Comparative Analysis of OFDM Sub-Carrier Modulation Using QPSK and π/4-QPSK

Babatunde Ogunleye, Lawrence Oborkhale, and Olusegun Ogundapo

***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) has become the most widely used signal carrier platform for many wireless transmission technologies. Since OFDM uses multiple sub-carriers in transmitting its signals with each sub-carrier mostly modulated using phase modulation, choosing the best phase modulation scheme is paramount to its optimal performance. Quadrature Phase Shift Keying (QPSK) is popularly used for OFDM sub-carrier modulation and it has proven to be quite stable and reliable. This paper compares OFDM's performance using QPSK alongside one of its variant, π/4-QPSK, especially when passed through a noisy channel, which is simulated using MATLAB's Additive white Gaussian noise (AWGN) channel.**

***Index Terms*—OFDM, QPSK, π/4-QP**SK, etc.

I. INTRODUCTION

In the past decade OFDM has proven to be a favorable solution where high efficient data communication system with high speed and data rate is paramount. Although it has been in existence since the 1960s, it is only of recent has it been recognized as an excellent method for high-speed cellular data communication, where its implementation relies on very high-speed digital signal processing, and this has only recently become available with cheaper prices of hardware implementation [1, 2]. Unlike conventional modulation schemes that modulate a signal on a single carrier, OFDM uses multiple carriers or subcarriers hence making it resistant to frequency selective fading that single carrier systems are prone to having [2].

The basic idea behind OFDM systems is the splitting up of the available frequency spectrum into several subcarriers. To obtain a high spectral efficiency, the frequency responses of the subcarriers are overlapping and orthogonal, hence the name OFDM [4].

In OFDM, the data is divided into large number of closely spaced carriers. This accounts for the part in its name "frequency division multiplex". It is *not* a multiple access technique, since there is no common medium to be shared. The entire bandwidth is filled from a single source of data. Instead of transmitting in serial way, data is transmitted in a parallel way. Only a small amount of the data is carried on each carrier, thus lowering of the bit-rate per carrier (not the total bit-rate), the influence of inter-symbol interference (ISI) is considerably reduced. In principle, many modulation schemes could be used to modulate the data at a low bit rate onto each carrier.

In a normal frequency-division multiplex system, many carriers are spaced apart in such a way that the signals can be received using conventional filters and demodulators. In such receivers, guard bands are introduced between the different carriers and in the frequency domain, which results in a lowering of spectrum efficiency [3].

OFDM signal is generated by converting serial data streams into parallel data streams which then act as inputs into an Inverse Fast Fourier Transform (IFFT). IFFT performs the process of modulation and multiplexing in a single step and ensures that the signals are orthogonal (at 90 degrees to each other). The subcarriers can either be phase/amplitude modulated (QPSK, 4-QAM, 16-QAM, 64-QAM). Filtering and D/A of samples results in baseband signal [6].

QPSK is one of the most popular digital modulation techniques used for Satellite communication, and sending data over cable networks. Its popularity comes from both its easy implementation and resilience to noise. The implementation of QPSK involves changing the phase of the transmitted waveform. Each finite phase change represents unique digital data. A phase modulated waveform can be generated by using the digital data to change the phase of a signal while its frequency and amplitude stay constant. A QPSK modulated carrier undergoes four distinct changes in phase that are represented as symbols and can take on the values of π/4, 3π/4, 5π/4, and 7π/4. Each symbol represents two binary bits of data [7]. The constellation diagram of a QPSK is shown in Fig. 1.

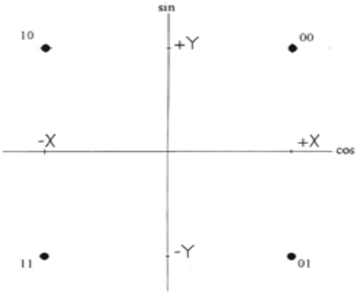

Fig. 1. A typical QPSK constellation diagram.

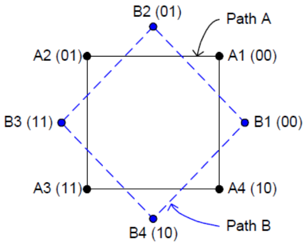

Fig. 2. π/4-QPSK constellation diagram [9].

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The π/4-QPSK variant as with QPSK has two bits coded onto each symbol, although the quadrature constellations for adjacent bits are offset by π/4 radians [8]. In QPSK there are four signals that are used to send the four two-bit symbols. In π/4-QPSK there are eight signals, every alternate symbol is transmitted using π/4 shift pattern of the QPSK constellation. The diagram in Fig. 2 which shows π/4-QPSK constellation, Symbol A uses a signal Path A and symbol B, even though it is exactly the same bit pattern uses a signal on Path B. Therefore, there is always a phase shift even when adjacent symbols are exactly the same [9].

OFDM has been successfully applied to a wide variety of digital communications applications over the past several years. OFDM has been chosen as the physical layer standard for a variety of important systems and its implementation techniques continue to evolve rapidly. These applications include Wireless LAN, digital radio systems (HD Radio), digital TV systems (DVB-T), terrestrial mobile TV systems (DVB-H), and mobile broadband wireless technologies (WiMAX and LTE).

The aim of this paper is to briefly explain the theory behind Orthogonal Frequency Division Multiplexing (OFDM) and to test its performance when its sub-carriers are modulated using Quadrature Phase Shift Keying (QPSK) as well as its variant, π/4-QPSK.

II. MATERIALS AND METHODS

In implementing the ideas on this paper, MATLAB was selected as the simulation tool and a simplified flowchart for the simulated OFDM model is shown in Fig. 3 below.

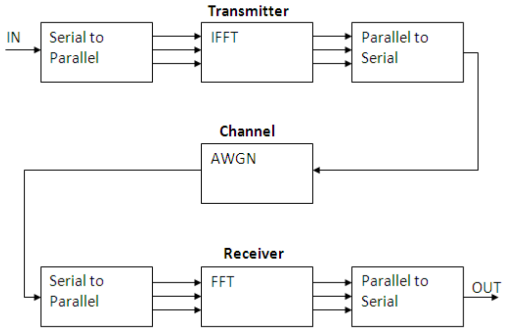

Fig. 3. OFDM simulation flowchart.

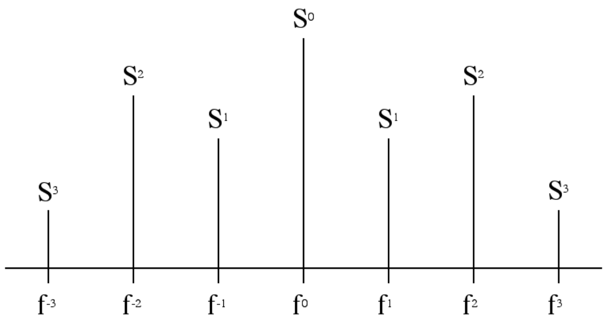

Fig. 4. Data frequency domain.

Looking at the Fig. 3 diagram, the transmitter does the job of converting input data from a serial stream to parallel sets of data. Let us assume that each set of data contains a single symbol, S_i for each subcarrier. For example, a set of four data would be [S_0, S_1, S_2, S_3]. Before performing the Inverse Fast Fourier Transform (IFFT), this example data set is arranged on the horizontal axis in the frequency domain which is done by the Serial-to-Parallel converter as shown in the Fig. 4.

This symmetrical arrangement about the vertical axis is necessary for using the IFFT to manipulate this data. An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data. Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with frequency components satisfying orthogonality conditions. Then, the parallel to serial block creates the OFDM signal by sequentially outputting the time domain samples.

The channel simulation allows examination of common wireless channel characteristics such as noise. By adding random data to the transmitted signal, a noisy channel is simulated using the AWGN channel.

The receiver performs the converse operations of the transmitter. In doing so, the received OFDM data signal is split from a serial stream into parallel sets. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The magnitudes of the frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.

A. *Range of Cases Examined*

The range of cases examined in the simulation of the OFDM system is highlighted in the Table I below:

TABLE I: SIMULATION CASE DATA.

Cases	OFDM Subcarrier Modulation	SNR	Data Type	Number of Random Data	No. Of Subcarriers
1	QPSK	20dB	Integer Data	100	10
2	Pi/4-QPSK	20dB	Binary Data	100	10

III. RESULTS AND ANALYSIS

A. *Simulation of QPSK-OFDM*

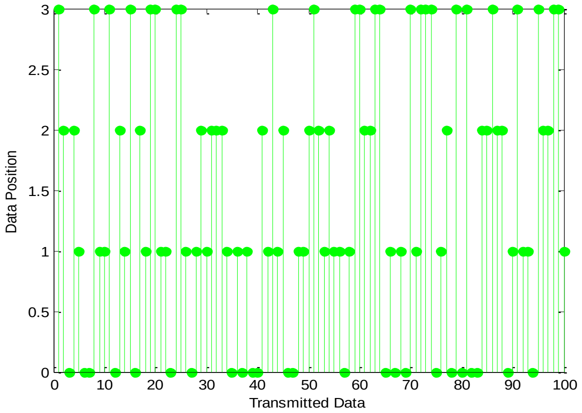

Fig. 5. Randomly generated data for OFDM-QPSK.

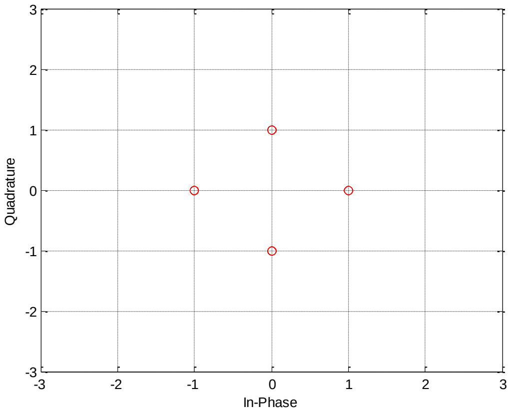

Fig. 6. QPSK constellation before transmission.

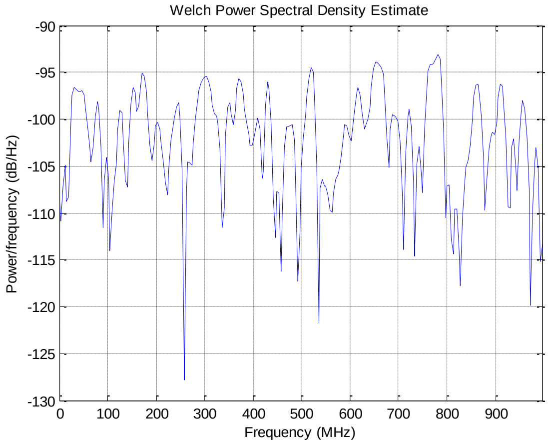

Fig. 7. QPSK-OFDM spectrum.

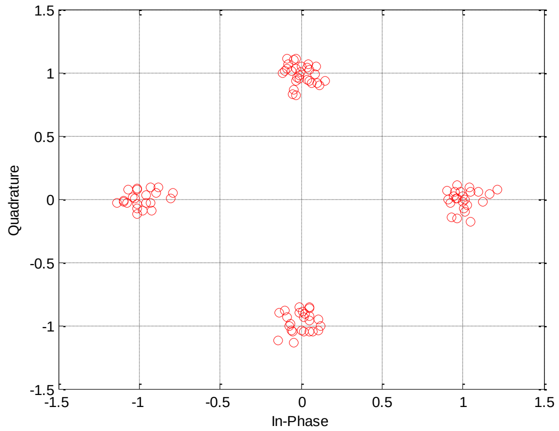

Fig. 8: QPSK Constellation after Transmission (SNR =20dB).

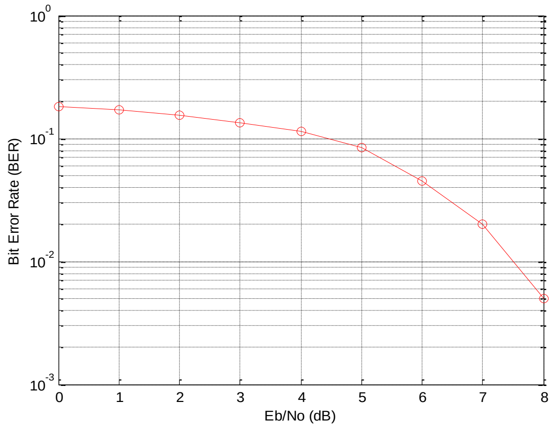

Fig. 9. BER of QPSK-OFDM.

The Fig. 5 shows the randomly generated signal to be transmitted and Fig. 6 shows the QPSK constellation of the signal before being passed through a noisy channel. Fig. 7 shows the OFDM spectrum after IFFT splits the transmitted data into different frequencies resulting in an OFDM signal. This generated OFDM signal is then passed through a noisy AWGN channel and Fig. 8 shows the QPSK constellation afterwards. The constellation points are for an SNR value of 20dB and it reveals the presence of noise within the signal. Since the constellation points tend to gravitate towards the data position the probability of receiving the data without error is very high. Fig. 9 shows the bit-error –rate (BER) of the signal and it can clearly be seen that as the SNR value or the Eb/No (which is its normalized value) increases there appears to be a gradual decrease in the BER meaning that the possibility of receiving the transmitted OFDM signal without much errors is very high. It drops steadily for an SNR value of 8 meaning after this point all other BERs will be zero.

B. *Simulation of π/4-QPSK –OFDM*

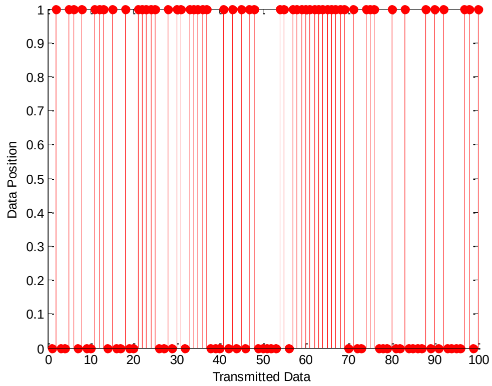

Fig. 10. Data transmitted for π/4-QPSK OFDM.

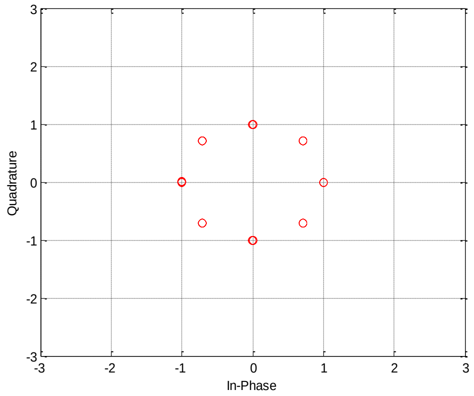

Fig. 11. π/4-QPSK constellation.

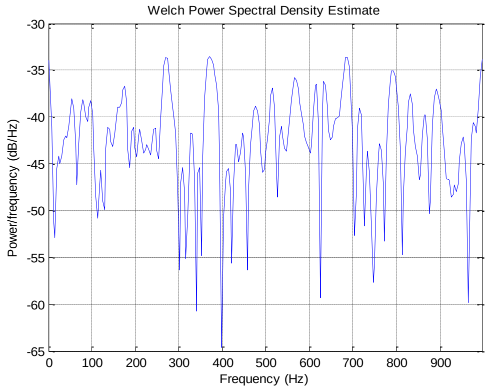

Fig. 12. π/4-QPSK OFDM spectrum.

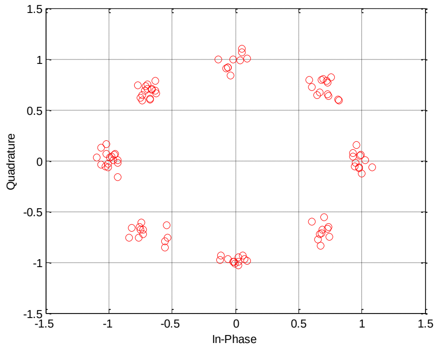

Fig. 13. π/4-QPSK constellation (SNR=20dB).

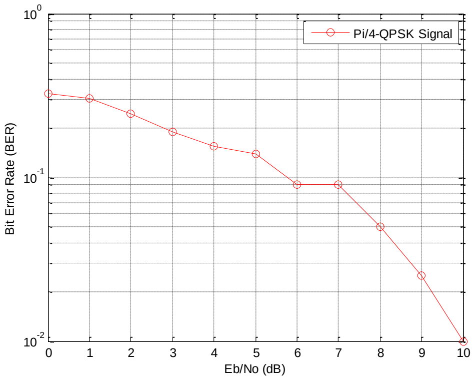

Fig. 14. BER for π/4-QPSK OFDM.

Again Fig. 10 shows the randomly generated signal to be transmitted for the π/4-QPSK –OFDM and Fig. 11 shows the π/4-QPSK constellation of the signal before being passed through a noisy channel. Fig. 12 shows the OFDM spectrumfor π/4-QPSK modulation of the subcarriers after the process of IFFT. This generated OFDM signal is then passed through a noisy AWGN channel and Fig. 13 displays the π/4-QPSK constellation after transmission. The constellation points are for an SNR value of 20dB and the fuzziness of the constellation is as a result of the noise present in the signal. The BER for π/4 QPSK OFDM just as was seen for the QPSK system reveals that for a high SNR value of there is a steady decrease in the BER making the probability of receiving a signal without errors very high with a large SNR value as shown in the Fig. 14 above. The figure also reveals that any SNR value after the point 10 will always have a BER value of zero.

IV. CONCLUSION

From all the results gathered and the analysis made on each of them it is clear that the OFDM system performed very well with both the QPSK and Pi/4-QPSK. In these two modulation schemes, the BER reduced dramatically for very small values of SNR showing the efficiency of OFDM in using these subcarrier modulation schemes. A closer observation of their individual results showed QPSK performed better than π/-QPSK for smaller values of SNR hence proving that QPSK is more efficient than Pi/4-QPSK when used within the OFDM platform.

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