50 Gb/s Transmission over Uncompensated Link up to 20 km Exploiting DSP-Free Direct-Detection

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Abstract: We experimentally transmit 50Gb/s over 20km uncompensated SMF with a conventional DSP-free OOK direct detection receiver, exploiting combined amplitude phase shift codes. A simplified implementation based on analog electronics is also validated at 50Gb/s.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.4080) Modulation; (060.5060) Phase modulation

1. Introduction

The continuous growth in the capacity of the access network, either fixed or mobile, is deeply transforming the aggregation network architecture by accelerating the evolution towards a converged infrastructure, usually referred to as Xhaul, able to support both backhaul and fronthaul services [1]. Today's DWDM systems, based on coherent 100 Gbit/s dual polarization quadrature shift keying, could already satisfy the capacity requirement of 5G transport networks, but would be too demanding in terms of cost and energy consumption. In an Xhaul network, the highest distance between the antenna and the baseband processing site is in the order of 20 km and is expected to occur in centralized radio access networks. Such a reach is achievable with optical direct detection formats, such as OOK or multilevel pulse amplitude modulation (PAM), thus avoiding expensive and power demanding digital signal processing (DSP). However, fiber chromatic dispersion effects are detrimental at 50 Gbit/s and beyond and countermeasures are required.

A possible alternative to OOK or PAM is using the combined amplitude phase shift (CAPS) codes for combating chromatic dispersion adopting a simple direct detection receiver [2]. The effectiveness of the order 3 CAPS code was experimentally verified at 25 Gb/s in [3] while in [4] a simpler implementation, named IQ-duobinary, was proposed. In this work, we extend the experimental demonstration of CAPS3 up to 50 Gb/s and we experimentally demonstrate the effectiveness of the IQ-duobinary for 50 Gb/s transmission up to about 17 km uncompensated.

2. Principles of CAPS coding and its IQ-duobinary approximate analog implementation

CAPS was first proposed in [2] as a family of optical line codes exhibiting a high tolerance to chromatic dispersion and requiring a simple direct detection receiver. For the order-3 CAPS code considered in this work, the in-phase and quadrature (IQ) components of the equivalent PAM pulse g(t) are represented in Fig.1(a). Parameters α and β can be tailored to optimize the performance for different amounts of accumulated dispersion. The effectiveness of CAPS3 was experimentally demonstrated at 25 Gb/s in [3] using a DAC for implementing the code, while a simpler implementation not requiring a DAC was proposed in [4], showing that a CAPS3 signal can be approximated by associating a quadrature component to a duobinary coded signal. Such a component is given by two attenuated replicas of the duobinary signal itself, respectively anticipated and delayed by a symbol time T. This novel format was named IQ-duobinary and a block diagram for its generation is reported in Fig. 1(b). Here, $g_2 = \rho g_1$ with $0.1 \leq \rho \leq 0.3$, such that the power associated to the quadrature component is much smaller than the in-phase one. The higher ρ the larger the distance that can be bridged but also the higher the penalty at intermediate distances. However, increasing ρ the

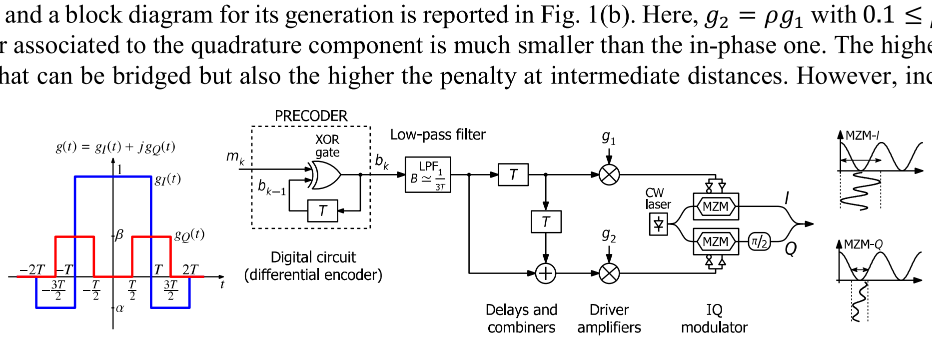

Fig. 1: a) Equivalent PAM pulse for the CAPS3 code; b) IQ-duobinary transmitter.

improvement becomes progressively smaller, such that there is no practical advantage using values greater than about 0.3. Simulation results in [4] show that, given a 3 dB penalty with respect to a back-to-back OOK system, a CAPS3 code is able to bridge about 20 km at a bit rate of 50 Gb/s, while IQ-duobinary about 17 km. Hereafter we report about the experimental results obtained in the laboratory at 50 Gb/s.

3. Experimental results

Fig. 2 (a) depicts the experimental setup used to verify the CAPS3 and IQ-duobinary line codes and compare them against conventional transmission techniques such as OOK and PAM4, all targeting 50 Gb/s over 20km reach. The testbed comprises a continuous wave laser which feeds an IQ-MZM. The two electrical signals driving the IQ-MZM are generated from two channels of a DAC running at 84 GSa/s with 3-dB bandwidth of 25 GHz after being amplified by two RF amplifiers each with ~ 40 GHz 3-dB bandwidth. For the CAPS3 and the IQ-duobinary cases, the I and Q signals are generated according to the theory presented in the previous section which was further detailed in [4]. The modulated signal is then launched into standard single mode fiber with varying lengths from 0 to 20 km. After the fiber, the received signal is pre-amplified by means of an erbium doped fiber amplifier (EDFA) and attenuated to set the received signal power to the desired level. Photodetection is performed by a PIN photodiode and the photocurrent is fed to a Keysight digital communication analyzer (DCA) to measure eyediagrams (Fig.2(b)) to assess qualitatively the received signal integrity. A 63 GHz, 160 GSa/s real-time oscilloscope is used to perform error counting offline. Prior to error counting, no DSP is performed on the received waveforms except for timing recovery to find the optimum decision point within the symbol duration as well as finding the optimum decision threshold.

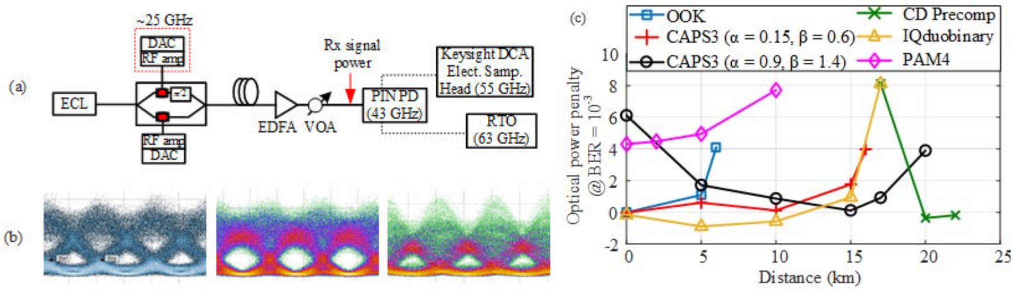

Fig. 2: a) Experimental setup; b) Eye diagrams of IQ-duobinary at 15 km, CAPS3 at 15 and 20 km, respectively; c) Optical power penalty at BER = 10^{-3} for the different modulation schemes, all at 50Gb/s, calculated relative to a reference OOK BtoB sensitivity at BER = 10^{-3}.

To evaluate and compare the performance of the different modulation schemes, receiver sensitivity at BER=10^{-3} is measured as a function of the transmission distance, in a thermal noise limited regime (being the impact of the EDFA noise negligible), assuming as a reference the OOK sensitivity in back-to-back (BtoB) configuration. All modulation schemes compared in Fig. 2 (c) deliver a bit rate of 50 Gb/s. As depicted in Fig. 2 (c), the maximum achievable distance for OOK is 6 km obtained while having to increase the received optical power by 4dB relative to BtoB. On the other hand, PAM4 at 25 GBd is capable of reaching at most 10 km with a severe optical penalty of nearly 8 dB with respect to OOK BtoB. The performance of 50 Gb/s CAPS3 has been evaluated considering two different configurations (corresponding to different values of the α and β parameters): in a first configuration (α = 0.15, β=0.6, red crosses), CAPS3 shows only 2 dB penalty up to 15 km and can reach up to 16 km at the expense of higher penalty of 4 dB. Even longer distances can be reached by reconfiguring the modulation parameters to α = 0.9, β=1.4 (black circles), enabling transmission up to 20 km with 4 dB of penalty at expense of an increased penalty at very short distances 0-5km due to the introduced pre-distortion. IQ-duobinary (triangles) with parameter ρ = 0.28, digitally emulated through the DAC, shows very good agreement with simulations in [4], with a very low (or even negative) penalty up to 15km. The penalty increases for longer distance, reaching 8 dB at a maximum reach of 17 km. Fig. 2 (c) also reports for comparison an example of a digitally CD-precompensated OOK for a nominal distance of 20km realized through the DAC driving the IQ-MZM. As expected, penalty-free performance is obtained only in a limited range close to the nominal compensated distance.

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4. References

[1] A. de la Oliva et al. "Xhaul: Towards an Integrated Fronthaul/Backhaul Architecture in 5G Networks", IEEE Wireless Comm., V.22,5,2015.
[2] E. Forestieri et al., "Novel optical line codes tolerant to fiber chromatic dispersion," *J. Lightwave Technol., Vol. 19, no. 11, p. 1675 (2001).*
[3] F. Fresi et al., "Short-reach distance extension through CAPS coding and DSP-free direct detection receiver," *in Proc. ECOC2016, Th.2.P.2.*
[4] E. Forestieri et al., "Extending the reach of short-reach optical interconnects with DSP-Free direct-detection," *J. Lightw. Technol.*, vol. 35, no. 15, pp. 3174–3181, Aug. 2017.