An Error-Free 100 Gb/s Time-Slotted SPECTS O-CDMA Network Testbed

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Abstract *A time-slotted SPECTS O-CDMA network testbed incorporating a NOLM time gate and a nonlinear fiber-based thresholder is demonstrated with error-free performance for up to 10 users distributed in two time slots at 10 Gb/s/user.*

Introduction

Optical Code Division Multiple Access (O-CDMA) is attracting growing interest with its promising advantages in local access networks [1,2]. In this paper, we present the performance of a synchronous, 10-user O-CDMA network testbed using the spectral phase encoded time spreading (SPECTS) technique [1] for encoding and decoding. In this method, a zero-dispersion pulse shaper encodes optical pulses in the spectral domain by applying a 0 or π phase shift on individual spectral components with a liquid-crystal spatial light phase modulator (LC-SLPM), according to a unique binary code. The encoded pulses are spread in time and can be reconstructed by the decoding pulse shaper, which uses the conjugate phase code. The phase code used by each user is chosen from a quasi-orthogonal code group, so that pulses from unintended users (interferers) are incorrectly decoded and remain spread in time. However, the integrated pulse energy for a spread pulse is the same as a correctly decoded short pulse, and a nonlinear thresholding receiver becomes necessary in O-CDMA systems.

To increase spectral efficiency in the SPECTS O-CDMA network, we introduce time-slotted operation [3,4] by assigning each user a time slot in addition to a unique phase code. Additionally, time-slotted O-CDMA networks allow code sharing among users in different time slots. In the O-CDMA receiver a nonlinear optical loop mirror (NOLM), acting as a time gate, is needed to select the desired time slot. The short time gate also suppresses a majority of incorrectly decoded user signals, also known as multi-user interference (MUI).

Experimental Setup

Fig. 1 shows the system diagram of the time-slotted, 10-user SPECTS O-CDMA network testbed. The laser source includes a modelocked fiber laser, an erbium doped fiber amplifier (EDFA) and a fiber-based pulse compressor. It generates 500-fs optical pulses centered at 1550 nm with a repetition rate of 9.95328 Gb/s (OC-192). After data modulation, the 10-Gb/s signal is time-multiplexed into two time slots, each 50-ps wide. The time-multiplexed signal is split into five spatially separate streams, and each feeds an individual encoder. Each encoder encodes both time slots with the same code (two users). A unique 64-chip Walsh code is used by each encoder to minimize the coherent MUI within each time slot. Specifically, Walsh (Hadamard) codes 5, 16, 40, 54, 1 (as defined in MATLAB®) are used on Encoders 1-5, respectively. The encoded data streams are combined, amplified and then sent through the decoder. The Walsh code used by the decoder is conjugate to that on Encoder 1, so that the two users (both time slots) from Encoder 1 get correctly decoded while the other eight users are incorrectly decoded and act as interferers.

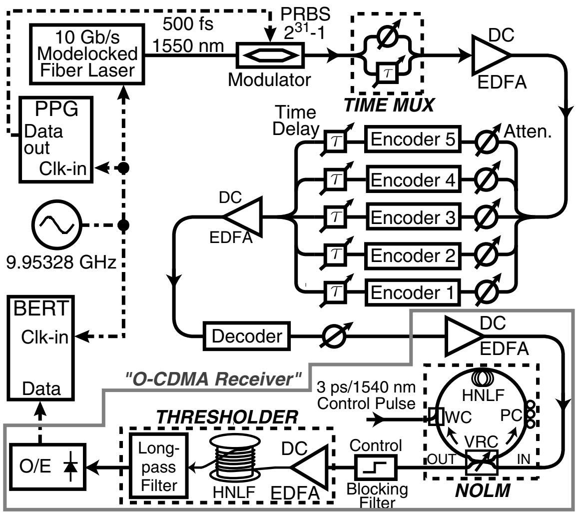

Fig. 1. 10-user SPECTS O-CDMA network testbed

The output of the decoder goes to the NOLM, which passes only the center portion of one time slot. The width of the time gate and its timing are set by the control pulses going into the NOLM. The control pulses consist of a 10-Gb/s stream of 3-ps wide pulses centered at 1540 nm. In the NOLM, cross-phase modulation from the control pulses in the 500 m of highly nonlinear fiber (HNLF) impresses a π phase shift onto the clockwise propagating signal, passing that part of the signal to the OUT port. Another 500 m of HNLF is used in the nonlinear thresholder, which selects the intended user from the remaining interfering signals [5]. The intended user's short pulse (high peak power) generates spectral components at longer and shorter wavelengths through self-phase modulation in the HNLF of thresholder while the interferers' signals remain nearly unchanged. The longpass filter passes wavelengths greater than 1578 nm to a 10-Gb/s optical receiver which converts the output of thresholder into an electronic signal that goes to the bit-error-rate tester (BERT).

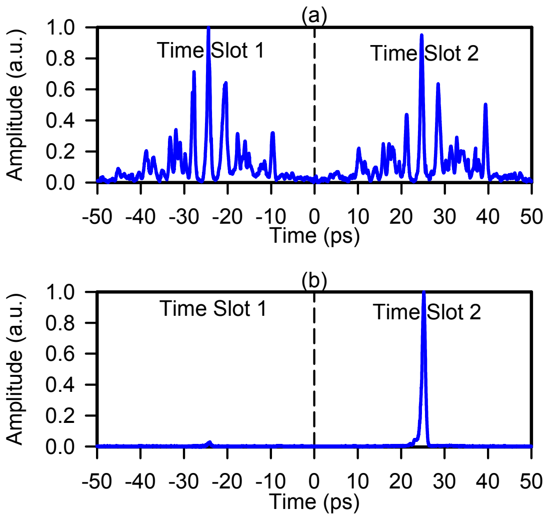

Fig. 2. Cross-correlation traces of the input (a) and output (b) signal of the NOLM time gate

Results and Discussion

Fig. 2 shows the cross-correlation traces of the combined signals from ten users distributed in two time slots, before and after passing through the NOLM. In Fig. 2(a), the high peak at the center of each time slot (i.e., ± 25 ps) is a correctly decoded user. Among both time slots, only a 3-ps wide portion around the center of time slot 2 is passed through the NOLM, as shown in Fig. 2(b). Most of the passed signal is from the intended user; however, the thresholder is still required to block the residual interferers' signals coming through the NOLM (e.g., center of time slot 1 in Fig. 2(b)).

The bit-error-rate (BER) of the testbed is taken with respect to the total received optical power at the input to the O-CDMA receiver (grey box in Fig. 1), which includes the NOLM, the thresholder and the optical-to-electrical (O/E) converter. The BER curves and corresponding eye diagrams are shown in Fig. 3. The back-to-back curve is taken while sending the time multiplexed signal directly into O-CDMA receiver, bypassing encoders and the decoder. In the two-user case, Encoder 1 and the decoder produce two correctly decoded users, one in each time slot. For each successive trace, another encoder is included, adding a pair of interfering users. In each case, the 10-Gb/s testbed remains error-free for more than 3 trillion bits ($BER<10^{-12}$). The arrows at the end of each curve indicate the minimum power required for error-free operation. This is also the power at which the eye diagrams are taken.

Significant sources of errors are burst errors due to the user-interferer, and the interferer-interferer interference. These burst errors seem to be responsible for the reduction in the slope of the BER curves for 2-10 users in the BER 10^{-7} - 10^{-8} range. Much of the power penalty associated with additional users is also related to this issue.

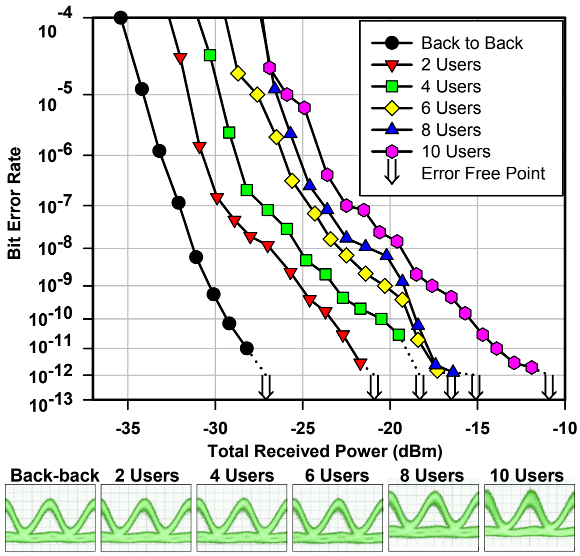

Fig. 3. BER performance of the 10 Gb/s/user SPECTS O-CDMA network testbed for up to 10 users, and corresponding eye diagrams.

Conclusion

We have demonstrated error-free performance of a SPECTS O-CDMA network testbed for up to 10 users at 10 Gb/s/user, which is the highest throughput achieved by a SPECTS O-CDMA network to date. Incorporating time-slotted operation enables code sharing among users in two different time slots and increased spectral efficiency. A NOLM time gate and a nonlinear fiber-based thresholder are employed to suppress multi-user interference.

References

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