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Empirical Validation of Frequency Scaling Factor for Fresnel-Kirchoff Diffraction Parameter

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Abstract: In this paper, topographic data for line-of-sight (LOS) communication link between Eket and Akwa Ibom state University are used to validate the frequency scaling factors for computing the radius of the Fresnel zone, Fresnel-Kirchoff diffraction parameter and the number of Fresnel zones that are partially or fully blocked by single knife edge obstruction in the signal path. The topographic data are obtained using Geocontext online topographic profile tool. In this paper, three microwave frequencies are considered, namely; 4 GHz for the C-band, 16 GHz for the Ku-band and 28 GHz for the Ka-band. The results confirmed that the frequency scaling factor between any two frequencies, f1 and f2 is $\sqrt{\frac{f2}{f1}}$ for the Fresnel-Kirchoff diffraction parameter; $\sqrt{\frac{f1}{f2}}$ for the radius of the Fresnel zone and $\frac{f2}{f1}$ for the number of Fresnel zones that are blocked by obstruction in the signal path. Consequently, if the value of any of the three parameters is known at frequency, f1, then the corresponding value of the same parameter at another frequency, f2 can be obtained by multiplying the parameter value at f1 with the frequency scaling factor for the parameter.

Keywords: Fresnel Zone, Knife Edge Obstruction, Frequency Scaling Factor, Line-of-Sight (LOS) Communication, Topographic Profile

1. Introduction

In the wireless communication systems, diffraction is one of the most prominent non-line-of-sight (NLOS) propagation mechanisms [1, 2]. Cellular systems rely on diffraction over rooftops and indoor systems rely on diffraction around wall edges and door openings for coverage (Casas, 2013). Also, line-of-sight microwave links are subject to diffraction loss when obstacles along the signal path projects into the key Fresnel zones.

Basically, diffraction is the bending of a wave around the edges of an opening or an obstacle. Diffraction occurs when a wave encounters an object in its path or when the wave is forced through a small opening. The loss that occurs due to the obstacle in the path of the signal is known as "diffraction loss" [3]. The concept of diffraction is explained by the Huygens-Fresnel principle which states that each point on a wavefront acts as a point source [5, 6]. This means that even if the direct path between the transmitter and receiver is blocked, some energy can reach the receiver from the portions of space that are visible to both the transmitter and receiver.

In order to estimate the losses caused by an obstacle in the signal path, it is usually assumed that the obstacle is a single knife-edge of negligible thickness or a thick smooth obstacle with a well-defined radius of curvature at the top [7, 8, 9]. Where more than one obstacles are involved, then the obstacles are treated as multiple knife edge. In both cases, Fresnel zones are used by propagation theory to calculate diffraction loss caused by obstruction located between the transmitter and receiver [10, 11]. The Fresnel zone in this case defines the cylindrical ellipsoidal path actually occupied by the signal as it propagates from the transmitter to the receiver. Fresnel zones are numbered starting from one and there is infinite number of Fresnel zones. The more the number of Fresnel zones obstructed, the higher the diffraction loss due to the obstruction. However, only the first 3 Fresnel zones have

any real effect on radio propagation.

According to the Fresnel zone geometry, the size of the ellipse is determined by the frequency of operation and the distance between the transmitter and receiver. Essentially, the radius of the Fresnel zones varies with frequency of operation and the distance between the transmitter and receiver [10, 12, 13]. Moreover, the diffraction loss caused by knife edge obstruction is a function of Fresnel diffraction parameter which in turn is a function of the frequency of operation and the distance between the transmitter and receiver [14, 15]. In view of the frequency dependence of the knife edge diffraction loss and its associated parameters, frequency scaling factors has been recently derived for parametric analysis of the variations of the diffraction knife edge parameters with frequency.

In this paper, empirical validation of frequency scaling factor for Fresnel-Kirchoff diffraction parameter for microwave communication links in the C-band, the Ku-band and the Ka-band is presented. Topological profile data of microwave link between Eket and Akwa Ibom state University is used in the study. The study shows how a simplified frequency scaling factor can be used to investigate the effect of frequency on the Fresnel zone and knife edge diffraction loss parameters.

2. Methodology

In this paper, the influence of frequency on diffraction loss is evaluated using empirical topographic data for line-of-sight (LOS) communication link between Eket and Akwa Ibom state University. For LOS links, the radius of the nth Fresnel zone ($r_{(n)}$) is given as [10, 12, 13];

$$r_{(n)} = \sqrt{\frac{n\{(d_{t(x)})(d_{r(x)})\}}{(d_{t(x)} + d_{r(x)})}} \quad (1)$$

where

$d_{t(x)}$ is the distance of location x from the transmitter

$d_{r(x)}$ is the distance of location x from the receiver, where x=1, 2, 3,…, N.

n is the nth Fresnel zone

λ is the wavelength of the radio wave in metres where;

$$= \frac{c}{f} \quad (2)$$

where, c is the speed of a radio wave ($c = 3x10^3 m/s$);
f is frequency of the radio wave in Hz.

In any case, the radius of the Fresnel zone can be expressed in terms of frequency as follows;

$$r_{(n,f)} = \sqrt{\frac{n\left(c(d_{t(x)})(d_{r(x)})\right)}{f(d_{t(x)} + d_{r(x)})}} \quad (3)$$

For two frequencies, f1 and f2, the radius of the Fresnel zone is given as;

$$r_{(x,f2)} = r_{(x,f1)}\left(\sqrt{\frac{f1}{f2}}\right) \quad (4)$$

The Fresnel-Kirchoff diffraction parameter ($V_{(x)}$) at any given location x between the transmitter and the receiver is given as;

$$V_{(x)} = h_{(x)}\left(\sqrt{\frac{2(d_{t(x)} + d_{r(x)})}{(d_{t(x)})(d_{r(x)})}}\right) \quad (5)$$

Where

$h_{(x)}$ is effective obstruction height which is the height (in meters) from the tip of the obstruction at location x to a point on the line of sight at location x, where x is between the transmitter and the receiver.

λ is the wavelength of the radio wave in metres

In terms of frequency, the diffraction parameter ($V_{(x,f)}$) at any given location x is given as;

$$V_{(x,f)} = h_{(x)}\left(\sqrt{\frac{2f(d_{t(x)} + d_{r(x)})}{c(d_{t(x)})(d_{r(x)})}}\right) \quad (6)$$

For two frequencies, f1 and f2, the diffraction parameter is given as

$$V_{(x,f2)} = V_{(x,f1)}\left(\sqrt{\frac{f2}{f1}}\right) \quad (7)$$

Lee's approximation for single knife edge diffraction loss, $G_d(dB)$ as a function of the diffraction parameter, $V_{(x,f)}$ is given as follows [15, 3];

$$\begin{cases} G_d(dB) = 0 \text{ for } V_{(x,f)} < -1 \\ G_d(dB) = 20\log(0.5 - 0.62V_{(x,f)}) \text{ for } -1 \le V_{(x,f)} \le 0 \\ G_d(dB) = 20\log\left(0.5\exp(-0.95V_{(x,f)}\right) \text{ for } 0 \le V_{(x,f)} \le 1 \\ G_d(dB) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1V_{(x,f)})^2}\right) \text{ for } 1 \le V_{(x,f)} \le 2.4 \\ G_d(dB) = 20\log\left(\frac{0.225}{V_{(x,f)}}\right) \text{ for } V_{(x,f)} > 2.4 \end{cases} \quad (8)$$

Usually, there are obstructions of different heights and sizes along the signal path. Let n_{tip} be the Fresnel zone in which the tip of a single knife edge obstruction lies, then;

$$n_{tip} = \left(\frac{v^2}{2}\right) \quad (9)$$

Furthermore, n_{tip} can be expressed in terms of frequency as follows;

$$n_{tip\ (f)} = \left(\frac{(V_{(x,f)})^2}{2}\right) \quad (10)$$

For two frequencies, f1 and f2, $n_{tip\ (f2)}$ is given as;

$$n_{tip\ (f2)} = n_{tip\ (f1)}\left(\frac{f2}{f1}\right) \quad (11)$$

The effective obstruction height, $h_{(x)}$ which is used to compute the diffraction parameter ($V_{(x,f)}$) is dependent on the earth bulge, the elevation as well as the transmitter and receiver antenna mast heights. The earth bulge at a distance $d_{t\,(x)}$ from the transmitter and distance $d_{r\,(x)}$ from the receiver is given as:

$$E_{b\,(x)} = \frac{(d_{t\,(x)})(d_{r\,(x)})}{12.75*K} \text{ for x=1, 2, 3,…, N.} \quad (12)$$

where,

$E_{b\,(x)}$ = earth's curvature at the point x between the transmitter and the receiver (m)

$d_{t\,(x)}$=distance between the point and the transmitter (km)

$d_{r\,(x)}$ =distance between the point and the receiver (km)

K is effective earth radius factor: Usually K is taken as $\frac{4}{3}$ (that is, 1.333.) of the actual earth radius to account for atmospheric refraction.

E_{bt} is the earth bulge at the transmitter. At the transmitter, $d_{t\,(x)}$=0, $d_{r\,(x)}$=d, hence, $E_{b\,(x)} = E_{bt} = \frac{(0)(d)}{12.75*K} = 0$.

E_{br} is the earth bulge at the receiver. At the receiver, $d_{t\,(x)}$=d, $d_{r\,(x)}$=0, hence, $E_{b\,(x)} = E_{br} = \frac{(d)(0)}{12.75*K} = 0$.

The path elevation is obtained from the topographic profile of the radio path. In this paper, the topographic profile between the transmitter and receiver is obtained using Geocontext online topographic profile tool available at: http://www.geocontext.org/publ/2010/04/profiler/en/). The topographic profile data consist of a number of elevation points along with the distance of each elevation point from the transmitter. The elevation profile is represented by E_x and $d_{t\,(x)}$ where;

E_x is the elevation taken at point x, where x=1, 2, 3,…, N

N is the number of elevation points in the topographic profile;

$d_{t\,(x)}$ is the distance of location x from the transmitter

E_t is the elevation at the transmitter location. $E_t = E_x$, at x=0 which is at the transmitter.

E_r is the elevation at the receiver location. $E_r = E_x$, at x=N which is at distance d from the transmitter.

$d_{r\,(x)}$ is the distance of location x from the receiver, where x=1, 2, 3,…, N.

d is the distance (in meters) between the transmitter and the receiver.

$$d_{t\,(x)} + d_{r\,(x)} = d \quad (13)$$

$$d_{t\,(x)} = d - d_{r(x)} \quad (14)$$

d_t is the distance at the transmitter. The transmitter is located at x=0, hence, $d_t = d_{t\,(0)} = 0$

d_r is the distance from the receiver to the transmitter. The receiver is located at x=N. Therefore, $d_r = d_{t\,(N)}$=d.

The effective transmitter and receiver antenna heights are given as

$$H_t = h_t + E_t + E_{bt} \quad (15)$$

$$H_r = h_r + E_r + E_{br} \quad (16)$$

Where;

h_t is the height (in meters) of the transmitter antenna mast measured from the ground

h_r is the height (in meters) of the receiver antenna mast measured from the ground

H_t is the overall height (in meters) of the transmitter antenna, including the elevation measured from the sea level and the earth bulge

H_r is the overall height (in meters) of the receiver antenna, including the elevation measured from the sea level and the earth bulge

Let $H_{LS\,(x)}$ be the overall height (in meters) of a point on the line of sight at location x between the transmitter and the receiver where point x is a distance of $d_{t\,(x)}$ from the transmitter. The equation for the line of sight that passes through the point ($d_{t\,(x)}$, $H_{LS\,(x)}$) is given as:

$$H_{LS\,(x)} = \left(\frac{H_r - H_t}{d}\right) d_{t\,(x)} + H_t \quad (17)$$

The effective obstruction height, $h_{(x)}$ is the height (in meters) from the tip of the obstruction at location x to a point on the line of sight at location x, where x is between the transmitter and the receiver. $h_{(x)}$ is given as;

$$h_{(x)} = \left(h_{ob\,(x)} + E_{(x)} + E_{b\,(x)}\right) - H_{LS\,(x)} \quad (18)$$

Where $h_{ob\,(x)}$ is the height of obstruction x from the ground

3. The Results and Discussions

The elevation data (in Table 1) for the Eket and Akwa Ibom state University LOS link are used along with the relevant mathematical expressions stated in this paper to determine the effective obstruction height, $h_{(x)}$ along with the diffraction parameter ($V_{(x,f)}$) and the single knife edge diffraction loss, $G_d(dB)$ for the three microwave frequency bands considered in the study. Other relevant diffraction and link parameters are computed as well. The three microwave frequencies considered in this paper are; 4 GHz for the C-band (4 to 8 GHz), 16 GHz for the Ku-band (12 to 18 GHz) and 28 GHz for the Ka-band (26.5 to 40 GHz.

Table 1. *Elevation Profile Data For The Eket To Akwa Ibom State University Microwave Link.*

S/N	Distance (m)	Elevation (m)	S/N	Distance (m)	Elevation (m)	S/N	Distance (m)	Elevation (m)
1	0.00	19.09	19	6554.71	15.37	37	13454.41	14.80
2	38.33	19.00	20	6938.03	12.26	38	13837.73	18.31
3	421.65	16.86	21	7321.35	13.76	39	14221.05	15.78
4	804.96	15.54	22	7704.66	15.17	40	14604.36	15.77
5	1188.28	17.95	23	8087.98	18.55	41	14987.68	8.87
6	1571.60	16.19	24	8471.30	21.10	42	15371.00	8.10
7	1954.91	13.00	25	8854.61	23.28	43	15754.31	11.75
8	2338.23	18.63	26	9237.93	16.83	44	16137.63	9.29
9	2721.55	27.55	27	9621.25	13.47	45	16520.94	10.46
10	3104.86	19.88	28	10004.56	22.23	46	16904.26	6.27
11	3488.18	24.03	29	10387.88	16.99	47	17287.58	21.97
12	3871.50	16.44	30	10771.20	13.45	48	17670.89	27.85
13	4254.81	12.90	31	11154.51	13.41	49	18054.21	30.03
14	4638.13	12.17	32	11537.83	16.76	50	18437.53	27.07
15	5021.45	13.24	33	11921.15	15.65	51	18820.84	26.45
16	5404.76	14.66	34	12304.46	16.53	52	19204.16	23.86
17	5788.08	19.08	35	12687.78	18.24	53	19587.48	25.07
18	6171.40	22.73	36	13071.10	13.69			

(Data source: Geocontext online topographic profile tool available at: http://www.geocontext.org/publ/2010/04/profiler/en/).

For the three frequencies considered, namely, 4 GHz, 16 GHz and 28 GHz, the square root of the ratios among the frequencies when compared to the ratio of the diffraction parameter in table 2 and figure 1 are as follows;

$$\sqrt{\frac{16}{4}} = 2 = \frac{\text{V (16) of 16GHz}}{\text{V (4) of 4 GHz}}$$

Hence; $\text{V(16) of 16GHz} = \{\text{V (4) of 4 GHz}\}\left(\sqrt{\frac{16}{4}}\right)$

$$\sqrt{\frac{28}{4}} = 2.645751 = \frac{\text{V (28) of 28GHz}}{\text{V (4) of 4 GHz}}$$

Hence; $\text{V(28) of 28GHz} = \{\text{V (4) of 4 GHz}\}\left(\sqrt{\frac{28}{4}}\right)$

$$\sqrt{\frac{28}{16}} = 1.322876 = \frac{\text{V (28) of 28 GHz}}{\text{V (16) of 16 GHz}}$$

Hence; $\text{V(28) of 28 GHz} = \{\text{V (16) of 16 GHz}\}\left(\sqrt{\frac{28}{16}}\right)$

In essence, $\sqrt{\frac{f1}{f2}}$ is a frequency scaling that can be used in equation (7) to determine the diffraction parameter at frequency f2 when the diffraction parameter at frequency f1 is known.

Table 2. *Diffraction Parameter and The ratios of the Diffraction Parameter for 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

Distance (m)	V (4) for f=4 GHz	V (16) for f=16 GHz	V (28) for f=28 GHz	Ratio of V (16) of 16GHz to V (4) of 4 GHz	Ratio of V (28) of 28GHz to V (4) of 4 GHz	Ratio of V (28) of 28 GHz to V (16) of 16 GHz
2.34	-2.72	-5.441	-7.197	2	2.645751	1.322876
3.49	-0.585	-1.169	-1.547	2	2.645751	1.322876
4.64	-2.222	-4.443	-5.878	2	2.645751	1.322876
5.4	-1.547	-3.094	-4.094	2	2.645751	1.322876
6.55	-1.179	-2.359	-3.12	2	2.645751	1.322876
8.09	-0.674	-1.347	-1.782	2	2.645751	1.322876
10	-0.309	-0.618	-0.817	2	2.645751	1.322876
10.39	-0.671	-1.343	-1.776	2	2.645751	1.322876
11.54	-0.651	-1.301	-1.722	2	2.645751	1.322876
12.3	-0.649	-1.297	-1.716	2	2.645751	1.322876
13.45	-0.727	-1.455	-1.925	2	2.645751	1.322876
14.99	-1	-2	-2.646	2	2.645751	1.322876
15.75	-0.853	-1.706	-2.257	2	2.645751	1.322876
16.9	-1.082	-2.164	-2.863	2	2.645751	1.322876
17.29	-0.42	-0.841	-1.113	2	2.645751	1.322876
18.44	-0.251	-0.502	-0.664	2	2.645751	1.322876
19.59	-0.369	-0.738	-0.976	2	2.645751	1.322876

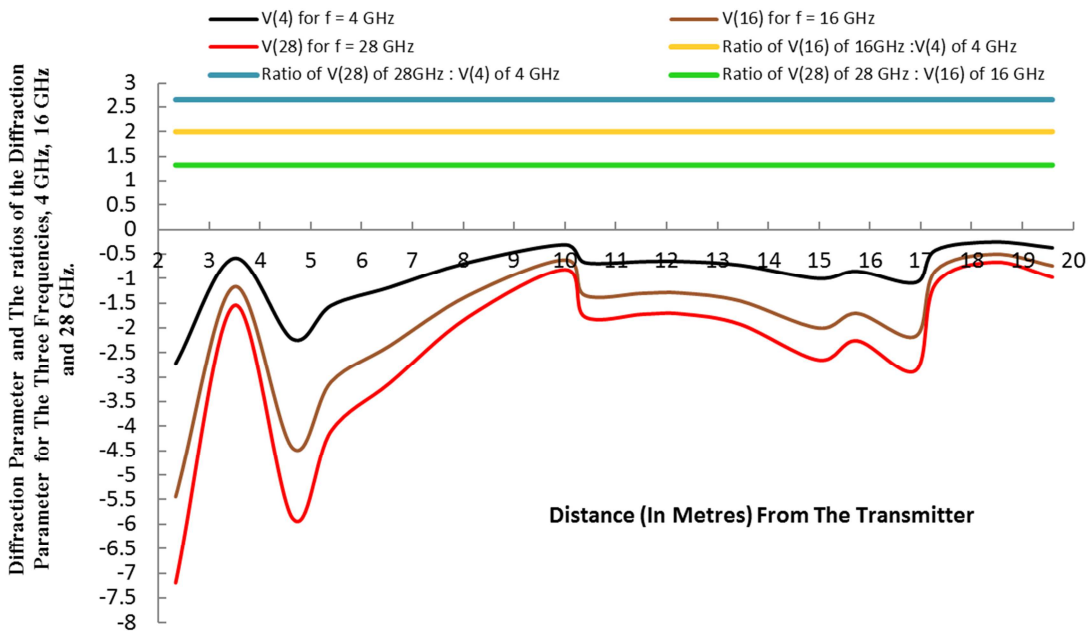

Figure 1. *Diffraction Parameter and The ratios of the Diffraction Parameter for 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

Again, for the three frequencies considered, the square root of the ratios among the frequencies when compared to the ratio of the radius of the first Fresnel zone $(r_{(1,f)})$ in table 3 and figure 2 are as follows;

$$\sqrt{\frac{16}{4}} = 2 = \frac{r_{(1,4)} \text{ of } 4\text{GHz}}{r_{(1,16)} \text{ of } 16 \text{ GHz}};$$

$$\text{Hence; } r_{(1,16)} \text{ of } 16 \text{ GHz} = \{r_{(1,4)} \text{ of } 4\text{GHz}\} \left(\sqrt{\frac{4}{16}}\right)$$

$$\sqrt{\frac{28}{4}} = 2.645751 = \frac{r_{(1,4)} \text{ of } 4\text{GHz}}{r_{(1,28)} \text{ of } 28 \text{ GHz}}$$

$$\text{Hence; } r_{(1,28)} \text{ of } 28 \text{ GHz} = \{r_{(1,4)} \text{ of } 4\text{GHz}\} \left(\sqrt{\frac{4}{28}}\right)$$

$$\sqrt{\frac{28}{16}} = 1.322876 = \frac{r_{(1,16)} \text{ of } 16 \text{ GHz}}{r_{(1,28)} \text{ of } 28 \text{ GHz}}$$

$$\text{Hence; } r_{(1,28)} \text{ of } 28 \text{ GHz} = \{r_{(1,16)} \text{ of } 16 \text{ GHz}\} \left(\sqrt{\frac{16}{28}}\right)$$

In essence, $\sqrt{\frac{f2}{f1}}$ is a frequency scaling that can be used in equation (5) to determine the radius of the first Fresnel zone at frequency f2 when the radius of the first Fresnel zone at frequency f1 is known.

Table 3. *Radius Of The First Fresnel Zone (In Metres) and The ratios of the Radius Of The First Fresnel Zone for The Three Frequencies, 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

Distance (m)	r ((1,4) for f=4 GHz	r ((1,16) for f=16 GHz	r (1,28) for f=28 GHz	Ratio of r ((1,4) of 4GHz to r ((1,16) of 16 GHz	Ratio of r (1,4) of 4GHz to r (1,28) of 28 GHz	Ratio of r (1,16) of 16 GHz to r (1,28) of 28 GHz
0.038	1.693849	0.846925	0.640215	2	2.645751	1.322876
1.188	9.14956	4.57478	3.458209	2	2.645751	1.322876
3.105	13.99831	6.999153	5.290862	2	2.645751	1.322876
4.638	16.29386	8.14693	6.1585	2	2.645751	1.322876
5.405	17.13205	8.566025	6.475306	2	2.645751	1.322876
6.555	18.08575	9.042873	6.83577	2	2.645751	1.322876
8.088	18.87126	9.435629	7.132665	2	2.645751	1.322876
10.005	19.15972	9.579862	7.241695	2	2.645751	1.322876
10.388	19.12887	9.564434	7.230032	2	2.645751	1.322876
11.538	18.85784	9.428919	7.127592	2	2.645751	1.322876
12.304	18.52373	9.261863	7.00131	2	2.645751	1.322876
13.454	17.77512	8.887561	6.718364	2	2.645751	1.322876
14.988	16.24718	8.123589	6.140856	2	2.645751	1.322876
15.754	15.20617	7.603087	5.747394	2	2.645751	1.322876
16.904	13.17854	6.589272	4.981021	2	2.645751	1.322876
17.288	12.33851	6.169255	4.663519	2	2.645751	1.322876
18.438	9.010145	4.505073	3.405515	2	2.645751	1.322876
19.204	5.30907	2.654535	2.00664	2	2.645751	1.322876

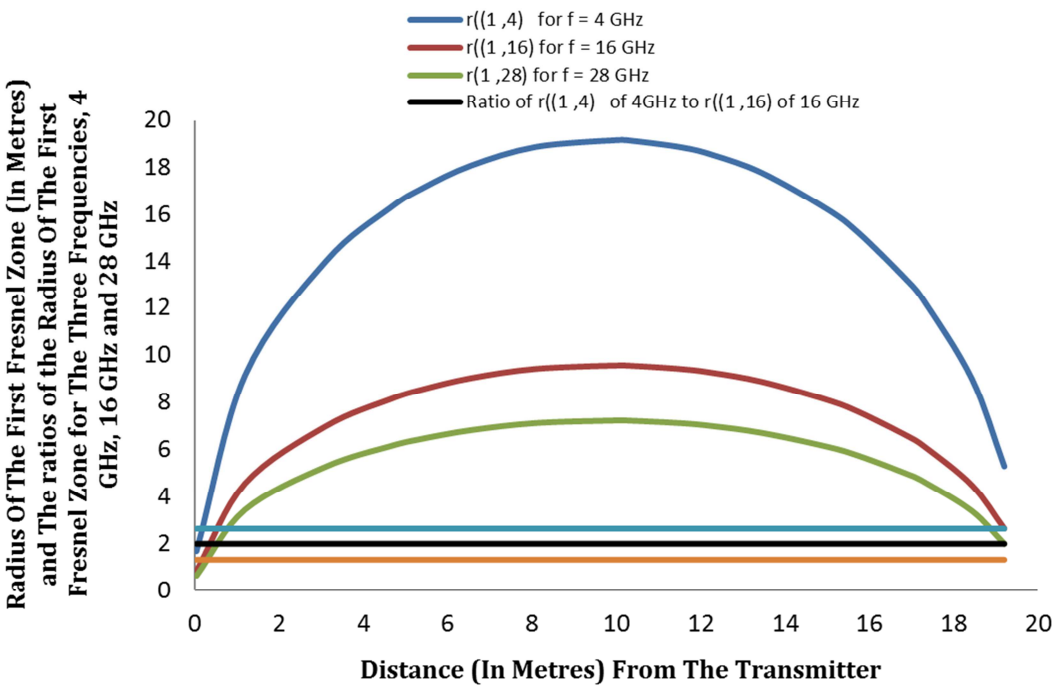

Figure 2. *Radius Of The First Fresnel Zone (In Metres) and The ratios of the Radius Of The First Fresnel Zone for The Three Frequencies, 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

Once more, for the three frequencies considered, the ratios among the frequencies when compared to the ratio of the number of Fresnel zones blocked by obstruction, $n_{tip\,(f)}$ in table 4 and figure 3 are as follows;

$$\frac{16}{4} = 4 = \frac{n_{tip\,(16)}\ \text{of}\ 16\text{GHz}}{n_{tip\,(4)}\ \text{of}\ 4\ \text{GHz}}$$

$$\text{Hence,}\ n_{tip\,(16)}\ \text{of}\ 16\text{GHz} = \{n_{tip\,(4)}\ \text{of}\ 4\ \text{GHz}\}\left(\frac{16}{4}\right)$$

$$\frac{28}{4} = 7 = \frac{n_{tip\,(28)})\ \text{of}\ 28\text{GHz}}{n_{tip\,(4)}\ \text{of}\ 4\ \text{GHz}}$$

$$\text{Hence,}\ n_{tip\,(28)}\ \text{of}\ 28\text{GHz} = \{n_{tip\,(4)}\ \text{of}\ 4\ \text{GHz}\}\left(\frac{28}{4}\right)$$

$$\frac{28}{16} = 1.75 = \frac{n_{tip\,(28)})\ \text{of}\ 28\ \text{GHz}}{n_{tip\,(16)}\ \text{of}\ 16\ \text{GHz}}$$

$$\text{Hence,}\ n_{tip\,(28)}\ \text{of}\ 28\ \text{GHz} = \{n_{tip\,(16)}\ \text{of}\ 16\ \text{GHz}\}\left(\frac{28}{16}\right)$$

In essence, $\frac{f2}{f1}$ is the frequency scaling factor that can be used in equation (11) to determine the at frequency (f2) the number of Fresnel zones blocked by obstruction when the number of Fresnel zones blocked by obstruction at frequency (f1) is known.

Table 4. *Number of Fresnel Zones Blocked By Obstruction and The Ratios Of The Number of Fresnel Zones Blocked By Obstruction for The Three Frequencies, 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

Distance (m)	ntip (4) for f=4 GHz	ntip (16) for f=16 GHz	ntip (28) for f=28 GHz	Ratio of ntip (16) of 16GHz to ntip (4) of 4 GHz	Ratio of ntip (28) of 28GHz to ntip (4) of 4 GHz	Ratio of ntip (28) of 28 GHz to ntip (16) of 16 GHz
3.48818	0.170862	0.683449	1.196036	4	7	1.75
4.25481	2.688455	10.75382	18.81918	4	7	1.75
5.02145	1.77212	7.08848	12.40484	4	7	1.75
6.55471	0.695397	2.781588	4.867779	4	7	1.75
7.32135	0.735	2.94	5.145	4	7	1.75
8.4713	0.092316	0.369265	0.646215	4	7	1.75
9.62125	0.470694	1.882775	3.294857	4	7	1.75
10.38788	0.225356	0.901422	1.577489	4	7	1.75
11.15451	0.385477	1.541908	2.698339	4	7	1.75
12.30446	0.210419	0.841678	1.472936	4	7	1.75
13.0711	0.316071	1.264282	2.212494	4	7	1.75
14.22105	0.223708	0.894832	1.565955	4	7	1.75
15.75431	0.363906	1.455624	2.547342	4	7	1.75
16.13763	0.461464	1.845857	3.23025	4	7	1.75
17.28758	0.088407	0.35363	0.618852	4	7	1.75
18.43753	0.031476	0.125905	0.220334	4	7	1.75
19.58748	0.068058	0.27223	0.476403	4	7	1.75

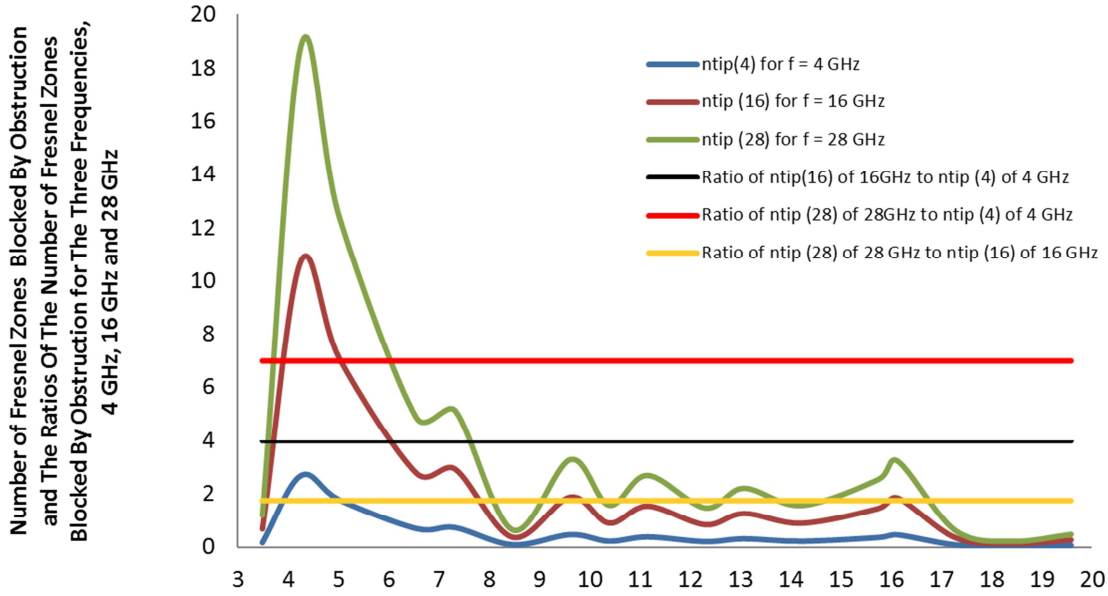

Figure 3. *Number of Fresnel Zones Blocked By Obstruction and The Ratios Of The Number of Fresnel Zones Blocked By Obstruction for The Three Frequencies, 4 GHz, 16 GHz and 28 GHz Versus Distance (In Metres) From The Transmitter.*

4. Conclusion

The frequency scaling factors for computing Fresnel zone and diffraction loss parameters based on frequency ratios are defined and validated. The frequency scaling factors are validated using empirical topographic data for line-of-sight (LOS) communication link between Eket and Akwa Ibom state University. The scaling factors considered are for the following three parameters, the radius of the Fresnel zone, Fresnel-Kirchoff diffraction parameter and the number of Fresnel zones that are partially or fully blocked by obstruction in the signal path. Specifically, three microwave frequencies are considered, namely; 4 GHz for the C-band, 16 GHz for the Ku-band and 28 GHz for the Ka-band. In all, the results show that when the value of any of the three parameters is known at frequency, f1, then the that same parameter can be determined at any other frequency by multiplying the value of the parameter at frequency f1 by the frequency scaling factor of that parameter.

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