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Original research article

A full-duplex optical fiber/wireless coherent communication system with digital signal processing at the receiver

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ABSTRACT

In this paper, a full-duplex, 120 Gbps optical fiber/wireless system is presented for high-speed and multicasting communication link. Both the wired and wireless systems use Dual Polarization 16 Quadrature Amplitude Modulation (DP-16-QAM) with homodyne detection. Blind Phase Search (BPS) algorithm, Constant Modulus Algorithm (CMA) and Viterbi Phase Estimation (VPE) algorithm are used at the receiver end to compensate for signal distortions such as Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD), nonlinear impairments, frequency and phase mismatch. The system performance is analyzed in terms of Error Vector Magnitude (EVM), Bit Error Rate (BER $\leq 10^{-12}$) and constellation diagram based on OptiSystem V.13 simulation platform. The maximum transmission distances achieved are 275 km and 1.1 km for Standard Single Mode Fiber (SSMF) and Free Space Optical Link (FSOL), respectively.

1. Introduction

The ongoing research on 100 G communication finds advanced modulation formats with coherent detection technology as one of the solutions for high-speed communication interfaces. To achieve higher data rates and spectral efficient transmission, higher order modulation formats such as Quadrature Phase-Shift Keying (QPSK), 16-QAM, 32-QAM, etc. need to be exploited [1,2]. But as we go higher, the fiber Kerr non-linearity becomes a limiting factor (i.e. higher signal-to-noise ratio requirements), it restricts the maximum power level over fiber [3]. Though multiplexing of wavelengths is one of the ways to increase the data rate, a single carrier transmission system is more preferred by the industry, because it provides the required data rate at a lesser cost and robust transmission. New high-speed Digital Signal Processors (DSP) essentially upgrade the system performance providing improved flexibility and programmability [4–7].

Recently, full-duplex systems have been reported using conventional In-phase and Quadrature Modulator (IQM) with both homodyne and heterodyne detection [8–11]. Li et al. proposed triple drive IQM to generate 64-QAM using binary signals with three modulators driven by Radio Frequency (RF) signals and optimized the I/Q synchronization issue in higher order modulation [12]. Zhou et al. reported a robust and double decision directed blind equalizer algorithm that combines soft decision directed algorithm with variable step size decision directed mode and achieved a faster convergence rate for eliminating the Inter-Symbol Interference (ISI) over fiber [5]. Yu et al. realized a fiber-wireless system with polarization multiplexing (pol-MUX) along with Multiple-Input Multiple-Output (MIMO) communication. DSP algorithm (i.e. CMA) was used to solve the multipath effect and demonstrated a fiber-wireless integration system [4]. Zhou et al. demonstrated modulation format independent (MFI) BPS algorithm for fiber impairments compensation which incorporates modulation format recognition and Carrier Phase Estimation (CPE) in a feed-forward manner [13]. Rashidi et al. reported a Spectrum-Sliced (SS) WDM based FSOL and achieved a data rate of 1.56 Gbps for 2.5 km at 1550 nm laser

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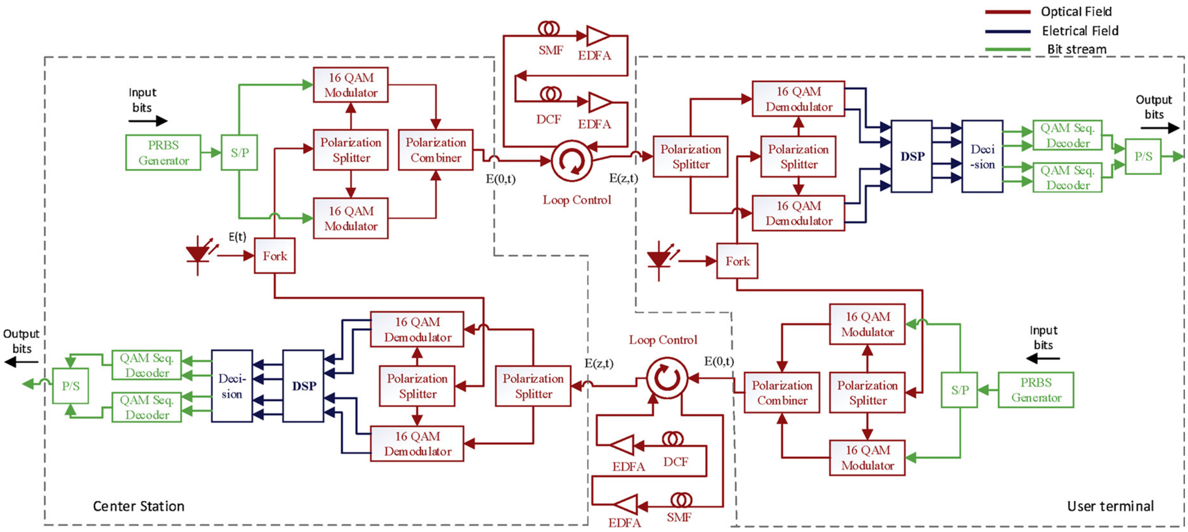

Fig. 1. Full-duplex fiber-optic link structure implementing DP-16-QAM modulation format with homodyne detection.

center wavelength and 0 dBm transmit power [14]. Yi et al. presented an asymptotic error rate analysis of the Double-Generalized Gamma (DGG) fading channel using subcarrier intensity modulation for MIMO-FSO system at high electrical SNR level [15]. Therefore, to meet the ever-increasing demand for bandwidth, it is desirable to design an efficient coherent communication system without additional complexity.

In this article, a full-duplex coherent transmission system is presented using 16-QAM modulation format and Polarization Division Multiplexing (PDM) technique with homodyne detection at the receiver. The proposed free space Line of Sight (LOS) link is examined for the effect of moderate fog attenuation with scintillation effect. FSOL is intended for use in the places where laying of optical fiber is not possible or cost becomes a major concern. As per the author's knowledge, the designed FSO system has a higher data rate than its predecessor using single optical carrier [14,16–21].

The rest of the paper is sorted out as follows. In Section 2, the design scheme and principle of the full-duplex link is described. In Section 3, the performance of the system is analyzed in terms of constellation diagram, BER and EVM and results are discussed. Section 4 draws a conclusion and future perspective of the design.

2. Principle of operation

Fig. 1 shows the design schematic of the full-duplex coherent communication system for high-speed fiber-optic link.

The downlink and uplink input data is represented by 120 Gbps Pseudo Random Bit Sequence (PRBS) generator with 2^{17} - 1 sequence length. The serial to parallel (S/P) converter divides the incoming bit stream into even and odd bits and send them to the upper and lower 16-QAM modulators, respectively. The polarization splitter splits the optical carrier into two orthogonal (i.e. X and Y) polarization components, which are modulated by respective 16-QAM modulators. Fig. 2 shows the internal block diagram of the 16-QAM modulator. The function of the QAM sequence generator is to group 4 bits as a symbol (required for 16-QAM) then even and odd position bits are fed to the upper and lower arms, respectively. The multilevel electrical signal at the M-ary pulse generator output is applied to the RF plates of the dual drive Mach-Zehnder Modulator (MZM). The DC bias points of the two MZMs are set at null point or V_π with an extinction ratio of 25 dB and switching voltage 3 V.

The electrical signals $V_I(t)$ and $V_Q(t)$ modulate their respective carriers and have a relative phase shift of π/2 (i.e. the phase shifter) at the lower branch which is required for the QAM signal generation. The modulated optical signals are combined using Polarization Combiner (PC) to get the DP-16-QAM signal. The CW lasers at the transmitter and the receiver have a linewidth 0.1 MHz. The lightwave at the transmitter has a center frequency $f_s = \omega_s/2\pi$, and can be expressed as

$$E(t) = E_s e^{j(\omega_s t+\phi_s)}.\, \mathrm{e}_s \quad (1)$$

Where, $E_s = \sqrt{P_s}$ is amplitude of the signal electric field, $\mathrm{e}_s(=\mathrm{e}_x + e_y.\, e^{j90^0})$ is polarization component, ω_s is center angular frequency, and zero initial phase (i.e. $\phi_s = 0$) is assumed. The multi-level driving signals at the inphase and quadrature branches (Fig. 2) are expressed as [2]

$$\begin{bmatrix} V_I(t) \\ V_Q(t) \end{bmatrix} = \begin{bmatrix} -V_\pi + \frac{2V_\pi}{\pi}\sum_k\{\sin^{-1}(i_k)p(t-kT_s)\} \\ -V_\pi + \frac{2V_\pi}{\pi}\sum_k\{\sin^{-1}(q_k)p(t-kT_s)\} \end{bmatrix} \quad (2)$$

Here, k denotes the symbol interval (k = {1, 2, 3, 4} for 16-QAM), T_s is symbol duration, i_k and q_k are the in-phase and quadrature normalized symbol coordinates and take values $\{-1, -1/3, 1/3, 1\}$, $p(t)$ is the pulse shape. The data-bearing optical signal at the