A Synchronous O-CDMA System Incorporating UNI-based Time Gating

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Abstract: We demonstrate a synchronous O-CDMA system, adding an ultrafast nonlinear interferometer time gate to double system capacity from three to six users while using only three encoders. The system achieves error-free performance at 10 Gb/s/user for six users.

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1. Introduction

Optical code division multiple access (O-CDMA) is of interest in local access networks since it provides flexible bandwidth access without being limited by the fixed wavelength or time slot restrictions of WDM/TDM systems. The maximum number of users in an O-CDMA system are determined by the cardinality of the code set, but demonstrations [1] show that the multi-user interference (MUI) arising from improperly decoded signals limits the number of users long before the system capacity reaches the code set size. For improved system performance, we have recently investigated synchronous O-CDMA systems [2]. These schemes employ specialized codes (such as Walsh codes) that temporally displace MUI away from the energy of the correctly decoded signal, thereby greatly reducing the impact of coherent interference. Additionally, synchronized O-CDMA allows code sharing among users as long as they do not transmit simultaneously, thereby allowing a system to support more users beyond the code set size. Thus, despite the added complexity, synchronous systems have the advantage over simpler asynchronous systems through improved performance and increased user capacity. This paper demonstrates an O-CDMA system that uses synchronized transmission to increase the user capacity. A key technology in its implementation is time gating, which selects between users that transmit with the same code, but at different times. To this end, the system employs an ultrafast nonlinear interferometer (UNI) [3]. Successful integration of the UNI-based time gate allows a 10-Gb/s three-user system to support up to six users while maintaining error-free operation.

2. System Description

For the synchronous O-CDMA system, we use an encoding/decoding scheme called spectral phase encoded time spreading (SPECTS) [4]. Fig. 1(b) illustrates the general setup for an encoder and decoder, as implemented in bulk optics with fiber coupled pigtails. The spectrum of a femtosecond pulse is spatially spread using a diffraction grating and a spatial light phase modulator (SLPM) applies 0 or π phase shift to different portions of the spectrum (chips). Upon recombination with a second diffraction grating, an encoded pulse spreads out in time and falls in peak amplitude, appearing as a pseudo-noise burst. For decoding, the SLPM applies the conjugate of the encoder's phase code. This will cause a pseudo-noise burst to reconstruct into the original pulse. If the code does not match, the decoded pulse is incorrectly decoded and remains as a pseudo-noise burst. These encoders are placed in the SPECTS O-CDMA testbed shown in Fig. 1(a). The system distributes a single ultrashort pulse stream to three encoders that are subsequently combined and sent into a single decoder. The single decoder matches one of the encoders and thus produces a correctly decoded pulse stream and two improperly decoded pseudo-noise bursts from the other encoders. Although these noise bursts spread out in time much more than the correctly decoded pulse, they are usually too short to be differentiated using standard telecom receivers. For this reason, a nonlinear thresholder is used to suppress the incorrectly decoded pulses. With three encoders, the system nominally supports three users. Adding time delays, the time multiplexer (mux) and the UNI time gate increase the system capacity to six users without having to add more encoders.

Fig. 1(c) illustrates the operation of the UNI time gate. The input signal to the UNI is linearly polarized and it separates between a fast and slow component when launched 45^{o} with respect to the axes of a polarization-maintaining (PM) fiber. The separated components are sent to a semiconductor optical amplifier (SOA) that serves as a nonlinear medium for time gating. A control pulse coincident with the slow component of the desired signal induces cross-phase modulation inside the SOA, imparting a π phase shift onto the slow component. Following the SOA, the fast and slow components recombine using a second piece of PM fiber of identical length. This produces a linearly polarized output pulse, but its orientation will vary depending on whether the control pulse imparted the phase shift. If present, the signal is gated and the pulse rotates 90° with respect to the ungated pulse. A polarizer can then discriminate between the pulses by blocking the ungated pulses while passing the cross polarized gated pulses.

For the system in Fig. 1a, the ultrashort pulse laser consists of a mode-locked laser that generates pulses with a full width at half maximum of 2.4 ps with a 10-GHz repetition rate. These are amplified and sent into a fiber-based pulse compressor that shortens the pulse width to 430 fs. The pulses are on-off keyed using a Mach-Zehnder modulator with a 10-Gb/s 2^{31}-1 pseudo-random bit stream. The time mux simulates users that share the same code but transmit at a different time to avoid interference. It divides the modulated pulse stream into two 10-Gb/s transmissions, temporally displacing them by 50 ps. Additional delay worth several bit lengths (100 ps each) is added, decorrelating the PRBS between the two transmissions and allowing each to effectively contain a different PRBS. To further decorrelate the PRBS, each encoder path also contains fixed delays consisting of several bit shifts. These delays are adjusted to precisely align the bits of each encoder, ensuring a synchronous system. Each encoder path also contains attenuators to equalize the power of the signals. The thresholder previously described in [2] contains an erbium-doped fiber amplifier (EDFA) that amplifies both correctly and incorrectly decoded pulses. The high peak power in a correctly decoded pulse drives self-phase modulation inside 500 m of highly nonlinear fiber (HNLF), causing the spectrum to shift to wavelengths above and below the center wavelength of the pulse. An edgepass filter selects the shifted spectra and then passes the spectra to the receiver. Incorrectly decoded pulses, with their low peak power, do not generate the shifted spectra and are thus suppressed. For the UNI, two 4.5 m spans of polarization-maintaining dispersion-shifted fiber (PM-DSF) separate and recombine the fast and slow component of the signal. This length causes the fast and slow components to separate by 6 ps. A sample of the 10 GHz ultrashort pulse laser is used for the control pulse. To ensure no crosstalk with the thresholded signal, it is wavelength converted using 1 km of dispersion shifted fiber (DSF). Similar to the thresholder, self-phase modulation in the DSF produces spectral shifting, and the component at 1540 nm is filtered through a 1 nm bandpass filter, producing a 3 ps pulse. The average optical power of this control pulse only needs to be 5 dBm as it enters the SOA, and it provides a switching window of approximately 6 ps. The average optical power of the signal pulse into the UNI is approximately -5 dBm.

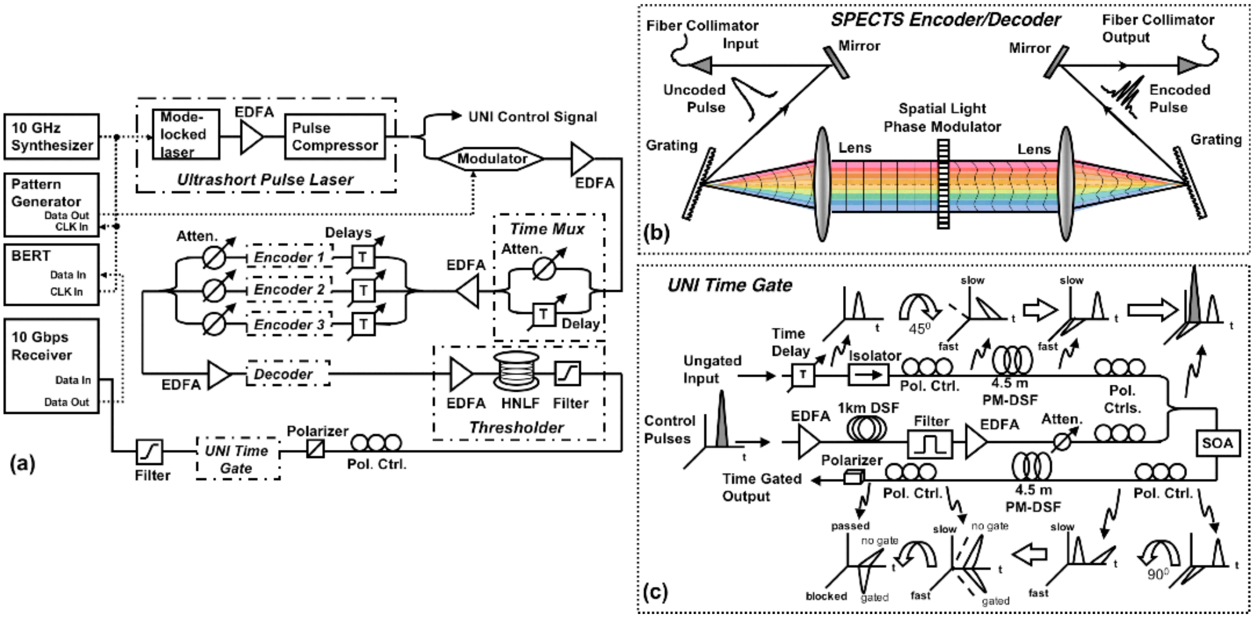

Fig. 1. Six user synchronous SPECTS O-CDMA testbed (a) featuring encoders/decoder (b) and UNI time gate (c).

3. Results and Discussion

Figure 2 shows results obtained from the system. Eye diagrams show proper time gating of the UNI (Fig. 2a), obtained using a 30 GHz oscilloscope with a horizontal scale of 50 ps/div. The input to the UNI shows two properly decoded 10 Gb/s signals transmitting 50 ps apart. The UNI gates one of the signals, and the resulting output yields a single 10 Gb/s pulse stream. Fig. 2a shows the bit-error-rates of this UNI output along with accompanying eye diagrams produced by the 10 Gb/s receiver (Fig. 2c). For the measurement, we define the receiver system to include the thresholder, the UNI time gate, and the 10 Gb/s receiver. The horizontal axis of the BER curves indicates the amount of average optical power at the input to the thresholder. The arrows at the end of each bit-error-rate curve indicates the power where BER < 10^{-12} was achieved. The back-to-back case considers the system where one of the paths in the time mux has been blocked and the array of encoders and the decoder have been removed. For the one-user case, a single encoder and decoder are added, but the mux remains blocked. The two-user case unblocks the mux, and thus “two users” refers to two 10 GHz bit streams placed 50 ps apart and sharing the same code. The four-user and six-user case each add an encoder to the system, and thus each encoder adds another pair of displaced 10 GHz bit streams that share codes. A 3 dB penalty at BER = 10^{-9} exists between the back-to-back and one user case, mostly resulting from spectral filtering due to the encoders and decoder. This causes the pulse to slightly spread out, reducing overall peak power available to the thresholder. With additional users, power sharing inside the saturated EDFA between the encoder and decoder as well as the thresholder results in additional 2 dB, 4 dB, and 7 dB penalties for the two-user, four-user, and six-user cases, respectively. In the six-user case, the accumulation of multi-user interference is large enough to generate some spectrum inside the thresholder. This added power causes the slight reduction in the BER curve slope. All cases achieve error free (BER < 10^{-12}) operation.

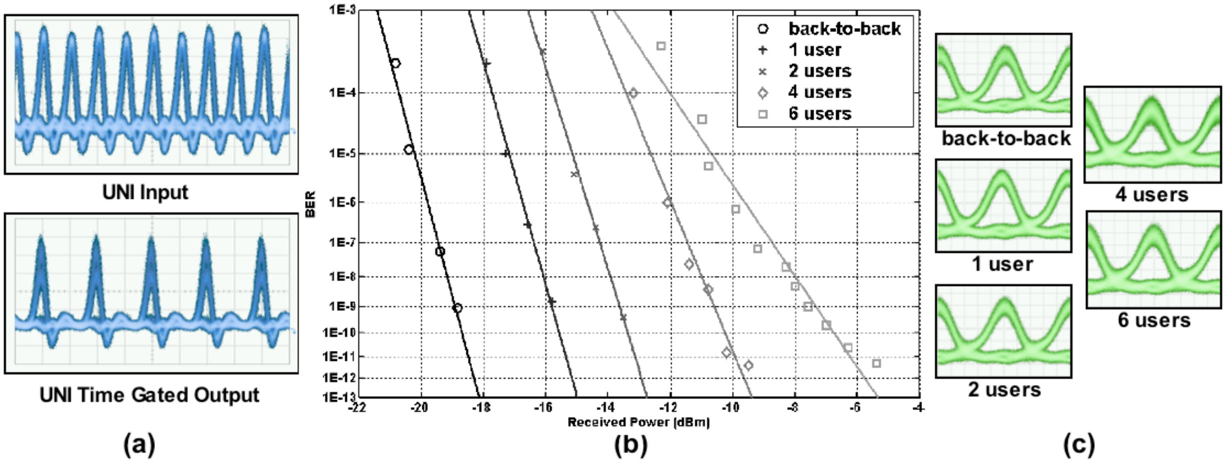

Fig. 2. Results from the O-CDMA system showing UNI input and output (a), bit-error-rate curves (b), and accompanying eye diagrams (c).

4. Conclusion

We have demonstrated a synchronous O-CDMA system incorporating time gating, thereby increasing its capacity to six users while using only three codes. With the implementation of an ultrafast non-linear interferometer, we successfully demultiplex the desired correctly decoded time slot and achieve bit error rates of less than 10^{-12} for a 10 Gb/s signal. Application of time gating to a fully realized O-CDMA system will effectively increase the number of users that can be supported by a single code set, subsequently increasing overall network capacity.

References

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