Digital Domain Power Division Multiplexing DDO-OFDM Transmission with Successive Interference Cancellation

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Abstract: Two independent 2.5-Gb/s DDO-OFDM signals are simultaneously transmitted over 25km SMF using digital domain power division multiplexing and successive interference cancellation. With optimized power division ratio and enhanced SD-FEC, the spectral efficiency can be doubled.

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1. Introduction

In order to support higher capacity transmission network, five available physical dimensions, namely time, frequency, quadrature, polarization and space, have been utilized for modulation and multiplexing in optical communications [1]. In these schemes, orthogonality must be assured so as to minimize the inference or crosstalk from other channels. Hence, the signals can be separated without any severe inter-channel interference. However, in common optical orthogonal systems, such as optical orthogonal frequency division multiplexing (OFDM) or Nyquist WDM, they do not allow frequency reuse within the same polarization state, time slot, and space channel to transmit multiple independent signals. Recently, non-orthogonal multiple access (NOMA), also known as power domain multiple access, has been proposed as a potential candidate for the upcoming 5G standard due to its superior spectral efficiency [2]. In NOMA, multiple users are multiplexed at different power levels using superposition coding at the transmitter side and successive interference cancellation (SIC) based multi-user detection at the receiver side. The non-orthogonal feature significantly improves the capacity and throughput in both wireless and visible light communication systems, by allocating the entire bandwidth to different users, simultaneously [3, 4]. Inspired by the idea of NOMA, a new multiplexing dimension is explored to enhance the fiber channel capacity by exploiting different signal power levels.

In this paper, we propose a digital domain power division multiplexing (DDPDM) scheme to transmit multiple signals and recover each signal using SIC algorithm. A direct detection optical OFDM (DDO-OFDM) transmission experiment over 25-km single mode fiber (SMF) is performed and experimental results demonstrates the feasibility of this approach. The power division ratio (PDR) can be optimized according to the quality of service (QoS) requirement of each signal. With proper forward error correction (FEC) coding, the system spectral efficiency can be nearly doubled.

2. System Model and Experimental Setup

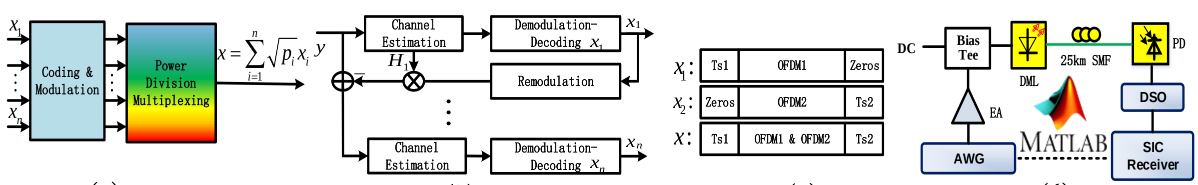

Fig.1. Schematic of proposed digital domain power division multiplexing transmission system: (a) baseband transmitter, (b) SIC receiver, (c) OFDM frame structure, (d) experimental setup.

As shown in Fig.1 (a), multiple baseband signals (x_i) are linearly combined together after coding and modulation using proposed DDPDM to form one new baseband signal $x=\sum_{i=1}^{n}\sqrt{p_i}\,x_i$, where p_i is the power of i^{th} signal, and the total power is normalized, namely $\sum_{i=1}^{n}p_i=1$. The idea of our non-orthogonal scheme is to utilize power division multiplexing in terms of using the same frequency but different power levels. Without loss of generality, we assume that the power levels (p_i) are arranged in descending order, namely $p_1>p_2>\cdots>p_n$. After transmission through the communication channel, the power multiplexed signal can be expressed as $y=\sum_{i=1}^{n}H_i\sqrt{p_i}x_i+n$, where H_i is the channel response of the i^{th} signal and n is the additive noise. Then at the receiver, the detected signal will be demodulated and decoded one by one in the descending order of power levels using SIC algorithm, whose flow chart is shown in Fig.1 (b). The SIC process mainly consists of three steps: (1) estimate the channel response and demodulate the strongest signal x_1 while treating all the other signals $x_2 \cdots x_n$ as interference noise; (2) re-modulate the estimated signal $\hat{x}_1$ and multiply it by the channel response H_1 before subtracting the product from the received signal y and then decode the second strongest signal x_2; (3) go on with the aforementioned steps until all the signals are decoded. As SIC algorithm suppresses interference from the stronger (earlier decoded) signals to the relatively weaker (yet to be demodulated) signals, even the signals with lower power can be correctly recovered. As a proof of concept, we demonstrate transmission of two DDO-OFDM signals over 25-km SMF just using one directly modulated laser (DML) and one photodetector (PD). The experimental setup and the OFDM frame structure are depicted in Fig.1(c) and (d), respectively.

3. Experimental Results

In our experiments, two sets of independent real-valued baseband OFDM signals were generated offline using Matlab before being sent to an arbitrary waveform generator (AWG Tektronic 7122C, at sampling rate of 2.5Gsap/s) after DDPDM with various PDR values (defined as PDR $= p_1/p_2$, in dB unit). After up-converted to the optical frequency by intensity modulating a DML, the multiplexed signal was launched into 25-km SMF. At the receiver, the directly detected signal was sampled by the real time oscilloscope (OSC) and offline processed with the SIC detection algorithm. The baseband QPSK-OFDM parameters were the same as that in [6] except for the specially designed frame structure with a length of 300, in which 11 symbols were used as training symbols for synchronization and channel estimation while another 11 symbols were zero padded.

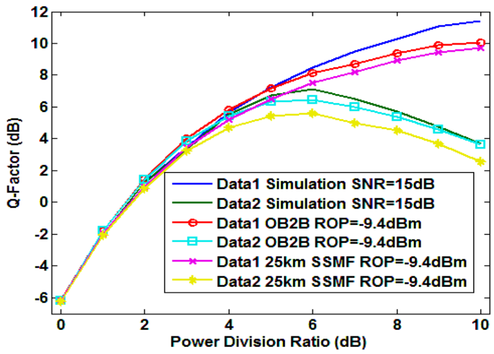

Fig.2. Simulation and experimental results of relationship between the received Q factor and power division ratio (PDR)

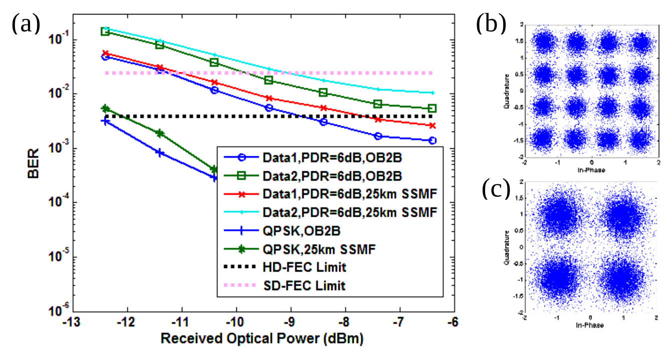

Fig.3. Transmission performance of power division multiplexed signal. (a) BER Vs ROP, (b)and (c) Constellation diagrams at ROP=-7.4

The relationship between the Q factor and PDR has been investigated by simulation and experiments. As shown in Fig.2, the optimized PDR to minimize the BER of weaker signal (Data2) was found to be 6 dB, in which scenario two superposed QPSK constellations would become exactly 16QAM. If the PDR > 6 dB, there was a tradeoff between the performances of the two power multiplexed signals. One could change the PDR and adjust the performance of the stronger signal, according to its QoS requirements. With PDR fixed at 6 dB, we measured the BER performance under different received optical power (ROP) and the results were summarized in Fig.3. As expected, BER for the weaker signal was worse than the stronger one, nevertheless, soft-decision (SD) FEC coding could be applied to the weaker signal to ensure error-free transmission. Compared with traditional QPSK DDO-OFDM, the power division multiplexed counterpart could double the data rate within the same bandwidth at a cost of about 4-dB power penalty to reach hard-decision (HD) FEC limit, which proved the feasibility of the proposed DDPDM scheme.

4. Summary

We have proposed and experimentally demonstrated a new DDPPDM scheme for DDO-OFDM transmission with SIC algorithm. The PDR can be optimized according to QoS requirement of each signal. With proper FEC coding, the system spectral efficiency can be nearly doubled at the cost of 4-dB power penalty.

5. References

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