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Intensity-Modulation Direct-Detection OCDM System Based on Digital Up-Conversion

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Abstract: We propose for the first time an orthogonal chirp-division multiplexed (OCDM) IM/DD system based on digital up-conversion for access network applications. It exhibits better resilience to impairments such as chromatic-dispersion-induced fading and noise than OFDM, with ~5 dB improved receiver sensitivity at 37.5 Gbit/s line rate at 80 km.
OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation; (060.4250) Networks

1. Introduction

Recently, we have proposed orthogonal chirp-division multiplexing (OCDM) as an attractive solution for high spectral efficiency, long-haul, coherent optical transmission systems as it exhibits improved resilience to the impairments with respect to orthogonal frequency-division multiplexing (OFDM) and single-carrier systems [1-3]. Instead of the subcarriers used in OFDM, in the OCDM system information is modulated by a large number of orthogonal chirps, attaining the Nyquist modulation rate. However, the chirps provide additional advantages inherited from the chirp spread spectrum, namely the resilience to channel fading, distortions and noise. In other words, OCDM not only has the same spectral efficiency as other Nyquist modulation techniques such as the OFDM and Nyquist single-carrier systems [4, 5], but is capable of more effectively alleviating the system impairments than those techniques.

For cost-sensitive short-reach systems and access networks, e.g., passive optical networks (PONs), optical systems based on intensity modulation (IM) and direct detection (DD) are preferred as they are simpler and cheaper to implement in practice [6]. However, to satisfy the orthogonality principle for Nyquist signaling, OCDM signals are complex-valued in the time domain; this is why up to now OCDM have only been proposed for coherent systems, rather than the IM/DD systems, which are indispensable for future cost-effect short-/mid-reach access network.

Here, we show, for the first time, to the best of our knowledge, how OCDM can be adapted for optical IM/DD systems, opening the potential for applications in future access systems. In our approach, digital up-conversion (DUC) is used to obtain the OCDM signal in the digital domain by mixing the baseband signals with a digital radio-frequency (RF) carrier with negligible complexity; the real part of the up-converted OCDM signal is an equivalent passband modulated signal, which can be directly used for modulating the intensity of an optical carrier. We demonstrate by numerical modeling that the proposed IM/DD-OCDM system has superior performance in terms of its ability to combat impairments arising from the chromatic-dispersion-induced fading and noise, compared to a discrete multi-tone (DMT) OFDM system with the same system setup (bandwidth and data rate) of similar complexity.

2. Principle of the Proposed IM/DD-OCDM System Based on Digital Up-Conversion

The system diagram of the proposed IM/DD-OCDM system is shown in Fig. 1. The OCDM signals are generated by the discrete Fresnel transform (DFnT) [7], with its in-phase and quadrature components being fed into the DUC unit. The DUC unit consists of an up-sampling function, which up-samples the equivalent complex baseband signal by a pulse-shaping filter (interpolation) to meet the Nyquist criterion for up-conversion, and an up-conversion function, which converts the frequency of the baseband signal to a passband on the positive frequency plane. The RF frequency should be at least higher than the bandwidth of the baseband signal to avoid aliasing, as shown in Fig. 1-(ii).

According to the complex signal representation, the real part of the up-converted OCDM signals is equivalent to the baseband OCDM signal mixed with a RF carrier. As the signal is interpolated with high sampling frequency, the real part of the up-converted signal preserves all the information in the OCDM signal without aliasing. Its spectrum is illustrated Fig. 1-(iii). Thus, the real part of the up-converted signal at the output of DUC can be used for intensity modulation directly. At the receiver a photodiode detects the intensity of the received optical signal. A digital down-conversion (DDC) unit performs the reversed processes with respect to the DUC, i.e., down-converts the baseband signal by a complex carrier, and down-samples the signal to the same sampling rate as the transmitter. The transmitted information can thus be recovered by a conventional OCDM receiver scheme [2], as shown in Fig. 1.

3. System Setup and Results

The system setup is shown in Fig. 1. In the OCDM, there are 256 chirps modulated in 4-, 16-, and 64-QAM, and the DUC unit up-samples the signal by a factor of 4 to 1024 samples. At the transmitter, the DAC is operated at 25 GS/s

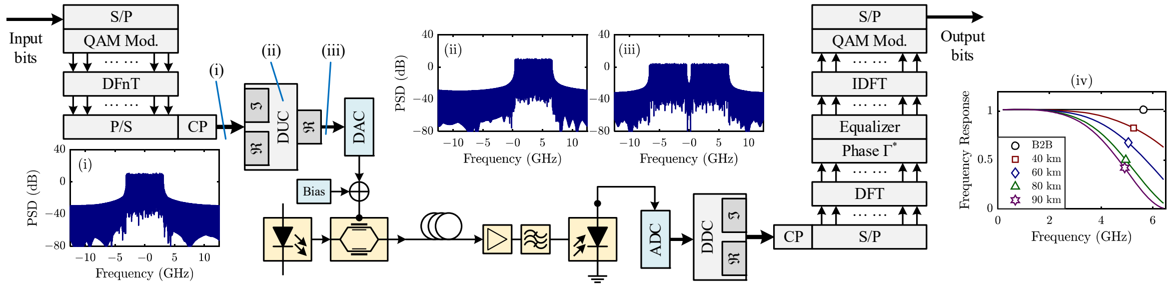

Fig. 1. System diagram of the proposed IM/DD-OCDM system based on DUC. Insets: the PSD of (i) the equivalent baseband signal, (ii) the OCDM signal after up-conversion, (iii) the double sideband (real part) of the signal, and the channel frequency response of the IM/DD system.

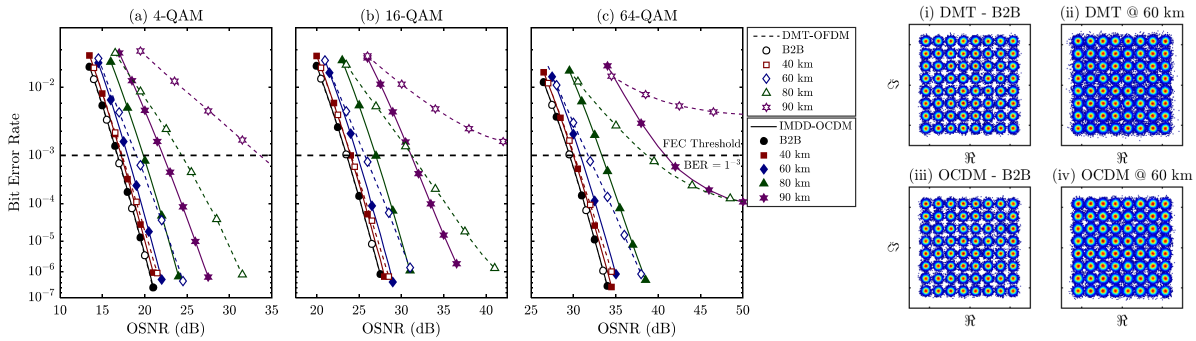

Fig. 2. BER versus received OSNR of IM/DD-OCDM and DMT-OFDM with (a) 4-, (b) 16-, and (c) 64-QAM; inset: the received constellation diagrams of DMT-OFDM at (i) B2B and (ii) 60 km, and that of IM/DD-based OCDM at (iii) B2B and (iv) 60 km with a received OSNR = 20 dB.

with a bandwidth of 12.5 GHz, and the baseband signal has a bandwidth of 3.125 GHz (6.25 GHz in passband), and the line rates are 12.5, 25, and 37.5 Gbit/s for 4-, 16-, and 64-QAM, respectively. The digital RF carrier is 3.45 GHz for up-conversion and the spectrum of up-converted signal is shown in Fig. 1-(ii). For intensity modulation, the real valued up-converted signal is fed into the optical modulator with 10 dB DC-bias. The laser is operated at 1550 nm, and the link consists of standard single-mode fiber up to 90 km followed by an optical amplifier and an optical filter. After the signal is received, a DDC converts the signal back to the equivalent complex baseband for demodulation. In the DMT-OFDM, there are 1024 subcarriers with 512 subcarriers for modulation, of which 256 are for positive frequency and 256 for negative with complex conjugate to get real-valued DMT signals. The center 16 subcarriers are left without modulation (zero) to avoid DC coupling. As a result, both systems have the same electrical spectra of the same bandwidth, and thus the same data rate for a fair comparison.

The simulation results are shown in Fig. 2. As the distance increases, the performance of the DMT-OFDM degrades, especially as the distance goes beyond 60 km. The degradation arises from the chromatic-dispersion-induced fading, as indicated in Fig. 1-(iv). In contrast, the proposed IM/DD-OCDM, by taking the advantage of the chirp that spreads the information over the entire bandwidth, outperforms the DMT-OFDM system, attaining the same BER with less received OSNR. The improvement is more obvious for high level modulation formats. For example, for the case of 64-QAM, the proposed IM/DD-OCDM requires about 5 dB less OSNR than the DMT-OFDM to attain a BER of 10^{-3} at 80 km. As the distance increases to 90 km, a significant error floor occurs for the DMT-OFDM, while the proposed IM/DD-OCDM can still achieve a BER well below the FEC threshold with 7% overhead.

4. Conclusion

In this study we propose, for the first time, an IM/DD-OCDM based on DUC. Simulations were carried out to validate the feasibility of the scheme, and the results confirmed the advantages of the proposed IM/DD-OCDM system, showing a 5 dB improved receiver sensitivity compared to a DMT-OFDM with a data rate of 37.5 Gbit/s at 80 km transmission distance.

5. References

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