

Performance Evaluation of Multi-Level FSK Modulation Techniques in Rayleigh and Rician Fading Channels

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Abstract

Reliable transmission and efficient use of the spectrum remain challenges, in modern wireless communication systems especially when multipath fading occurs. This study looks at how Multi-Level Frequency Shift Keying (MFSK) works using 4-FSK, 8-FSK and 16-FSK when signals travel through Additive White Gaussian Noise (AWGN) Rayleigh fading and Rician fading. We built simulation models in MATLAB/Simulink to check Bit Error Rate (BER) against bit energy-to-noise ratio (E_b/N_0) and Signal-to-Noise Ratio (SNR). The study also goes over radio-propagation loss models and key features of fading channels. The simulation shows that BER drops when E_b/N_0 and SNR rise for every MFSK scheme studied. It also shows that Rician fading usually gives BER than Rayleigh fading because Rician fading has a Line-of-Sight (LOS) component. Even though higher-order MFSK can send symbols in each signal it also needs bandwidth.

Keywords: MFSK, Fading Channels, Rayleigh Fading, Rician Fading, AWGN Bit Error Rate (BER) MATLAB/Simulink.

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1. INTRODUCTION

Wireless communication signals lose strength bounce off surfaces bend around obstacles and spread out as they travel through complicated built surroundings. Maxwell's equations give the rules for how electromagnetic waves move. Using them directly for real-world environments can be very hard to compute [1].

For this reason, practical communication-system studies commonly rely on empirical and statistical propagation models [2].

A. Free-Space Loss Model:

For an ideal unobstructed propagation environment, the received power at a distance s can be described by the Friis transmission equation:

B. Plane Earth Loss Model:

The plane-earth model considers two propagation components: the direct Line-of-Sight (LOS) path and a path reflected from the ground. In the far-field region, the corresponding path-loss exponent approaches 4. The difference between the two path lengths can be approximated as:

C. Okumura-Hata and COST-231 Models:

The Okumura-Hata and COST-231 models are empirical models developed from field measurements and are commonly used to estimate path loss in macrocellular environments, For the applicable frequency range, the total path loss L in dB can be expressed as:

II. WIRELESS CHANNEL FADING CHARACTERISTICS:

Fading refers to rapid variations in the received signal amplitude, phase, or propagation delay over relatively short distances or time intervals [6], [7]. These variations are mainly caused by the interaction of multiple propagation paths.

A. Rayleigh Fading Channel:

When there is no dominant direct LOS component between the transmitter and receiver, the received signal envelope is commonly modeled using a Rayleigh distribution. In this case, the in-phase (I) and quadrature (Q) components are independent zero-mean Gaussian random variables, while the signal phase is uniformly distributed over $[-\pi, \pi]$:

B. Rician Fading Channel:

When a dominant stationary LOS component is present together with scattered multipath components, the received envelope follows a Rician distribution. The joint probability density function (PDF) of the amplitude r and phase ϕ is given by:

III. MULTI- LEVEL FREQUENCY SHIFT KEYING (MFSK):

M-ary Frequency Shift Keying (MFSK) is an extension of binary FSK in which M distinct tones or carrier frequencies are used to represent $\log_2(M)$ bits per symbol. The tones are selected to be orthogonal, which allows non-coherent detection at the receiver without requiring phase synchronization [10]. By increasing the number of available tones, MFSK can transmit more bits per symbol, although this generally requires additional bandwidth. Common choices of M include 4, 8, 16, and higher values such as 64 [11], [12].

IV. SIMULINK MODELING AND SIMULATION:

A digital communication link was developed in MATLAB/Simulink to evaluate the behavior of the MFSK schemes under the considered channel conditions, as shown in Fig. 1 and Fig. 2. The main components of the simulation model are described below:

Simulink Model Architecture for MFSK System Performance Evaluation



Fig. 1. Simulink model used to evaluate MFSK performance over Rayleigh and Rician fading channels.

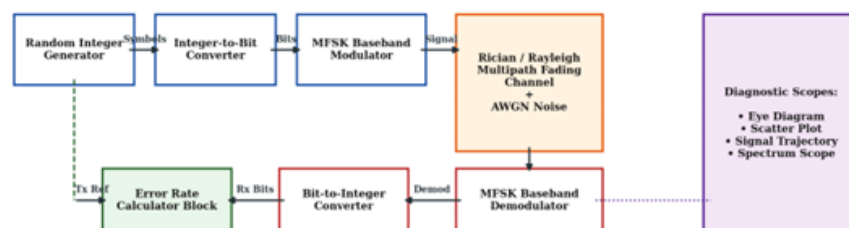


Fig. 2. Complete Simulink block diagram used for the MFSK performance evaluation.

V. SIMULATION RESULTS AND DISCUSSION:

Simulations were performed for 4-FSK, 8-FSK, and 16-FSK using various values of E_b/N_0 and SNR. The results of simulation in terms of BER have been shown in Figs. 3 and 4, whereas the numerical values have been shown in Tables 1–6.

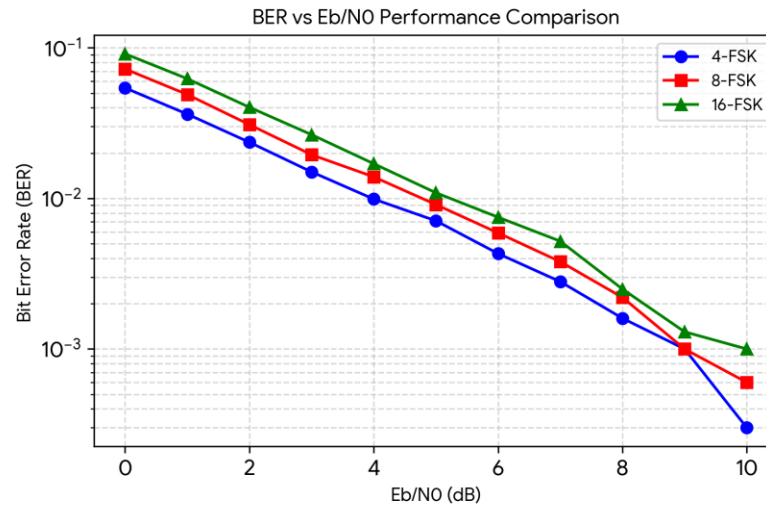


Fig. 3. BER versus E_b/N_0 for the 4-FSK, 8-FSK, and 16-FSK modulation schemes.

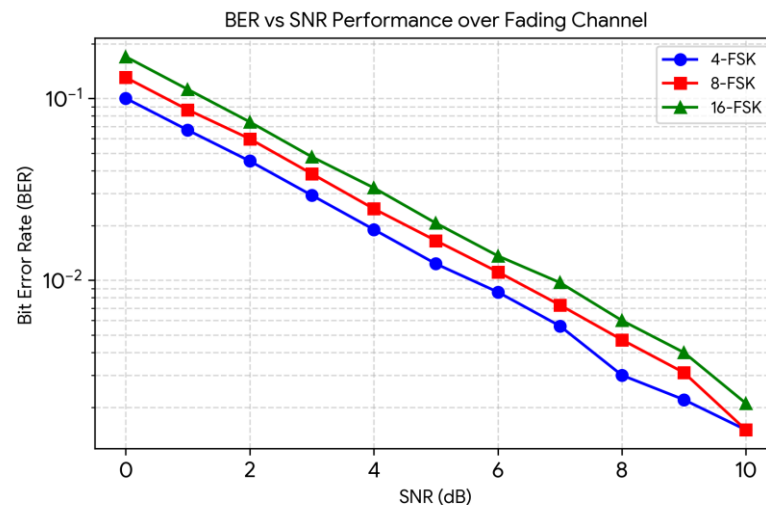


Fig. 4. BER versus SNR for the 4-FSK, 8-FSK, and 16-FSK schemes under the considered fading conditions.

Table 1. BER versus E_b/N_0 for the 4-FSK scheme

E_b/N_0 (dB)	Error Bits	Total Bits	Bit Error Rate (BER)
0	542	10,000	0.05419
1	363	10,000	0.03630
2	236	10,000	0.02360
3	150	10,000	0.01500
4	99	10,000	0.009899
5	71	10,000	0.007099
6	43	10,000	0.00430
7	28	10,000	0.00280
8	16	10,000	0.00160
9	10	10,000	0.0009999
10	3	10,000	0.00030

Table 2. BER versus E_b/N_0 for the 8-FSK scheme

E_b/N_0 (dB)	Error Bits	Total Bits	Bit Error Rate (BER)
0	724	10,000	0.07239
1	490	10,000	0.04900
2	309	10,000	0.03090
3	195	10,000	0.01950
4	139	10,000	0.01390
5	91	10,000	0.009099
6	59	10,000	0.005899
7	38	10,000	0.00380
8	22	10,000	0.00220
9	10	10,000	0.0009999
10	6	10,000	0.0005999

Table 3. BER versus E_b/N_0 for the 16-FSK scheme

E_b/N_0 (dB)	Error Bits	Total Bits	Bit Error Rate (BER)
0	913	10,000	0.09129
1	624	10,000	0.06239
2	403	10,000	0.04030
3	265	10,000	0.02650
4	170	10,000	0.01700
5	109	10,000	0.01090
6	75	10,000	0.007499
7	52	10,000	0.005199
8	25	10,000	0.00250
9	13	10,000	0.00130
10	10	10,000	0.0009999

Table 4. BER versus SNR for the 4-FSK scheme

SNR (dB)	Bit Error Rate (BER)
0	0.10010
1	0.06689
2	0.04520
3	0.02930
4	0.01900
5	0.01230
6	0.008599
7	0.005599
8	0.00300
9	0.00220
10	0.00150

Table 5. BER versus SNR for the 8-FSK scheme

SNR (dB)	Bit Error Rate (BER)
0	0.13030
1	0.08659
2	0.05989
3	0.03850
4	0.02470
5	0.01650
6	0.01110
7	0.007299
8	0.00470
9	0.00310
10	0.00150

Table 6. BER versus SNR for the 16-FSK scheme

SNR (dB)	Bit Error Rate (BER)
0	0.16950
1	0.11210
2	0.07419
3	0.04770
4	0.03220
5	0.02060
6	0.01360
7	0.009699
8	0.005999
9	0.00400
10	0.00210

The numerical results show a clear reduction in BER as either SNR or E_b/N_0 increases. This trend is observed for all three MFSK configurations. The results also indicate that Rician fading experiences fewer severe signal fades than Rayleigh fading because the Rician channel includes a

direct LOS propagation component. The corresponding eye diagram, constellation scatter plot, and complex signal trajectory are presented in Fig. 5, Fig. 6, and Fig. 7, respectively.

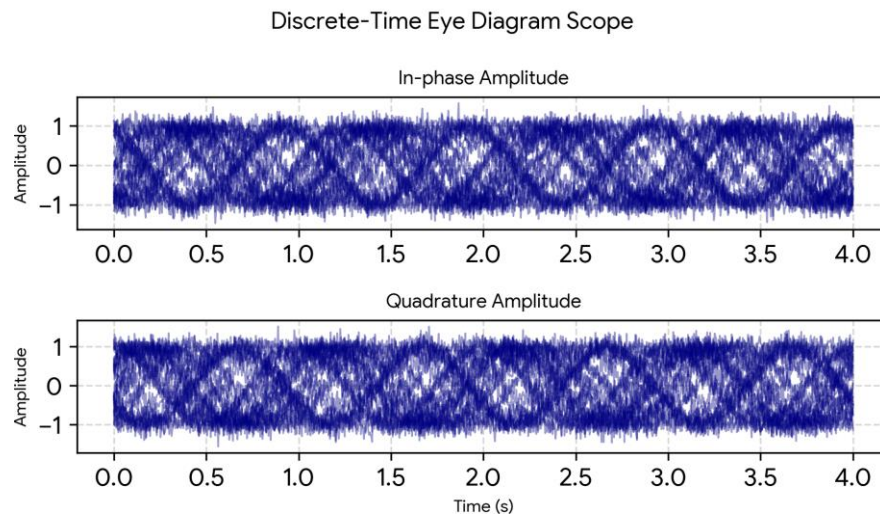


Fig. 5. Discrete-time eye diagram illustrating the amplitude transitions of the MFSK signal.

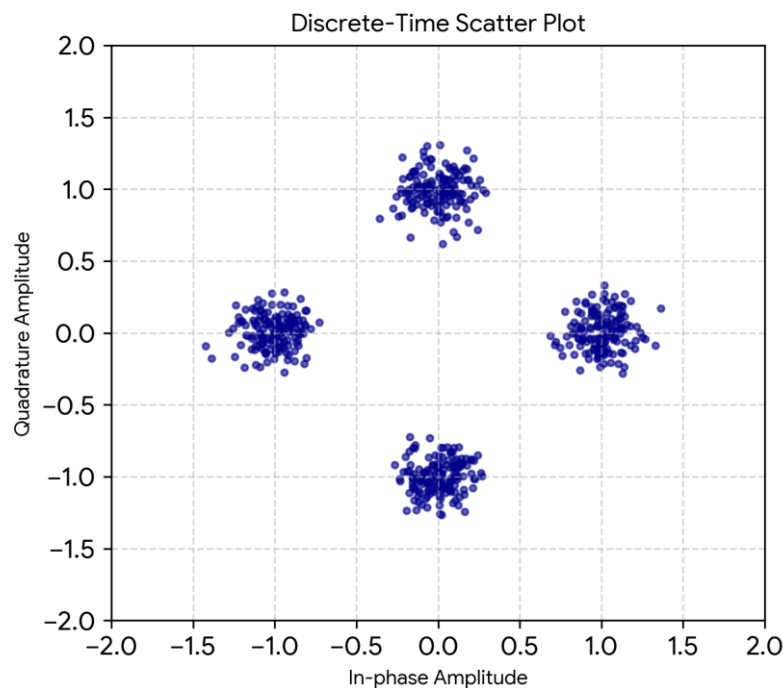


Fig. 6. Scatter plot of the MFSK tone constellation in the presence of noise and multipath fading.

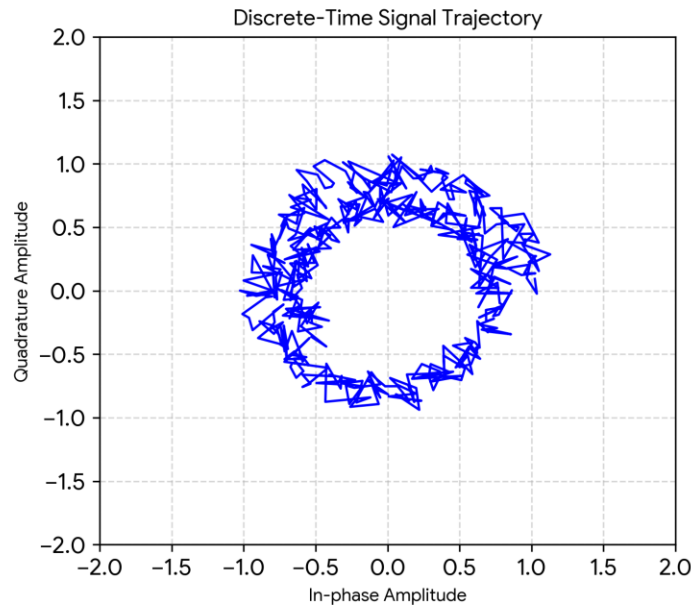


Fig. 7. Discrete-time signal trajectory in the complex plane under Rician fading conditions.

VI. CONCLUSION:

In this paper, the performance of 4-FSK, 8-FSK, and 16-FSK modulations under the Rayleigh and Rician fading channels is analyzed through MATLAB Simulink software. The study also reviewed the mathematical descriptions of small-scale fading and several propagation-loss models. The simulation results show that increasing E_b/N_0 or SNR reduces the BER for the investigated MFSK schemes. In addition, the Rician channel generally provides better BER performance than the Rayleigh channel because of its dominant LOS component. Future work can extend this analysis to higher-order MFSK combined with Forward Error Correction (FEC), including Reed-Solomon and convolutional coding, and can consider urban macrocellular channel models.

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