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Guerrero Gonzalez, Neil; Caballero Jambrina, Antonio; Amaya Fernández, Ferney Orlando; Zibar, Darko; Tafur Monroy, Idelfonso

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Experimental 2.5 Gbit/s QPSK WDM Coherent Phase Modulated Radio-over-Fibre Link with Digital Demodulation by a K-means Algorithm

N. Guerrero [(1)], A. Caballero[(1)], F. Amaya[(1,2)] D. Zibar[(1)] and I. Tafur Monroy[(1)]

[(1)] DTU Fotonik, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark, nggo@fotonik.dtu.dk
[(2)] GIDATI Research Group, Universidad Pontificia Bolivariana, Medellín, Colombia, foafe@fotonik.dtu.dk

Abstract *Highest reported bit rate of 2.5 Gbit/s for optically phase modulated radio-over-fibre link employing coherent detection is demonstrated. Demodulation of 3x2.5 Gbit/s QPSK modulated WDM channels, is achieved after 79km of transmission through deployed fiber.*

Introduction

Coherently detected optically phase-modulated radio over fiber (RoF) links are a promising technology for future applications in wireless networks where a large bandwidth, channel selectivity and low transmit power is required[1]. Optically phase modulated RoF links can potentially enable large spurious–free dynamic range, high-capacity, high-spectral efficiency, enhanced receiver sensitivity and simplified antenna base stations implementation. However, phase modulated links require an optical coherent receiver for detection and linear signal demodulation[2]. A promising approach for linear signal demodulation is a digital coherent receiver that comprised stages for removing frequency offset between the local optical local oscillator and incoming signal, carrier recovery, timing recovery, radio frequency (RF) phase estimation and signal demodulation. We have recently proposed and experimentally demonstrated a novel DSP based digital coherent receiver for phase-modulated WDM RoF optical links employing a simple BPSK modulation format at 50 Mbit/s for RF carrier over 25 km of SMF[3]. In this paper, we experimentally demonstrate a 3 channel wavelength division multiplexing (WDM), 2.5 Gbit/s quadrature phase-shift keying (QPSK) optical phase modulated RoF, including transmission over a 78.8 km long field deployed optical fibre in the Copenhagen area. QPSK signal is generated by a Pulse Pattern Generator (PPG) and demodulation is performed offline employing a k-means algorithm featuring low complexity and simplicity for digital implementation.

Setup Description

The experimental setup is shown in Fig. 1. The transmitter consists of 3 tuneable Distributed Feedback Laser (DFB) lasers, with an average optical output power of 1 dBm and a linewidth of ~3 MHz. The output of the transmitter laser array is then connected to an optical phase modulator (PM). The wavelengths of the channels were spaced at 50 GHz from 1552.444 nm to 1552.048 nm. Two independent output signals from a PPG at 1.25 Gbit/s are used to feed the I&Q mixer of a Vector Signal Generator (VSG), which performs QPSK modulation at 6 GHz carrier frequency.

The RF power driving the PM is set to 18 dBm, corresponding to 0.8662 modulation index. The optically phase modulated signal is transmitted over a 78.8 km of field-deployed optical fiber. The fiber is a G.652 standard single mode fiber (SMF) type. The total link loss was measured to be 25 dB. This deployed link incorporates dispersion compensation by using a matched length of dispersion compensating fiber (DCF) whose loss is compensated by an erbium doped fiber amplifier (EDFA).

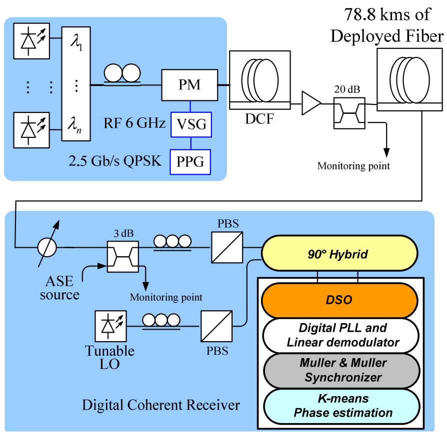

Fig. 1: Experimental setup

As a Local Oscillator (LO), a tuneable external cavity laser is used, with ~100 kHz linewidth and 0 dBm input power was delivered to the 90° optical hybrid. Both signals are passed through Polarization Beam Splitters (PBS) so the beating of both lasers is maximized. In practice, a polarization diversity scheme or polarization tracking can also be implemented. The in-phase and quadrature signals resultant after the 90° Hybrid coherent receiver are detected with two pairs of balance photodiodes, with 7.5 GHz bandwidth. The detected photocurrents are digitalized using a sampling oscilloscope at 40 Gs/s (Agilent Infinium DSO91304A) for offline processing. The employed digital receiver uses carrier-recovery digital phase-locked loop (PLL), linear signal

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demodulation[2], and k-means algorithm for RF phase estimation and signal demodulation.

K-means Algorithm for RF phase recovery

In contrast to using phase rotation methods to align a recovered constellation, an iterative clustering approach called k-means algorithm[4] can be applied to the complex QPSK data mapped into the In-phase and quadrature space. This algorithm subdivides the constellation iteratively into L clusters (or classes) once the centroid of every cluster is found. Complex multiplications to rotate the constellation and certain number of data to estimate the phase are not required for signal demodulation.

An example of phase recovery for our QPSK signal using k-means is shown in Fig. 2.

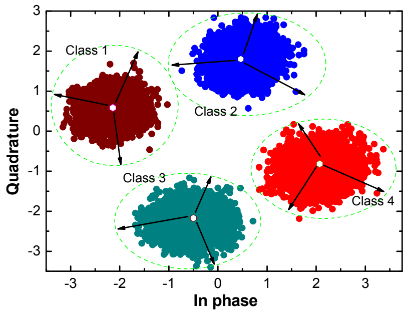

Fig. 2: Phase recovery by k-means algorithm

Experimental Results

Fig. 3 shows the electrical spectrum of the QPSK signal with 2.5 GHz double side-band bandwidth.

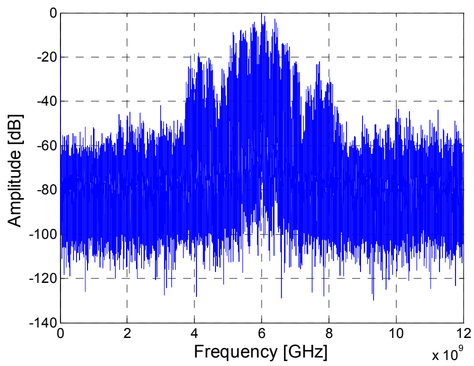

Fig. 3: Electrical spectrum of digital demodulated QPSK signal, 2.5 Gbit/s at 6 GHz carrier frequency

Fig. 4 shows the measured optical spectrum of the 50 GHz WDM space signals. Amplified spontaneous emission (ASE) noise was added to the system using two cascades EDFA with a tuneable filter in between to measure the optical signal to noise ratio (OSNR) at 0.1 nm of resolution.

To assess the performance of our system, we have computed the BER curve as a function of OSNR for the central wavelength channel alone and for the case of two added, simultaneous neighbouring channels spaced 50 GHz. Fig. 5 shows the offline computed results for Back-to-Back (B2B) transmission and after the deployed fibre.

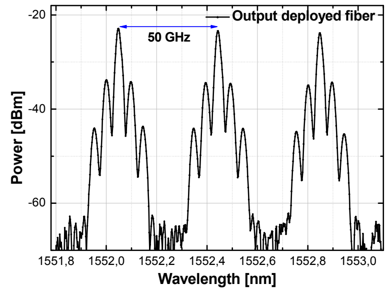

Fig. 4: Optical spectrum of WDM channels

A penalty of 1 dB is observed for a single wavelength ($\lambda_2 = 1552.44$ nm) after 78.8 km of transmission with respect to its B2B performance and approximately 2.5 dB of penalty for the case of two added neighbour channels. The reason for the observed penalty, we believe, it is associated with polarisation dispersion issues in the field deployed fibre.

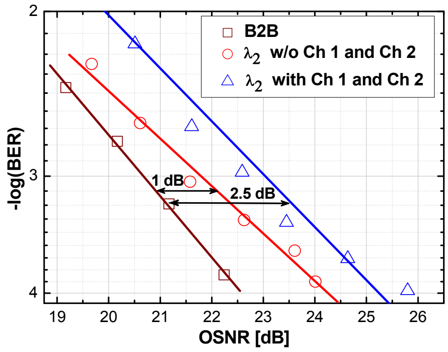

Fig. 5: BER curve for back-to-back (B2B), and after transmission for one and three wavelengths, simultaneously

Conclusions

We have experimentally demonstrated successful coherent detection and digital demodulation for 3xWDM of 2.5 Gbit/s QPSK phase modulated RoF optical link after transmission over a 78.8 km of field deployed fibre. The k-means algorithm is used for RF phase recovery. To the best of our knowledge, this is the highest reported baud rate for optical phase modulated RoF, coherent optical links.

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