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LINK BUDGET ANALYSIS FOR LINE OF SIGHT WIRELESS COMMUNICATION LINK WITH KNIFE EDGE DIFFRACTION OBSTRUCTION

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***Abstract*—In this paper, link budget analysis for line of sight (LOS) wireless communication link with knife edge diffraction obstruction is presented. The LOS percentage clearance of the obstruction is specified and then used to determine the diffraction loss that will be caused by the knife edge obstruction. The relevant mathematical expressions for the link budget analysis are presented. Sample link budget analysis was presented for a 12 GHz Ku-band microwave link and the path length was varied from 5 km to 10 km. The analysis was conducted for four different LOS percentage clearances of -100%, 0%, 20% and 100%. The results showed that for LOS percentage clearance of -100%, the link outage started at a path length of 8.852 km whereas for LOS percentage clearance of 100%, the link outage started at a path length of 6.3245km. In all, the knife edge diffraction obstruction causes diffraction loss which decreases the maximum path length that the communication link can achieve with acceptable quality of service. Also, the results showed that the higher the LOS percentage clearance, the higher the diffraction loss and the lower the maximum path length**

Keywords— Link Budget Analysis, Line Of Sight Link, Wireless Communication, Diffraction Obstruction , The Knife Edge Diffraction, Percentage Clearance

1. INTRODUCTION

In the last few decades, wireless communication technologies have dominated communication technologies across the globe [1,2,3,4,5]. This is due to the wide application and ever growing demand for wireless communication services. As the demand for more bandwidth and better quality of service increases, wireless network service providers and researchers are faced with more challenges associated with meeting such demands [6,7,8,9,10].

In practice, the line of sight communication links are desired to be without any obstruction along the signal path. However, in reality there are always a number of obstructions that can lead to significant diffraction loss in addition to the free space path loss [12,13,14,15]. Such additional loss will affect the network coverage and also the parameters of the network infrastructure needed to achieve a certain quality of service.

In this paper, the link budget analysis [16,17,18,19,20] is conducted for a wireless LOS communication link with knife edge obstruction [21,22,23,24] in the signal path. Such obstruction will introduce certain level of diffraction loss that depends on the percentage clearance of the obstruction tip with respect to the link line of sight. For obstructions that are below the link line of sight, the diffraction loss may be negligible. However, as the obstruction tip approaches or crosses above the link line of sight, the diffraction loss must be considered in the link budget analysis and quality of service assessment of the link. This paper, examines such issues for a Ku-band microwave link. Particularly, in this paper, among other link parameters, the link outage is examined for different LOS percentage clearance of the knife edge obstruction.

2.0 METHODOLOGY FOR THE LINK BUDGET CALCULATION

Link budget calculations is used to compute the received signal strength and thereby check whether the signal is stronger than the receiver's sensitivity at the required Bit Error Rate (BER, typically 10^{-6}). Link budget computes the received signal strength (P_R)based on the knowledge of the network and the link parameters that includes the transmitter power(P_T), the transmitter antenna gain (G_T), the loses at the transmitter (L_T), the path losses along the link(L_{PAT}), the loses at the receiver (L_R) and the receiver antenna gain (G_R). Hence, a simplified expression for link budget analysis is given as;

$$P_R = P_T + G_T - L_T - L_{PAT} + G_R - L_R \tag{1}$$

Where all the parameters are in dB. The path losses along the link(L_{PAT})include the free space path loss (LFSP) and other losses. In this paper, the additional path loss considered is the diffraction loss,G_d(dB)which is caused by a knife edge obstruction located along the signal path. The free-space loss (LFSP) is given as [25];

$$LFSP = 32.4 + 20 \log (f) + 20 \log (d) \tag{2}$$

Where f is the frequency of the emitted signal (MHz) and d is the length of the link (km)

In this paper, the link budget analysis is performed for line of sight (LOS) wireless microwave link with a single knife edge obstruction in the signal path. The knife edge obstruction causes diffraction loss (G_d(dB)) which is determined from the percentage clearance value (denoted as $P_{c\%}$). The value of $P_{c\%}$ is the ratio of the clearance height (denoted as $h_{cl(x)}$, as shown in Figure 1) of the obstruction to the radius of the first Fresnel zone (denoted as $r_{(x)}$, as shown in Figure 1) at the location under consideration. Hence, $P_{c\%}$ is computed as follows;

$$P_{c\%} = \left(\frac{h_{cl(x)}}{r_{(x)}}\right) 100\ \% \tag{3}$$

In practice, computation of the clearance height, ($h_{cl(x)}$) requires knowledge of detailed link parameters as shown in Figure 1. As such, most design calculations specify the percentage clearance, $P_{c\%}$ required for LOS clearance in the link.

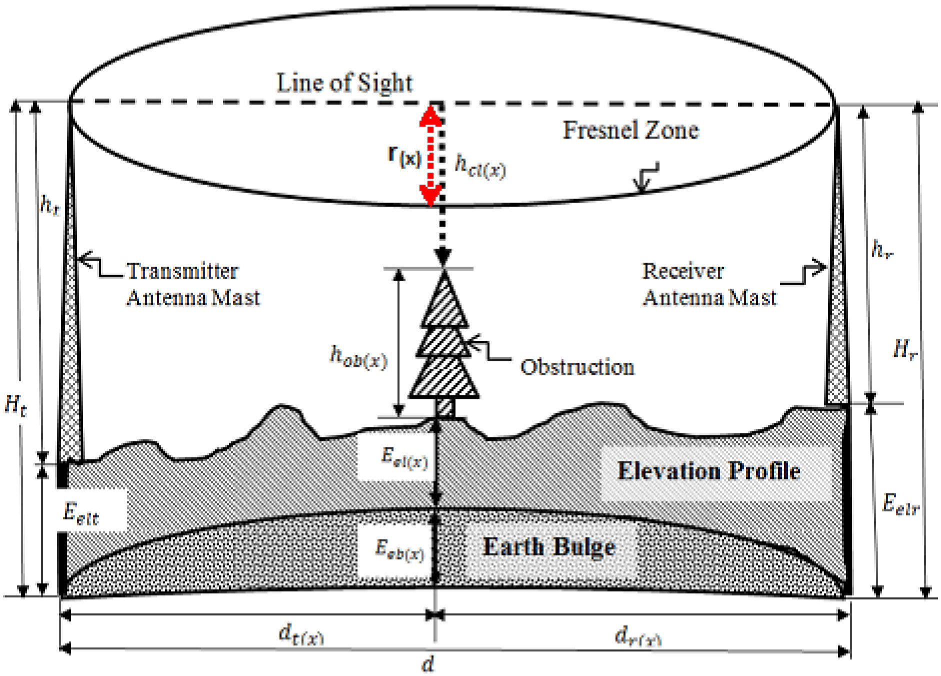

Figure 1. Fresnel geometry model for computing the clearance height in a point-to-point line-of-sight (LOS) microwave link with knife edge diffraction obstruction

Accordingly, in this paper, the value of $P_{c\%}$ is specified and then used to compute the diffraction parameter (denoted as v) and hence the diffraction loss, $\mathbf{G_d(dB)}$ due to the given percentage clearance value ($P_{c\%}$) of the obstruction. The diffraction parameter (v) is computed from the obstruction percentage clearance value ($P_{c\%}$) as follows:

$$v = \left(\frac{(\sqrt{2})P_{c\%}}{100}\right) \quad (4)$$

When the value of diffraction parameter (v) is known, the knife-edge diffraction loss, $\mathbf{G_d(dB)}$ can be computed from the Lee' piecewise model given as [26,27]:

$$\left.\begin{array}{ll} \mathbf{G_d(dB)} = 0 & \text{for} \quad v < -1 \\ \mathbf{G_d(dB)} = 20\log(0.5 - 0.62v) & \text{for} \ -1 \le v \le 0 \\ \mathbf{G_d(dB)} = 20\log\left(0.5\exp(-0.95v)\right) & \text{for} \ 0 \le v \le 1 \\ \mathbf{G_d(dB)} = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right) & \text{for} \ 1 \le v \le 2.4 \\ \mathbf{G_d(dB)} = 20\log\left(\frac{0.225}{v}\right) & \text{for} \quad v > 2.4 \end{array}\right\} \quad (5)$$

where;
v is the Fresnel-Kirchoff diffraction parameter

2.1 DETERMINATION OF THE LINK OPERATING FADE MARGIN

After the link budget is used to determine the received signal strength, the effective fade depth prevalent in the LOS link is computed. Then, the effective fade margin of the link is determined from which value the status of the link will be determined. In this paper, the fade mechanisms considered are the rain fading [28] and the multipath fading [29,30,31]. The two fade mechanisms are mutually exclusive; as such the one with the larger value is taken as the effective link fade depth.

2.2 CALCULATION OF THE RAIN FADING DEPTH

The rain fading depth is computed using the ITU-R outage model, which is stated for the horizontal and vertical polarization as follows [32,33];

$$\left.\begin{array}{ll} \langle\gamma_{\delta o}\rangle_h = K_h(R_{\delta o})^{\alpha_h} & \text{in dB/km for horizontal polarization} \\ \langle\gamma_{\delta o}\rangle_v = K_v(R_{\delta o})^{\alpha_v} & \text{in dB/km for vertical polarization} \end{array}\right\} \quad (6)$$

Where k_h, α_h are constants for horizontal polarization; Kv, α_v are constants for vertical polarization; $\langle\gamma_{\delta o}\rangle_h$ is the rain attenuation per kilometre for horizontal polarization; $\langle\gamma_{\delta o}\rangle_v$ is the rain attenuation per kilometre for horizontal polarization; δo is the percentage outage time (or percentage unavailability time) of the link and δa is the percentage availability time of the link. Then,

$$\delta o = (100\% - \delta a) \quad (7)$$

Now, let d be the total distance of the receiver from the transmitter; let A_{Rh} be the total rain attenuation for horizontal polarization over the distance d; let A_{Rv} be the total rain attenuation for vertical polarization over the distance d and let A_{Rain} be the effective rain attenuation for both horizontal and vertical polarization, then;

$$\left.\begin{array}{l} A_{Rh} = d * \langle\gamma_{\delta a}\rangle_h \\ A_{Rv} = d * \langle\gamma_{\delta a}\rangle_v \end{array}\right\} \quad (8)$$

The horizontal and the vertical polarizations do not add up. Rather, the larger of the two is taken as the effective rain attenuation for the link. Thus;

$$A_{Rain} = Minimum\ \{A_{Rh}, A_{Rv}\} \quad (9)$$

2.3 CALCULATION OF THE MULTIPATH FADING DEPTH

In order to calculate the probability of outage due to multipath fading, the ITU model for providing predictions of multipath fade depths ($\boldsymbol{A_{multpt}}$)in the average worst month is used. The ITU model is given as;

$$\delta o = K(d^{3.2})(1+\varepsilon_p)^{-0.97}(10)^{\left(0.032(f) - 0.00085h_L - \left(\frac{A_{multpt}}{10}\right)\right)} \quad (10)$$

Where d is the link distance (km); f is the frequency (GHz); h_L is the altitude of lower antenna (m); A is the fade depth (dB) ; K is the geoklimatic factor and can be obtained as follows [34]:

$$K = 10d^{(-4.2-0.0029dN1)} \quad (11)$$

The term dN1 is provided on a 1.5° grid in latitude and longitude in ITU-R Recommendation P.453. From the antenna heights $\boldsymbol{h_1}$ and $\boldsymbol{h_2}$ (in meters about sea level), the magnitude of the path inclination $|\varepsilon_P|$ (mrad) can be calculated using the following expression:

$$|\boldsymbol{\varepsilon_p}| = \frac{(|\boldsymbol{h_1}-\boldsymbol{h_2}|)}{\boldsymbol{d}} \quad (12)$$

Where *d* is link distance (km) and h_1, h_2 are the antenna heights above sea level (m). Also,

$$h_L = minimum(h1, h2) \quad (13)$$

Now, thefade depth, $\boldsymbol{A_{multpt}}$ (in dB) is obtained from the expression for δo by making $\boldsymbol{A_{multpt}}$ the subject of the formula in the expression for δo as follows;

$$\boldsymbol{A_{multpt}} = \mathbf{10(0.032}\boldsymbol{f} - \mathbf{0.00085}\boldsymbol{h_L}) - \mathbf{(10)log}\left(\frac{\delta o}{\{K(d^{3.2})(1+|\varepsilon_p|)^{-0.97}\}}\right) \quad (14)$$

where $\boldsymbol{A_{multpt}}$ is attenuation due to multipath or the multipath fade depth.

2.4 CALCULATION OF THE EFFECTIVE FADE MARGIN AND DETERMINATION OF THE LINK OPERATING STATUS

The effective fade margin of the link is the amount in dB that the received signal strength is above the receiver sensitivity of the radio. The fade margin is used to accommodate the expected fade depth, for the purpose of ensuring that the required quality of service is maintained. In this paper, two fade depths considered are the rain and multipath fade depth. Fortunately, mutual relation exists between rain and multipath fading, hence it rules out the possibility that the link could be affected by both types of attenuation at the same time. Hence, the larger of the two fade depths determines the effective fade depth of the link. Let A_e be the effective link fade depth of the link, then;

$$A_e = minimum(A_{multpt}, A_{Rain}) \quad (15)$$

Let P_S be the receiver sensitivity in dB and M_e be the effective link fade margin, then;

$$M_e = P_R - P_S \quad (16)$$

Importantly, the effective fade margin is expected to be more then the largest fade depth in the link. If $M_e < A_e$ then the link is not feasible or it can be said that the link is not closed or the link is not available. In that case, there is link outage and so the link parameters may have to be tuned in some ways to ensure that $M_e \geq A_e$.

3. RESULTS AND DISCUSSION

The link budget was conducted for a 12 GHz LOS wireless communication link with the following network and link parameters:

i. Signal frequency, f = 12 GHz
ii. Transmitter power in dB, PT = 30 dB ;
iii. Transmitter Antenna Gain in dBi, $G_T = 35\ dB$;
iv. Receiver Antenna Gain in dBi, $G_R = 35\ dB$;
v. The loses at the transmitter $(L_T = 0\ dB)$
vi. The loses at the receiver $(L_R = 0\ dB)$
vii. Transmitter antenna height, $(h_1 = 80\ m)$;
viii. Receiver antenna height, $(h_2 = 65\ m)$;
ix. The link percentage outage, Po = 0.01%;
x. Refraction gradient dN1 = -200 units;
xi. Receiver Sensitivity in dB , P_S = - 80 dB ;

At the given signal frequency of 12 GHz, the link budget was conducted for four different percentage clearances, namely:

i. Pc% = -100 % , where obstruction tip is below the line of sight; which means , no significant obstruction in the link
ii. Pc% = -0 % , where obstruction tip is just on the line of sight; which means , significant obstruction in the link
iii. Pc% = 20 % , where obstruction tip is above the line of sight; which means , very significant obstruction exist in the link
iv. Pc% = 100 % , where obstruction tip is above the line of sight; which means, very significant obstruction exist in the link

For LOS percentage clearance, Pc% = -100%, the link path length, d is varied between 5 km and 10 km and the results are shown in Table 1. The link outage begins at a path length of 8.852 km. In essence , for the given network and link parameters and with LOS percentage clearance, Pc% of -100%, the link remains available for all d ≤ 8.852 km. Beyond that distance, the link will never be available whenever the maximum fade depth in the link occurs. However, since the rain and multipath fade mechanism vary with time and the atmospheric conditions, the link can be available for some times for d >8.852 km.

Table 1 :The link budget analysis results for LOS percentage clearance , Pc% = -100%,

	d = 5 km	**d = 8.852 km**	**d = 10 km**

Free Space Loss [FSL] (dB)	127.96	132.92	133.98
Diffraction Loss	0.00	0.00	0.00
Received Power (Pr) in dB	-27.96	-32.92	-33.98
Multipath Fade Depth in dB	3.61	13.22	15.23
Rain Fade Depth in dB	26.59	47.08	53.18
Effective Fade Depth (Ae) in dB	26.59	47.08	53.18
Receiver Sensitivity (Ps) in dB	-80.00	-80.00	-80.00
Effective Fade Margin (Me) in dB	52.04	47.08	46.02
Link Status	The Link Is Feasible	The Link Is Just Feasible	The Link Is Not Feasible

For LOS percentage clearance, Pc% = 0%, the link path length, d is varied between 5 km and 10 km and the results are shown in Table 2. The link outage begins at a path length of 7.905 km. In essence, for the given network and link parameters and with LOS percentage clearance, Pc% of0 %, the link remains available for all d ≤ 7.905 km. Beyond that distance, the link will never be available whenever the maximum fade depth in the link occurs.

Table 2 :The link budget analysis results for LOS percentage clearance, Pc% = %,

	d = 5 km	d = 7.905 km	d = 10 km
Free Space Loss [FSL] (dB)	127.96	131.94	133.98
Diffraction Loss	6.02	6.02	6.02
Received Power (Pr) in dB	-33.98	-37.96	-40.00
Multipath Fade Depth in dB	3.61	11.34	15.23
Rain Fade Depth in dB	26.59	42.04	53.18
Effective Fade Depth (Ae) in dB	26.59	42.04	53.18
Receiver Sensitivity (Ps) in dB	-80.00	-80.00	-80.00
Effective Fade Margin (Me) in dB	46.02	42.04	40.00
Link Status	The Link Is Feasible	The Link Is Just Feasible	The Link Is Not Feasible

For LOS percentage clearance, Pc% = 20%, the link path length, d is varied between 5 km and 10 km and the results are shown in Table 3. The link outage begins at a path length of 7.183 km. In essence, for the given network and link parameters and with LOS percentage clearance, Pc% of20%, the link remains available for all d ≤ 7.183km. Beyond that distance, the link will never be available whenever the maximum fade depth in the link occurs.

Table 3 :The link budget analysis results for LOS percentage clearance, Pc% = 20%,

	d = 5 km	d = 7.183 km	d = 10 km
Free Space Loss [FSL] (dB)	127.96	131.11	133.98
Diffraction Loss	10.69	10.69	10.69
Received Power (Pr) in dB	-38.65	-41.8	-44.67
Multipath Fade Depth in dB	3.61	9.74	15.23
Rain Fade Depth in dB	26.59	38.2	53.18
Effective Fade Depth (Ae) in dB	26.59	38.2	53.18
Receiver Sensitivity (Ps) in dB	-80	-80	-80
Effective Fade Margin (Me) in dB	41.35	38.2	35.33
Link Status	The Link Is Feasible	The Link Is Just Feasible	The Link Is Not Feasible

For LOS percentage clearance, Pc% = 100%, the link path length, d is varied between 5 km and 10 km and the results are shown in Table 1. The link outage begins at a path length of 6.3245 km. In essence , for the given network and link parameters and with LOS percentage clearance, Pc% of -100%, the link remains available for all d ≤ 6.3245 km. Beyond that distance, the link will never be available whenever the maximum fade depth in the link occurs. However, since the rain and multipath fade mechanism varies with time and the atmospheric conditions, the link can be available for some time when d >6.3245 km.

Table 4 :The link budget analysis results for LOS percentage clearance, Pc% = 100%,

	d = 5 km	d = 6.3245 km	d = 10 km

Free Space Loss [FSL] (dB)	**127.96**	**130.00**	**133.98**
Diffraction Loss	**16.36**	**16.36**	**16.36**
Received Power (Pr) in dB	**-44.32**	**-46.36**	**-50.34**
Multipath Fade Depth in dB	**3.61**	**7.60**	**15.23**
Rain Fade Depth in dB	**26.59**	**33.64**	**53.18**
Effective Fade Depth (Ae) in dB	**26.59**	**33.64**	**53.18**
Receiver Sensitivity (Ps) in dB	**-80.00**	**-80.00**	**-80.00**
Effective Fade Margin (Me) in dB	**35.68**	**33.64**	**29.66**
Link Status	**The Link Is Feasible**	**The Link Is Just Feasible**	**The Link Is Not Feasible**

In all, the diffraction loss caused by the knife edge diffraction obstruction reduces the effective path length that is achievable in the link.

4. CONCLUSION

Computation of link budget and determination of the effective link fade margin and link status are presented for line of sight wireless communication link with knife edge diffraction obstruction. The relevant mathematical expressions for the link budget analysis are presented. Sample link budget analysis was presented for a Ku-band microwave link. The results show that the knife edge diffraction obstruction causes diffraction loss which decreases the maximum path length that the communication link can achieve with acceptable quality of service.

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