Experimental demonstration of secure 16-ary, 2.5Gbit/s OCDMA using single multi-port en/decoder

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Abstract

Secure 16ary OCDMA is experimentally demonstrated by encoding four serial bits at 2.49Gbps into 16optical codes via serial-to-parallel conversion and decoding by a multiport optical encoder/decoder.

Introduction

In an M-ary transmission, a set of M code words is assigned to each user, and the different sequences of $\log_2 M$ bits of a bit stream are mapped onto different code words [1-3]. M-ary optical code division multiple access (OCDMA) uses optical code as code words, and it has prominent advantages over conventional OCDMA: improved data confidentiality and enhanced spectral efficiency. On the other hand, the number of encoders/decoders required for each user is M times larger than standard single-code OCDMA, and, to overcome this limitation, in our experiments we used a multi-port arrayed waveguide grating (AWG)-type optical encoder/decoder that can simultaneously generate as many codes as the number of its ports [4].

In this paper, secure 16-ary OCDMA is experimentally demonstrated by encoding four serial bit at 2.49 Gbit/s into 16 optical codes via serial-to-parallel conversion and decoding via parallel-to-serial conversion by using a single multi-port optical encoder/decoder. This scheme corresponds to a stream cipher that has larger confidentiality than standard OCDMA bit ciphering methods [5].

Operation principle

Figure 1 shows the architecture of 16-ary OCDMA system. At the transmitter, a serial data bit stream is segmented every four bits b_i (i=1,2,3,4) by the serial-to-parallel (SP) converter and mapped onto a code word, i.e. an optical code c_j (j=1~16) by the 16-ary 4-to-16 line coder with sixteen output ports, according to the code lookup table. Each output of this line coder generates the corresponding optical code by driving the 16 optical gate array that is connected to the 16x16-port optical encoder. Only the optical pulse train passing through the optical gate is forwarded to a designated input port of the optical encoder, and one of 16 optical codes is generated. We note that the output port number automatically determines the optical code, for a given input port number. It is also noted that the pulse repetition rate is equal to the symbol rate, i.e. the bit rate divided by $\log_2 M=4$.

At the receiver, the optical codes are sent to the 16x16 multi-port optical decoder, which has the same configuration as the encoder. An auto-correlation waveform only appears at one of the 16 output ports of the optical decoder, the output port number indicates the received optical code. The output optical pulse from the decoder is optically threshold and O/E-converted by 16ch O/E array. The output signal is launched into the 16-to-4 line decoder, and the four-bit original data sequence is regenerated after the parallel-to-serial (PS) converter using code lookup table.

The system confidentiality relies on both the optical codes and the code lookup table, i.e. the correspondence between the four-bit sequence and the optical code. An eavesdropper that is able to sift the encoded signal first has to be able to decode the optical code (physical layer security) and later has to discover the correspondence between each optical code and the sequence of four bits (electrical layer security). Therefore, an M-ary OCDMA transmission presents higher degree of confidentiality, with respect to standard two-code OCDMA systems, that cannot be broken by a differential phase shift keying (DPSK) receiver.

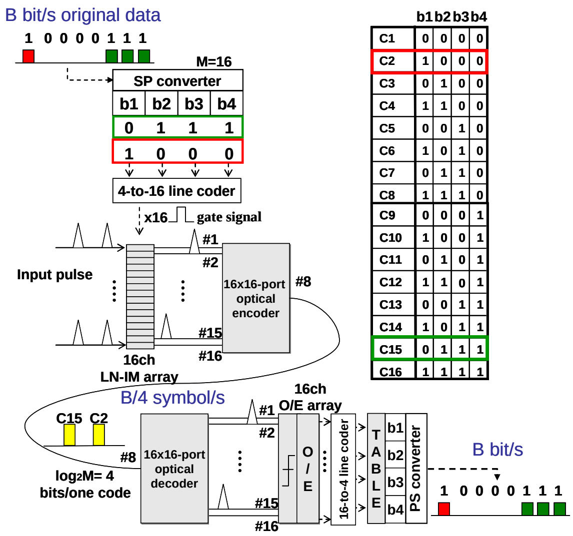

Figure 1: Architecture of 16-ary OCDMA system.

Experimental Setup

Figure 2 shows the experimental setup of 16-ary OCDMA system. At the transmitter, a pulse pattern generator (PPG) generated a fixed pattern data sequence, which includes all the code words, at 2.48832 Gbit/s (as shown in inset (i)). Each group of four bits in the data sequence is mapped onto a code word, according to the code lookup table, by the field programmable gate array (FPGA)-based 16-ary line coder. Depending on the code words, the gate signal was sent into the corresponding $LiNbO_3$ switch (LN-SW). In the optical part, we employed a super-continuum (SC) light source, which is composed of a mode-locked laser diode (MLLD), an erbium-doped fiber amplifier (EDFA), and 2-km dispersion-flattened-fiber (DFF). The MLLD at 1565 nm was driven at 9.95328 GHz (as shown in inset (ii)). The spectrum of the SC signal is shown in inset a. The SC signal was fed into an optical band-pass filter (OBPF) with 7.5 nm bandwidth at the center wavelength of 1550 nm (as shown in inset b). These pulse streams were down-converted to 622.08 MHz by the $LiNbO_3$ intensity modulator (LN-IM) (as shown in inset (iii)) and split into sixteen arms by optical couplers. Each arm is connected to a LN-SW respectively. In each LN-SW, only when the pulse arrival timing corresponded to the gate signal from the line coder, the optical pulse was sent through. Inset (iv) of Fig. 2 shows the output pulse of a LN-SW. Each output of LN-SWs was connected to a different input port of a multi-port optical encoder, which generates 500 Gchip/s, 50-chip phase shift keying optical codes. Inset (v) in Fig. 2 shows the waveform of the multi-port optical encoder output. Therefore, the optical encoder output a 16-ary, 622.08 MSymbol/s OCDM signal, with a single code word in each symbol time interval. Figure 3(a) shows the spectrum of the multi-port optical encoder output.

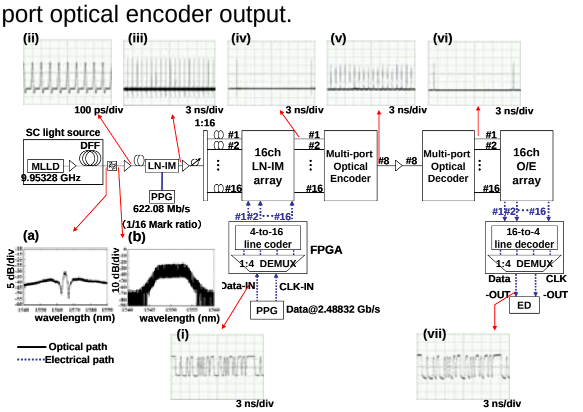

Figure 2: Experimental setup and results of 16-ary OCDMA system.

At the receiver, the 622.08 MSymbol/s OCDM signal was sent into the multi-port optical decoder. Each output port of the multi-port optical decoder generated the auto-correlation waveform corresponding to each optical code (as shown in inset (vi)). The extended auto-correlation waveform is shown in Fig. 3(b). We can also notice the small lobes due to the cross-correlation. These auto-correlation pulses were launched into sixteen photo detectors (PDs), respectively. The received signals were converted to four parallel bits according to the input port by the FPGA-based 16-ary 16-to-4 line decoder. Each four parallel bits were finally converted to the 2.48832 Gbit/s serial data by the PS converter. Inset (vii) in Fig. 2 shows the waveform of regenerated serial data, which corresponds to original serial data.

In addition, we also measured 2^7-1 pseudo-random bit sequence (PRBS) pattern generated by a PPG (as shown in Fig. 3(c)). The waveform of regenerated serial data was shown in Fig. 3(d). Finally, we measured bit error rates (BERs) of regenerated serial data in two cases. The measured BER results of 16-ary OCDMA system are shown in Fig. 3(e). In both cases, error-free transmission (BER < 10^{-9}) has been achieved. The random pattern sensitivity is better than the fixed pattern one that the reason why the random pattern is not including all the code words.

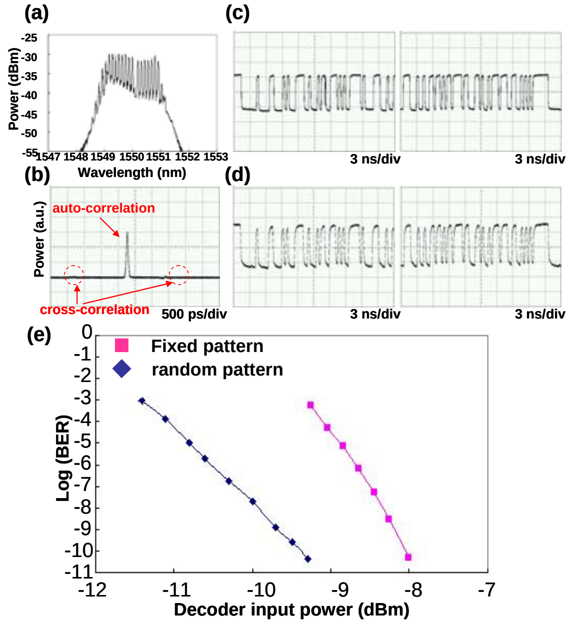

Figure 3: (a)Spectrum of the multi-port optical encoder output; (b)Waveform of the multi-port otical decoder output; (c) Waveform of original random pattern data (2^7-1 PRBS); (d) Waveform of regenerated random pattern data (2^7-1 PRBS); (e) Measured BERs (fixed and random pattern).

Conclusions

Secure 16-ary, 622MSymbol/s, coherent OCDMA transmission has been demonstrated. The capability of multiple code generation of multi-port optical en/decoder has been exploited as the key enabler. The discussions on the performance for the input random bit as well as the multiple access interference (MAI) noise, and data confidentiality will be presented on site.

References

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