A Sixteen-User Time-slotted SPECTS O-CDMA Network Testbed

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Abstract: We present a time-slotted SPECTS O-CDMA network testbed supporting up to 16 users at 10 Gb/s/user. Error-free performance is achieved using a NOLM time gate and a nonlinear thresholder and without FEC.

OCIS codes: (060.2330) Fiber optics communications; (999.9999) Optical code division multiple access

1. Introduction

Optical code division multiple access (O-CDMA) has received much attention recently as a promising candidate in all-optical local area networks (LANs) [1]. Compared with wavelength division multiple access (WDMA) and time division multiple access (TDMA) techniques, O-CDMA has significant advantages in accessing the wide optical bandwidth with enhanced efficiency, flexibility, security and the capability of rapid reconfiguration. Various O-CDMA schemes using different light sources and coding methods have been proposed in the literature [2–4]. This paper demonstrates a 16-user coherent O-CDMA network testbed based on a spectral phase encoded time spreading (SPECTS) technique. In SPECTS O-CDMA, the spectrum of ultrashort optical pulses is divided into portions that are usually referred to as chips, and a particular phase delay (0 or π) is added onto the individual spectral chips according to a binary code from an orthogonal code set. This spectral encoding spreads the optical pulses in the time domain. A decoder can reconstruct the short pulses by applying the conjugate spectral phase code, while the pulses remain spread in time if an incorrect code from the same code set is used in the decoder. However, traditional bandwidth-limited optical receivers will not be able to discriminate between a correctly decoded and incorrectly decoded optical pulse since they have the same integrated pulse energy within one bit period. For this reason, a time gating or nonlinear thresholding technology is necessary in high speed O-CDMA networks to differentiate the short optical pulses of the intended user from the mixture of noise-like multi-user interference (MUI) signals [5].

This summary presents a synchronous SPECTS O-CDMA network testbed which achieves error-free performance for up to 16 users at 10 Gb/s/user. The impact of MUI on network performance was minimized through careful system engineering including code selection and alignment, maximization of optical signal-

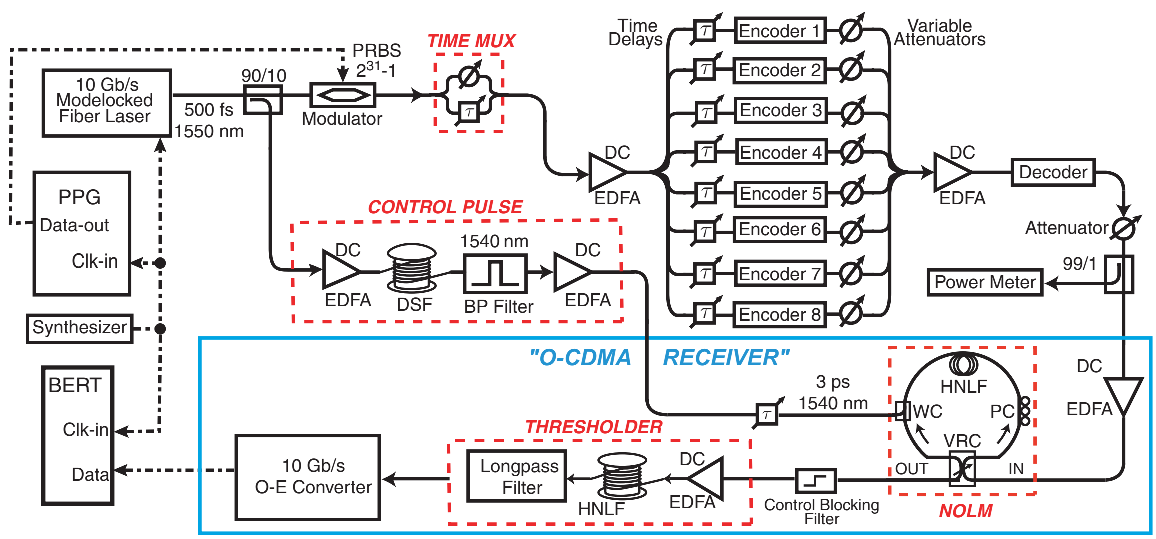

Fig. 1. Sixteen-user time-slotted SPECTS O-CDMA testbed. PPG: pseudorandom pattern generator. DC-EDFA: dispersion-compensated EDFA. VRC: variable ratio coupler. WC: wavelength combiner.

to-noise ratio, matching encoder/decoder characteristics, and time-slotted operation. The use of time slots also allows for the same code to be used by multiple O-CDMA users in different time slots (code sharing). A nonlinear optical loop mirror (NOLM) acts as a time gate to demultiplex the time slots while additionally providing MUI suppression.

2. Testbed description

In the SPECTS O-CDMA testbed, encoding and decoding in the spectral domain are realized by zero-dispersion pulse shapers with liquid crystal spatial light phase modulators (LC-SLPM) at the Fourier plane [5]. Fig. 1 shows the details of the testbed. A modelocked fiber laser generates 500-fs pulses centered at 1550 nm with a repetition rate of 9.95328 GHz (OC-192). The pulses are on-off key (OOK) modulated with $2^{31}-1$ pseudo-random bit sequence (PRBS) data and then time-multiplexed into two time slots each 50-ps wide. After amplification with a dispersion compensated erbium-doped fiber amplifier (DC-EDFA), the signal is split into eight branches, and each feeds an individual encoder. A unique 64-chip Hadamard Walsh code is used by each encoder to encode two users (one in each time slot). The encoded signals from the 16 users (eight in each time slot) are equalized in power, combined, and sent to the decoder. In the experiment, one of the two users from Encoder 1 is used as the intended user, and it is distinguished from the combined 16-user signal by the decoder and an O-CDMA receiver. The decoder correctly decodes both the two users from Encoder 1 by using the conjugate Walsh code, and one time slot is then gated out by the NOLM. The 3-ps wide control signal pulses of the NOLM are generated by the same laser source, but the wavelength is shifted to 1540 nm using the nonlinearity in 1 km of dispersion shifted fiber (DSF). Further suppression of MUI is accomplished by the nonlinear thresholder which is based on self-phase modulation (SPM) in 500 m of highly nonlinear fiber (HNLF). The high peak intensity of the short pulses from the intended user shifts the spectrum to longer wavelengths and a longpass filter separates it from the nearly unchanged spectral components of the spread MUI signals. The NOLM, the thresholder and the optical-electrical (O-E) converter are defined as the "O-CDMA receiver" in the testbed. The output of the O-CDMA receiver feeds into a bit-error-rate tester (BERT) for BER measurement.

3. Results and discussion

Synchronous operation can exploit Walsh codes to great advantage, because Walsh-encoded pulses have minimum energy at their temporal center. Walsh code multiplication is a closed set (e.g.,Walsh times Walsh is another Walsh) and any incorrectly decoded pulse will also have an energy minimum at its center. This minimizes MUI for the correctly decoded pulse. 64-chip Walsh codes 5, 40, 34, 54, 6, 16, 28, 52 (numbered as generated by MATLAB) are used by encoders 1 to 8 respectively, with the conjugate of code 5 used for decoding. Cross-correlation traces of the combined and decoded signal from all 16 users taken before and after the NOLM are shown in Figs. 2(a) and 2(b). In Fig. 2(a), the center peaks in Time Slots 1 and 2 are from the correctly decoded users and other noise-like signals are from the 14 incorrectly decoded users. The NOLM has a 3-ps time window and it passes the center portion of Time Slot 1, while blocking the other signals with a ~16 dB extinction ratio, as shown in Fig. 2(b). Fig. 2(c) is scaled to reveal the low intensity signals along the bottom of Fig. 2(b), showing the residual MUI from the NOLM and the necessity of using a nonlinear thresholder for further MUI suppression. At the output of the thresholder, the power contrast ratio between the intended user and fifteen interfering users is more than 30 dB.

Fig. 3 displays the BER statistics of the 16-user testbed taken versus the total input power to the O-CDMA receiver (cf., Fig. 1). The back-to-back case is taken at the output of the time MUX, without any

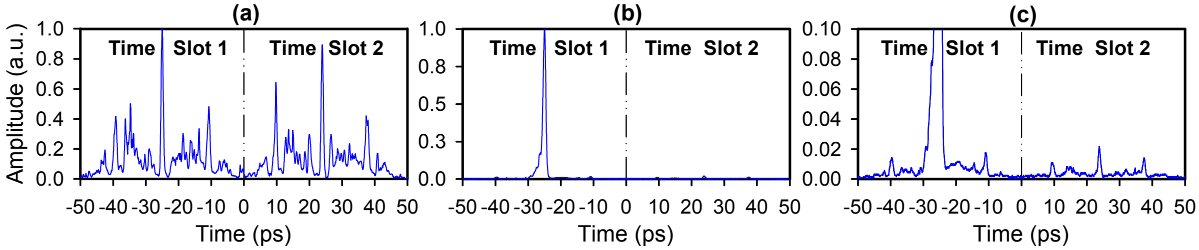

Fig. 2. Cross-correlation measurements of the combined sixteen users. (a) Input to NOLM. (b) Output of NOLM. (c) Scaled view of (b) showing the residual MUI signals. Reference pulse width is 0.5 ps.

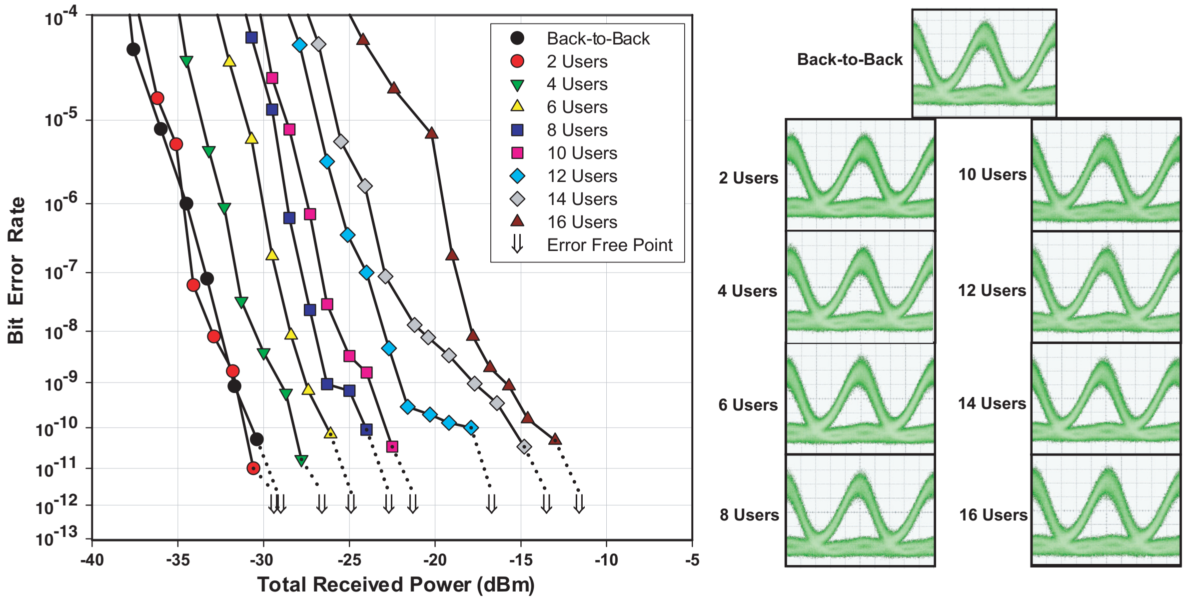

Fig. 3. BER statistics of SPECTS O-CDMA testbed for 2 to 16 users at 10 Gb/s/user, and corresponding eye diagrams.

encoders or the decoder in the testbed. In the two-user case, only Encoder 1 and the decoder are present in the testbed (one user in each time slot). For successive curves, one decoder is added to bring in another pair of interfering users. For up to 16 users, the testbed performs error free while detecting more than 10^{12} bits. The arrows at the end of each curve indicate the minimum power levels for error-free operation. They are also the power levels where the corresponding eye diagrams shown on the right side are taken. Power sharing in the DC-EDFAs after the 8:1 combiner causes a 3-dB power penalty for each doubling of the number of users. The additional power penalties are mostly caused by MUI, both the user-interferer and the interferer-interferer type. This is especially true for large numbers of users since the coherent interference between interferers can briefly result in high peak powers. This additional power penalty is apparent when looking at the curves for 10 to 12, 12 to 14, or 14 to 16 users. They exhibit 2-dB power penalties (BER $= 10^{-8}$) on top of the expected penalties obtained from DC-EDFA power sharing.

4. Conclusion

We have presented error-free performance for a 16×10-Gb/s synchronous time-slotted SPECTS O-CDMA network testbed without the assistance of FEC. This is the highest throughput reported to date for any spectral phase encoding O-CDMA network. In this testbed, an O-CDMA receiver combines nonlinear thresholding and a NOLM time gate to time-demultiplex the signal and also successfully suppress MUI.

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