

Performance of DCO-OFDM in Optical Wireless Communication System

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Abstract- OFDM scheme is widely adopted as it has high data rate and good performance under various channel conditions. In this paper, a number of unipolar optical OFDM scheme has been used for IM/DD system using simulink. To develop such a complex system, this paper proposes MATLAB as the platform for its implementation. The modeling of block diagram is done using Fast Fourier Transform and Hermitian symmetry. The concept of Optical OFDM uses LED at the transmitter and Photodiode at the receiver to demonstrate the optical characteristics of the system. The model has been implemented using different modulation techniques and under various channels. The paper suggests that using QPSK modulation in white Gaussian noise with 5dB SNR gives best result in terms of BER. Similarly, DBPSK modulation technique performs better with the increase in fading frequency. Thus, the complete model description suggests novelty in the modulation schemes that can be accepted for channels applicable in optical OFDM communication.

Keywords : OFDM, DCO-OFDM, FLIP-OFDM, IM/DD, AWGN and Rician Channel.

I. INTRODUCTION

OFDM is widely used in wireless communication system due to reduced inter symbol interference. OFDM is now considered as a modulation technique for optical system. In conventional OFDM, the signals transmitted are in bipolar and complex form. But, such signals are not suitable for transmission in IM/DD optical wireless system [1]. Therefore, Hermitian symmetry is applied to the signal. This converts the bipolar and complex signals into real time signal. In wireless optical signals, intensity modulation is done by LED's and direct detection is done using photodiode [2]. There are a number of schemes that make use of OFDM in optical Communication. Two forms of unipolar OFDM have been considered in this paper: DCO-OFDM (DC biased Optical OFDM) and Flip-OFDM. In DC biased OFDM, a DC bias is added to the signal. However, because of large peak to average power ratio of OFDM, even with a large bias some negative peaks of the signal will be clipped. While in Flip-OFDM, the bipolar and complex signal is converted into unipolar signal by applying hermitian symmetry. The unipolar signal consists of Positive and negative part. The flipped negative component is transmitted after the positive part [3].

This paper provides a comparative analysis between the DCO-OFDM and Flip-OFDM for IM/DD optical system in terms of BER and varying SNR and Doppler Frequency with different modulation techniques using three different channels. In this paper, Section II describes the simulation model and both OFDM techniques. Section III describes the proposed work with their results and related graphs. Section IV consists of conclusion and future scope on the basis of work done.

II. SIMULATION MODEL

In this section, a brief discussion on DCO-OFDM and Flip-OFDM is presented.

A. HERMITIAN SYMMETRY

To drive light sources such as LED's and Lasers, OFDM signal must be real and positive. To extract real OFDM signals, the frequency symbols are confined to hermitian symmetry before passing through IFFT[4].

$$X(N-k)=X^*(k), \quad k=1,2,\dots,(\frac{N}{2})-1 \quad (1)$$

Where * denotes complex conjugation. To evade complex component in time domain, the DC and Middle components are set to zero.

$$X(0) = X(\frac{N}{2}) = 0 \quad (2)$$

By performing IFFT on X(k), the discrete time signal at IFFT output can be expressed as,

$$x(n) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi \frac{kn}{N}) \quad (3)$$

Thus,

$$x(n) = \frac{1}{N} \left\{ X(0) + \sum_{k=1}^{\frac{N-1}{2}} X(k) \exp(j2\pi \frac{kn}{N}) + X(\frac{N}{2}) \exp(j2\pi \frac{N}{2} \frac{n}{N}) + \sum_{k=\frac{N}{2}+1}^{N-1} X(k) \exp(j2\pi \frac{kn}{N}) \right\} \quad (4)$$

When DC and middle component are set to zero, the equation can be written as:

$$x(n) = \frac{1}{N} \left\{ \sum_{k=1}^{\frac{N-1}{2}} X(k) \exp(j2\pi \frac{kn}{N}) + \sum_{k=\frac{N}{2}+1}^{N-1} X(k) \exp(j2\pi \frac{kn}{N}) \right\} \quad (5)$$

Let $k'=N-k$, substituting k' we get,

$$x(n) = \frac{1}{N} \left\{ \sum_{k=1}^{\frac{N-1}{2}} X(k) \exp(j2\pi \frac{kn}{N}) + \sum_{k'=1}^{\frac{N-1}{2}} X(N-k') \exp(j2\pi \frac{(N-k')n}{N}) \right\} \quad (6)$$

Rearranging the above equation gives,

$$\begin{aligned} x(n) &= \left\{ \sum_{k=1}^{\frac{N-1}{2}} X(k) \exp(j2\pi \frac{kn}{N}) + \sum_{k=1}^{\frac{N-1}{2}} X(N-k) \exp(-j2\pi \frac{kn}{N}) \right\} \\ &= \left\{ \sum_{k=1}^{\frac{N-1}{2}} X_R(k) \exp(j2\pi \frac{kn}{N}) - 2 \sum_{k=1}^{\frac{N-1}{2}} X_I(k) \exp(-j2\pi \frac{kn}{N}) \right\} \quad (7) \end{aligned}$$

where $X_R(k)$ and $X_I(k)$ are respectively the real and imaginary components of $X(k)$. Due to hermitian symmetry of signal, the imaginary part of the signal at the IFFT output becomes zero.

B. CHANNEL DESCRIPTION

In the proposed work, two channels have been used: AWGN and Rician.

1) *AWGN Channel*: To analyze modulation techniques, AWGN is the most commonly used model. White Gaussian noise is added to the signal that passes through this channel. For all the frequencies, channel's phase frequency response is linear and amplitude frequency response is flat. Therefore, modulated signal goes without any phase distortion and amplitude loss. Signal is not affected by fading while propagating through this channel.

The received signal is as follows:

$$r(t) = s(t) + n(t) \quad (8)$$

where $s(t)$ and $n(t)$ are transmitted and noise signal respectively[5].

2) *Rician Channel*: Rician fading arises, when Line of sight is present between the transmitter and the receiver. It can also be stated that, rician fading arises when Rayleigh fading has strong LOS.

Rician distribution is described as follows:

$$k = \frac{m}{2\sigma^2} \quad (9)$$

The model becomes Rayleigh fading if the value of $k=0$ and if k approaches ∞ , then it gets converted into AWGN channel[5].

C. OPTICAL OFDM MODEL

In OFDM system, the IFFT operation is applied to a frequency domain signal $X=[X_0, X_1, X_2, \dots, X_{N-1}]$ to generate a discrete time domain signal $X=[x(0), x(1), x(2), \dots, x(N-1)]$.

$$x(n) = \text{IFFT}(X_k) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \exp\left(j2\pi \frac{kn}{N}\right) \quad (11)$$

Where N is the IFFT size and $j^2=-1$ [3]. In OWC, electrical signal has to be real and positive valued for IM/DD scheme. While, the output of IFFT operation is in complex form. So, a real signal is obtained by applying the hermitian symmetry:

$$X_n = X_{N-n}^*, \quad n = 0, 1, 2, \dots, N/2-1 \quad (10)$$

Where, * denotes complex conjugate. X_0 and $X_{N/2}$ are set to zero and do not carry information [6]. The unipolar signal thus obtained after applying hermitian symmetry is used to modulate the intensity of LED. At the receiver, received optical signal is converted into an electrical form by the photodiode. In this paper, AWGN channel, rician channel and Rayleigh channel has been considered [3].

1) FLIP-OFDM

The unipolar signal comprises of a positive and a negative part.

$$x[n] = x^+[n] + x^-[n], \quad (11)$$

where, polarities positive $x^+[n]$ and negative $x^-[n]$ are obtained as described below:

$$x^+[n] = \begin{cases} 0, & x < 0 \\ x[n], & x \geq 0 \end{cases}$$

$$x^-[n] = \begin{cases} x[n], & x < 0 \\ 0, & x \geq 0 \end{cases}$$

The cyclic prefix of Δ samples are appended to each subframe [6]. In the first frame, positive polarity is transmitted, while flipped version of negative polarity is transmitted in the second frame with a delay of $N+\Delta$ samples. Therefore, all the samples are positive real valued in both the frames[3].

At the receiver, reconstruction of bipolar OFDM symbols is done from positive and flipped polarities. Now, from both the data frames, cyclic prefix are removed and then original bipolar signal is retrieved after performing subtraction operation.

$$y(n) = y^+(n) - y^-(n) \quad (12)$$

Where, $y^+(n)$ is the positive part and $y^-(n)$ is the flipped part of the frame. Now, original complex conjugate data is obtained by performing FFT operation on the above bipolar signal. Binary stream is reconstructed from the complex signal by the demodulation process[7].

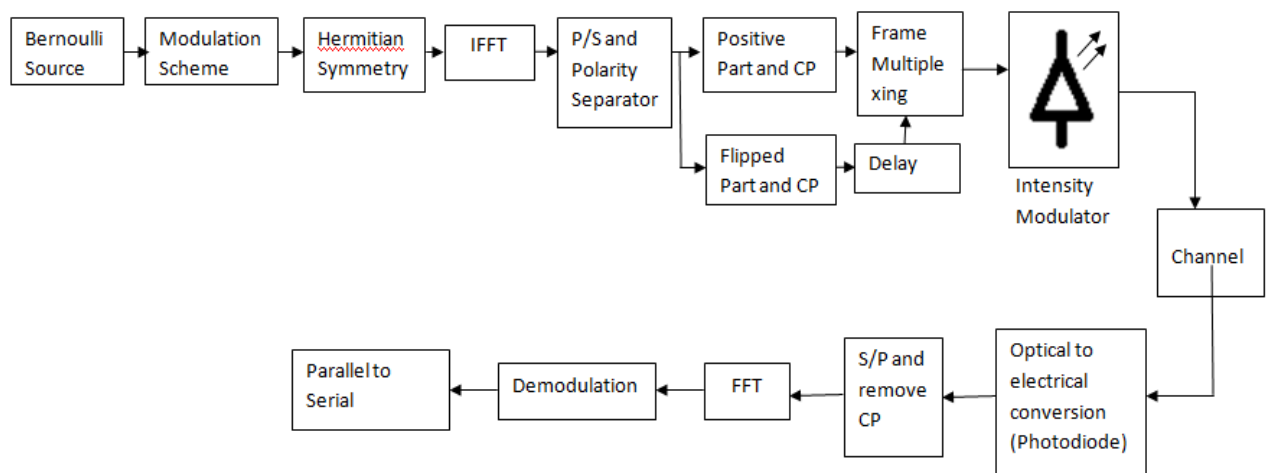


Fig 1: Block Diagram of Flip-OFDM

2) DCO-OFDM

To remove the negative peaks, a suitable DC bias is applied to the unipolar signal. Cyclic prefix is added to the signal. As OFDM signals have very high PAPR, so a large DC bias is required. But, it makes the system inefficient in terms of optical power. So a moderate DC bias is applied. In this paper, an ideal optical modulator is used. Therefore, the intensity of output optical signal is directly proportional to the input current. The resulting signal is transmitted over an AWGN channel. On the receiver side, the received signal is first converted from an optical signal to an electrical signal using a photodiode. Now the appended cyclic prefix and the signal is converted from serial to parallel. The signal then passes through the FFT block. Then it is demodulated and converted from parallel to serial data[8].

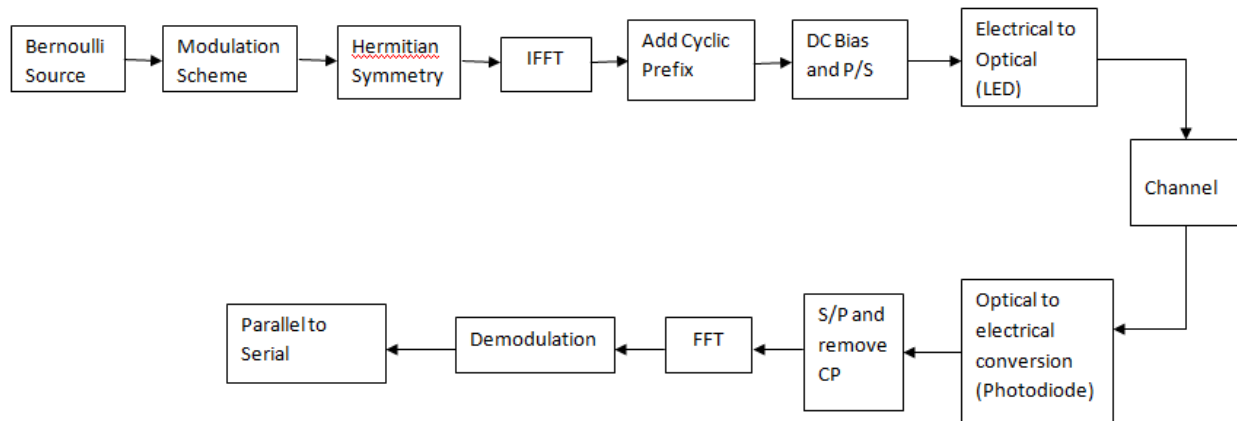


Fig 2 : Block Diagram of DCO-OFDM

III. PROPOSED WORK

This paper evaluates the performance of two different optical OFDM models. In the previous work done so far, the authors did not suggest the applicability of different modulation techniques and different effects of channel. Thus, the current paper emphasizes strongly on the usage of modulation schemes and the channel effects that deeply drive the IM/DD optical OFDM system. Now, the DCO-OFDM model has a performance comparison related to four different modulation schemes and two different channels. The analysis shows that 8 QAM is the best modulation scheme with a minimum BER value over a wide range of SNR in additive white Gaussian noise. The results of SNR v/s BER for AWGN channel are tabulated in table 1.

The best results of DCO OFDM appear in 8 QAM using AWGN channel. The results show that the value of BER comes close to 0.178 to 0.138 when SNR is varied between 1 to 5 dB. Similarly, when DCO OFDM model is modeled with Rician channels, it shows a good level of BER and SNR relationship using DBPSK modulation. Best results could be seen in fading channels for BER when Doppler frequency is 1 to 5 Hz, and BER varies between 0.007 to 0.008.

TABLE 1 : SNR v/s BER FOR DCO-OFDM WITH AWGN CHANNEL.

SNR dB	BER (AWGN CHANNEL)			
	8 QAM	16 QAM	BPSK	QPSK
1	0.178	0.1937	0.2661	0.2677
2	0.166	0.1904	0.2434	0.2449
3	0.155	0.189	0.2186	0.2206
4	0.146	0.1879	0.1918	0.1936
5	0.138	0.187	0.1645	0.166

TABLE 2 : DOPPLER FREQUENCY V/S BER FOR DCO-OFDM WITH RICIAN CHANNEL.

DOPPLER FREQUENCY	BER (RICIAN CHANNEL)			
	DBPSK	DQPSK	BPSK	QPSK
1	0.00764	0.09132	0.4937	0.5166
2	0.00763	0.09133	0.4938	0.5165
3	0.00761	0.09132	0.4939	0.5166
4	0.00765	0.09135	0.4942	0.5166
5	0.00767	0.09131	0.4944	0.5166

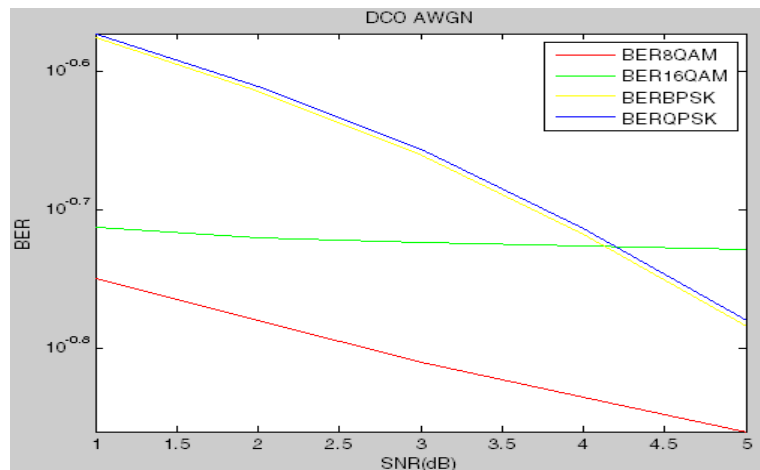


Fig 3 : BER v/s SNR for AWGN channel

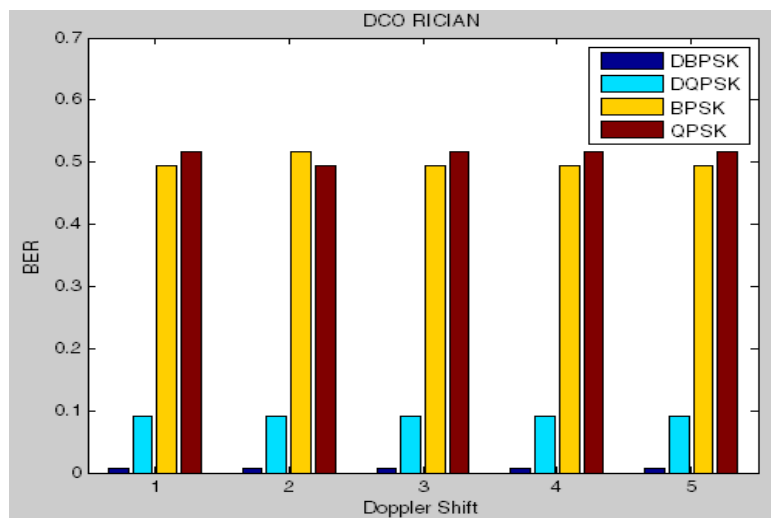


Fig. 4 : BER v/s Doppler Frequency for Rician channel

The Fig 3 shows that 8-QAM gives best result with AWGN channel. While, DBPSK shows best result with Rician channel. Now, the FLIP-OFDM model has a performance comparison related to three different modulation schemes and three different channels. The analysis shows that 8 QAM is the best modulation scheme with a minimum BER value over a wide range of SNR in additive white Gaussian noise. The simulation results are depicted in table 3.

The best results of Flip-OFDM appears in 8 QAM using AWGN channel. Now, implementation indicates the value of BER comes close to 0.26 to 0.21 when SNR is varied between 1 to 5 dB. Similarly, Flip-OFDM when modeled with Rician fading channel shows a good level of BER and SNR relationship when DBPSK modulation scheme. Best results could be seen in fading channels for BER when Doppler frequency is 1 to 5 Hz, and BER varies between 0.092 to 0.098.

TABLE 3 : SNR v/s BER FOR FLIP-OFDM WITH AWGN CHANNEL.

SNR dB	BER (AWGN CHANNEL)			
	8 QAM	16 QAM	BPSK	QPSK
1	0.26	0.2538	0.352	0.3431
2	0.2457	0.2493	0.335	0.3244
3	0.234	0.2451	0.3162	0.3054
4	0.221	0.242	0.295	0.2808
5	0.21	0.241	0.2715	0.255

TABLE 4 : DOPPLER FREQUENCY v/s BER OF FLIP-OFDM WITH RICIAN CHANNEL.

DOPPLER FREQUENCY	BER (RICIAN CHANNEL)			
	DBPSK	DQPSK	BPSK	QPSK
1	0.09287	0.3022	0.4928	0.4875
2	0.09311	0.3023	0.4931	0.4875
3	0.0932	0.3024	0.4934	0.4876
4	0.0933	0.3023	0.4928	0.4877
5	0.0939	0.3024	0.493	0.4877

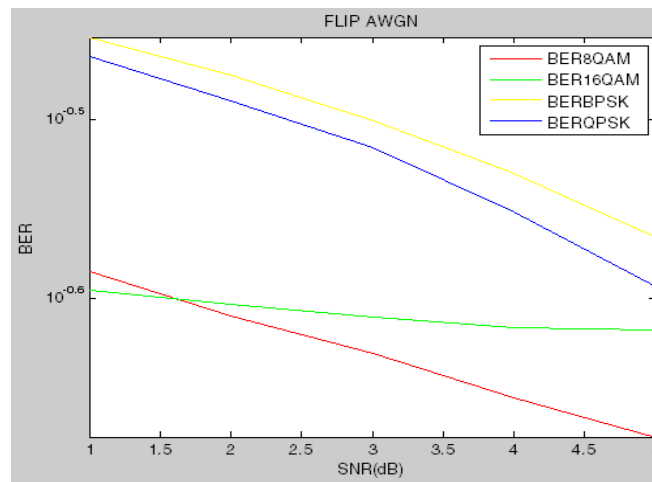


Fig 5 : BER v/s SNR for AWGN channel

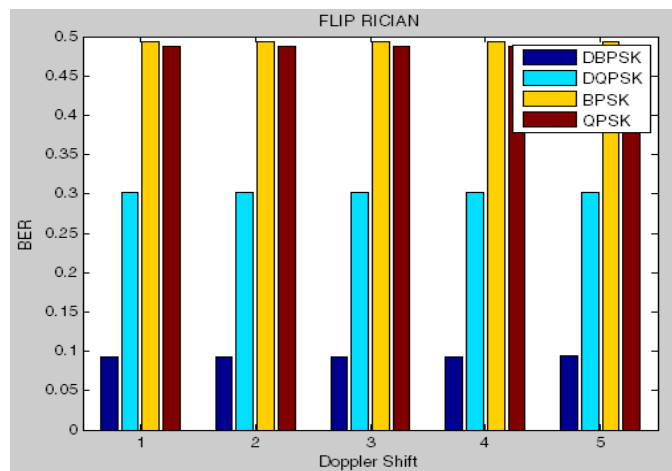


Fig 6 : BER v/s Doppler Frequency for Rician channel

IV. CONCLUSIONS

The optical wireless communication technique has shown a tremendous demand over the past few years resulting change in the technological demand. To cope up with latest technological advancements the paper intends to propose a novel modulation technique that could be offered in the optical wireless communications. The expectation of complete modeling is to induce a analysis of BER with varying SNR and Doppler frequencies. After thorough calculation and simulation the analysis proves that DCO OFDM system performs better than FLIP OFDM using 8 QAM modulation technique. The BER is approximately 13 to 17 % in DCO and 21 to 26% in Flip-OFDM. Thus an improvement of 35% in BER for DCO-OFDM indicates that for future technological purposes the DCO-OFDM will be used and further improvements can be made. The modeling is done using SIMULINK. However, the extension of work in this paper has also been done by incorporating fading effects. Due to fading, the optical system may suffer losses. So, the analysis proves that differential BPSK modulation scheme can be used in Rician fading channel.

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