A Flexible OFDM System Simulation Model with BER Performance Test

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Abstract

This work aims at developing flexible simulation model for orthogonal frequency division multiplexing (OFDM). In this model, the system parameters such as modulation scheme symbol order, or the number of subcarriers can be changed easily according to specific OFDM system implementation. This system can serve as a key tool for researchers in the area of OFDM systems.

In this work, the proposed model is used to conduct different experiments to examine the performance of OFDM system. For instance, the Bit Error Rates (BER) of OFDM system under different noise conditions have been computed. In
addition, a comparison between BERs resulting from different constellation schemes have been performed. Simulation results indicate that the proposed model is working efficiently.

Keywords: AWGN, Bit Error rate, orthogonal frequency division multiplexing, Signal to Noise Ratio

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been successfully applied to a wide variety of digital communication applications over the past several years[5][4]. While OFDM principle was adopted as a physical layer for many important communication systems such as asymmetric digital subscriber loop(ADSL), Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), high-definition television (HDTV), wireless local area network (WLAN) and the fourth generation of mobile cellular[5][4], the theory, algorithms, and implementation techniques of OFDM are topics of high interest[3][4]. Despite that OFDM systems have lot of advantages in providing high data rates with sufficient robust against radio channel impairments. OFDM systems have suffered from several drawbacks such as high dynamic range of the transmitted signal. Thus intensive works have to be performed to improve the OFDM systems performance.

This paper is intended to develop an efficient and flexible simulation model for OFDM systems using Matlab. The rest of this paper is organized as follows: section II presents the mathematical model of OFDM system. Section III describes the proposed Simulation model. Section IV presents the proposed model test by performing bit error rate (BER) performance analysis for different system configurations as an example of the proposed model usage while section V concludes the paper.

II. Mathematical Model of OFDM System

It is worth mentioning that OFDM is a special class of Multicarrier modulation (MCM). Figure 1 (a) shows a general implementation of MCM system[6]. The structure of a complex multiplier (IQ modulator/demodulator) which is commonly used in MCM systems, is also shown in Figure 1 (b). The MCM transmitted signal S(t) can be represented by Equations 1-3 [6].
Where \( C_{ki} \) is the \( i \)th information symbol at the \( k \)th subcarrier, \( S_k \) is the waveform for the \( k \)th subcarrier, \( N_{sc} \) is the number of subcarriers, \( f_k \) is the frequency of the subcarrier, \( T_s \) is the symbol period, and \( \pi(t) \) is the pulse shaping function.

The optimum detector for each subcarrier uses a filter that matches the subcarrier waveform. In other words, this filter is worked as a correlator that matches the subcarrier, see Figure 1. Therefore, the detected information symbol \( C_{ki}^* \) at the output of the correlator is given by

\[
C_{ki}^* = \frac{1}{T_s} \int_0^{T_s} r(t - iT_s)S_k^*dt = \frac{1}{T_s} \int_0^{T_s} r(t - iT_s)e^{-j2\pi f_it}dt
\]
Where \( r(t) \) is the received time domain signal. Because classical MCM uses nonoverlapped band limited signals it requires excessive bandwidth [6].

The main advantages of OFDM system is its ability to employ the overlapped yet orthogonal signal sets. This orthogonality originates from a straightforward correlation between any two subcarriers, given by

\[
\delta_{kl} = \frac{1}{T_s} \int_{0}^{T_s} s_k^* s_l \, dt = \frac{1}{T_s} \int \exp(j2\pi(f_k - f_l)t) \, dt =
\]

\[
\exp(j\pi(f_k - f_l)T_s) \frac{\sin(\pi(f_k - f_l)T_s)}{\pi(f_k - f_l)T_s}
\]

For the two subcarriers to be orthogonal the following condition should be satisfied

\[
f_k - f_l = m \frac{1}{T_s}
\]

OFDM modulation/demodulation can be implemented by using inverse discrete Fourier transform (IDFT)/discrete Fourier transform (DFT). This is evident by analyzing equations (1) and (4)[5]. The OFDM technology divides a wideband frequency selective channel into Narrow band flat fading channel. Thus it has a strong resistance to multipath fading and anti-carrier interference [3].

### III. Simulation Model Description

An OFDM model is built using MATLAB. In this model, the number of bits in the stream, the number of subcarriers, and the modulation scheme are user input parameters.

Figure 2 displays the block diagram of the proposed OFDM model.
The proposed OFDM model can be summarized as follows. Bit stream with the given length is generated using the random function `randint(nbit,1,2)`. In this function, `nbit` denotes the length of the bit stream that should be divisible by number of subcarriers. Consequently these generated bits are modulated using Matlab "modem.qammod" object. This built in object allows the user to set the desired M-ary value as well as the symbol order which can be binary, gray, or user defined. Afterwards, the bit stream is converted to a parallel stream where the number of streams is corresponds to the desired number of subcarriers. Now, the inverse Fourier transform can be computed.

To demonstrate and simulate the channel conditions and effects, a white Gaussian noise of different powers is added to the OFDM signal. At the receiver end, reverse operations are performed which include Fourier transform computation, parallel-to-serial conversion,, and demodulation, respectively. Thus the proposed model allows the user to simulate the OFDM signal formulation, transition, and receiving. Here, as was previously mentioned, the user can select the desired modulation scheme, symbol order, bit stream size, and number of subcarriers.

IV.OFDM Model Testing

Here, the simulated OFDM model is scrutinized using different SNR values. As a result, a figure that shows the behavior of BER versus the (Eb/No) change is obtained. The acquired results are compared with those standard results obtained.
from the Matlab BERTool [7]. Fortunately, a close match between the simulator results and the standard ones has achieved.

As was previously mentioned, this study aims at studying the OFDM system performance (i.e., measuring BER) according to the change of the following system parameters.

1. BER performance for different constellation sizes

The model was run for 4, 16, and 32 QAM constellations. Figure 3 displays BER vs. Eb/No for these constellations. Figure 3 shows that the BER performance of the system is inversely dependent on constellation size. This means that when the constellation size increases, the BER increases accordingly. For instance, to achieve BER = 10^{-4} for 4 QAM constellation, we need 7 dB SNR. However, a 12 dB SNR is required to achieve the same BER for 16 QAM.

![Figure 3: BER vs. SNR for different constellation sizes](image)

Similar results are achieved for 2 (i.e., BSK), 4, and 16 constellations as shown in Figure 4.
2. BER Performance for Different Number of Subcarriers To scrutinize the effect of number of subcarriers on BER performance, the model has been run for different number of subcarriers. Figure 5 shows the BER vs. Eb/NO for 512, 256, and 1028 subcarriers are. From the BER curves (Fig. 5), it can be observed that the BER performance is almost independent of the number of subcarriers except at very high SNR.
3. BER performance for different Symbol mapping

The proposed model gives the user the opportunity to choose symbol order (binary, gray, etc). Figure 6 shows the BER curves for two symbol mapping; gray and binary.
Figure 6: BER vs. SNR for Binary and Gray mapping

V. CONCLUSION

In this paper, a flexible OFDM simulation model has been developed. In this model the system parameters can be easily changed according to specific system requirements. The BER vs. SNR curves for OFDM system are obtained for different system parameters. The analysis of the obtained results shows that the developed model can efficiently simulate and demonstrate the effect of changing of OFDM system parameters. Thus, the developed model can be used as a research tool (or educational tool) to perform deepen study and investigation to improve OFDM systems performance.

References


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Received: May, 2012