10 GHz Multiuser Optical CDMA Based on Spectral Phase Coding of Short Pulses

Wanyong Ruan*, In-Jae Won*, Jae-Hyun Park*, and Dongsun Seo*★

Abstract

We propose an ultrashort pulse optical code-division multiple-access (O-CDMA) scheme based on a pseudorandom binary M-sequence spectral phase encoding and decoding of coherent mode-locked laser pulses and perform a numerical simulation to analyze its feasibility. We demonstrate the ability to properly decode any of the multiple (eight) 10 Gbit/s users by the matched code selection of the spectral phase decoder. The peak power signal to noise ratio of properly and improperly decoded 8 x 10 Gb/s signals could be greater than 15 for 127 M-sequence coding.

Key words: Optical CDMA, Spectral phase coding, Optical pulses, Optical networks

I. Introduction

Optical code-division multiple-access (O-CDMA) is receiving increased attention due to its potential features for enhanced information security, simplified and decentralized network control, improved spectral efficiency, and increased flexibility in the granularity of bandwidth that can be provisioned [1-4]. Several different O-CDMA schemes have been reported, based on different coding and detection schemes. It generally classified incoherent (power summation) and coherent (field amplitude summation) processing. Incoherent scheme is easy to implement but shows relatively poor performance. Time-wavelength (2-D) coding schemes have been studied [5,6], where each code chip is assigned a specific time slot and wavelength slot determined by a code matrix. This scheme may utilize either coherent or incoherent sources but employ incoherent detection processing. However, the incoherent detection fundamentally induces larger multiuser access interference (MAI) and lower spectral efficiency [4]. Coherent processing based on manipulation of optical fields, which can make added code sum to be zero, can greatly suppress MAI for performance enhancement. Coherent O-CDMA employing a coherent source (mode-locked laser) and coherent processing has recent research interests, mainly due to its potentially excellent performance proved in RF (radio-frequency) OCDMA. Each spectral chip of mode-locked laser is appropriately phased coded and decoded to recover the original phase of the spectral chip. In the temporally phased coded O-CDMA, short pulses from mode-locked laser are spread directly in time, and appropriate random phases are then imposed onto different temporal chips [7,8]. The decoding (dispersion compensation and phase recovering) is achieved by superstructures fiber Bragg gratings (SSFBGs). This scheme has a potential for integration, but has poor flexibility and requires precise matching between dispersive element and SSFBG characteristics, which is difficult to achieve with fixed elements. The other scheme, spectral phase coded O-CDMA, has been studied

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significantly [3,4,9]. In the spectral phase coded O-CDMA, short pulses from a mode-locked laser are spacially dispersed in space by a grating, and a spacial phase modulator is used to apply appropriate pseudorandom phases onto different spectral chips. This results in pulse spread in time, converting the input short pulses into noise like signals. Decoding can be done using the exactly same apparatus used in encoding, noise like time spread signals spacially dispersed in space and a spacial phase modulator impose matched phases onto different spectral chips. A properly decoded signal back to in-phase and noise-like signal is converted back to the original pulse-like signal, while improperly decoded signals remain low-intensity, noise-like, temporally broad waveforms [4]. To separate out broad MAI (multiple access interference) from the pulse signal, we may use a nonlinear optical intensity discriminator to remove low power signal. This scheme has strong flexibility by using programmable spacial phase modulator, and in addition, it has a potential to be integrated by applying an arrayed waveguide grating coupled with each channel phase modulation capability. In this paper, we choose the spectral phase O-CDMA scheme and investigate numerically the performance of the spectral phase O-CDMA encoding and decoding. Some of the results are compared with experiments. We also demonstrate that eight user spectral phase encoding and decoding at 10 GHz can be easily achieved.

II. Ultrashort Pulse Source

For spectral phase coding with sufficiently large code number and chip length, we need a stable pulse source with reasonably large number of spectral lines (short pulses). For those applications, a mode-locked fiber laser (sometimes coupled with pulse compressor) is one of best candidates. Our actively mode-locked fiber laser produces stable 2.5 ps optical pulses at repetition rate of 10 GHz. It's wavelength can be tuned from 1530 nm to 1560 nm, but we normally operate at 1550 nm. To confirm the stable operation of the laser, we measured optical spectrum as shown Fig. 1, and RF(radio frequency) noise spectrum of its fast detector output as shown in Fig. 2. We can see clear spectral comb spacing 10 GHz (0.08 nm), and fully suppressed supermode beating RF noise peaks at harmonics of the cavity resonance frequency (about 20 MHz). The optical spectral with of 1.4 nm may not enough to spectral phase coding. Next we will discuss pulse compression to increase the spectral width (to use more spectral lines).

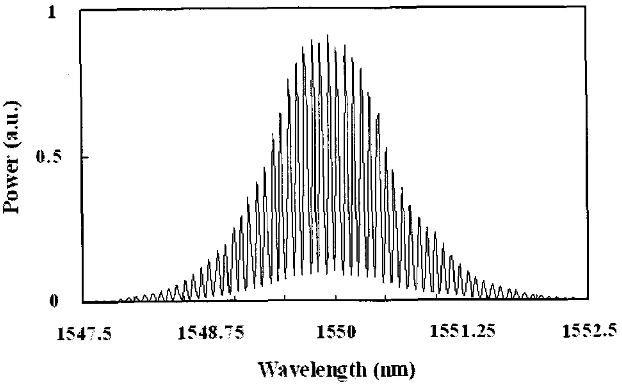


Fig. 1. Optical spectrum of the mode-locked laser showing spectral comb with 0.08 nm spacing.

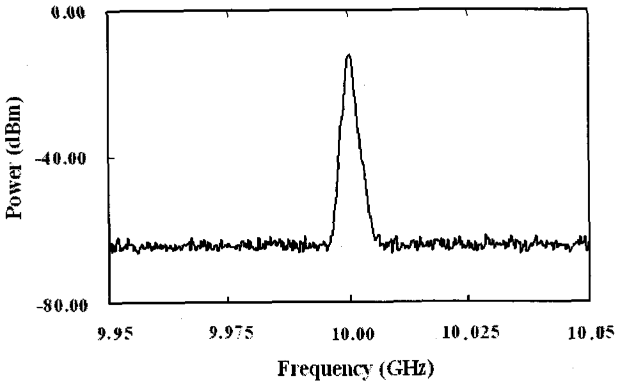


Fig. 2. RF spectrum of the mode-locked laser detected by a fast photodetector.

Pulse compressor fiber (PCF), a special designed dispersion decreasing fiber, is a low cost, passive pulse compressor to compress picosecond pulses to sub-picosecond pulses. Here we used a PCF from Calmar Optcom and produce subpicosecond pulses with low pedestal (< 3%) [10]. Optical spectrum of the pulse compressed output is shown in figure 3, showing about 6 nm spectral width. Figure 4 shows the autocorrelation trace of the compressed pulses, showing about 0.7 ps pulse width. Relative large measured pulse width is mainly caused by a 5-m single mode fiber dispersion (we expect the direct output of the PCF has about 0.5 ps width).

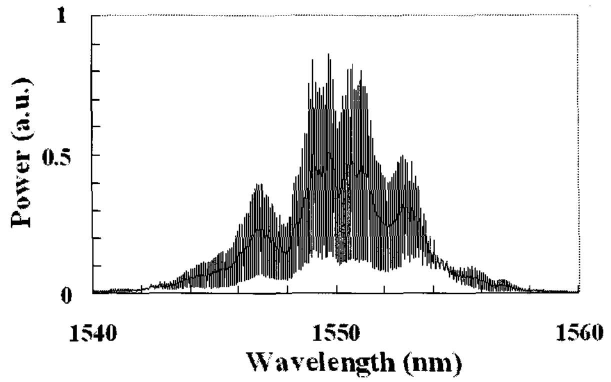


Fig. 3. Spectrum of mode-locked pulses compressed by PCF

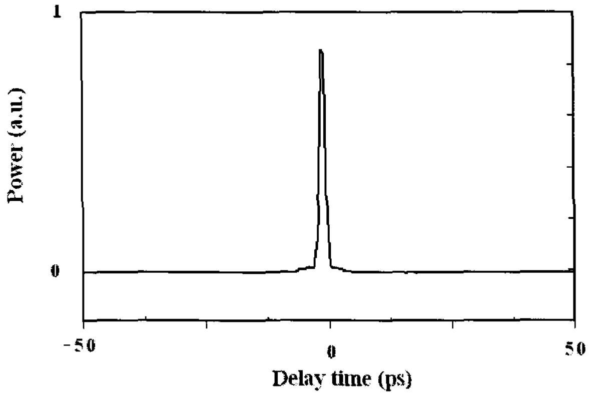


Fig. 4. Autocorrelation trace of the compressed pulses showing 0.7 ps width.

III. Numerical Simulations

We perform a numerical simulation to analyze the feasibility of our spectral phase optical CDMA encoding and decoding scheme. An M-Sequence (MS) code with binary phase shift of 0 or π is adopted in our scheme. Fig. 5 shows simulation result of encoded pulses with five different length MS code (the length of 7, 15, 31, 63, 127 bite MS code) for 5 ps short pulses. As expected, longer code length induces more spread in the time domain to show noise-like waveform. Since spread signals are noise-like, they are hard to detect, to intercept and to demodulate. Note that the peak powers of the encoded pulses for 63 and 127 MS codes are reduced to ~11% and ~7% of the original pulses, respectively. This means that the MAI can be easily removed (or compressed greatly) by an optical hard limiter.

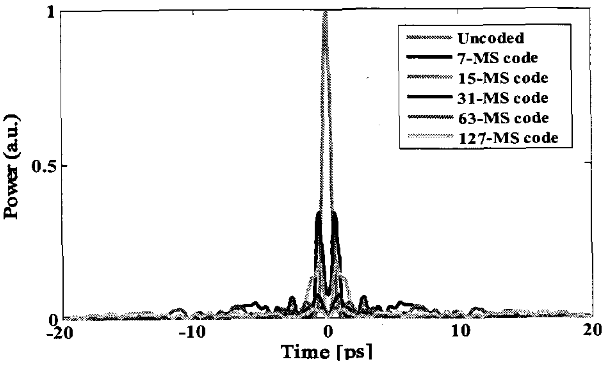


Fig. 5. Pulse spread vs. binary MS code-length.

Experimental results of the encoded pulses with corresponding lengths of MS code are shown in Fig. 6. Comparing with Fig. 5 the experimental results agree well with simulations.

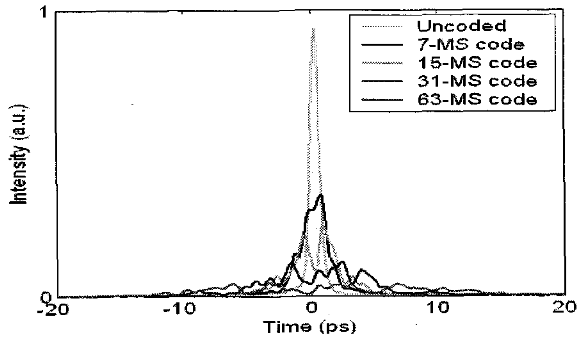


Fig. 6. Experimental result of pulse spread vs. binary MS code-length.

Next, we perform decoding and examine the results. To assure peak signal (properly coded) to MAI noise (improperly coded) power ratio greater than 10, we choose a length-127 MS code. Figs. 7 and 8 show the original pulse and encoded noise-like waveform, and the properly and improperly decoded waveforms, respectively. After decoding, the properly decoded signal is converted back to the original pulse-like signal, while improperly decoded signal remain low-intensity, noise-like, temporally broad waveform. Due to an inherent transparency of our scheme [11], the encoded (Fig. 7) and improperly decoded (Fig. 8) signals show very similar noise-like waveforms, where its peak power less than 7% of that of the properly decoded channel. The transparency also enable to use the same encoder structure as a decoder. The peak intensity contrast ratio between properly decoded and improperly decoded is around 16 which clearly illustrates the stretching of input short pulse into time-spread noise-like pulse by pseudo-random spectral phase coding. As we discussed, the noise-like MAI can be easily removed by using an optical hard limiter.

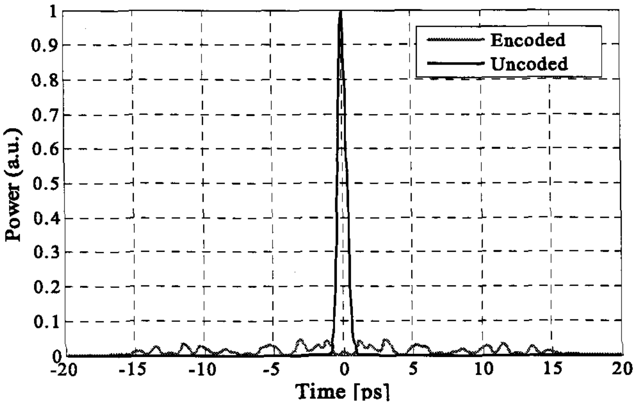


Fig. 7. Uncoded pulse and 127 MS encoded noise-like waveform.

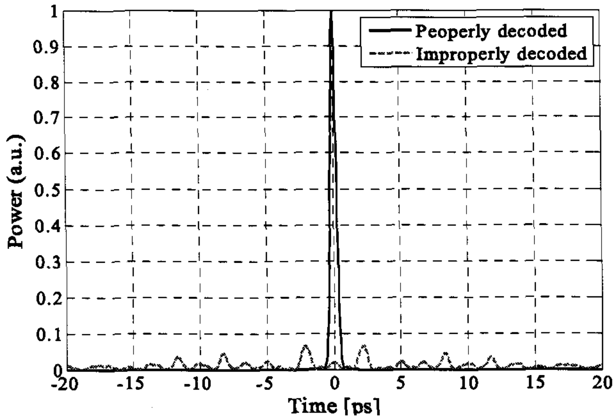
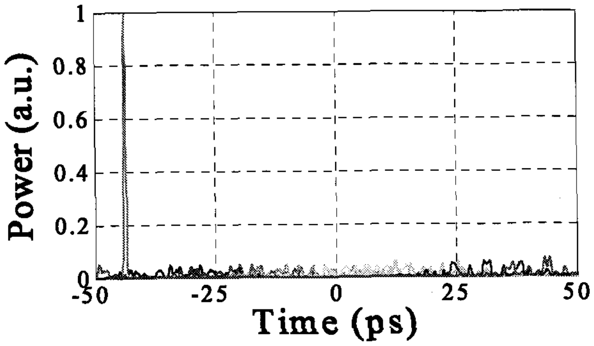


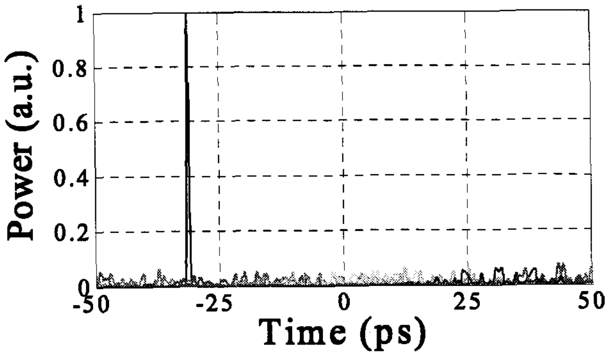
Fig. 8 Properly and improperly decoded waveforms.

IV. Multiuser OCDMA Encoding/Decoding

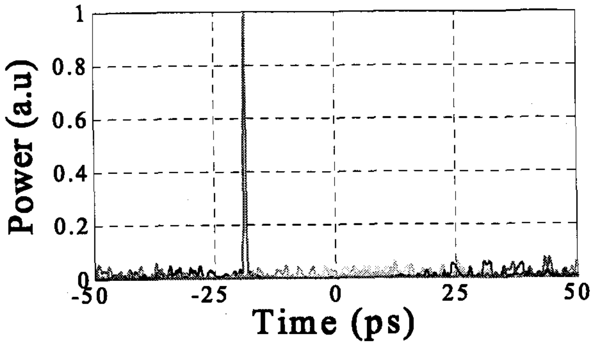
By using short pulses, as implicitly shown in Fig. 8, there are enough time space for multiple users (multiuser OCDMA). Here we have in mind eight simultaneous users at 10 Gbit/s. Since temporally overlapped user signals give more serious interference noise [4, 12], the signal from each user is roughly (equally) separated by ~12.5 ps. We set the decoder phase code to match with the encoder from one of the users #1 ~ #8. Here we take sequentially first four users as a target signal to demonstrate selective decoding capability. Fig. 9 shows the results. For an example, when the user #1 is properly decoded, the signal from user #1 is only converted back to the original pulse while other signals from seven MAI users remain low-intensity noise-like waveforms.



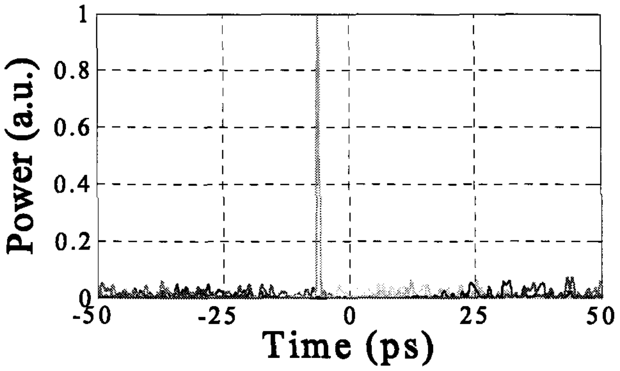
(a) User #1



(b) User #2



(c) User #3



(d) User #4

Fig. 9. Time traces of properly decoded users from #1(a) to #4(d). User #5 ~ #8 are not shown here.

V. Conclusion

We proposed a spectral phase O-CDMA encoding and decoding scheme, where each spectral line (or group) is pseudorandom phase coded and then converted back to the original phase at proper decoding. Inherent transparency of the scheme enable us to use the same coder for decoding and the encoded and the improperly decoded signals showed similar low intensity noise like waveforms. The feasibility of the scheme was proved by simulation for a multiuser O-CDMA system (8 x 10 Gb/s). The comparison between properly decoded and improperly decoded signals showed the peak power signal to noise ratio of properly and improperly decoded 8 x 10 Gb/s signals could be greater than 16 for 127 MS code. Further experimental proof is under taking.

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