Experimental Demonstration of a Hybrid 1/2-dimentional En/Decoding Optical Code Division Multiple Access System

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ABSTRACT

A hybrid 1D/2D en/decoding O-CDMA system is proposed to support multiple bit rates. To the best of our knowledge, a hybrid O-CDMA system with 2.5Gb/s (OC-16) and 155Mb/s (OC-3) transmission along the single mode fiber with length of 60km is first successfully demonstrated. In this experimental demonstration, phase coded SSFBGs with chip rate up to 320Gchip/s are applied as 1-dimensional en/decoders in 2.5Gb/s transmission while 2D en/decoders are applied in 155Mb/s real time video transmission. Error free transmission is achieved in 1D encoded 2.5Gb/s link; while 2D encoded 155Mb/s channel carrying video signal can be transmitted along the same fiber. This proposed hybrid 1D/2D en/decoding O-CDMA system can also be used for O-CDMA PONs to reduce the costs at the ONU side.

Keywords: Hybrid coding, fiber bragg grating (FBG), optical code-division-multiple-access (O-CDMA)

1. INTRODUCTION

Optical Code Division Multiple Access (O-CDMA) techniques developed rapidly in the recent decades. In the O-CDMA systems, each user is assigned with a unique signature, namely, an optical code, and the encoded data streams of all users can then be transmitted through the same medium. O-CDMA techniques can offer various advantages including the possibility of full asynchronous operation, flexible network management, and more importantly, the potential of security enhancement due to its encoding characteristics.

Various en/decoding techniques have been proposed in [2-5], among which phase coded super structured fiber bragg gratings (SSFBG) are used frequently. An SSFBG is an FBG which has a slow varying refractive index along its length [4], and can be applied as an 1-dimensional (1D) en/decoder in the O-CDMA system. 1D en/decoder based on SSFBG has the capability to generate ultra-long chip length for the optical code, thus enabling relative large number of users. On the other hand, 2-dimensional (2D) wavelength-time en/decoding techniques employing broadband ASE (Amplified Spontaneous Emission) for sources can offer relative low cost. Besides, 2D wavelength-time en/decoding techniques can also support large number of users since encoding is realized in both of wavelength and time slots domains. A typical 2D wavelength-time encoder structure made by the FBG is shown is fig.1. It consists of multiple FBGs with different reflecting wavelength (which can choose different wavelength for coding) are connected by different length of fibers (which can provide different time delay for temporal coding).

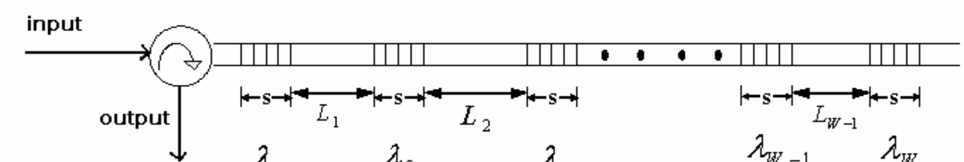

Fig. 1 Diagram of a typical 2D wavelength-time encoder.

In this paper we propose a hybrid 1D/2D en/decoding O-CDMA system supporting multiple bit rates, and to the best of our knowledge, first experimentally demonstrate the hybrid O-CDMA system with 2.5Gb/s (OC-16) and 155Mb/s (OC-

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3) transmission along the single mode fiber with the length of 60km. Error free transmission is achieved in 1D encoded 2.5Gb/s transmission, while 2D encoded 155Mb/s video transmission is also successfully demonstrated.

2. PROPOSED HYBRID O-CDMA SYSTEM

Mohammad M. Rad, et al, first proposed hybrid 1D /2D O-CDMA in order to decrease the system beat noise in O-CDMA PONs [6],. In their proposed system, 2D encoding is used in OLT, while ONU employs 1D encoding techniques. Since 1D O-CDMA system involves a relatively expensive laser source; ONUs in this scheme is not cost.-effective. Fig. 2 shows our proposed hybrid 1D/2D O-CDMA PON architecture. Coherent 1D encoders are employed at the OLT side, which provides better performance and enhanced security by employing longer optical codes compared with 2D encoders. Coherent ultra short pulse lasers, though, are needed for the 1D encoders. On the other hand, 2D encoders are used at the ONU side. As only broadband ASE sources are needed when 2D encoders are applied, the costs can be dramatically reduced. Besides, beat noise can be decreased by the usage of hybrid coherent and incoherent techniques as [6].

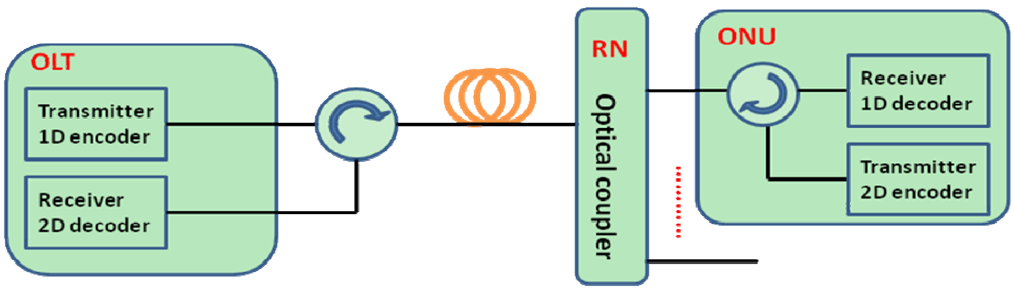
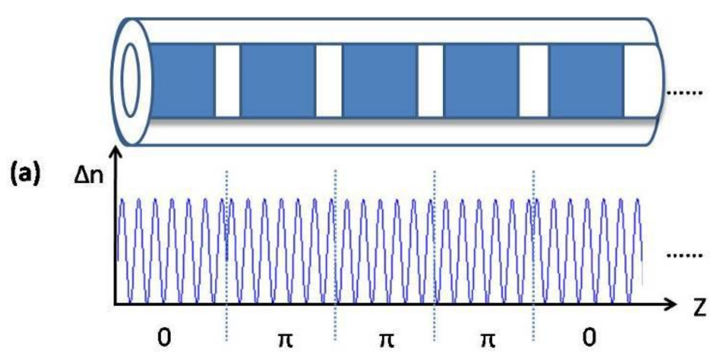


Fig. 2 Diagram of our proposed hybrid 1D/2D O-CDMA PON.

3. HYBRID 1D/2D O-CDMA EXPERIMENT

Fig. 4 shows the diagram of experimental setup of our proposed hybrid 1D/2D O-CDMA system. Phase coded super structured fiber bragg gratings (SSFBG), with the structure diagram shown in fig. 3(a), are employed as 1D en/decoders. The SSFBGs has chip length of 127, with chip rate of up to 320Gchip/s. while 2D en/decoder with 5 wavelengths and 25 time-chips is employed for 155Mb/s data transmission. For the 2.5Gb/s transmission link, the 1.76ps pulses are generated by a mode locked laser source (MLLD) with the repetition rate of 9.953GHz. These pulses, with the wavelength centered at 1552.3nm, are modulated by an electro absorption modulator to generate a 2.488GHz pulse train. Then the amplified 2.488GHz pulse train is modulated by a Mach-Zehnder intensity modulator with 2^{23}-1 pseudo random bit sequence (PRBS). The data stream is finally encoded by an SSFBG to perform 1D encoding in time domain. For the 155 Mb/s transmission link, a broadband ASE is used as the light source. The ASE source is polarized, then modulated by the output signal of the SDH add & drop multiplexer (ADM), and finally encoded by the 2D encoder. The signal from the SDH carries the real-time video collected from the camera.



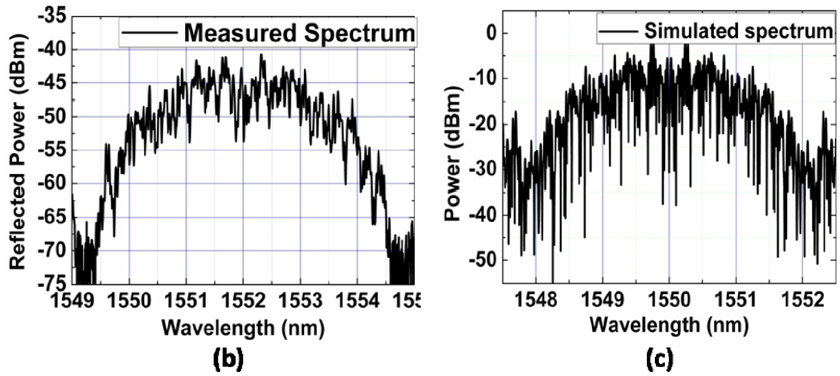


Fig. 3 Structure diagram and its reflected spectrum of a phase coded superstructured fiber bragg grating (SSFBG).

(a) Structure diagram; (b) Measured reflected spectrum; (c) Simulated reflected spectrum

The two encoded signals with data rates of 2.5Gb/s and 155Mb/s, respectively, are combined by a 3dB coupler, amplified by an EDFA, and then fed into the single mode fiber with length of 60km. A dispersion compensation fiber (DCF) module is used to compensate the dispersion of the fiber link. At the receiving part, a 3dB splitter is employed to split the signal for decoding of both 2.5Gb/s and 155Mb/s data streams.1D decoded signal is OE converted by a 10GHz photo detector. The electrical signal is amplified and filtered using an LPF and then sent to an error detector (MT1810). For the 155Mb/s link, an Optical band pass filter (OBPF) is employed to filter out the 1D spectrum. The signal is then decoded and sent to an SDH terminal. Finally, the video signal is displayed on a PC.

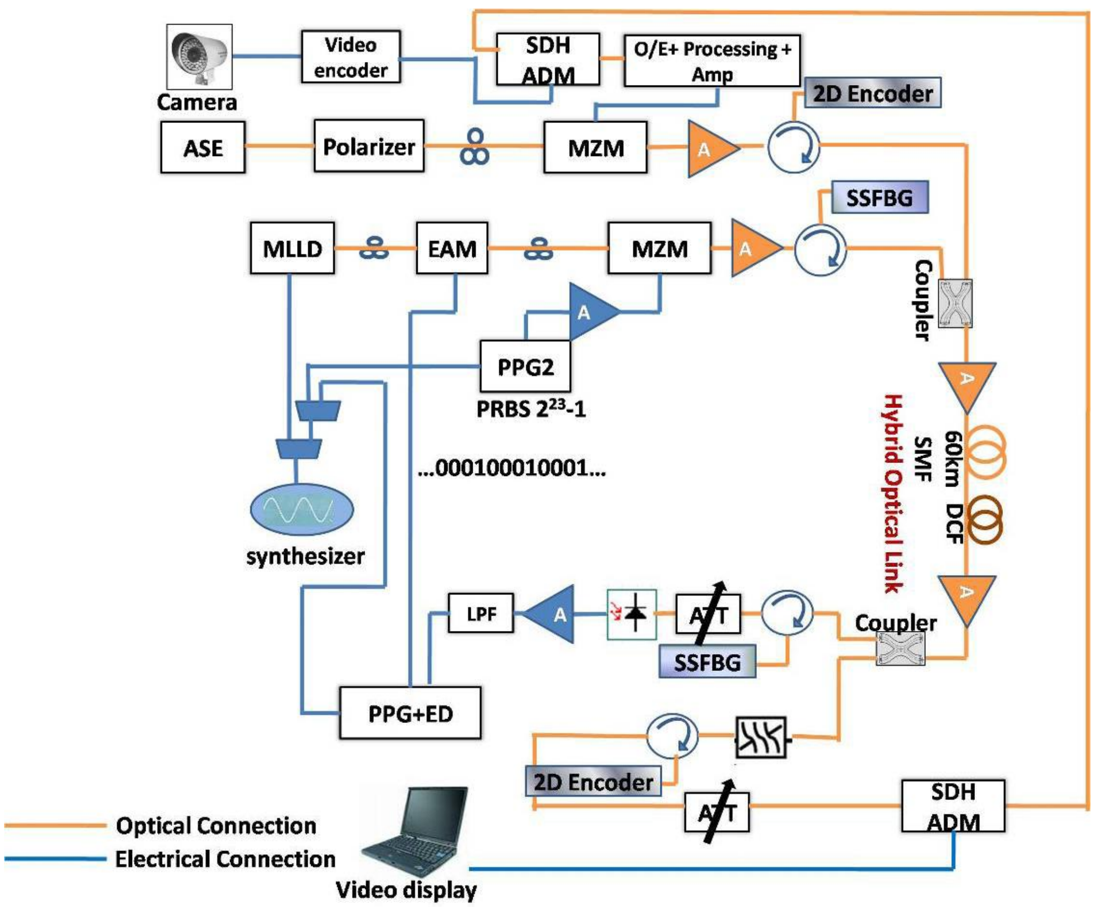


Fig. 4 Diagram of the experimental setup.

The eye diagrams of the 2.5Gb/s transmission through the 1D en/decoder based on the SSFBG are shown in fig. 5. We measured the autocorrelation trace of the output of the mode locked laser diode (MLLD). The full width at half maximum (FWHM) of the autocorrelation trace is about 1.76ps (see fig. 5(a)). It should be noted that the 9.953GHz pulse train is down-converted to be 2.488GHz by a "...00010001…" pattern to perform single pulse RZ-OOK modulation. We failed to eliminate the power at '0' bit (see fig. 5(b)) because of the voltage level of the electrical signal. This may bring some power penalty to the whole system. The eye diagrams of the encoded signal, the autocorrelation signal (matched decoding) and the cross correlation signal (mismatched decoding) are shown in fig. 5(c)-(e), respectively. The pulses are extended to the whole bit period after encoding, and the eyes are closed. It is worth noting, though, that one can still extract the data transmitted by simply using a photo detector in the transmission link when there is only one user in the system. Therefore, advanced modulation formats, as well as security enhanced encoding techniques should be employed to prevent eavesdropping. Fig. 5(d) shows a clear eye after matched decoding. Fig. 5(d)-(e) show a very good autocorrelation and cross correlation property.

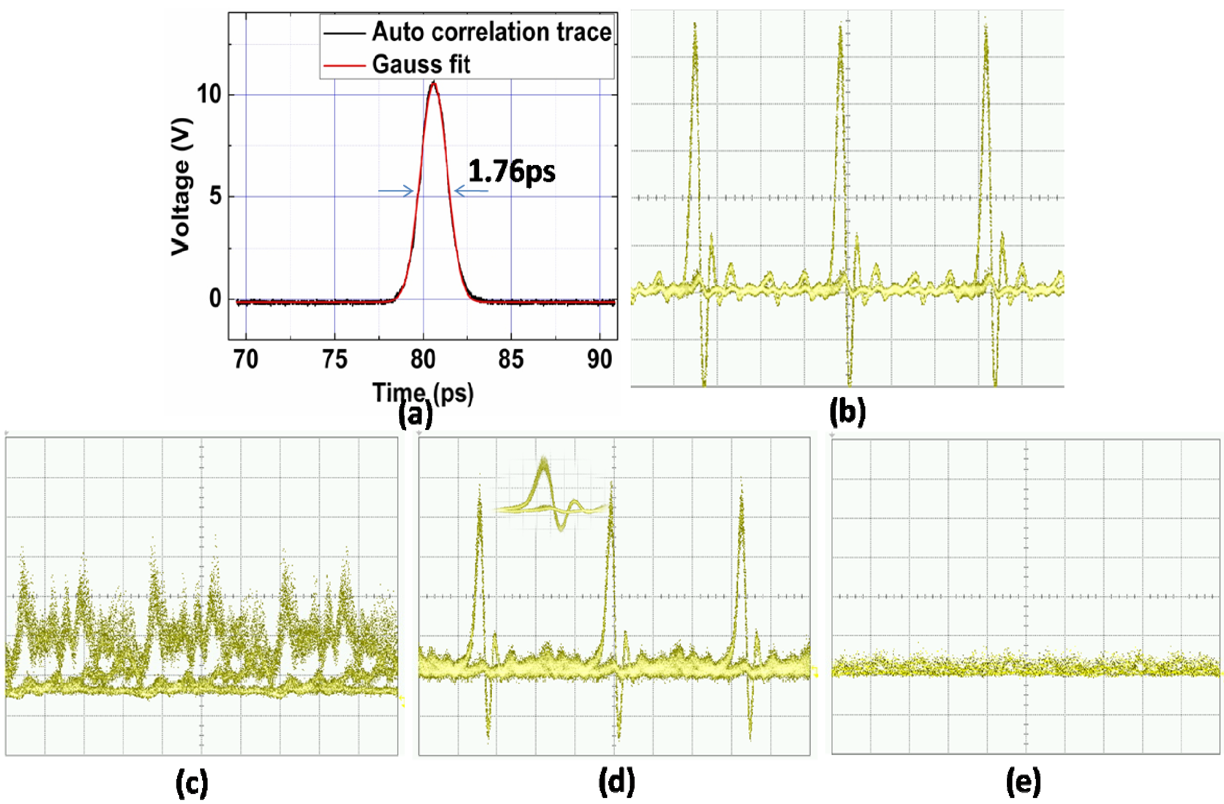


Fig. 5 Eye diagrams. (a) Autocorrelation trace of the output of the MLLD; (b) input pulse; (c) encoded signal; (d) eye diagram after matched decoding; (e) eye diagram after mismatched decoding.

The bit error ratio (BER) of the 2.5Gb/s transmission link is measured both with and without 155Mb/s link for back-to-back and 60km conditions, as shown in fig. 6. Error free transmission is achieved for all the above conditions, i.e., no error bit is observed in 1hr when the received power is tuned to >-19.7dBm (single, B2B), >-19.3dBm (single, 60km), >-18dBm (hybrid, B2B), >-17.5dBm (hybrid, 60km), respectively. From fig. 6 one can see that: a) a power penalty of about 1.9dB is observed for single link condition and a power penalty of about 0.9dB for hybrid 1D/2D condition for a BER=10E-9. b) The influence of the addition of the 155Mb/s link is very small, indicating that 1D coherent O-CDMA systems encoded via SSFBGs has a strong resilience to ASE noise. In fact, the spectra of the two links are partly overlapped, as shown in fig. 7(d), yet no filter is added in the 2.5Gb/s link. c) The measured BER results suffer from temperature fluctuation, indicating that SSFBGs are very sensitive to temperature variation. Proper packaging and temperature controlling techniques are necessary to keep the system stable. Besides, it should be noted that neither FEC nor nonlinear thresholding techniques are employed in this experiment.

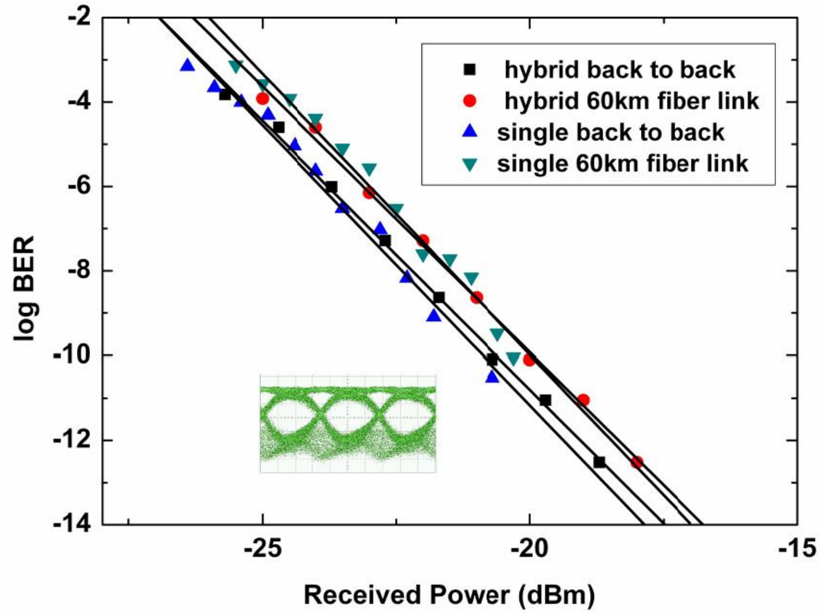


Fig. 6 Measured bit error ratio (BER) for back-to-back and 60km transmissions.

We have also successfully demonstrated the 155Mb/s real-time video transmission via 2D en/decoding techniques, shown in fig. 7. Fig. 7(a)-(c) are eye diagrams of the input data, encoded signal, and decoded electrical signal, respectively. From fig. 7 (d) and (e), one can see that the spectrum for 2.5Gb/s and 155Mb/s transmission is partly overlapped. Therefore, a filter is used before decoding to decrease the impact to the 2.5Gb/s transmission performance. Although SNR (signal to noise ratio) of the signal after matched decoding is much lower than the one before encoding, the video data can still be successfully demutiplexed and regenerated by the 155Mb/s SDH terminal equipment.

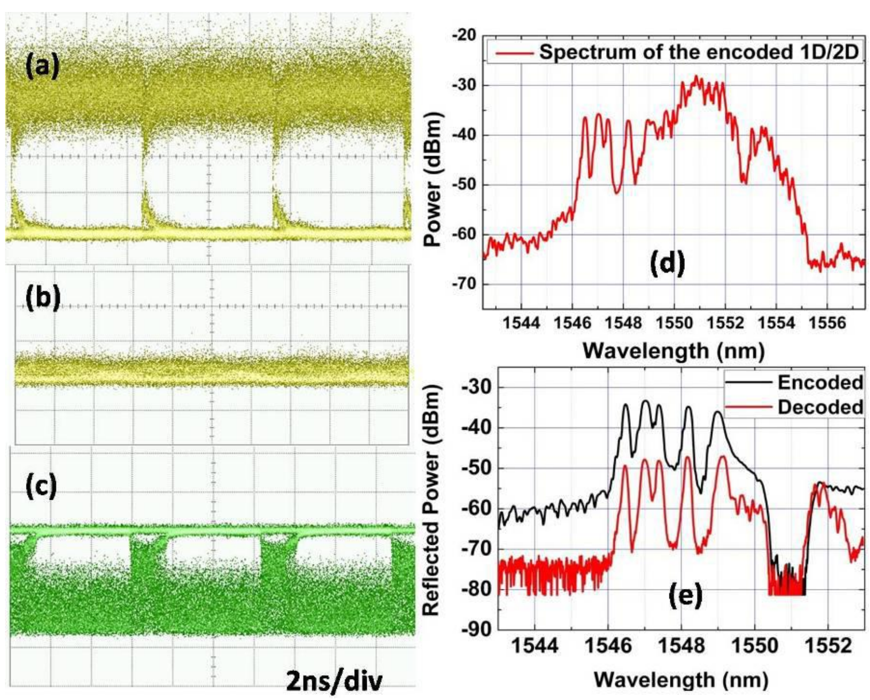


Fig. 7 Eye diagrams and measured spectra of 155Mb/s transmission. (a)eye diagram of the input signal; (b) eye diagram of the encoded signal; (c) eye diagram after PD; (d) spectrum of the encoded 1D/2D system.(e) reflected spectra of the 155Mb/s encoded and decoded signal. An optical band pass filter is added to eliminate the impact of the 1D link.

4. CONCLUSION

In this paper, we propose a novel hybrid 1D/2D en/decoding O-CDMA system supporting signals transmission of multiple bit rates, and to the best of our knowledge, first realize the corresponding experimental demonstration. Error free transmission is achieved for 2.5Gb/s 1D phase coded link, while 155Mb/s real-time video transmission via 2D en/decoding techniques is also successfully demonstrated. From the BER result, one can see that the influence of the addition of the 155Mb/s link is very small, indicating that 1D coherent O-CDMA systems encoded via SSFBGs has a strong resilience to ASE noise. The experiment results show that the multi-granularity can be well supported by the O-CDMA system, and that this hybrid en/decoding technique has a potential in building a cost effective O-CDMA PON, with strong resilience to beat noise and ASE noise.

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