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Performance of Optical Fast-OFDM in MMF-Based Links

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Abstract: 19.375Gb/s optical Fast-OFDM signals can be transmitted over 500m worst-case MMF DML-based links having 3-dB effective bandwidths of 150MHz.km. This performance is similar to that corresponding to a conventional OFDM having twice the bandwidth.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

Over the past several years, as a promising candidate for spectral-efficiency in optical communication systems, conventional orthogonal frequency division multiplexing (OFDM) [1-2] has been rapidly and widely adopted in wireless, wire-line and broadcast systems for efficiently dealing with linear signal distortions encountered when transmitting over dispersive fading channels [3]. In OFDM, multiple subcarriers with equal frequency interval are utilized to form parallel data transmission, and each separate data stream is modulated with one of equally-spaced subcarriers [4]. Reducing the spacing between subcarriers in OFDM system, results in improved bandwidth efficiency. For this purpose, optical Fast-OFDM (FOFDM) [5] has been proposed. In contrast to conventional OFDM, FOFDM uses half of the subcarrier spacing with single-dimensional signal modulation formats being used such as M-ary amplitude shifted keying (M-ASK), due to the increased inter-symbol interference (ISI) between adjacent narrowband FOFDM subcarriers [6].

Very recently, FOFDM has been effectively implemented experimentally in single-mode fiber (SMF) systems by employing discrete cosine transform (DCT) for double-side band (DSB) signals [7], while for single-side band (SSB) signals, the real-to-Hermitian symmetric property of fast Fourier transform (FFT)/inverse FFT (IFFT) was preferred [8,2]. Due to limited bandwidths associated with multi-mode fibers (MMFs), FOFDM can be considered as an effective solution to combat optical modal dispersion in MMF-based transmission links. Moreover, analogue-to-digital converters (ADCs) have been considered as one of the most important devices for a conventional OFDM system limiting the maximum achievable transmission performance [9], and therefore, in the same manner ADC parameters are also a crucial factor for a FOFDM system.

The present paper presents, for the first time, two important issues: 1) The impact of the signal quantization and clipping effects in order to identify a set of ADC parameters for a targeted BER of 10^{-3} using various FOFDM single-dimensional modulation formats. 2) Having identified the ADC parameters, the transmission performance of the FOFDM system is investigated and compared with the conventional OOFDM over worst-case MMF-links. It is shown that FOFDM and conventional OFDM can support similar signal capacity as high as 19.375Gb/s over 500m worst-case MMF-links having 3-dB effective bandwidths of 150MHz.km.

2. System model and simulation parameters

Typical single-channel, un-amplified, intensity-modulation and direct detected (IM-DD) MMF links are considered, consisting of a conventional OFDM transceiver using FFT/IFFT, connected by the MMFs, similarly to architectures reported in [9]. The FOFDM system is implemented in a similar way, as shown in Fig. 1, only for the subcarrier multiplexing/de-multiplexing a discrete cosine transform (DCT)/inverse DCT (IDCT) is attached and single-modulation format mapping is generated [2,7-8]. In the transceiver, an ADC (DAC) is used to convert an analogue (digital) signal into a digital (analogue) signal, having an automatic gain control unit which sets a finite dynamic amplitude range [9]. Amplitude clipping occurs if the input signal exceeds that dynamical amplitude range, which will introduce distortions to the input signals [9]. The ADC/DAC impairments are considered in this paper. The 3-dB bandwidths (differential mode delays [DMDs]) of the adopted MMF link are of 202.5 MHz • km (2.0ns/km) for central launch conditions [9-10].

Since the influence of nonlinearities of directly modulated lasers (DMLs) under typical driving and bias currents is negligible on the transmission performance of FOFDM/OFDM signals in MMF-based transmission links [7,9-10], for simplicity, here the DML is assumed to be an ideal-intensity modulator at 1550nm. It is also assumed that the 3-dB effective bandwidth of the link is proportional to the inverse of transmission distance [9-10]. The rest of the simulation parameters are shown in Fig. 1 (a).

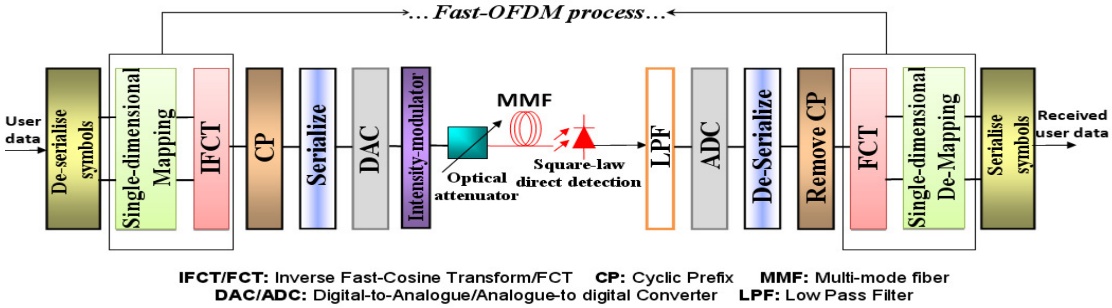


Fig.1: FOFDM transmission link diagram.

3. Results

Initially, simulations for both FOFDM and conventional OFDM models were undertaken over an additive-white-Gaussian noise (AWGN) channel. The purpose of using AWGN channels is to isolate the quantization and clipping effects from other transmission-link impairments to ease the process identifying the ADC parameters. Over such a channel the bit-error-rate (BER) performance for both systems, without suffering quantization and clipping impairments is shown in Fig. 1 (b), where the total BER as a function of electrical signal-to-noise ratio (SNR) is plotted using only single-dimensional modulation formats for both systems such as amplitude shift-keying (ASK)-4 up to ASK-16. As shown in Fig. 1 (b), different signal modulation formats require different SNRs for achieving BERs of 10^{-3} and the difference between these two systems is almost negligible.

Parameter	Value
Transmitted subcarriers	64
Data-carrying subcarriers	31
DAC &ADC sample rate	12.5GS/s
Cyclic prefix	25%
Launched optical power	5dBm
PIN detector sensitivity	-19dBm
PIN detector quantum efficiency	0.8

(a)

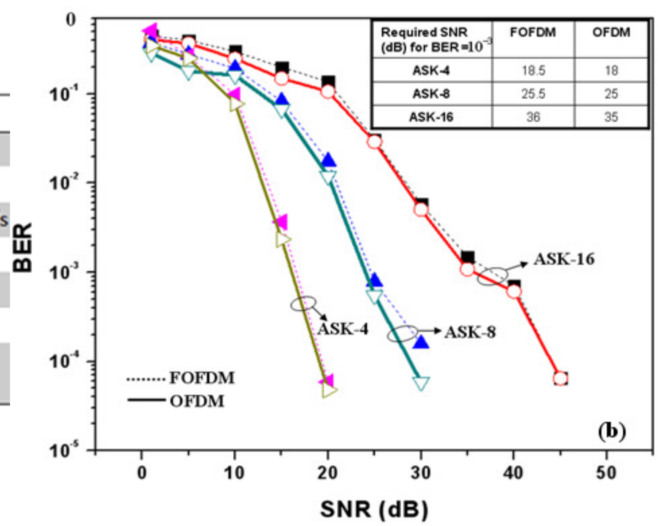


Fig.1: (a) Simulation parameters. (b) Comparisons between FOFDM and conventional OFDM using single-dimensional modulation formats, for both systems.

In Fig. 2, simulations are undertaken for FOFDM using differential binary shift-keying (DBPSK), and ASK-8 up to ASK-16, in order to identify the effects of quantization and clipping for a BER of 10^{-3}, over an AWGN channel. It is shown that from DBPSK to ASK-16 quantization bits and clipping ratios should be taken up to 8-bits and 12dB respectively. It is noted that for higher modulation format such as ASK-32 the input signal exceeds the ADC dynamical amplitude range, introducing distortions to the signal and therefore unrealistic ADC parameters are defined.

Having identified the FOFDM ADC parameters, simulations are undertaken over a MMF-link with its parameters discussed in Section 2. For performance comparisons, BER versus transmission distance is plotted in Fig. 3, including a table with the corresponding signal capacity values, for both FOFDM and conventional OFDM under identical ADC parameters, which were identified previously. Single-dimensional (FOFDM) and 2-dimensional (conventional OFDM) modulation formats are used, varying from ASK-4 up to ASK-16, differential quaternary PSK (DQPSK), quadrature amplitude modulation (QAM)-8 and QAM-16. It is shown that for a required BER of 10^{-3}, a maximum signal capacity of 19.375Gb/s (ASK-16) is feasible over 500m. For the conventional OFDM system 19.375Gb/s (QAM-16) is feasible over 800m, and therefore for distances up to 500m

FOFDM and conventional OFDM have similar transmission performance. For distances >500m, the BER for ASK-16 is degraded significantly due to the increased modal dispersion which affects the FOFDM information spectral density (ISD), reducing the received SNR.

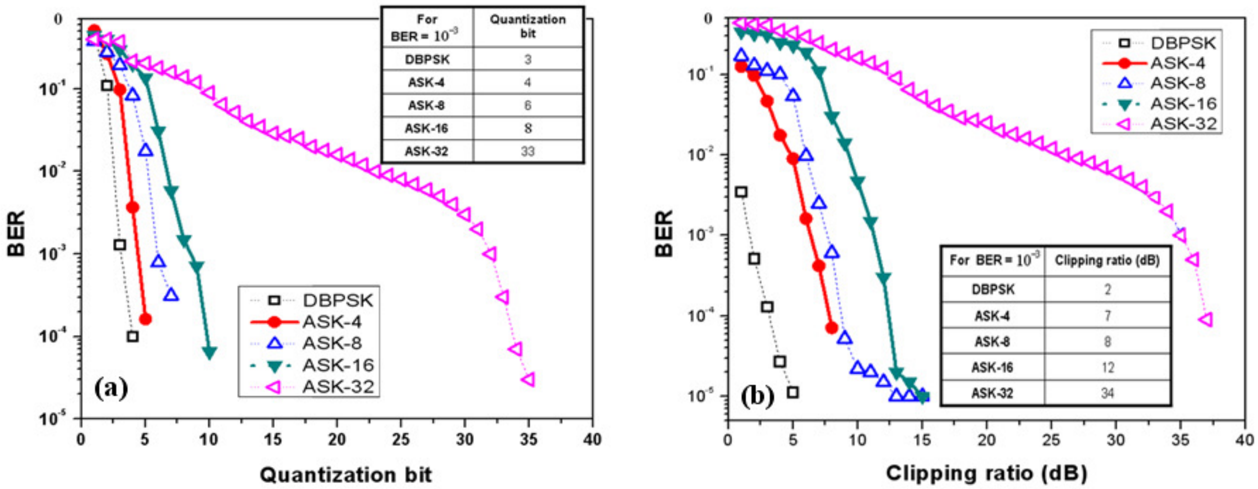
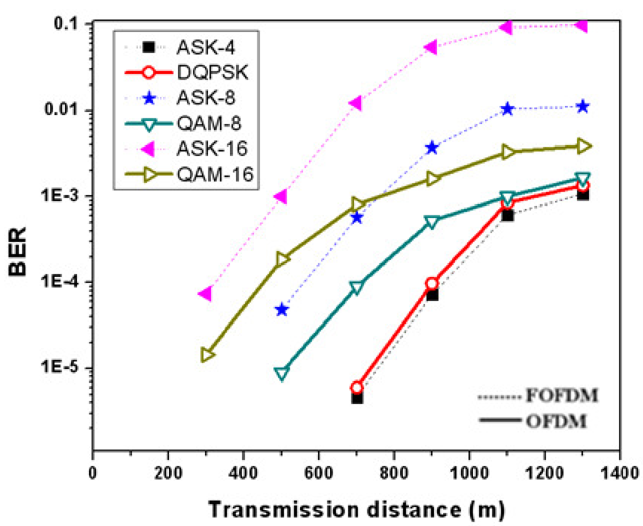


Fig. 2: BER versus (a) quantization bit and (b) clipping ratio for a FOFDM system using single-dimensional modulation formats over AWGN channel.



FOFDM: For BER = 10^{-3}	Distance (m)	Signal capacity (Gb/s)
ASK-4	1100	9.687
ASK-8	800	14.53
ASK-16	500	19.375

OFDM: For BER = 10^{-3}	Distance (m)	Signal capacity (Gb/s)
DQPSK	1100	9.687
QAM-8	1300	14.53
QAM-16	800	19.375

Fig. 3: Comparisons of required BER versus transmission distance and signal capacity between single-dimensional modulation formats (FOFDM) and 2-dimensional modulation formats (OFDM) over a MMF-link.

4. Conclusions

The work reported indicates that FOFDM is a promising technique for providing a cost-effective, high-speed solution, with half the bandwidth efficiency compared to conventional OFDM, excellent flexibility and robustness, for upgrading installed MMF-based 10Gb/s and above Ethernet backbones and up to 19.375Gb/s.

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