Alexandria University
Faculty of Engineering
Electrical Engineering Department

Advanced Communications

Experiment 4

Simulation of complete OFDM system

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Simulation of complete OFDM system

Fading	Modulation	Delay Spread	Channel BER snrPerSubcarrierdB=0	Coded BER snrPerSubcarrierdB=0	Coded FER snrPerSubcarrierdB=0	Channel BER snrPerSubcarrierdB=12	Coded BER snrPerSubcarrierdB=12	Coded FER snrPerSubcarrierdB=12
Uniform	BPSK	5	0.1460	0.0872	0.4028	0.0151	6.8e-6	7e-05
		15	0.1495	0.0618	0.4044	0.0151	0.0	0.0
		25	0.1504	0.0547	0.4144	0.0182	0.0	0.0
	QPSK	5	0.2130	0.2912	0.9349	0.0290	1.5e-4	0.0022
		15	0.2132	0.3204	0.9853	0.0289	4.8e-7	2e-05
		25	0.2136	0.3281	0.9901	0.0347	0.0	0.0
	16-QAM	5	0.3199	0.4874	1.0	0.0867	0.0125	0.1477
		15	0.3198	0.4857	1.0	0.0877	0.0021	0.0718
		25	0.3220	0.4922	1.0	0.1023	0.0033	0.1446
	64-QAM	5	0.3781	0.4967	1.0	0.1651	0.1422	0.8340
		15	0.3793	0.4983	1.0	0.1666	0.1275	0.9481
		25	0.3827	0.4992	1.0	0.1854	0.2069	0.9950
Exponential	BPSK	5	0.1456	0.0941	0.4223	0.0151	1.1e-5	1.3e-4
		15	0.1460	0.0560	0.3764	0.0150	0.0	0.0
		25	0.1482	0.0517	0.3873	0.0172	0.0	0.0
	QPSK	5	0.2105	0.2951	0.9437	0.0289	1.6e-4	0.0026
		15	0.2088	0.2942	0.9617	0.0289	9.7e-8	1e-05
		25	0.2159	0.3225	0.9950	0.0329	0.0	0.0
	16-QAM	5	0.3241	0.4879	1.0	0.0894	0.0128	0.1757
		15	0.3227	0.4872	1.0	0.0880	0.0019	0.0712
		25	0.3237	0.4908	1.0	0.0980	0.0021	0.1097
	64-QAM	5	0.3800	0.4967	1.0	0.1670	0.1472	0.8627
		15	0.3770	0.4971	1.0	0.1664	0.1262	0.9393
		25	0.3786	0.4959	1.0	0.1785	0.1722	0.9805

Curves for All Results

Figure 1. Uniform Fading Profile, BPSK, Delay Spread = 5

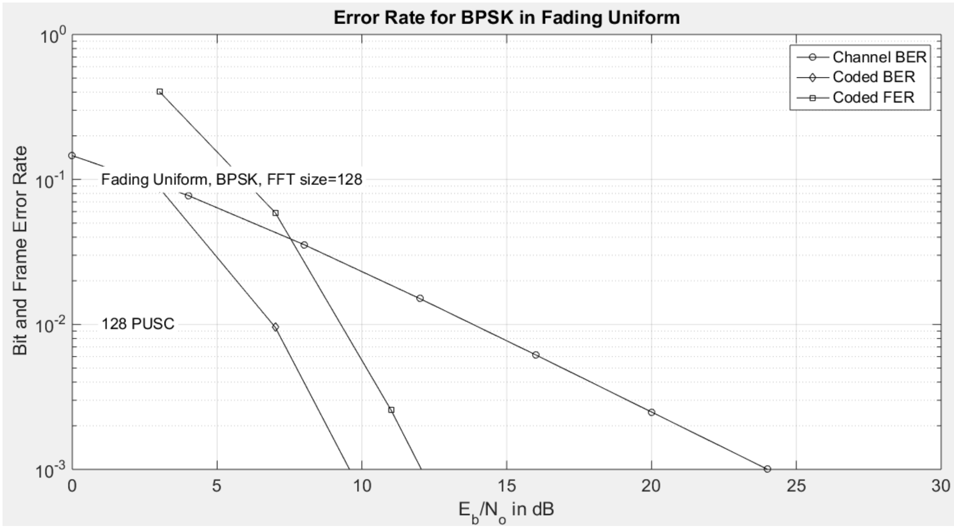


Figure 2. Uniform Fading Profile, BPSK, Delay Spread = 15

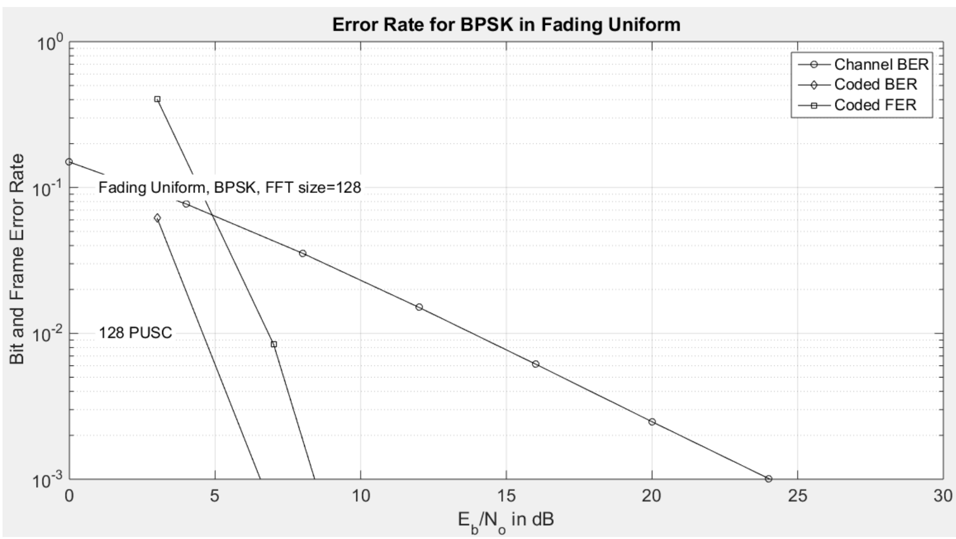


Figure 3. Uniform Fading Profile, BPSK, Delay Spread = 25

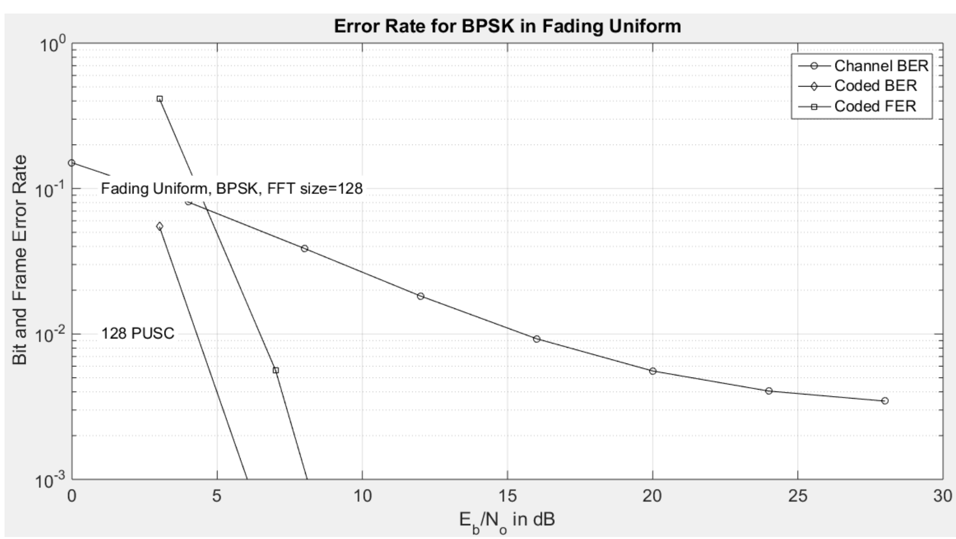


Figure 4. Uniform Fading Profile, QPSK, Delay Spread = 5

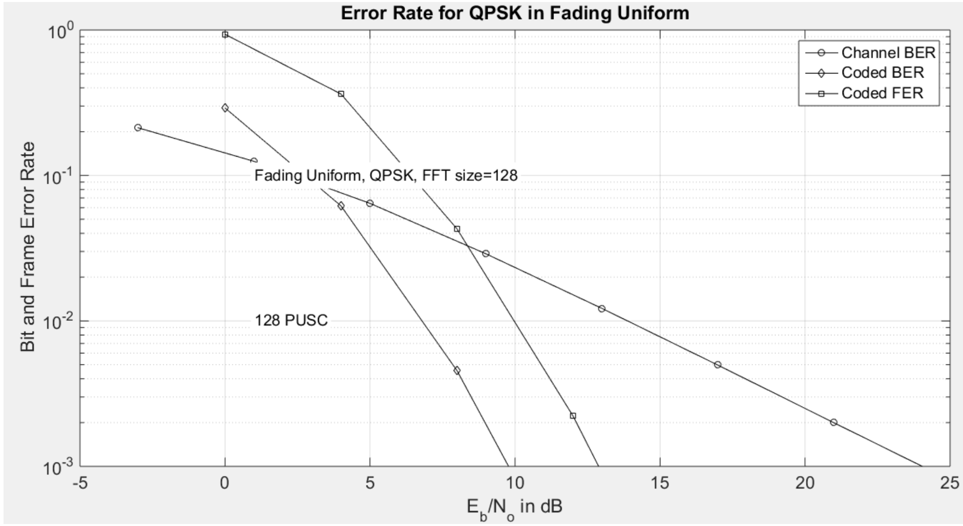


Figure 5. Uniform Fading Profile, QPSK, Delay Spread = 15

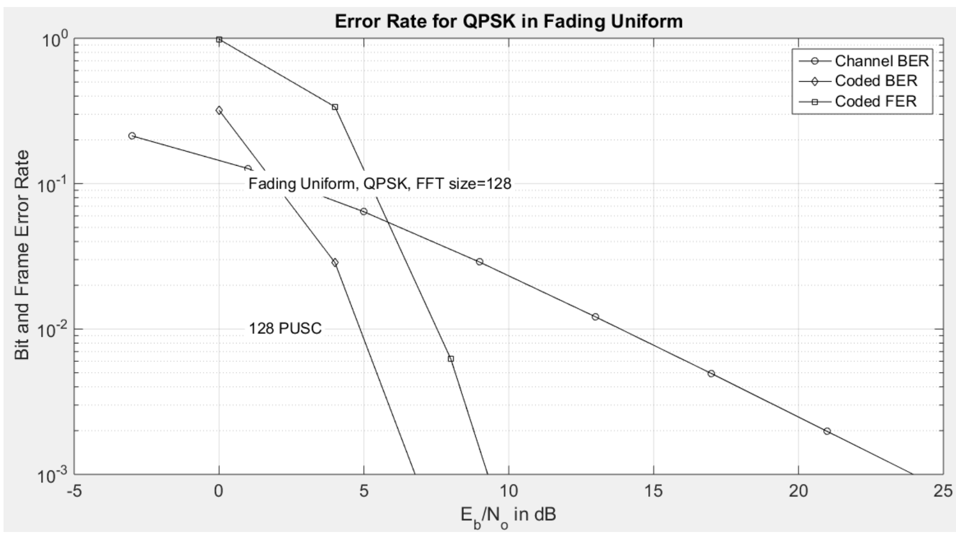


Figure 6. Uniform Fading Profile, QPSK, Delay Spread = 25

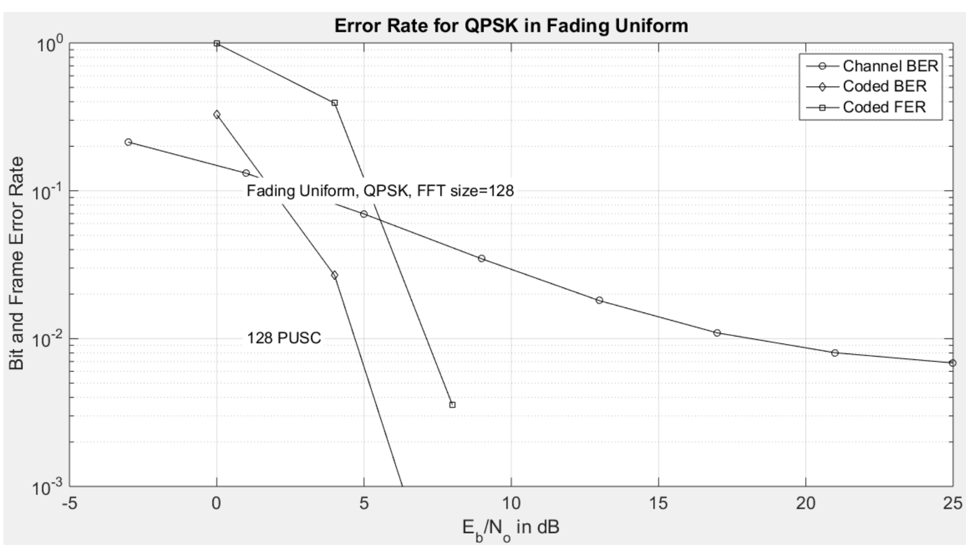


Figure 7. Uniform Fading Profile, 16-QAM, Delay Spread = 5

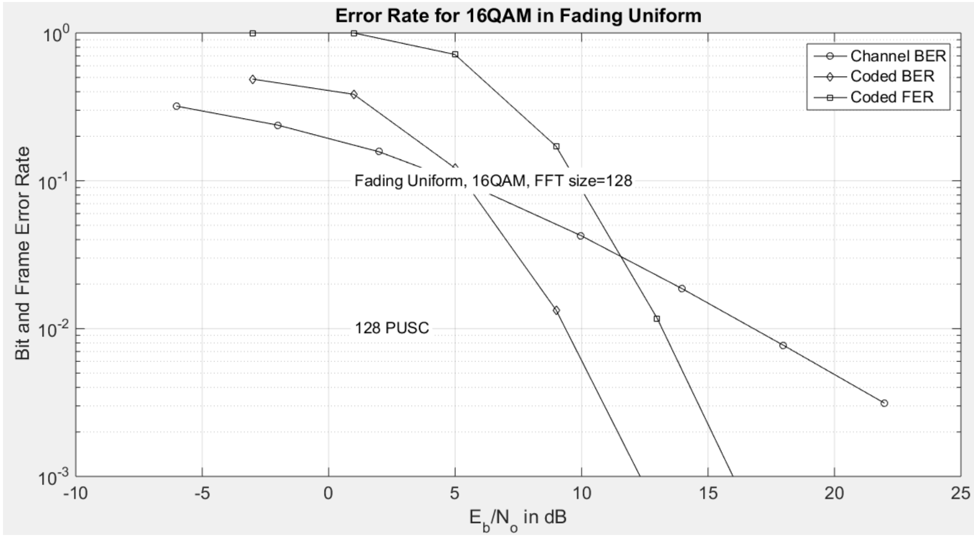


Figure 8. Uniform Fading Profile, 16-QAM, Delay Spread = 15

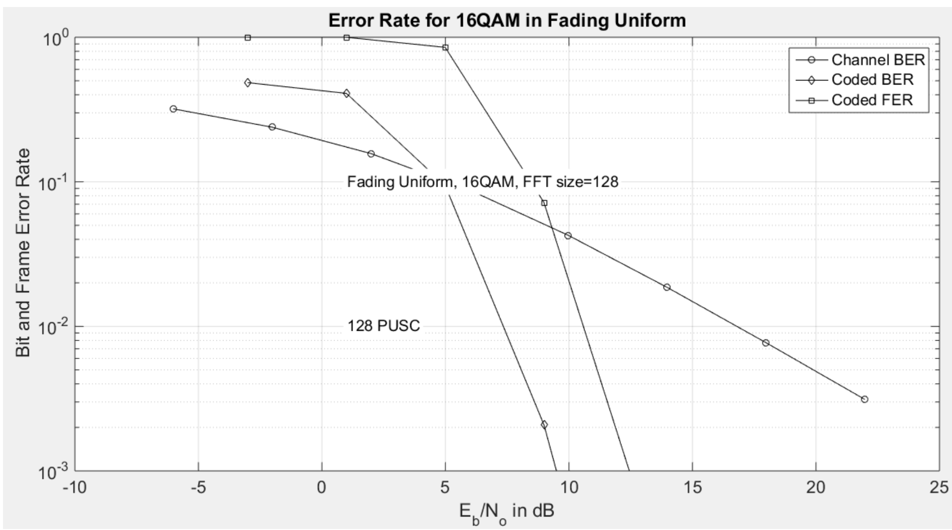


Figure 9. Uniform Fading Profile, 16-QAM, Delay Spread = 25

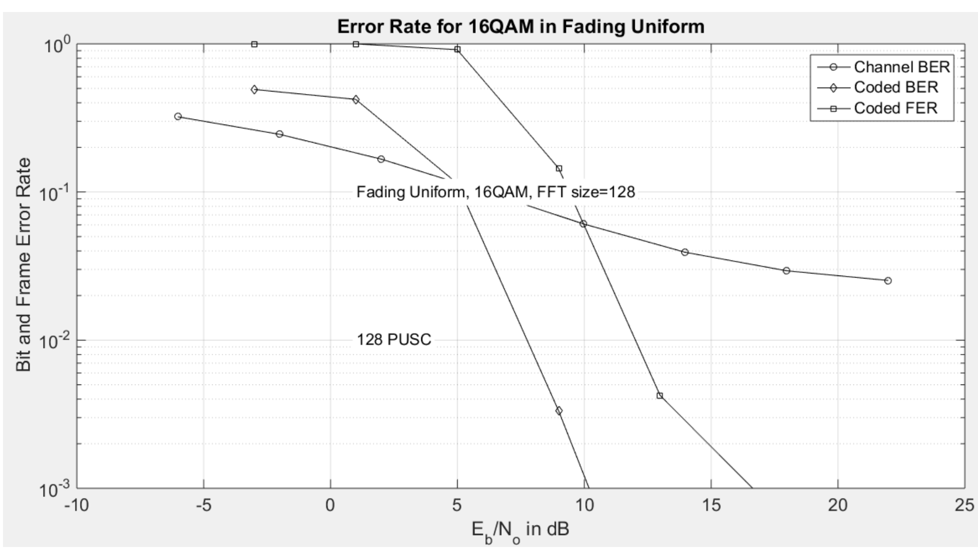


Figure 10. Uniform Fading Profile, 64-QAM, Delay Spread = 5

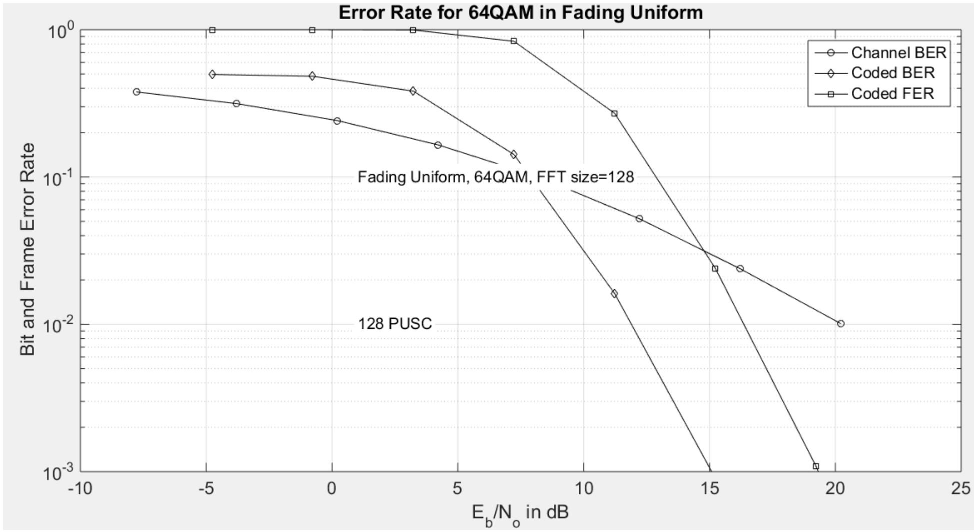


Figure 11. Uniform Fading Profile, 64-QAM, Delay Spread = 15

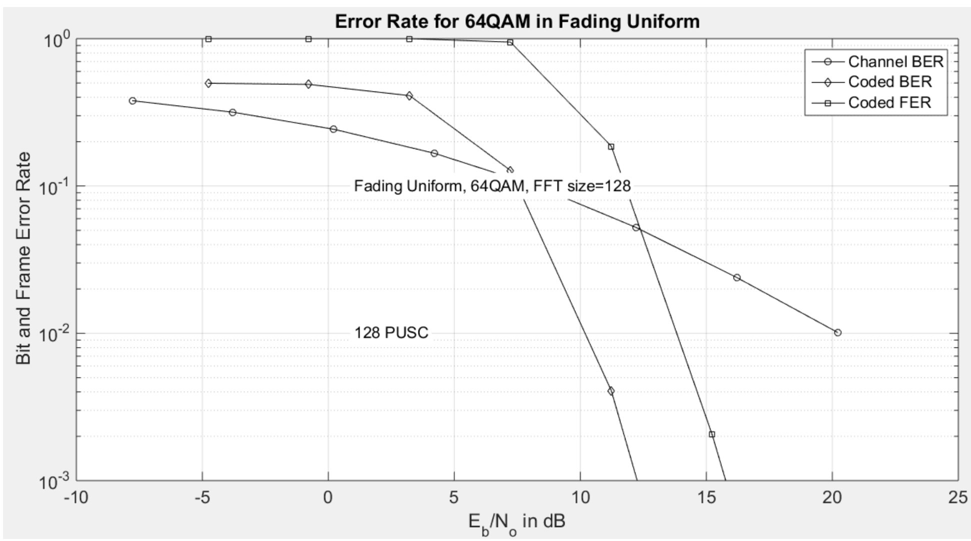


Figure 12. Uniform Fading Profile, 64-QAM, Delay Spread = 25

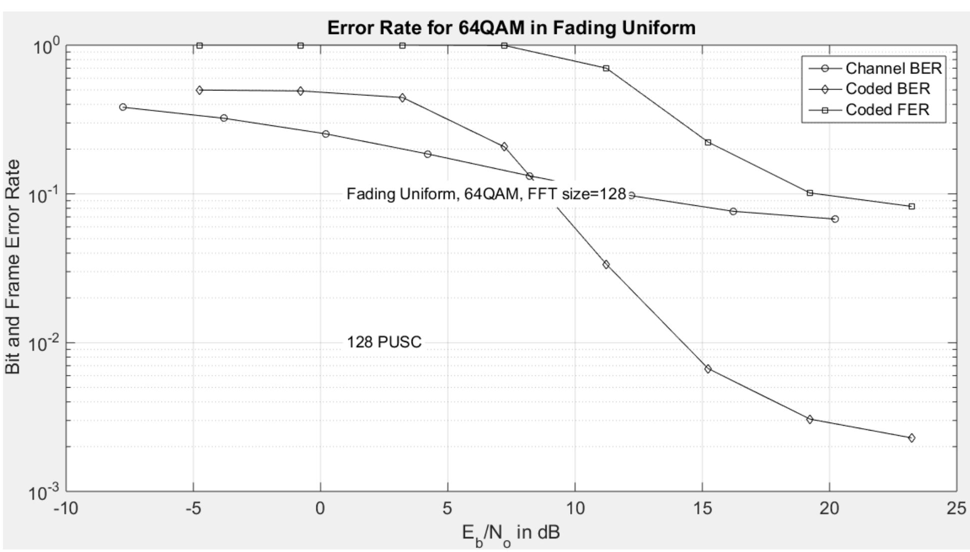


Figure 13. Exponential Fading Profile, BPSK, Delay Spread = 5

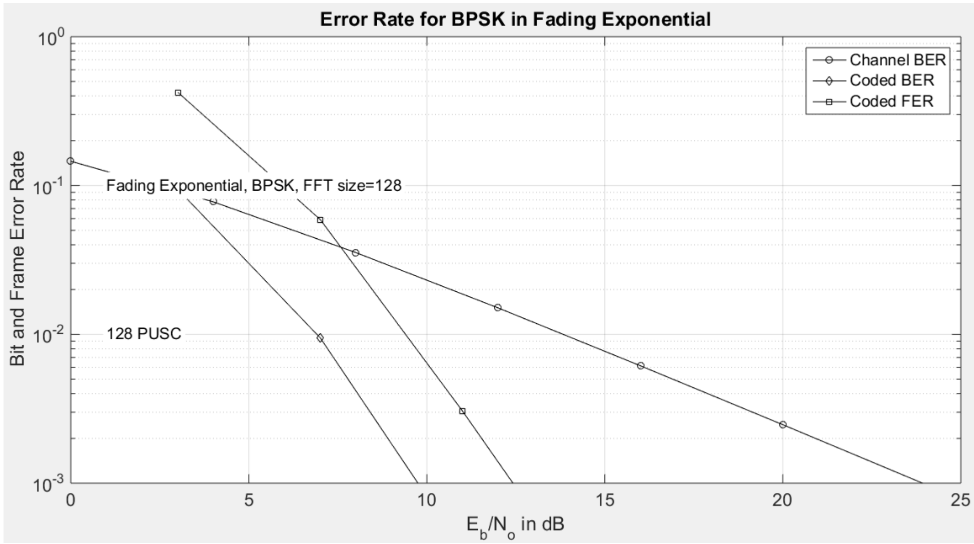


Figure 14. Exponential Fading Profile, BPSK, Delay Spread = 15

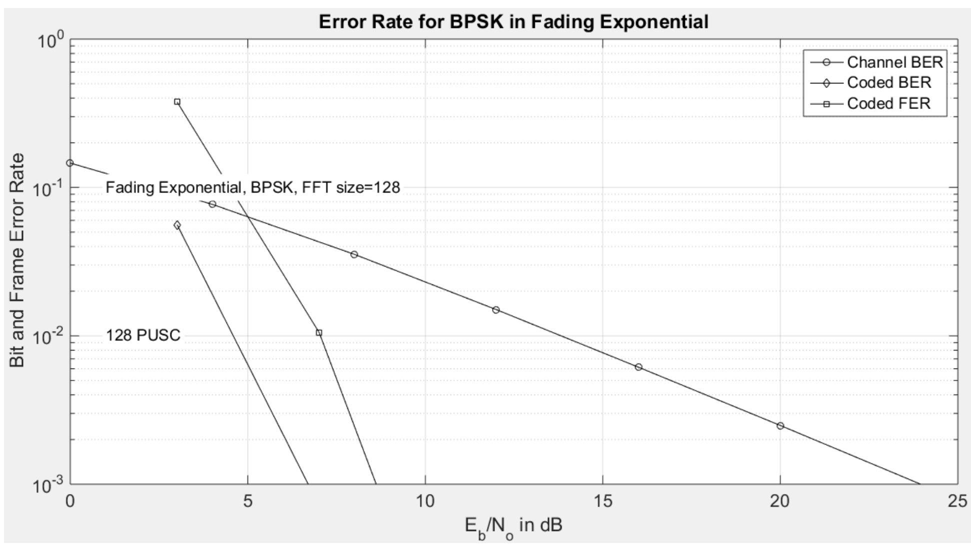


Figure 15. Exponential Fading Profile, BPSK, Delay Spread = 25

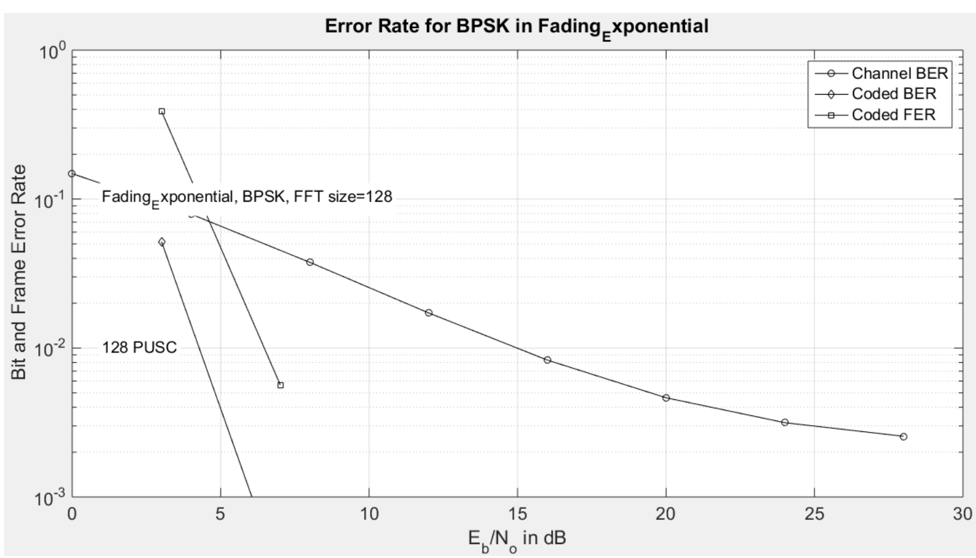


Figure 16. Exponential Fading Profile, QPSK, Delay Spread = 5

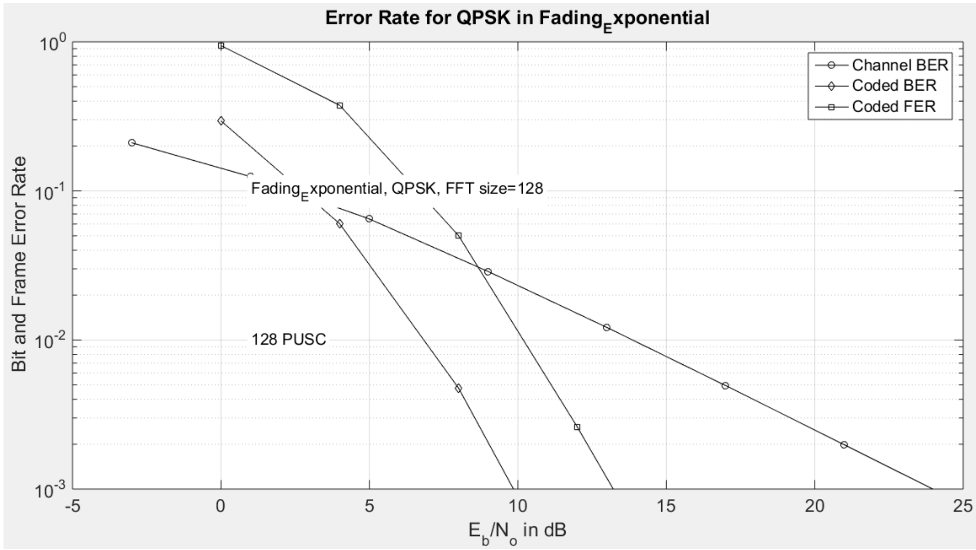


Figure 17. Exponential Fading Profile, QPSK, Delay Spread = 15

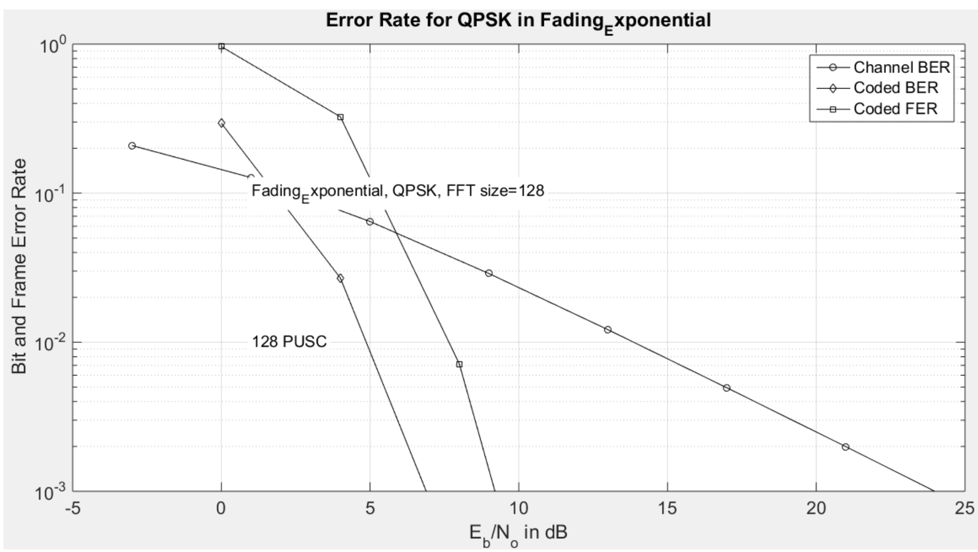


Figure 18. Exponential Fading Profile, QPSK, Delay Spread = 25

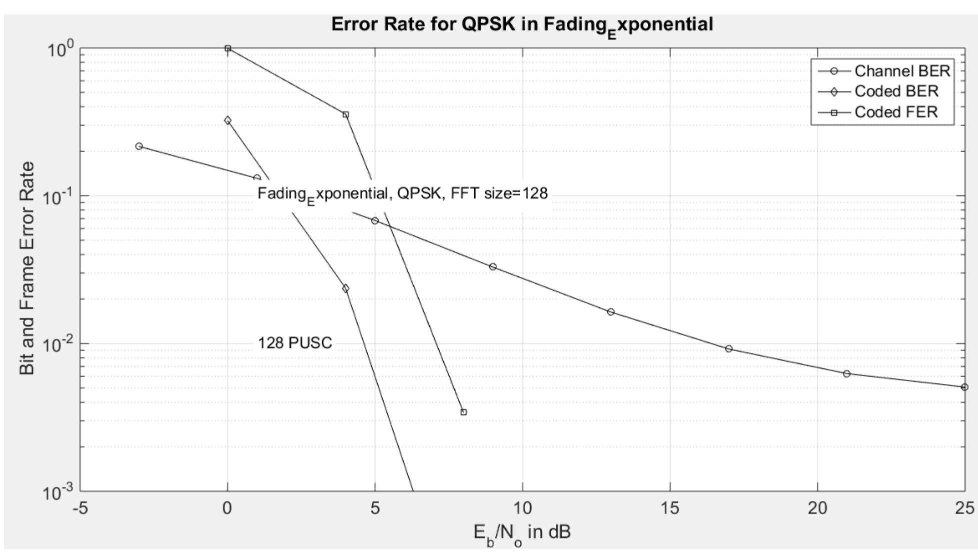


Figure 19. Exponential Fading Profile, 16-QAM, Delay Spread = 5

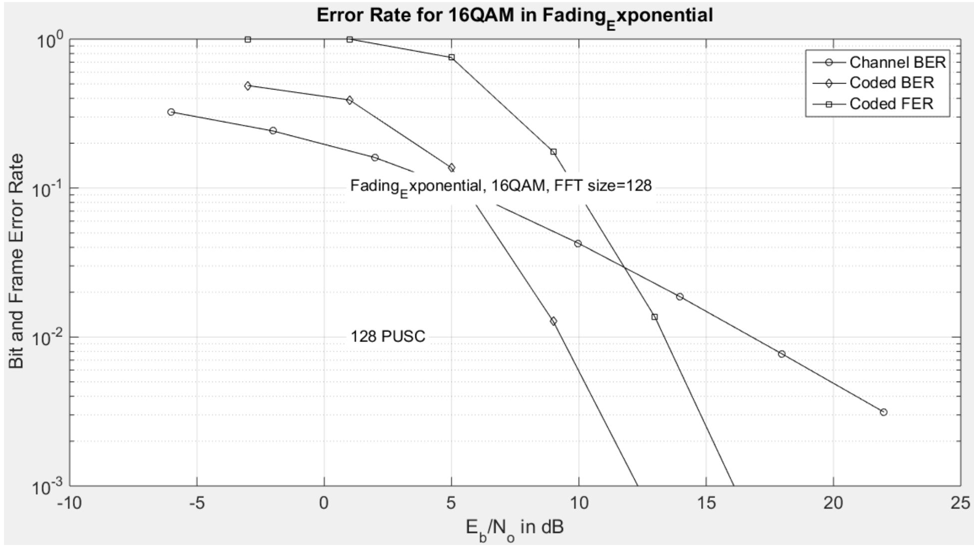


Figure 20. Exponential Fading Profile, 16-QAM, Delay Spread = 15

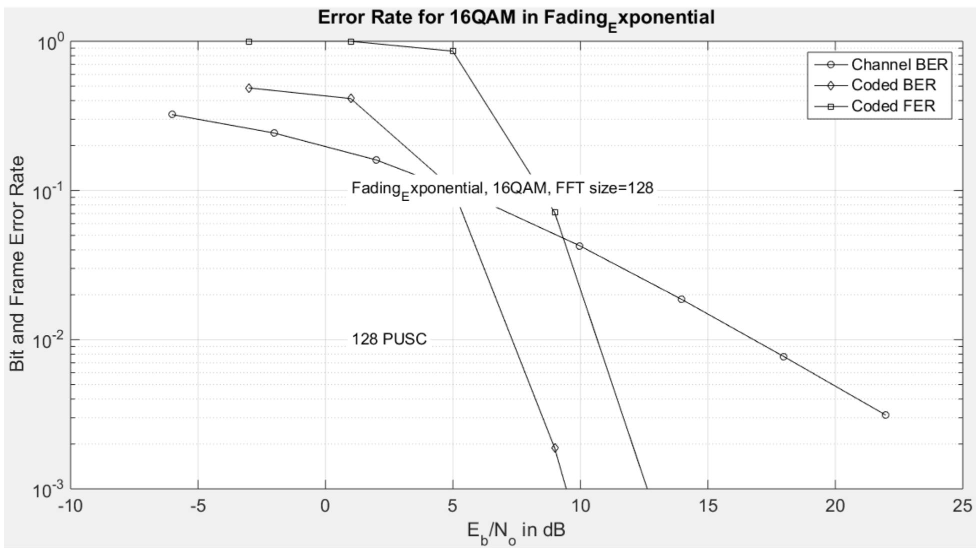


Figure 21. Exponential Fading Profile, 16-QAM, Delay Spread = 25

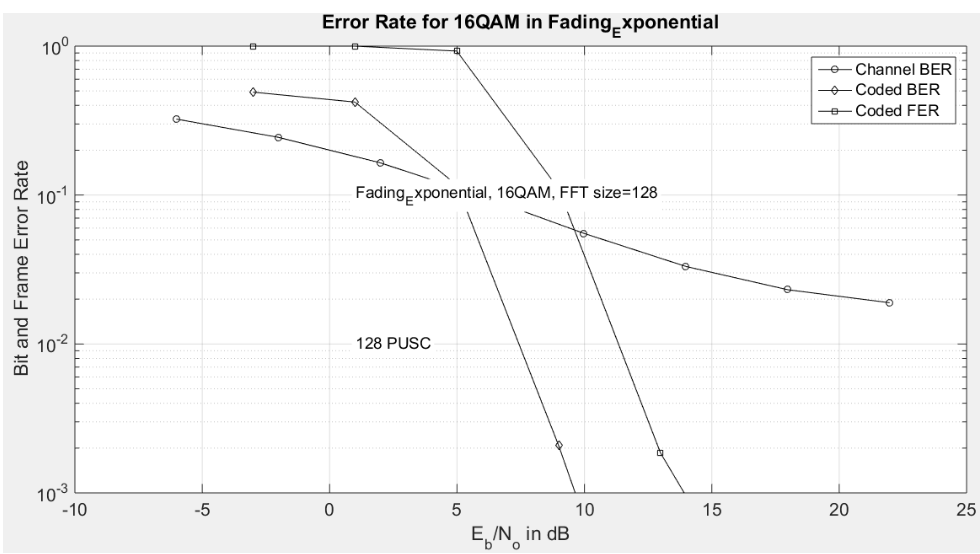


Figure 22. Exponential Fading Profile, 64-QAM, Delay Spread = 5

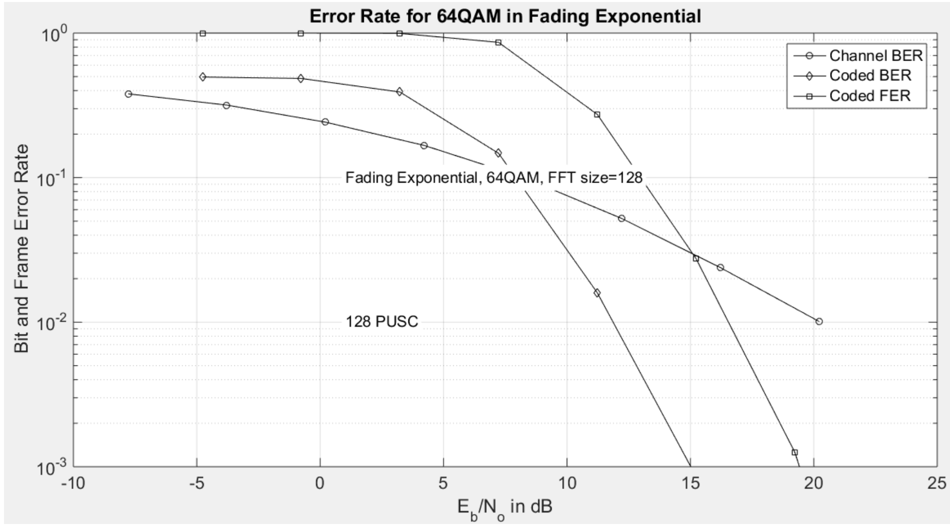


Figure 23. Exponential Fading Profile, 64-QAM, Delay Spread = 15

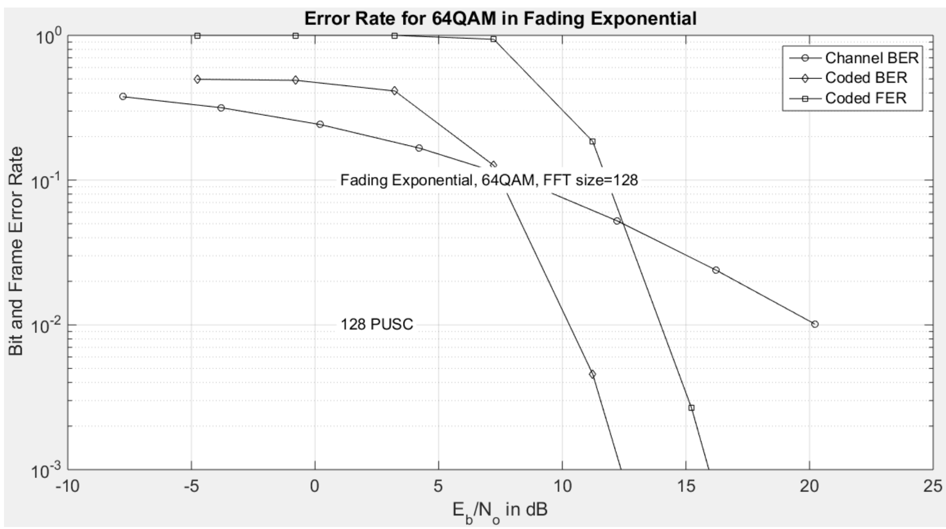
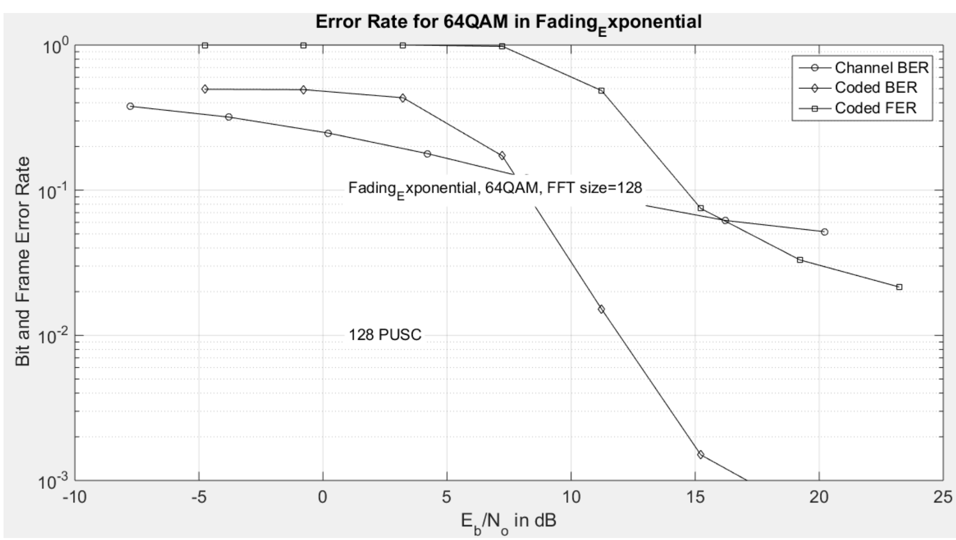


Figure 24. Exponential Fading Profile, 64-QAM, Delay Spread = 25



Explanation of the simulation

Orthogonal Frequency Division Multiplexing (OFDM) enables high data rate transmissions over frequency selective fading channels. Its beneficial qualities are a low implementation complexity; drawbacks of OFDM are the requirement for a cyclic prefix (CP) to avoid interference between OFDM symbols and the high peak to average power ratio (PAPR). The CP causes transmission overhead and hence reduces throughput.

In this simulation, the performance of the OFDM system is tested with respect to different modulation types (BPSK, QPSK, 16-QAM, and 64-QAM), different delay spread values (5, 15 and 25 Samples), and different fading profiles (uniform, and exponential). The code calculates channel BER, coded BER, and coded FER at SNR per subcarrier starting from 0 dB to 28 dB with 4 dB increments.

Other constant parameters in the simulation include (`fftSize=128; cyclicPrefixRatio=0.125; numOFDMsymbols=2; lowestNeededFER=1.0E-4; maxSimulationFrames=100000;`) The convolutional coding parameters are (`codeRate=0.5; K=7; Generator1=171; Generator2=133; Generator3=165;`)

Steps of the simulation

1- Set simulation parameters
2- Loop over enough number of slots for simulation (from 1 to `maxSimulationFrames`), and for each frame do the following:
   a. Generate random bits of desired user
   b. Encode data using convolutional encoder provided by the Matlab function `convenc`
   c. Random interleaver using the matlab function `randintrlv` which reorders symbols using random permutations
   d. Apply modulation using the function `mapping` provided with the code
   e. Make the symbols in matrix format and perform OFDM using the provided function `ofdmTx` which outputs an array of samples ready to go to the channel
   f. Apply fading using the provided function `ApplyFading` and generate unit variance Gaussian noise
   g. Stop running SNR values if not getting enough errors
   h. Stop running Eb/No values after getting enough errors
   i. Apply noisy faded samples to OFDM receiver using the provided function `ofdmRx`
   j. Perform channel estimation per OFDM symbol using the function `channelEstimation`.
   k. Perform equalization using the function `channelEqualizer`
   l. Demap the received symbols to get soft bits using the function `demapping`
   m. Deinterleave using the matlab function `randdeintrlv`
   n. Viterbi decoder `vitdec`
3- Save all BER and FER values in .dat files and plot the results on semiology plots

Some Definitions

FFT Size: FFT size directly affects the resolution of the resulting spectra. The number of spectral lines is always 1/2 of the selected FFT size. The frequency resolution of each spectral line is equal to the Sampling Rate divided by the FFT size. Larger FFT sizes provide higher spectral resolution but take longer to compute.

Cyclic Prefix Ratio: In telecommunications, the term cyclic prefix refers to the prefixing of a symbol with a repetition of the end it eliminates the intersymbol interference from the previous symbol

Delay Spread: the delay spread is a measure of the multipath richness of a communications channel. In general, it can be interpreted as the difference between the time of arrival of the earliest significant multipath component and the time of arrival of the latest multipath components

Comments

1- The choice of M-PSK modulation or M-QAM affects the BER and FER values. The *higher order of PSK or QAM* leads to *larger symbol size*, thus less number of symbols are needed to be transmitted, and *higher data rate* is achieved. However, this results in a *higher BER* because the range of 0-360 degrees of phases will be divided into more sub-regions, and hence received phases have higher chances to be decoded incorrectly. Therefore, *higher order modulation schemes require larger SNR to minimize BER*.

2- Coded systems generally outperform uncoded systems because coding schemes provide error correction capabilities. In the simulations, channel BER starts *lower* than coded BER at SNR=0 dB (except for BPSK), but as SNR increases, coded BER decreases much faster than channel BER. For higher order modulation schemes, *larger SNR values are needed for coded BER to outperform channel BER*.

3- Delay spread happens because of multipath reflections. From the simulations, delay spread does not seem to affect BER significantly at low SNR values. However, at high SNR values, larger delay spread leads to larger BER (compare figure 3 to figure 1 and 2 for example). This is because longer path length increases the probability of error.

4- Uniform fading profile led to slightly better performance in terms of BER and FER compared to exponential fading especially at higher SNR values.

What happens if the delay spread is greater than cyclic prefix?

The duration of the cyclic prefix should be greater than the duration of the delay spread. So, if the Delay spread is greater than cyclic prefix, each delay spread component cannot provide a complete representation of the signal within the FFT processing window.
(64-QAM is the Most Affected Modulation scheme)