Demonstration of a 6×10 Gb/s Multiuser Time-slotted SPECTS O-CDMA Network Testbed

Wei Cong, R. P. Scott, V. J. Hernandez, Kebin Li, B. H. Kolner, J. P. Heritage and S. J. Ben Yoo
Department of Applied Science, Department of Electrical and Computer Engineering, University of California, Davis, One Shields Avenue, Davis, California 95616
wcong@ucdavis.edu

Abstract: We demonstrate error-free performance of a six-user, 10 Gb/s/user, time-slotted SPECTS O-CDMA network testbed. Careful system engineering and a nonlinear thresholder effectively suppress multiuser interference.

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

1. Introduction

Code division multiple access (CDMA) dominates today's wireless communication networks. On the other hand, there is currently no dominant access method for optical fiber networks. Wavelength division multiple access (WDMA) and time division multiple access (TDMA) have simplicity and flexibility limitations. For this reason, optical CDMA (O-CDMA) has been drawing increasing interest in local access optical networks, because of the advantages afforded by its reconfiguration flexibility [1, 2].

In this paper, we show the first time-slotted spectral phase encoded time spreading (SPECTS) O-CDMA network testbed which accommodates up to six simultaneous, synchronous users. In SPECTS O-CDMA, signal pulses from the transmitters are phase modulated in the spectral domain using a zero-dispersion pulse shaper as originally developed by Heritage and Weiner [3]. In our version, we employ fiber coupling and a two-dimensional liquid crystal spatial light phase modulator (LC-SLPM) in reflection mode [4]. Across the spectrum of each pulse we apply a 0 or π relative phase shift associated with unique binary codes onto individual spectral components (chips). The codes are chosen from a group of orthogonal sequences so that at the receiver short pulses can be reconstructed for any individual transmitter by applying the conjugate phase code, while at the same time incorrectly decoded pulses from other transmitters remain spread in time. In our testbed, Walsh codes were chosen because the resulting spread pulses have an intensity minimum at their center, minimizing multiuser interference (MUI) in our slotted system. To reduce interference from adjacent time slots we limit the code length to 64 chips, since the amount of time spreading is proportional to the number of O-CDMA chips.

2. Testbed description

Figure 1 shows a diagram of the testbed used to simulate six simultaneous users divided into two time slots with a maximum of four users in one time slot. The 0.5-ps compressed pulses from a 10 Gb/s modelocked fiber laser are modulated with a $2^{31}-1$ pseudo-random bit sequence (PRBS), amplified using a dispersion-compensated erbium-doped fiber amplifier (DC-EDFA) and initially split into three separate paths. The two

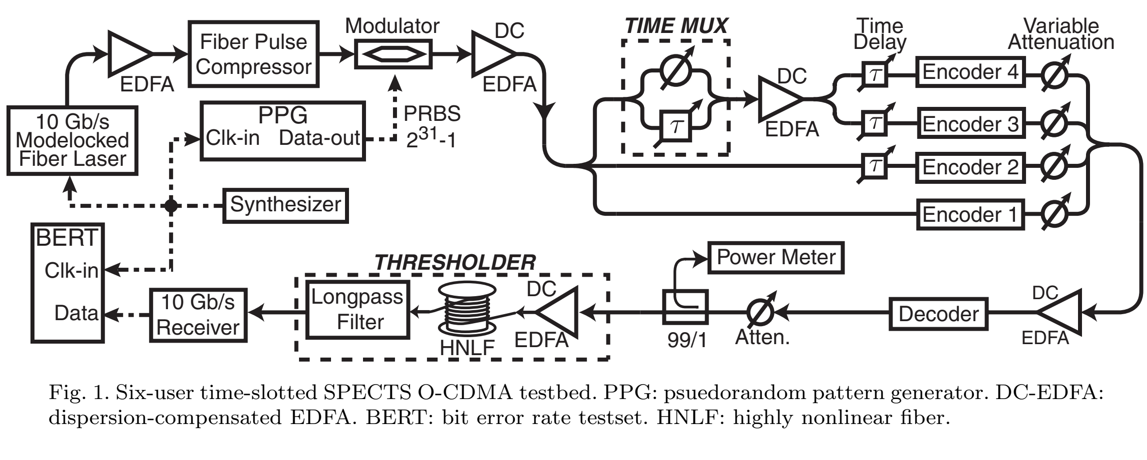

Fig. 1. Six-user time-slotted SPECTS O-CDMA testbed. PPG: psuedorandom pattern generator. DC-EDFA: dispersion-compensated EDFA. BERT: bit error rate testset. HNLF: highly nonlinear fiber.

lower paths in the diagram go directly to Encoders 1 and 2, which apply the 64-chip Walsh codes across the spectrum of each data stream. The upper path is time multiplexed into a 20 Gb/s data stream and then amplified before being split again. The two resulting 20 Gb/s data streams are then encoded by Encoders 3 and 4. In this testbed, Encoder 1 is used for the correctly decoded user or "intended user" and the other encoders result in incorrectly decoded users and are termed "interfering users". Variable time delays are used to slot-align the users to subpicosecond accuracy. The six users, four in Time Slot 1 and two in Time Slot 2, are then combined and the variable attenuators are used to equalize each user's power after the combiner. A DC-EDFA is used after the 4:1 combiner to compensate for system losses and then the Decoder applies the conjugate code to that used by Encoder 1. A highly nonlinear fiber-based thresholder is then used to select the correctly decoded user as previously described in [5]. The 99/1 splitter and power meter are used to monitor the total thresholder input power.

The testbed can be easily configured as a one to six user system, allowing for the sequential measurement of BER statistics. We do this by blocking various combinations of the encoders. For the BER data presented later in this paper, we used the following combinations: 1 user; Encoders 2–4 are blocked, 2 users; Encoders 3 and 4 are blocked, 3 users; Encoders 2 and 4 are blocked, 4 users; Encoder 3 is blocked, 5 users; Encoder 2 is blocked, 6 users; all encoders are unblocked.

3. Results and discussion

Figure 2 shows cross-correlation traces of the decoder output and it verifies O-CDMA parameters including time-slot alignment, correct time spreading and correct decoding. The reference pulse width for these traces is 500 fs. Fig. 2(a) shows the combined signals from all six users across two time slots with three interferers in Time Slot 1 and two interferers in Time Slot 2. The short pulse from the correctly decoded user can be seen at the center of Time Slot 1, and the interfering users remain spread in their respective time slots, appearing as noise-like signals along the bottom. For Fig. 2(b), we blocked Encoder 1 and one arm of the time MUX leaving three interfering users from Encoders 2–4 in Time Slot 1. This shows that the interferers do not spread into adjacent time slots. Note: no attempt was made to equalize the power of the interferers for Fig. 2(b) and since the saturated output power of the DC-EDFA following the time MUX was shared by both time slots, the interferers from Encoders 3 and 4 have twice the power of the interferer from Encoder 2 giving rise to the differing interferer amplitude profiles shown in Figs. 2(a) and 2(b).

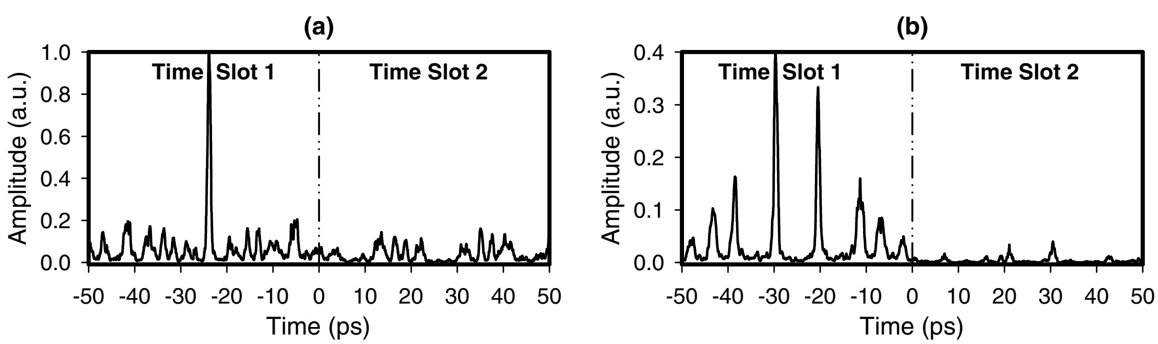

Fig. 2. Cross-correlation traces of the decoder output. (a) Four users in Time Slot 1 and two users in Time Slot 2. (b) Magnified view of (a) showing just the three interfering users in Time Slot 1.

The thresholder is a key component for differentiating the intended user from the interferers. The intended user's high peak-power pulses generate red-shifted spectra in the thresholder's highly nonlinear fiber (HNLF) due to self-phase modulation and other optical nonlinearities and this extra spectra is selected by a longpass filter. At the same time, the spectra of the interferers remains unchanged due to their low peak powers, and they are blocked by the filter. The measured power contrast ratio of the thresholder exceeds 20 dB between the intended user and all interferers. Operation of the thresholder is detailed in [5].

Figure 3 shows the bit error rate (BER) results of this time-slotted O-CDMA system measured versus the total received power at the thresholder. Trace A is the back-to-back measurement bypassing encoders and the decoder. Trace B is the BER curve for the intended user alone, traces C through G add 1 to 5 additional interferers, respectively. In each case, we ultimately achieve error-free performance. The arrows at the bottom of each BER curve indicate the power level at which no error is detected while collecting

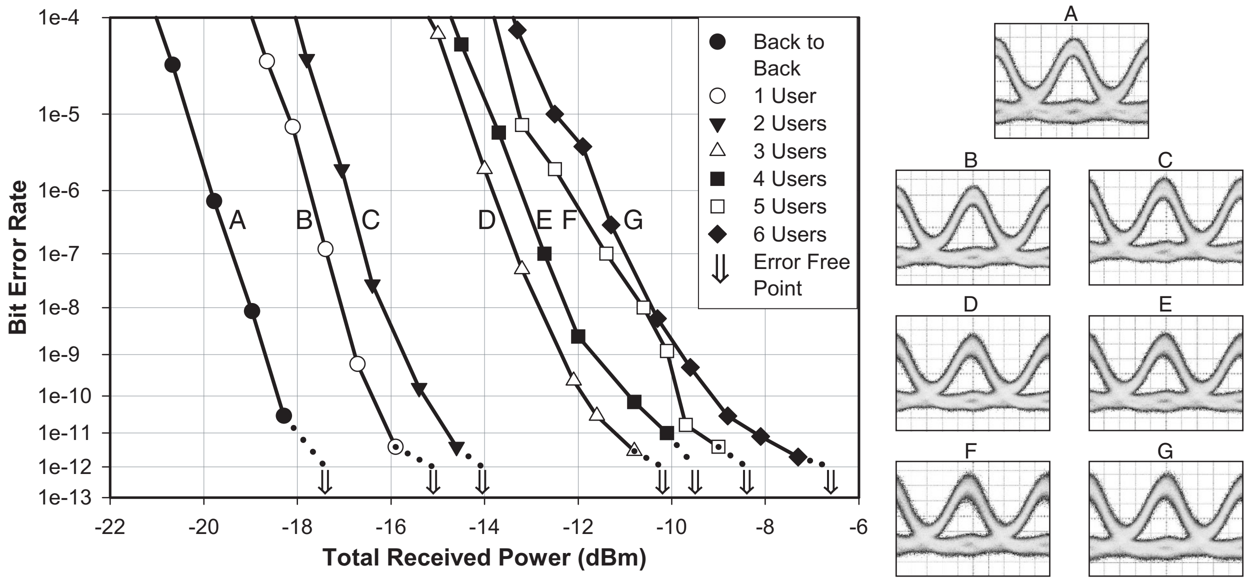

Fig. 3. Plot of BER statistics showing the change in system performance with an increasing number of users, each at 10 Gb/s. The total received power is measured at the thresholder input and the minimum power for error-free operation is indicated by an arrow. Corresponding eye diagrams are shown at right.

more than 3×10^{12} bits (BER $< 10^{-12}$). The corresponding eye diagrams are shown on the right-hand side of Fig. 3. The 3-dB power penalty between the back-to-back BER curve and one-user curve is due to pulse broadening in the encoder-decoder setup caused by residual dispersion and spectral filtering. During the BER measurement, the total input power to the thresholder increases with each additional user since all users have the same average power, but only the intended user's signal is of value. This normally appears as a 3-dB power penalty for each doubling in the number of users. However, there are other factors to consider. First, the thresholder EDFA is operated in saturation for these measurements and its output power is shared by all of the users. We simulate an adaptive system by adjusting the thresholder EDFA's output power to compensate for changes in the number of users. i.e., to keep the intended user's peak power approximately constant into the HNLF, the EDFA output power is increased by 3 dB for each doubling in the number of users. The MUI also contributes to the power penalty, but due to differences in interferer spreading by individual Walsh codes, the power penalty also varies. Finally, some users are added to the time slot without the intended user and therefore should not cause significant MUI.

4. Conclusion

We have demonstrated the error-free operation of a synchronous time-slotted SPECTS O-CDMA system, which accommodates up to six simultaneous users in two time slots operating at 10 Gb/s/user. Using time-slotted O-CDMA achieves cardinality beyond the number of spectrum chips, which is the limit of the traditional SPECTS O-CDMA.

References

1. H. P. Sardesai, C. C. Chang and A. M. Weiner, "A femtosecond code-division multiple-access communication system test bed," J. Lightwave Technol. **16**(11), 1953–64 (1998).
2. A. Stok and E. H. Sargent, "The role of optical CDMA in access networks," IEEE Commun. Mag. **40**(9), 83–7 (2002).
3. J. P. Heritage, A. M. Weiner and R. N. Thurston, "Picosecond pulse shaping by spectral phase and amplitude manipulation," Opt. Lett. **10**(12), 609–11 (1985).
4. J. C. Vaughan, T. Feurer and K. A. Nelson, "Automated two-dimensional femtosecond pulse shaping," J. Opt. Soc. Amer. B **19**(10), 2489–95 (2002).
5. R. P. Scott, W. Cong, K. Li, V. J. Hernandez, J. P. Heritage, B. H. Kolner and S. J. Ben Yoo, "Demonstration of an error-free 4×10 Gb/s multiuser SPECTS O-CDMA network testbed," IEEE Photon. Technol. Lett. **16**(9), 2186–88 (2004).

This work was supported in part by DARPA and SPAWAR under agreement N66001-02-1-8937 and by the AFOSR through the UC Davis Center for Digital Security.