1} - H_{E\,(j-1)})}{d_1 + \cdots + d_{j+1}}\right) \quad (11)$$

Where

$$H_{E\,(j)} = H_j + \frac{(d_1 + \cdots + d_j)(H_j - H_{j+1})}{d_{j+1}} \quad (12)$$

A piecewise function is a function that is broken into two or more pieces.

The single knife edge diffraction, $G_j(dB)$ for each of the virtual hops is computed using Lee's piecewise knife edge diffraction loss [16, 20-25]. According to Lee's piecewise model, $G_j(dB)$ can be expressed as:

$$G_j(dB) = \begin{cases} 0 \text{ for } v_j < -1 \\ 20\log(0.5 - 0.62v_j) \text{ for } -1 \le v_j \le 0 \\ 20\log\left(0.5\exp(-0.95v_j)\right) \text{ for } 0 \le v_j \le 1 \\ 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v_j)^2}\right) \text{ for } 1 \le v_j \le 2.4 \\ 20\log\left(\frac{0.225}{v_j}\right) \text{ for } v_j > 2.4 \end{cases} \quad (13)$$

Where v_j is the diffraction parameter for virtual hop j. Then, According to the Shibuya multiple diffraction loss method, the effective diffraction loss for all the m hops is given as [1];

$$G\,(dB) = G_1(dB) + G_2(dB) + \cdots + G_m(dB) \;=\; \sum_{j=1}^{j=m}\left(G_j(dB)\right) \quad (14)$$

3. Case Study: 10 Knife Edge Diffraction Loss Computation

In the case study of figure 2 there are 10 knife edge obstruction with heights H1, H2,…, H10 while H0 and H11 are the transmitter and receiver respectively. Also, the distance of obstruction (i+1) from obstruction (i) is d (i+1) where i= 0, 1, 2,…, 10. The i includes the transmitter with i=0 and the receiver with i=11. Table 1 gives the height, H (i) and the distance d (i) for the 10 knife edge obstructions along with the transmitter and the receiver. The dataset in Table 1 and Figure 2 are used to present numerical computations of 10 knife edge diffraction loss using the Shibuya method.

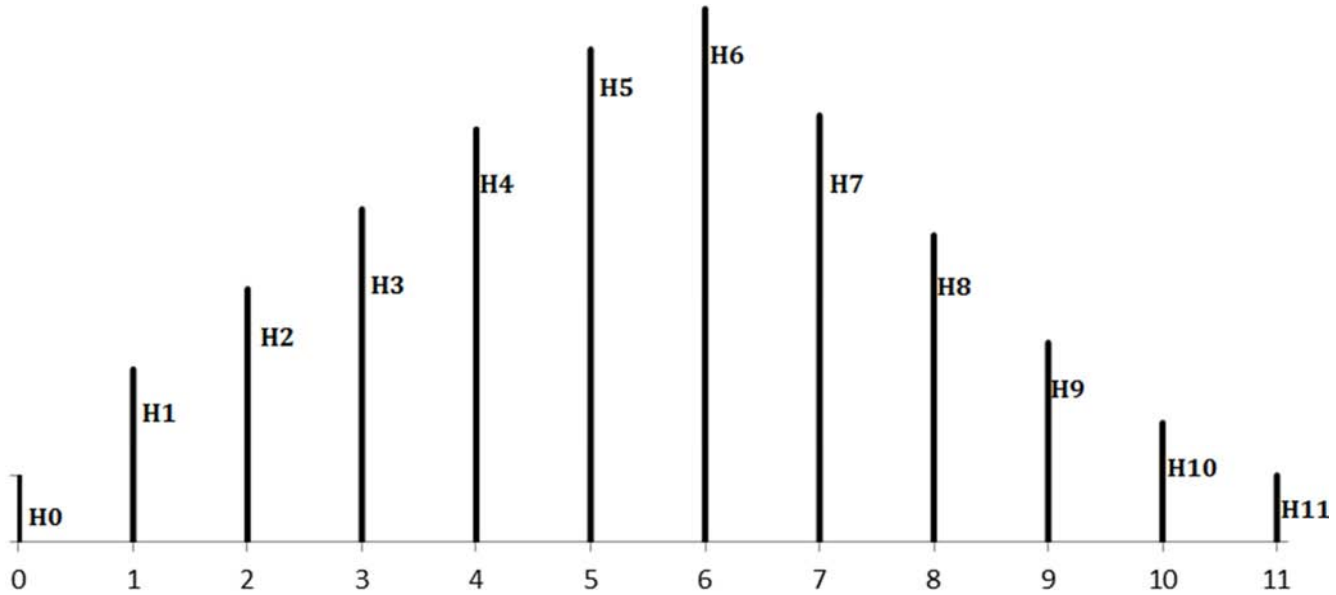


Figure 2. *Ten (10) Knife Edge Obstructions used For The Study On Shibuya Method.*

Table 1. *The Height Of The Ten (10) Knife Edge Obstructions and the Distance Between Adjacent Obstructions.*

Distance (km) Between Adjacent Obstructions		Knife Edge Obstruction Height	
		(Transmitter) H0	10
d1	1	H1	18
d2	2	H2	24
d3	3	H3	30
d4	4	H4	36
d5	5	H5	42
d6	6	H6	45
d7	5	H7	37
d8	4	H8	28
d9	3	H9	20
d10	2	H10	14
d11	1	(Receiver) H11	10
d	36	F =1GHz	λ = 0.3

Table 2. *The LOS Clearance Height, h (j), The Diffraction Parameter, V (j) and The Diffraction Loss, A (j) For The 10 Virtual Hops As Computed By Shibuya Method.*

j	d (j)	d (1)+…+d (j)	d (j+1)	H (j)	H (j+)	HE (j-1)	h (j)	V (j)	$\lvert G_j(dB) \rvert$
1	1	1	2	18	24	10	3.333333	0.316228	8.62999
2	2	3	3	24	30	15	1.5	0.106066	6.89581
3	3	6	4	30	36	18	1.2	0.070993	6.60641
4	4	10	5	36	42	21	1	0.051962	6.44937
5	5	15	6	42	45	24	3	0.140712	7.1817
6	6	21	5	45	37	34.5	8.480769	0.397783	9.30294
7	5	26	4	37	28	78.6	2.253333	0.117087	6.98675
8	4	30	3	28	20	95.5	1.136364	0.067228	6.57534
9	3	33	2	20	14	108	0.628571	0.044447	6.38736
10	2	35	1	14	10	119	0.972222	0.092233	6.78167
11	1	36	f (MHz)	900		λ	0.333333	Total	71.7973

In Shibuya the transmitter E is replaced here by a fictitious transmitter with height $H_{E\,(j)}$. Table 2 and figure 3 show that the height $H_{E\,(j)}$ of the fictitious transmitter increases with the distance of the obstruction from the anctual transmitter. Also, in the Shibuya multiple knife edge diffraction loss method, each knife edge constitutes a virtual hop with two adjacent knife edge obstructions, or with the transmitter and a knife edge obstruction or with a knife edge obstruction and with the receiver. In this study, the 10 knife edge obstructions gave rise to 10 virtual hops. In Table 2, the results of the LOS clearance height, h (j), the diffraction parameter, V (j) and the diffraction loss, $G_j(dB)$ computed for the 10 virtual hops using the Shibuya method are presented for a 900 MHz GSM network. The highest LOS clearance height h (j) =8.480769 m occurred in virtual hop j =6 as shown in Table 2 and figure 3. Also, the highest diffraction parameter, V (j) =0.397783 is obtained in virtual hop j =6, as shown in Table 2 and figure 4. The lowest LOS clearance height h (j) =0.628571 m occurred in virtual hop j = 9. Also, the lowest diffraction parameter, V (j) =0.044447 occurred in virtual hop j = 9.

In Table 2 and figure 5 the lowest absolute value of virtual hop diffraction loss, $|G_j(dB)|$=6.38736dB occurred in virtual hop j = 9 whereas, the highest virtual hop diffraction loss, $|G_j(dB)|$ =9.30294dB occurred in virtual hop j =6. In all, the overall effective diffraction loss for the 10 knife edge obstructions as computed by the Shibuya method is 71.7973 dB.

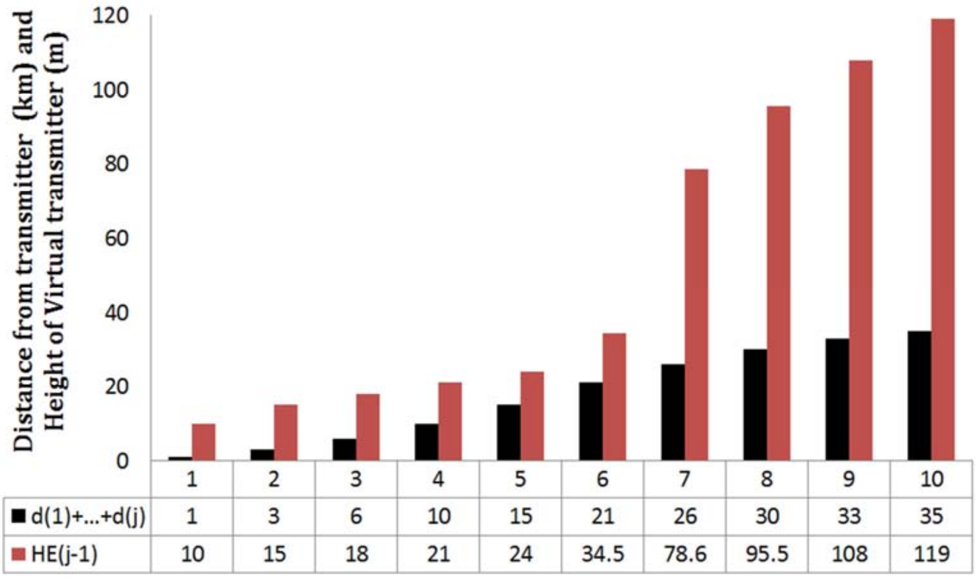


Figure 3. *Height $H_{E\,(j)}$ of the Fictitious Transmitter and Distance Of The Obstruction From The Anctual Transmitter.*

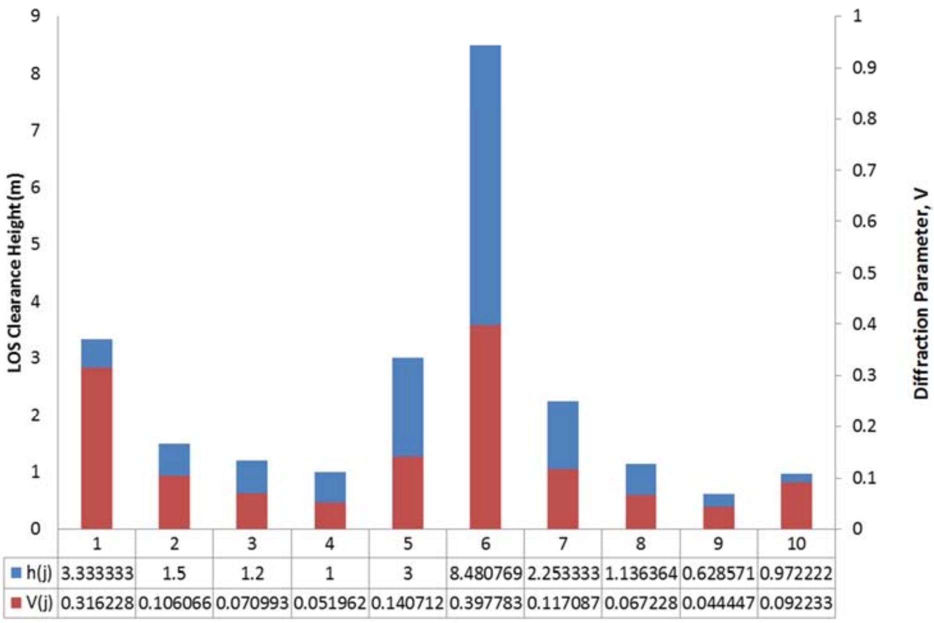
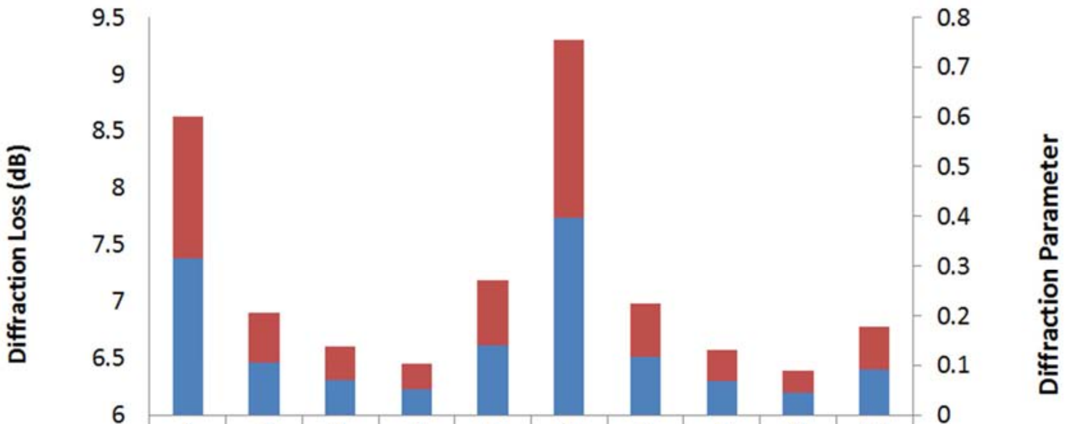


Figure 4. *The LOS Clearance Heights, h (j) and Diffraction Parameter, V (j) For The 10 Virtual Hops Of The 10 Knife Edge Obstructions.*



	1	2	3	4	5	6	7	8	9	10
A(j)	8.63	6.896	6.606	6.449	7.182	9.303	6.987	6.575	6.387	6.782
V(j)	0.316	0.106	0.071	0.052	0.141	0.398	0.117	0.067	0.044	0.092

Figure 5. *The Diffraction Parameter, V (j) and the Absolute Value Of Diffraction Loss,* $|G_j(dB)|$ *For The 10 Virtual Hops Of The 10 Knife Edge Obstructions.*

4. Conclusions

The application of Shibuya method in the computation of ten multiple knife edge diffraction loss is presented. The study is conducted for a 900 MHz GS|M network. In the computation, each of the ten 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 ten virtual hops. What is peculiar to the Shibuya method is how the virtual hops are identified or defined and the introduction of fictitious transmitters to replace the actual transmitterin each of the virtual hops.

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