SSY135 – Wireless Communications MATLAB Project-2

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***Abstract*—OFDM communication system designing and simulation for transmitting over the simulated channel with QPSK modulation.**

I. INTRODUCTION

The objective of this project is to analyze the performance of the orthogonal frequency division multiplexing(OFDM) system over the time-varying frequency selective channel in comparison to the AWGN channel. Here we use Rayleigh fading channel as the time-varying frequency selective channel. The system's performance is evaluated using scatter plots and by analyzing the symbol error rate(SER) with respect to parameters including signal-to-noise ratio(SNR) and cyclic-prefix length(N_{cp}).

II. IMPLEMENTATION AND WORKING OF OFDM COMMUNICATION SYSTEM

OFDM is a modulation scheme that uses less spaced sub-carriers in a frequency range to transmit data in a parallel way and thus allowing it to transmit at high data rates over the wireless channel. It also uses the available bandwidth in a very efficient manner. In OFDM, the sub-carriers are orthogonal to each other and thus are independent and do not interfere with each other and thus reducing the chance of inter-symbol interference(ISI). The main advantage is that OFDM has the ability to mitigate the multi-path interference effect which is one of the major problems faced in the field of wireless communication.

Here we use QPSK modulation as the type of modulation and generate QPSK sequence of length N which is denoted as $s^{(m)}$ which satisfies the energy constraint which is $\mathbb{E}(|s_k^{(m)}|^2) = E$. To this, we add cyclic prefix which is the last part of length N_{cp} of the sequence added at the beginning of the sequence that makes the overall length of the sequence $N + N_{cp}$ which makes the sequence periodic and thus helps to avoid inter-symbol interference(ISI) and then apply Inverse Fast Fourier transform(IFFT) to covert it to the time-domain which is given by the equation below,

$$z_n^{(m)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} s_k^{(m)} \exp \frac{j2\pi nk}{N}, n = 0, 1, ..., N-1 \quad (1)$$

where, $s_k^{(m)}$ is the each entry in $s^{(m)}$ and N is the length of the sequence.

A. Determine value of N, N_{cp} and E

The sequence length N should be a power of 2 in order to reduce the complexity of the DFT operation. This constraint is used because transmitting OFDM symbols over the channel should be approximately constant in order to increase the accuracy of equalization at the receiver end. Here, we have delay spread(T_{DS}) given as $5.4\mu s$. we have,
Sampling time,

$$T_s = \frac{1}{BW}$$

The number of taps L is chosen such that it satisfies the condition,

$$L \geq \frac{T_{DS}}{T_s}$$

such that the length of cyclic-prefix(N_{cp}) should satisfy the inequality,

$$N_{cp} \geq L - 1$$

Here, we have been given that the speed of the receiver(v) is 15m/s and carrier frequency(f_c) is $2GHz$. We know that the Doppler frequency can be calculated using the below equation,

$$f_D = \frac{v \times f_c}{c}$$

Using the above measurement we can measure the value of N such that, it satisfies the below condition,

$$(N + N_{cp}) \times f_D \times T_s \ll 1$$

Here we consider the $(N + N_{cp}) \times f_D \times T_s \times 10$ to be less than 1 .

The noise power spectral density, $N_o = 2.07 \times 10^{-20} \times BW$ The symbol energy(E), can be measured using the equation, $E = P \times T_s$, where value of average transmit power(P) is already known to be 0.1W.

B. OFDM system over AWGN channel

In this case, at the transmitter part, we initially use QPSK modulator to modulate the sampled message sequence of length N. After this, the corresponding output is converted to time-domain using the Inverse Discrete Fourier transform and is normalized by multiplying it with $\sqrt{N}$. To this time-domain signal, we add the cyclic prefix of length N_{cp} which is done by taking a copy of this length of QPSK symbols from the end and adding it at the beginning of the sequence which makes the overall length to be $N + N_{cp}$ and thus making this signal periodic. After the addition of the cyclic prefix, the corresponding output is transmitted through the AWGN channel ($c_0(nT_s) = 1$, $\forall n$ and $c_{l \neq 0}, (nT_s) = 0$, $\forall n$) and it results in the addition of complex Gaussian distributions which affects the path loss.
At the receiver end initially, we remove the cyclic prefix part. The channel estimation is done by analyzing the change in the amplitude and phase of the received signal. Finally, the receiver makes the decision about the received symbols based on the quadrant in which it is present which can be visualized by plotting the scatter plot. From this scatter-plot, We can observe a slight scaling in the amplitude of the symbols which is introduced by the channel.[Figure 1, 2, 3, 4]

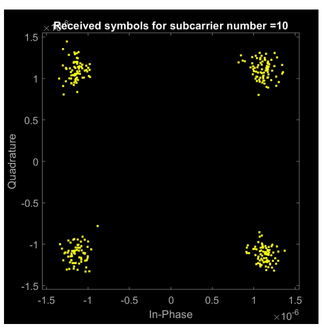


Fig. 1.

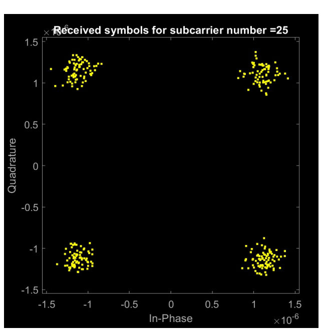


Fig. 2.

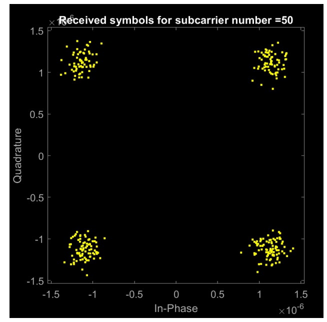


Fig. 3.

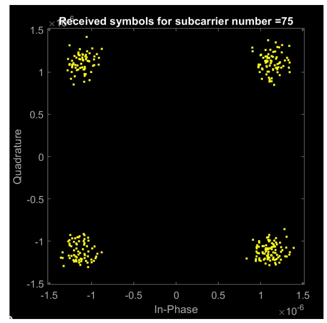


Fig. 4. Scatter plot for OFDM system subcarriers over AWGN channel

C. OFDM system over time-varying and frequency selective channel

In this case, the transmitter part consists of the same block of operations of QPSK modulator and IFFT as in the OFDM system over AWGN channel. But the channel here we choose is Rayleigh fading channel which is a time-varying and frequency-selective channel. As the signal passes through this channel, the channel introduces a lot of distortions to the signal in terms of amplitude variation and phase rotations. Since this is a fading channel as,

$$T_s \ll T_{coh}$$

This results in a corresponding response in time-domain. Thus resulting in path loss and the addition of noise to the signal.
At the receiver end, we remove the cyclic-prefix and perform FFT in order to convert back the signal from time-domain to frequency-domain such that the m-th OFDM symbol will be of the form:

$$y_n^{(m)} = C_n^{(m)}.s_n^{(m)} + w_n^{(m)}$$

To this, we perform equalization by dividing the output with the effective channel in order to remove the distortion introduced by the channel and to get the actual massage we use the maximum-likelihood method which is done by minimizing the distance between the actual QPSK constellation position and the received points in the Cartesian plane. [Figure 5, 6, 7, 8]

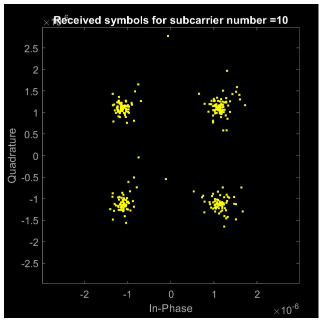


Fig. 5.

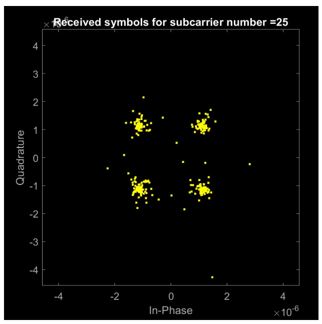


Fig. 6.

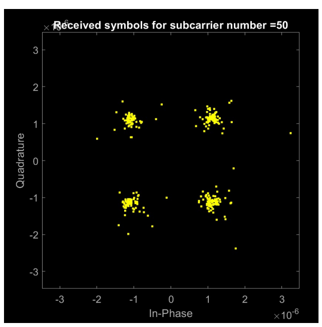


Fig. 7.

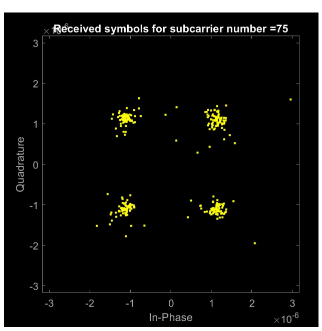


Fig. 8. Scatter plot for OFDM system subcarriers over time-varying and frequency selective Rayleigh channel

D. Analysis of symbol error rate(SER) v/s signal to noise ratio(SNR)

Here, we compare SER v/s SNR for two types of channels including AWGN and Rayleigh fading channel with respect to theoretical bound by varying E. In the case of the Rayleigh fading channel, at low SNR, the SER value is close to the theoretical value but as the SNR increases, the SER increases very rapidly such that at larger SNR there is a huge difference between the SER of the Rayleigh fading channel and the theoretical bound. Whereas, the AWGN channel performs very close to the theoretical bound. Thus, the AWGN channel performs far better in comparison to the Rayleigh fading channel.

[Figure 9, 10]

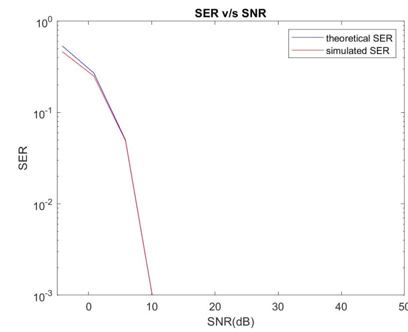


Fig. 9. Symbol error rate(SER) v/s signal to noise ratio(SNR) plot for OFDM system over AWGN channel

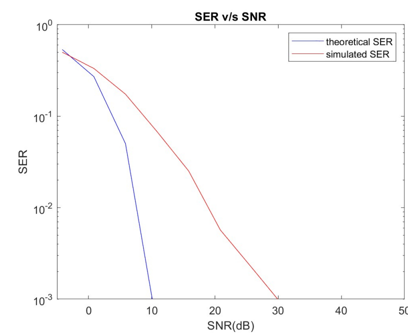


Fig. 10. Symbol error rate(SER) v/s signal to noise ratio(SNR) plot for OFDM system subcarriers over time-varying and frequency selective Rayleigh channel

E. Determining effective data rate

The effective data rate using QPSK modulation can be calculated using the below equation:

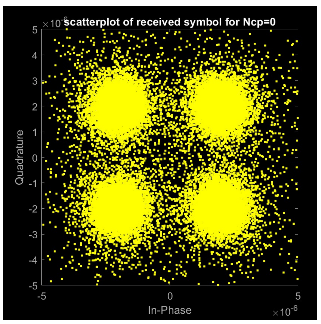
$$datarate = \frac{N}{N + N_{cp}} \times 2 \times f_c = 3.98 \times 10^9 bps$$

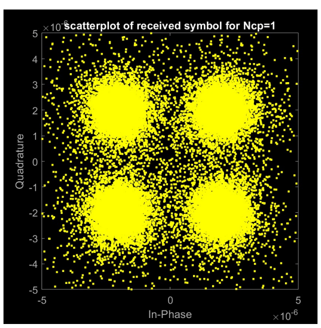
F. Analysis of scatter plot and SER change w.r.t cyclic-prefix length(N_{cp})

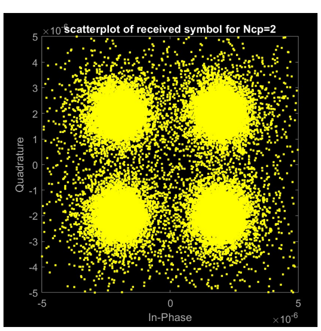
The cyclic prefix is mainly used as a guard between adjacent symbols for reducing inter-symbol interference(ISI). The ISI is reduced by maintaining orthogonality between the OFDM sub-carriers. Also, it provides robustness to OFDM signals against timing errors. OFDM is highly sensitive to synchronization

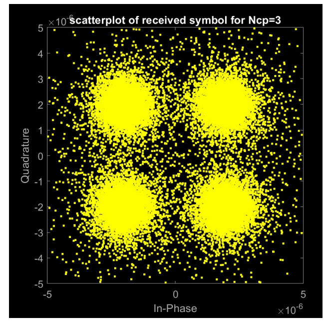
error which results in inter-carrier interference and can be resolved to an extent using the cyclic prefix. The transmission rate and the performance of the system vary with respect to the length of this cyclic prefix used.
In this project, we varied N_{cp} from 0 to 5 and observed the variation in SER. If N_{cp} is very short, the adjacent OFDM symbol will spread to one another which causes ISI and result in a larger SER. Also if the N_{cp} is very long, even though it reduces the SER and avoids ISI, the system suffers from a very low transmission rate because N_{cp} occupies more portion of the sequence. So, it is always better to maintain the N_{cp} length in such a way that it doesn't affect the transmission rate but also reduces SER by avoiding ISI. Therefore, there is always a trade-off between SER and transmission rate with respect to the length of the cyclic prefix.

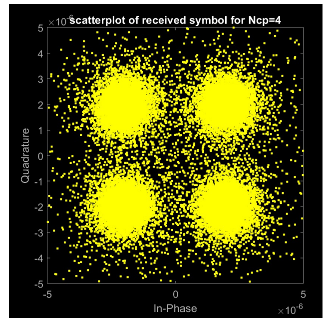
[Figure II-F, II-F, II-F, II-F, II-F, 11, 12, 13]











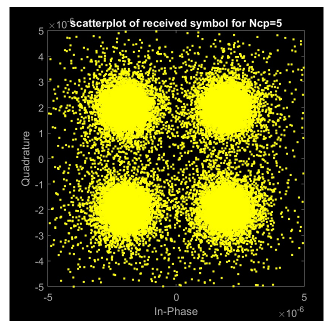


Fig. 11. Scatter plot of received symbols for N_{cp} values 0,1,2,3,4,5 respectively

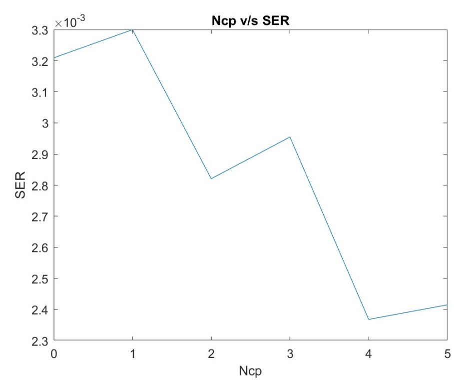


Fig. 12. Cyclic-prefix length(N_{cp}) v/s symbol error rate(SER) plot for OFDM system over AWGN channel

III. References

[1] Goldsmith, Wireless Communications, Cambridge University Press, 2005.

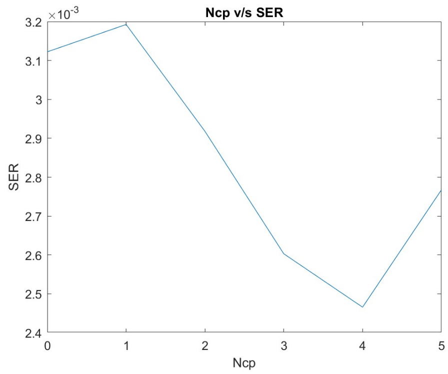


Fig. 13. Cyclic-prefix length(N_{cp}) v/s symbol error rate(SER) plot for OFDM system subcarriers over time-varying and frequency selective Rayleigh channel

IV. MEMBERS CONTRIBUTION

Ann Priyanga Dhas Climent Jackey(Determining value of N, Ncp and E + Report writing)
Anakha Krishnavilasom Gopalakrishnan(OFDM system over AWGN channel + Determining effective data rate + Report writing)
Akshay Vayal Parambath(OFDM system over time-varying and frequency selective channel + Analysis of SER v/s SNR and Ncp v/s SER + Report writing)