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Analysis Of Bit Error Rate Of Bpsk, 4 QAM And 4PAM Modulation Schemes For A Partial Line Of Site Microwave Communication Link

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Abstract— In this paper, analysis of the bit error rate of BPSK, 4 QAM and 4PAM digital modulation schemes applied in a partial line of site microwave communication link are presented. Particularly, the effect of variations in percentage clearance (Cp%) of 1st Fresnel zone on diffraction loss, bit energy per noise-density $\left(\frac{E_b}{N_0}\right)$ in dB and bit error rate (BER) are presented. The results show that reduction in Cp% reduces the $\frac{E_b}{N_0}$ and BER. In all, for any given Cp%, the BPSK has the smallest number of error bits per second and the largest percentage change in error bits per second. Also, the lowest BER and the lowest number of error bits per second occur at about 70% clearance of 1st Fresnel zone. For any given amount of reduction in Cp%, the corresponding increase in BER and number of error bits per second increases as data rate increases.

Keywords— Bit Error Rate, Bit Energy Per Noise-Density , Digital Modulations , Diffraction Loss, Fresnel Zone, Diffraction Parameter

1. INTRODUCTION

In the electronics and telecommunication industries, digital modulation is widely used to enhance information capacity, data security and other salient channel parameters that can affect quality of service [1,2,3,4,5,6,7,8]. Basically, digital modulation enables digital information signal to be encoded by varying the phase, amplitude or frequency of the transmitted signal [9,10,11,12,13,14,15,16,17,18,19,20]. This can be achieve in many ways and each approach affects the symbol rate and the bandwidth of the signal transmitted. Particularly, in this paper, three different modulation approaches are considered, namely, Binary Phase Shift Keying (BPSK) [21,22,23,24,25,6,27,28,29,30], Quadrature Amplitude modulation (QAM) [31,32,33,34,35,36,37] and Pulse Amplitude Modulation (PAM) [38,39,40,41,42,43,44,45,46,47,48,49].

Binary Phase Shift Keying (BPSK), sometimes referred to as phase reversal keying (PRK) is a modulation scheme in which the sine wave carrier signal is made to assume to phases that are separated by 180° [50,51,52,53,54]. In the multilevel version, that is, M-ary BPSK, the carrier signal assumes M different phases. On the other hand, QAM is a modulation scheme which employs both Amplitude Shift Keying (ASK) and Phase-shift keying (PSK) modulation schemes on two different sinusoidal waves that have the same frequency but have a phase difference of 90° [55,56,57,58,59,60]. In addition, PAM4 is the acronym for 4-level Pulse Amplitude Modulation (PAM) modulation scheme. It is developed from the conventional two state NRZ (non-return-to-zero) modulation. Notably, compared to the 2-level pulse amplitude modulation scheme, PAM4 doubles the data rate but at the same time, it reduces the SNR (signal to noise ratio).

Specifically, in this paper, the study is focused on analyzing the it error rate of BPSK, 4 QAM and 4PAM for a partial line of site microwave communication link. In the partial line of sight link, obstruction in the signal part cause diffraction loss. The magnitude of the diffraction loss depends on the percentage of the Fresnel zones that are obstructed. Furthermore, the diffraction loss occasioned by the obstruction affects the bit error rate of each of the modulation scheme. Accordingly, in this paper, the impact of different degrees of obstructions on the bit error rate of different modulation schemes are presented. The requisite mathematical expressions are presented and the computations are implemented in Matlab software.

2. METHODOLOGY

2.1 Determination of Bit Energy Per Noise-Density Using Link Budget Equation

The energy per bit (E_b) in dBW is related to the received power, P_{TX} as;

$$E_b = P_{RX} - 10 \text{ Log } (R_{bps}) \quad (1)$$

Where R_{bps} is bit rate in bits per second. Also, the noise power density (N_o) in dBW is given as;

$$N_o = -204 + NF_{dB} \quad (2)$$

Where NF_{dB} is noise figure in dB. Then, the bit energy per noise-density $\left(\frac{E_b}{N_0}\right)$ is given as [60];

$$\frac{E_b}{N_o} = P_{RX} - 10 \text{ Log } (R_{bps}) + 204 - NF_{dB} \quad (3)$$

Hence, link budget expression gives;

$$P_{RX} = P_{TX} + G_{TXA} + G_{RXA} - L_{TX} - L_{RX} - L_{FSL} - L_{oL} - \text{FM} \quad (4)$$

Where

P_{TX} = Transmitter power measured in dBW
G_{TXA} =Transmitter antenna gain in dBi.
G_{RXA} = Receiver antenna gain in dBi.
L_{TX} = Transmitter losses in dB
L_{RX} = Receiver losses in dB
L_{FSL} = free-space loss in dB
L_{oL} = other path losses (in dB) including losses like diffraction loss,
FM = fade margin in dB

Now,

$$L_{FSL} = 92.4 + 20\log(f) + 20\log(d) \quad (5)$$

Where f is transmitted frequency in GHz and d is path length in km. In this paper, L_{oL} is taken to be the single knife edge diffraction loss designated as L_{DFL}. Therefore,

$$P_{RX} = P_{TX} + G_{TXA} + G_{RXA} - L_{TX} - L_{RX} - L_{FSL} - L_{DFL} - \mathrm{FM} \quad (6)$$

$$\frac{\mathrm{E_b}}{\mathrm{N_o}} = P_{TX} + G_{TXA} + G_{RXA} - L_{TX} - L_{RX} - L_{FSL} - L_{DFL} - \mathrm{FM} - 10\,\mathrm{Log}(\mathrm{R_{bps}}) + 204 - \mathrm{NF_{dB}} \quad (7)$$

2.2 Determination of Single Knife Edge Diffraction Loss as a function of Percentage Clearance of Fresnel Zone

Let $Cp_{(x,n)}$ be the percentage clearance required for Fresnel zone n. In practice, at least 60% of $\mathbf{r}_{(1)}$ (that is, 0.6 of $\mathbf{r}_{(1)}$) clearance is required for the first Fresnel zone. $Cp_{(x,n)}$ clearance for $\mathbf{r}_{(n)}$ translates to effective obstruction height $h_{(x,CP)}$ given as;

$$h_{(x,CP)} = \frac{Cp_{(x,n)}}{100}\left(-\mathbf{r}_{(n)}\right) = \left(\frac{Cp_{(x,n)}}{100}\right)\left(\sqrt{\frac{n\{\lambda(d_{t(x)})(d_{r(x)})\}}{(d_{t(x)} + d_{r(x)})}}\right) \quad (8)$$

Where $Cp_{(x,n)} > 0\%$ (i.e. positive) if the obstruction height is below the line-of-sight (LOS).
$Cp_{(x,n)} = 0\%$ if the obstruction height is on the LOS.
$Cp_{(x,n)} < 0\%$ (i.e. negative) if the obstruction height is above the LOS. Hence, for $Cp_{(x,n)} = 60\%$, $h_{(x,60)} = 0.6\left(-\mathbf{r}_{(n)}\right)$. In terms of $Cp_{(x,n)}$, the Fresnel-Kirchoff diffraction parameter at any given location x between the transmitter and the receiver can be represented as ($V_{(x,CP)}$) and it is given as;

$$V_{(x,CP)} = h_{(x,CP)}\left(\sqrt{\frac{2(d_{t(x)} + d_{r(x)})}{\lambda(d_{t(x)})(d_{r(x)})}}\right) \quad (9)$$

$$V_{(x,CP)} = -\left(\frac{Cp_{(x,n)}}{100}\right)\left(\sqrt{2n}\right) \quad (10)$$

Lee's approximation for single knife edge diffraction loss, $\mathrm{G}_d(dB)$ as a function of $V_{(x,CP)}$ is given as;

$$\begin{cases} L_{DFL} = 0 & \text{for } V_{(x,CP)} < -1 \\ L_{DFL} = 20\log(0.5 - 0.62V_{(x,CP)}) & \text{for } -1 \le V_{(x,CP)} \le 0 \\ L_{DFL} = 20\log\left(0.5\exp(-0.95V_{(x,CP)})\right) & \text{for } 0 \le V_{(x,CP)} \le 1 \\ L_{DFL} = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1V_{(x,CP)})^2}\right) & \text{for } 1 \le V_{(x,CP)} \le 2.4 \\ L_{DFL} = 20\log\left(\frac{0.225}{V_{(x,CP)}}\right) & \text{for } V_{(x,CP)} > 2.4 \end{cases} \quad (11)$$

2.3 Bit Error Performance Of Digital Wireless Communication System

In terms of total number of bits transmitted, bit error rate (BER) can be expressed as :

$$\mathrm{BER} = \frac{\text{Number of Errors Bits}}{\text{Total Number of Bits Sent}} \quad (11)$$

Also, in terms of bit rate, BER can be expressed as;

$$\mathrm{BER} = \frac{\text{Average Bits Error Per Second}}{\text{Bit Rate}} \quad (12)$$

The bit error probability is the expectation value of the BER. The BER is a function Eb/No. Usually, Eb/No is used to compare two or more digital modulation techniques that uses different transmission rate. For Binary Phase Shift Keying Modulation (BPSK) modulation in additive white-gaussian-noise (AWGN) the theoretical BER can be calculated with respect to $\frac{\mathrm{E_b}}{\mathrm{N_o}}$ as follows;

$$\mathrm{BER}_{(\mathrm{BPSK})} = \frac{1}{2}erfc\left(\sqrt[2]{\frac{\mathrm{E_b}}{\mathrm{N_o}}}\right) \quad (12)$$

Where $erfc(x) = 1 - \mathrm{erf}(x)$ and $\mathrm{erf}(x) = \frac{2}{\pi}\int_0^x e^{-t^2}dt$. For Pulse Amplitude Modulation (4-PAM) modulation in an AWGN channel, the theoretical BER is given by;

$$\mathrm{BER}_{(4\mathrm{PAM})} = \frac{3}{4}erfc\left(\sqrt[2]{\frac{\mathrm{E_b}}{5(\mathrm{N_o})}}\right) \quad (13)$$

For 4 Point Quadrature Amplitude Modulation (4-QAM) modulation in an AWGN channel, the theoretical BER is given by;

$$\mathrm{BER}_{(4\mathrm{QAM})} = erfc\left(\sqrt[2]{\frac{\mathrm{E_b}}{2(\mathrm{N_o})}}\right) \quad (14)$$

3 RESULTS AND DISCUSSIONS

The modulation schemes considered in the simulation are;

i. Binary Phase Shift Keying Modulation (BPSK) modulation
ii. Pulse Amplitude Modulation (4-PAM) modulation
iii. 4 Point Quadrature Amplitude Modulation (4-QAM)

The theoretical BER versus $\frac{E_b}{N_o}$ for each of the three digital modulations techniques are obtained. First, a sample computation is done with diffraction loss of 0db , data rate of 150 Mbps and with the following C-band microwave link specifications; $P_{TX} = 10$ dBW , $G_{TXA} = 30$ dBi, $G_{RXA} = 30$ dBi, $L_{TX} = 3.08$ dB, $L_{RX} = 3.08$ dB ,$NF_{dB} = 8$ dB, f = 6.0 GHz, d = 40 km, FM=20dB, $R_{bps} = 1.544$ Mbps = 1.544×10^6 bps and $L_{oL} = L_{DFL} = 0\ dB$. The results of the sample computation are as follows;

$L_{FSL} = 92.4 + 20 \log (6.0) + 20 \log (40) = 140.0042$ dB

$P_{RX} = 10 + 30 + 30 - 3.08 - 3.08 - 140.0042 - 0 - 20 = -96.1642$ dB

$\frac{E_b}{N_o} = -96.1642 - 10 \text{ Log } (150 \times 10^6) + 204 - 8 = 18.07486$ dB

$$\text{BER}_{(\text{BPSK})} = \frac{1}{2} erfc\left(\sqrt[2]{18.07486}\right) = 9.13621 \times 10^{-10}$$

$$\text{BER}_{(4\text{QAM})} = erfc\left(\sqrt[2]{\left(\frac{18.07486}{2}\right)}\right) = 2.12387\text{E} \times 10^{-05}$$

$$\text{BER}_{(4\text{PAM})} = \frac{3}{4} erfc\left(\sqrt[2]{\left(\frac{18.07486}{5}\right)}\right) = 0.005377305$$

The second set of results is for simulations conducted for -100% ≤ $Cp_{(x,n)}$ ≤ 100% and for different data rates of 150 Mbps and 100Mbps. Sample plot of theoretical probability of bit error rate (Log10(BER) versus Eb/No is given in Figure 1 for the three different digital modulations schemes.

In the results in Table 1 and Figure 2, the diffraction loss is zero for 80% ≤ Cp (%)≤100% but it increased above zero for 60% ≤ Cp (%)<80%. For all Cp (%) <60% the diffraction loss loss falls as Cp (%) falls. Similarly, bit energy per noise-density $\left(\frac{E_b}{N_o}\right)$ in dB follows the changes in diffraction loss.

In the results in Table 2 and Figure 3, the BER is not affected by for 80% ≤ Cp (%)≤100% since the diffraction loss is zero in this region. However, BER decreased for 60% ≤ Cp (%)<80% and then for all Cp (%) <60% the BER increases as Cp (%) decreases.

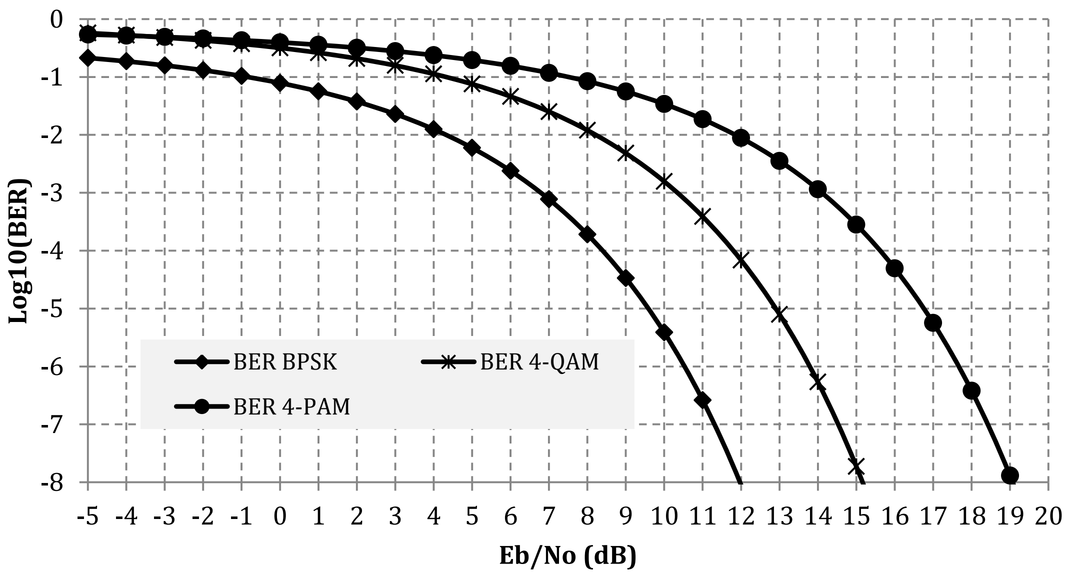

Figure 1. The Plot of Theoretical Probability Of Bit Error Rate (Log10(BER) Versus Eb/No For Three Different Digital Modulations Schemes In Additive White-Gaussian-Noise (AWGN)

Table 1. Variation of Diffraction Parameter (V), Diffraction Loss In dB and Bit Energy Per Noise-Density $\left(\frac{E_b}{N_o}\right)$ In dB With Percentage Clearance (Cp (%)) Of The 1st Fresnel Zone

Cp (%) percentage clearance for 1st Fresnel zone	V	Diffraction Loss (dB)	Eb/No (dB)
100	-1.41421	0	18.07486
80	-1.13137	0	18.07486
60	-0.84853	0.223687	18.29855
40	-0.56569	-1.40422	16.67065

20	-0.28284	-3.40926	14.6656
0	0	-6.0206	12.05426
-20	0.282843	-8.3545	9.720359
-40	0.565685	-10.6884	7.386456
-60	0.848528	-13.0223	5.052552
-80	1.131371	-14.7614	3.313474
-100	1.414214	-16.3604	1.714473

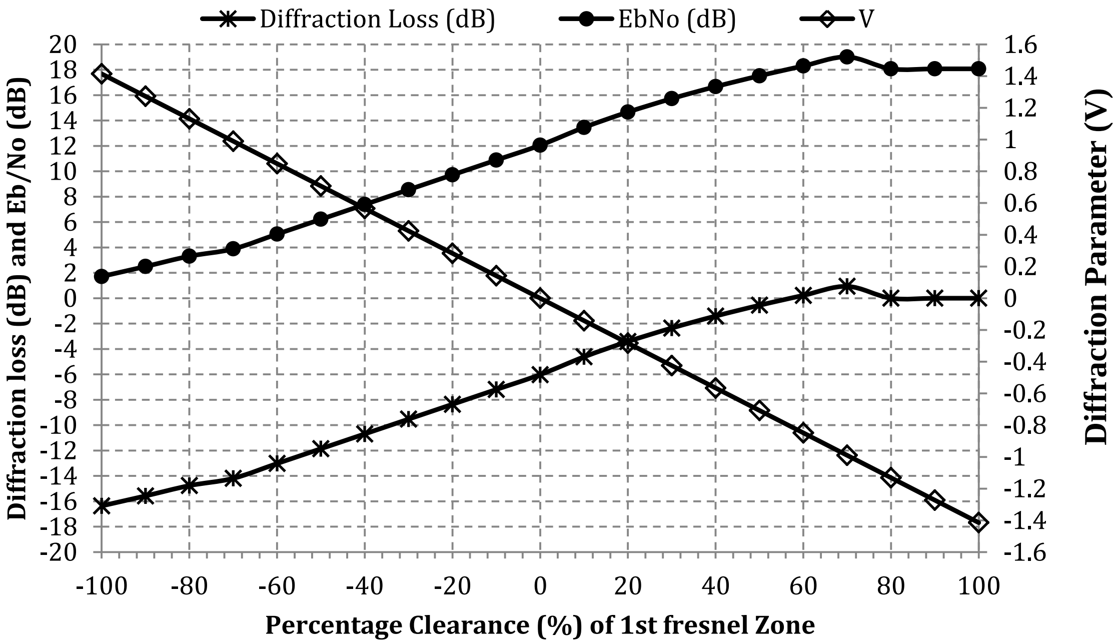

Figure 2. Variation of Diffraction Parameter (V), Diffraction Loss In dB and Bit Energy Per Noise-Density $\left(\frac{E_B}{N_0}\right)$ In dB With Percentage Clearance (Cp (%))Of The 1st Fresnel Zone

Table 2. Log10(BER) Versus Percentage Clearance (Cp (%))Of The 1st Fresnel Zone for The Three Digital Modulations Techniques At Data Rates Of 150 Mbps.

Cp (%)	Log10(BER) for BPSK	Log10(BER) for 4-QAM	Log10(BER) for 4-PAM	Diffraction Loss (dB)
100	-9.03923	-4.67287	-2.26944	0
80	-9.03923	-4.67287	-2.26944	0
60	-9.13892	-4.72388	-2.29107	0.223687
40	-8.41272	-4.35199	-2.13307	-1.40422
20	-7.51566	-3.89154	-1.93646	-3.40926
0	-6.34172	-3.28673	-1.67618	-6.0206
-20	-5.28495	-2.73936	-1.43805	-8.3545
-40	-4.21729	-2.18232	-1.19229	-10.6884
-60	-3.13118	-1.60925	-0.93423	-13.0223
-80	-2.29909	-1.16295	-0.72765	-14.7614
-100	-1.49442	-0.72032	-0.5147	-16.3604

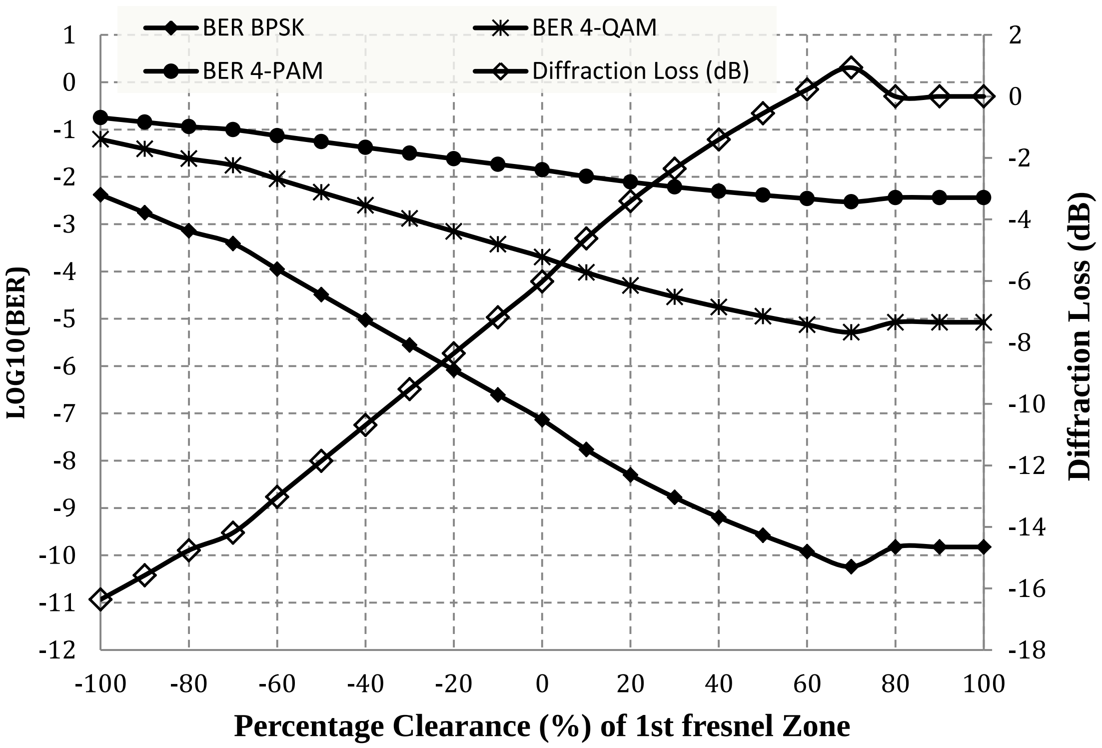

Figure 3. Log10(BER) Versus Percentage Clearance (Cp (%)) Of The 1st Fresnel Zone for The Three Digital Modulations Techniques At Data Rates Of 150 Mbps.

In Table 3, the BPSK has 0.14 error bits per second at CP% = 100% whereas 4-QAM and 4-PAM have 3185.8 and 806595.8 error bits per second respectively. The error bits per second reduced at 60 % clearance. For the BPSK there is 20.5% reduction in error bits per second whereas 4-QAM and 4-PAM have 11.1% and 4.9%reduction in their error bits per second respectively. The percentage change in error bit per second is computed with respect to the BER at CP% = 100%. However, for all Cp (%) <60% the number of error bits per second increased for all the three modulation schemes. In all, for any given Cp (%), the BPSK has the smallest number of error bits per second and the largest percentage change in error bits per second.

In Table 4, the computation is done with data rate of 100Mbps. The difference between the results in Table 3 and Table 4 is that the for any given Cp (%), the number of error bits per second for data rate of 100Mbps (in Table 4) is smaller than that of data rate of 150Mbps (in Table 3). Also, the percentage change in error bits per second in Table 4 is smaller than that of 150Mbps Table 3. In essence, the higher the data rate, the higher the impact of changes in Cp (%) on number of error bits per second.

Table 3. Average Error Bits Per Second (AVEBPS) Versus Percentage Clearance (Cp (%))Of The 1st Fresnel Zone for The Three Digital Modulations Techniques At Data Rates Of 150 Mbps.

Cp (%)	AVEBPS For BPSK	AVEBPS For 4-QAM	AVEBPS For 4-PAM	%Δ AVEBPS For BPSK	%Δ AVEBPS For 4-QAM	%Δ AVEBPS For 4-PAM
100	0.14	3185.8	806595.8	0	0	0
80	0.14	3185.8	806595.8	0	0	0
60	0.11	2832.76	767401	-20.5	-11.1	-4.9
40	0.58	6669.56	1104132	323.2	109.4	36.9
20	4.58	19255.16	1736323	3238.7	504.4	115.3
0	68.29	77511.12	3161647	49732.6	2333	292
-20	778.28	273356.9	5470666	567809.9	8480.5	578.2

-40	9094.88	985753	9633874	6636406	30842	1094.4
-60	110894.4	3688454	17452667	80919236	115677.8	2063.7
-80	753354.5	10307115	28083048	5.5E+08	323432.6	3381.7
-100	4804725	28560915	45855043	3.51E+09	896405.5	5585

Table 4. Average Error Bits Per Second (AVEBPS) Versus Percentage Clearance (Cp (%))Of The 1st Fresnel Zone for The Three Digital Modulations Techniques At Data Rates Of 100 Mbps.

Cp (%)	AVEBPS For BPSK	AVEBPS For 4-QAM	AVEBPS For 4-PAM	%Δ AVEBPS For BPSK	%Δ AVEBPS For 4-QAM	%Δ AVEBPS For 4-PAM
100	0.02	843.88	363795.9	0	0	0
80	0.02	843.88	363795.9	0	0	0
60	0.01	750.71	346252.4	-20.5	-11	-4.8
40	0.06	1761.17	496681.9	321.7	108.7	36.5
20	0.5	5057.29	777575	3208	499.3	113.7
0	7.34	20170.05	1405136	48775.4	2290.1	286.2
-20	82.59	70301.01	2408399	549666.6	8230.7	562
-40	946.15	249076.1	4182665	6297661	29415.4	1049.7
-60	11148.21	904730.6	7407319	74204874	107110.3	1936.1
-80	72198.68	2428187	11568414	4.81E+08	287639.5	3079.9
-100	418915.7	6228822	17878431	2.79E+09	738013.7	4814.4

4 CONCLUSION

The effect of diffraction loss on bit error rate is examined. Particularly, the mathematical expressions for examining the variations of the diffraction parameter, diffraction loss, bit energy per noise-density $\left(\frac{E_b}{N_0}\right)$ in dB and bit error rate (BER) with percentage clearance of 1st Fresnel zone are presented. The study considered three different digital modulations in additive white-Gaussian-noise (AWGN). The modulation schemes considered are Binary Phase Shift Keying Modulation (BPSK) modulation, Pulse Amplitude Modulation (4-PAM) modulation and 4 Point Quadrature Amplitude Modulation (4-QAM). The results show that reduction in percentage clearance of 1st Fresnel zone reduces the bit energy per noise-density thereby increasing the BER. For each of the modulation schemes, the actual number of error bits per second and percentage change in error bits per second are determined for any given percentage clearance of 1st Fresnel zone. The results and mathematical expressions presented in this paper are useful for digital wireless network planners and designers to ensure that the selected parameters will not violate the specified error performance when subjected to variations in the available diffraction loss in the communication link.

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