Performance Evaluation using M-QAM Modulated Optical OFDM Signals

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Abstract— OFDM (Optical Orthogonal Frequency Division Multiplexing) in the optical domain is an emerging technology for fulfilling increased bit rate demand of real time sophisticated applications. In this work an optical OFDM system is designed using different M-ary QAM (Quadrature amplitude Modulation) techniques by varying M to 16, 65, 256. Performance evaluation has been carried in terms of SNR (Signal to noise ratio) and BER (bit error rate). In present research OPTSIM and MATLAB has been used as Simulation tools.

Index Terms— OFDM, OSNR, BER, QAM

I. INTRODUCTION
Orthogonal Frequency Division Multiplexing (OFDM) has emerged as leading technology for high data rates due to its robustness and flexibility in resource allocation. [1,2]. OFDM is based on Multi carrier transmission which transforms a high data rate signals into a group of parallel low data rate signals which are transmitted over subcarriers. The spectrum has been utilized much more efficiently by spacing the channels much closer together. OFDM offers robustness against channel dispersion and ease of phase and channel estimation in a time-varying environment. OFDM uses digital signal processing of fast-Fourier transforms (FFTs) to obtain high sub-carrier density and computationally-efficient phase and amplitude equalization [3]. Optical OFDM (OOFDM) technology has witnessed increase of interest in recent years [4]. OOFDM technique could be classified into two categories based on detection techniques - direct detection and coherent detection. A dramatic growth has been observed in number of publications in OOFDM as it has been evolved to be vibrant and fast progressing for long-haul transmission in coherent detection or in direct detection [1]. In this work a system is demonstrated by using the simulative environment for optical fiber in OPTSIM software, which allows the design of many configurations regarding optical communications. In this work, an optical OFDM transmission is simulated based on direct detection. The programming of the OFDM coder and decoder has been done with MATLAB software. It has been proposed that the concept of software defined radio (SDR) is a practical solution, for software implementation of the radio transceiver which is capable of adapting itself dynamically to the user environment instead of relying on dedicated hardware [5, 6]. Performance analysis could be carried over by monitoring various signal conditioning parameters like OSNR, chromatic dispersion, and electrical Signal to Noise Ratio (SNR) Bit error Rate (BER) [7]. We can use these parameters for identifying the fault [8]. On the basis of conclusion drawn for values of these parameters system may dynamically adapts and reconfigure itself for better transmission.

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In this work OOFDM transmission has been carried over by using M-Quadrature Amplitude Modulation (QAM) by varying M to 16, 64, and 256. Performance has been monitored in terms of BER and SNR. A block diagram of optical OFDM transmitter diagram has been shown in Fig. 1. Fourier transform techniques have been used for encoding the data. Information has been carried over many lower rate parallel subcarriers [6]. System transmitting OFDM modulated data over optical channel is divided into three parts; transmitter, channel, receiver. Transmitter section involves presenting data into N parallel paths where data at each path could be modulated using various digital modulation techniques including QPSK (Quadrature phase shift keying), 16 QPSK, M-QAM etc. In this work M-QAM has been implemented by varying M to 16, 64, 256 [8]. Various sub-carriers frequencies required for parallel transmission could be fulfilled by using an inverse-FFT (IFFT) which generates dense comb of OFDM sub-carrier frequencies [7].

II. SIMULATION MODEL

For analysing and performance monitoring the optical OFDM transmission system is modelled using OPTSIM. OFDM modulated data from MATLAB has been interfaced with OPTSIM to carry the transmission over fiber. Random generator has been used for generating OFDM signal binary data. M-ary QAM technique has been used for mapping of binary data values to symbols. Before sending information a training frame of pilot sub-carriers of length 96 samples is inserted which could be used at receiver for carrying out channel estimation for compensating the effect of channel on transmitted signal. 64-bit IFFT has been used for generating OFDM symbol data containing complex words frame and pilots frame. Extension of the frame is carried over by insertion of zeros to reduce the effect of Inter-carrier Interference. Cyclic prefix of 16 bits has been added which consists of the end of the OFDM symbol to be copied into the guard interval. OFDM data after being conversion from parallel to serial by using Parallel-to-Serial (P/S) converter has been interfaced with OPTSIM to carry over optical transmission [8].

Figure 2 represents simulation model of an optical communication system working at 10 Gb/s around 1550 nm central wavelength. Standard single mode (SM) fiber of length 100 km with attenuation of 0.2 dB/km, dispersion 16 ps/nm/km at reference frequency, zero dispersion at 1391.5354633 nm wavelength, average beat length 5 m. has been used. CW Lorentzian Laser having center emission wavelength 1550 nm, CW power 1mW and FWHM linewidth 10 MHz as main characteristics has been used as the optical source.
To obtain modulation of optical signal amplitude dual-arm Mach Zehnder modulator has been used. Mach Zehnder modulator have excess loss 0 dB offset voltage corresponding to the phase retardation in the absence of any (on both arms) electric field 0.5 V, extinction ratio 20 dB, chirp factor 0 and average power reduction due to modulation 3 dB. Reverse operations are employed at receiver side by doing serial to parallel conversion, removing cyclic pre-fix. For recovering sub-carriers FFT operations has been performed. To obtain binary values de-mapping of M-ary QAM has been carried over. Various important parameters values used during simulation are listed in Table I [8].

### III. Simulation Results

SNR is very important figure of merit for monitoring the performance of transmission quality. In this work performance analysis has been reported in terms of SNR by varying M to 16, 64 and 256 QAM. Analytical expression of Eq. (1) [9] has been used to evaluate theoretical BER for M-QAM transmission.

\[
\text{BER} = 1 - \left( 1 - \frac{2}{\log_2 M} \left( 1 - \frac{1}{\sqrt{M}} \right) Q \left( \sqrt{\frac{3}{M+1}} \frac{\text{SNR}}{\text{SNR}_0} \right) \right)^2
\]

Where M represents modulation order; Q is quality factor; SNR is Signal to Noise Ratio. Figure 3(a), 3(b), 3(c) is showing performance comparison curve for BER and signal to noise ratio for M-QAM optical OFDM system with M to be 16, 64 and 256.

![Figure 3(a). BER Vs SNR for Theoretical and Simulated 16-QAM](image1)

![Figure 3(b). BER Vs SNR for Theoretical and Simulated 64-QAM](image2)

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**Table I. Optical OFDM Simulation Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>10Gbps</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1550nm</td>
</tr>
<tr>
<td>Fiber length</td>
<td>100km</td>
</tr>
<tr>
<td>CW laser frequency</td>
<td>193.1THz</td>
</tr>
<tr>
<td>Gain</td>
<td>35dB</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>16 bit</td>
</tr>
<tr>
<td>FFT</td>
<td>64 bits</td>
</tr>
</tbody>
</table>

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Simulation has been conducted for a QAM modulated OFDM system and comparison of simulated result with that obtained theoretically using the analytical expression of Equation (1) [9] has been represented. It has been observed that simulated results match closely to the theoretical performance with small deviation at very low BER values. Figure 3(a) represents that the theoretical BER predicts a SNR of almost 24.9 dB at a BER of $10^{-10}$ for 16-QAM. At the same BER of $10^{-10}$ the simulated results suggest a SNR of about 27.9 dB, which is not far from the theoretical prediction, but may suggest additional noises and losses in fiber channel during transmission, inadequacy in the statistical sampling of the error process at extremely low error rates. From figure 3(b) for BER $10^{-10}$ theoretical SNR has been reported to 27 dB whereas simulated SNR is 30 dB. From figure 3(c) for BER $10^{-10}$ theoretical SNR has been reported to 30 dB whereas simulated SNR is 32 dB. Simulated Optical OFDM system is performing 3-3.5 dB worse than the theoretical formula. Theoretical formulas do not consider synchronization errors and quantization of received samples which degrade the performance of system [10].

Table II. Summarizes simulation results for 16, 64, 256 QAM OOFDM system. Comparison of BER Vs SNR for different modulation order depicts that a change in modulation order M from 16 to 64 QAM results approximately a change from 3 dB to 3.5 dB for SNR, whereas change of M from 64 to 256 QAM make SNR to change between 2 dB to 2.5 dB. The results clearly depicts that selecting higher modulation index requires high value of SNR to achieve the same BER as compared to lower modulation index. Selecting high modulation index definitely improve spectral efficiency but require higher values of SNR to achieve same BER as compared to lower modulation index.

### IV. Conclusions

OOFDM system has been simulated and compared over M-ary QAM by varying M to 16, 64, 256. Comparison of simulated and theoretical results find deviation of 3-3dB from theoretical results, which is not far from the theoretical prediction, but implies additional noises and losses in fiber channel during transmission, inadequacy in the statistical sampling of the error process at extremely low error rates. Higher
modulation order requires higher value of SNR to achieve a target BER as compared to lower modulation index.

REFERENCES