Feasibility of Employing OCDMA on Passive Optical Network

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***Abstract*--We study, by computer simulation, the possibility of employing the optical code-division multiple access (OCDMA) on passive optical network (PON). When the data rate per subscriber is 1.25 Gbps, we demonstrate that the bit error rate smaller than 10^{-9} at the distance of 20 km is achieved for 4 and 8 subscribers with inline dispersion compensation.**

I. INTRODUCTION

As the growth of demands for high-speed data services increase very rapidly, time-division multiple access (TDMA) based PON may not be a converged solution for the future fiber access network due to the difficulty in bandwidth sharing among N users, the strict synchronization between optical line terminal (OLT) and optical network units (ONUs) [1], [2].

Optical code-division multiple access (OCDMA) is a multiple access scheme based on signal coding in optical domain [3]. In OCDMA, there is no time slot and bandwidth sharing between subscribers; therefore, the subscribers can access to a transmission media without contention. Currently, most of studies on OCDMA have mainly focused on only long-haul applications. Latest, 3-channel WDM, where each channel is shared by OCDMA among 10 subscribers with the total data rate for each channel is 10.71 Gbps, was successfully transmitted over 111 km with an error free [4].

According to the advantages of OCDMA, the implementation of OCDMA on PON instead of TDMA can eliminate all synchronization process between OLT and ONUs. Moreover, subscribers can access to, or receive their own data, with full capacity supported by the system.

For the first time to our knowledge, this paper reports the feasibility study of employing the OCDMA on PON for 4, 8 and 16 subscribers by computer simulations. The optical en/decoder is implemented by a programmable en/decoder without any active components. We show that a transmission of 1.25-Gbps downlink OCDMA signal over 20 km, incorporated with the optimized dispersion compensation, is achieved with bit-error rate (BER) smaller than 10^{-9} for 4 and 8 subscribers. We also show, by simulation, the maximum reach of the system at 2, 4, 8 and 16 subscribers, respectively.

II. CONFIGURATION OF OCDMA-PON

In Fig. 1, the proposed OCDMA-PON is shown with focusing on the system for supporting 16 subscribers as a representative. At OLT side, 16 optical Gaussian pulse-generators generate 2-ps-width pulses at every 800 ps (equivalent to bit period of 1.25 Gbps) with central wavelength of 1,490 nm. The number of bit sequence for simulation is 128. These narrow pulses are then intensity-modulated with 16 different electrical signals at a bit rate of 1.25 Gbps. Then, each optical signal is encoded by a programmable 511-chip gold-code bipolar phase-shifted coherent time-spreading encoder in which T_{chip} is approximately 1.67 ps [5]. Finally, all 16 encoded signals, after being delayed with different time-delays to confirm asynchronous property, will be combined by a 16×1 power combiner and fed into a standard single-mode fiber (SMF) G.652C. Before the combined signal is launched to the inline 1×16 optical splitter, a dispersion compensation fiber (DCF), with the optimal amount of dispersion cancellation, is placed. The network reach is 20 km. At the ONU side, the combined signal is decoded with a decoder that matched to each encoder in OLT. Then, each decoded signal is detected with PIN photodetector whose responsivity is 1 A/W, dark current 10 nA, and thermal noise 1.52×10^{-12} A/Hz$^{1/2}$. The low-pass filter (LPF) exhibits the Gaussian shape. The signal transmission is simulated by OptiSys 8.0.

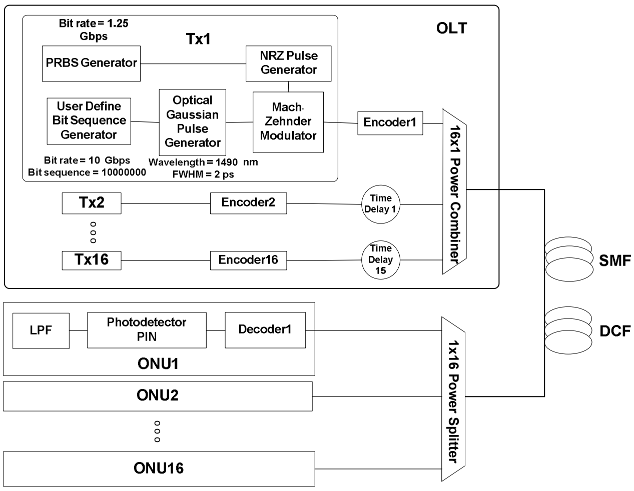

Fig.1: OCDMA-PON architecture for 16 subscribers

III. DISPERSION COMPENSATION

Fiber dispersion is a very serious problem for OCDMA transmission even in such a short link. The dispersion value of G.652C is about 13.8 ps/nm·km at 1,490 nm. Since the chip period of the signal is only 1.67 ps; therefore, the signal pulses propagating in fiber will

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broaden 8 times of chip period every 1 km. Fig. 2 shows the numerical BER of code#2, #4, #7 and #8 versus the length of SMF. The numerical BER is calculated from the detected auto-correlation-peak (ACP), which can be interpreted as the difference between "1" and "0". Because of fiber dispersion, it is clearly seen that the BERs are degraded from the range of $10^{-20}-10^{-15}$ to 10^{-3} after propagating along the fiber for a distance less than 1.4 km. However, when a 260-m of slope-compensated DCF with the optimal amount of dispersion compensation of -1048.6 ps/nm·km when the dispersion slope is -4.8 ps/nm^2 ·km at 1,490 nm. As shown by Fig.2, the BER, at distance of 20 km, significantly reduces to a range of $10^{-12}-10^{-8}$.

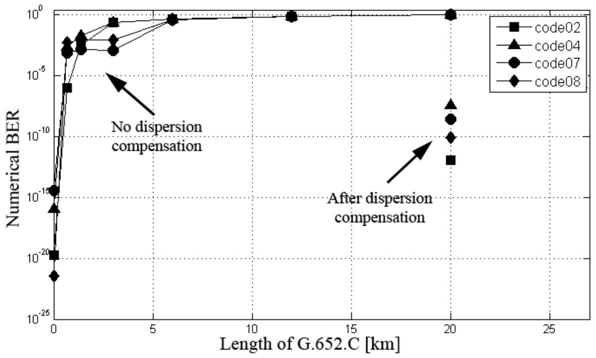

Fig. 2: Degradation of BER with distance due to dispersion, comparing to BER after being dispersion compensated when distance is 20 km.

IV. OCDMA SIGNAL TRANSMISSION OVER PON

A. 4 Subscribers

In this case, we use different 4 OCDMA transmitters and 4 encoders at OLT side. Four different coded optical signals are combined and fed into the fiber. The split ratio in this case is 1:4. Fig. 3(a) shows three eye diagrams, obtained as the superposition of ACPs, of signal using code#3 with different bandwidths (unlimited, 20 GHz, and 10 GHz) of LPF. The transmitted power is 10 dBm. The average ACP is -5.85, -14.09 and -16.78 dBm, respectively. When the LPF with unlimited bandwidth is used, most of frequency components of ACP can enter to the receiver, we almost obtain the 2-ps pulses with high peak as the original input pulses. On the other hand, when we reduce the bandwidth of LPF to 20 GHz and 10 GHz, the LPF rejects all frequency components beyond the bandwidths, the signal power is filtered out, resulting in low ACP.

As shown in Fig. 3(a), the eye openings are relatively large, and the sidebands are very low, indicating the great correlation property of en/decoder. As a result, BERs of signals in Fig. 3(a) are 10^{-104}, 10^{-32} and 10^{-16} respectively. Furthermore, the result mentions that when the LPF with large bandwidth is used, we can achieve high ACP as well as small BER. However, the larger bandwidth of LPF, the higher cost of receiver that we have to sacrifice due to the increase in its complexity, as well as its necessity of high-speed response, in signal processing on electrical-domain.

B. 8 Subscribers

In this case, 8x1.25 Gbps for 8 different users are encoded and multiplexed together along the fiber. Fig. 3(b) shows the eye diagrams of signal using code#3 with the transmitted power of 10 dBm. In comparison to the case of 4 subscribers at identical bandwidths of LPF, the average ACP are -11.55, -19.59 and -22.37 dBm, which are smaller than the case of 4 subscribers because of higher split ratio and more severe multiple access interference (MAI) noise. As a result, the BERs of signals in Fig. 3(b) are 10^{-16}, 10^{-9}, and 10^{-6}, for the unlimited, 20-GHz, and 10-GHz bandwidths of LPF, respectively.

C. 16 Subscribers

In this case, the configuration of OCDMA-PON for 16x1.25 Gbps transmission to 16 subscribers is the same as shown in Fig. 1. Fig. 3(c) shows three eye diagrams of signal ACPs using code#3 with the transmitted power of 10 dBm, and the bandwidths of LPF are unlimited, 20 GHz, and 10 GHz. The average ACPs, corresponding to the different bandwidths of LPF, are -16.99, -25.69, and -28.24 dBm, respectively. Since the received optical power is significantly smaller than the cases of 4 subscribers and 8 subscribers due to the highest split ratio of 16, and the MAI increases proportionally to the number of subscribers (split ratio) [3], As a result, the eye opening of all three eye diagrams shown in Fig. 3(c) are smaller than those of eye diagrams shown in Fig. 3(a), and (b). Therefore, the BERs are 10^{-4}, 10^{-3} and 10^{-2}, respectively.

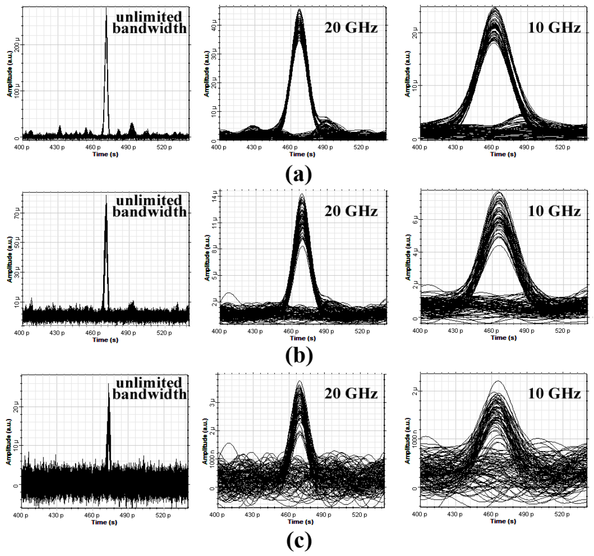

Fig. 3: Eye diagrams of detected OCDMA signal using code#3 with different bandwidth of the LPF, for the cases of (a) 4 subscribers, (b) 8 subscribers, and (c) 16 subscribers.

Fig. 4 illustrates the relationship between the numerical BER, obtained from 4 selected codes (code#1, #3, #5 and #6), as a function of received optical power. The bandwidth of the LPF is set at unlimited. We can see that the OCDMA transmission at the BER less than 10^{-9} is achieved for the case of 4 and 8 subscribers only with the approximately received optical power of -37.8 and -33.2 dBm, respectively.

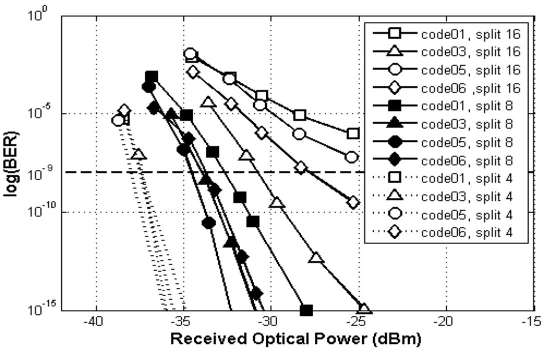

Fig. 4: Numerical BER of all decoded signals from the cases of 4, 8, and 16 subscribers, as a function of received power. The bandwidth of the LPF is unlimited.

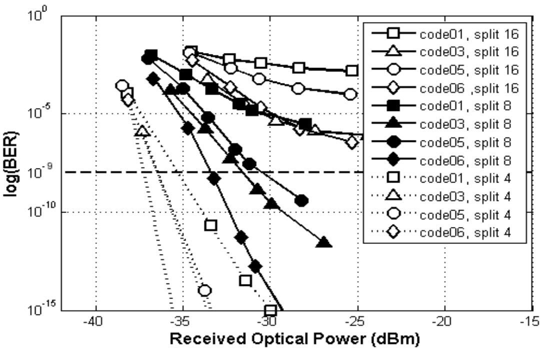

Fig. 5: Numerical BER of all decoded signals from the case of 4 ,8 and 16 subscribers, as a function of received optical power. The bandwidth of the LPF is 20 GHz.

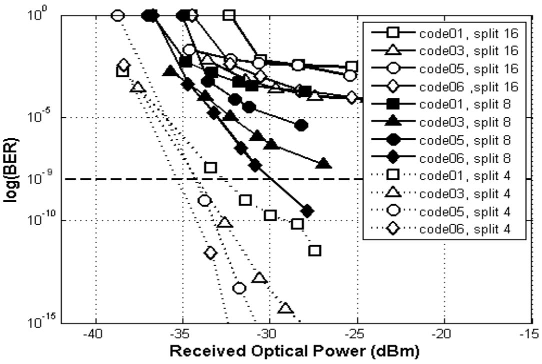

Fig. 6: Numerical BER of all decoded signals from the case of 4 ,8 and 16 subscribers, as a function of received optical power. The bandwidth of the LPF is 10 GHz.

Next we reduce the bandwidth of the LPF to 20 GHz. The numerical BER of 4 8 and 16 subscribers versus its received optical power is shown in Fig. 5. The BERs of all signals in Fig. 5 become slightly higher than those shown in Fig. 4 due to smaller bandwidth of the LPF, and lower ACPs. However, all of signal from the case of 4 subscribers still achieve BER smaller than 10^{-9}.

Finally, we further reduce the bandwidth of the LPF to 10 GHz. As shown in Fig. 6, at the same received power, the signal quality is the worst among three cases. However, all the signals for the case of 4 subscribers still can achieve BER less than 10^{-9}, while the BER of the other 2 cases (8 and 16 subscribers) can only approach to 10^{-6} and 10^{-4}, respectively.

V. MAXIMUM REACH VS. SPLIT RATIO

In this section, we investigate the achievable distances between OLT and ONU of 2, 4, 8 and 16 subscribers OCDMA-PON at fixed transmitted powers of 4 and 10 dBm under the condition that all subscribers must receive their signal with BER less than 10^{-9}. Furthermore, the maximum reach is determined by the achievable transmission distance of the signal code that yields the worst BER (however not exceed 10^{-9}). The data rate per subscriber is 1.25 Gbps. Fig. 6 shows the maximum reach of the OCDMA-PON for split ratios of 1:2, 1:4, 1:8, and 16 (refers to the number of subscriber 2, 4, 8, and 16), with 3 different bandwidths (unlimited, 20 GHz, and 10 GHz) of LPF . We can observe from Fig. 6 that the use of higher transmitted power and larger bandwidth of LPF can give longer transmission distance. For example, with a transmitted power of 10 dBm and unlimited bandwidth LPF, the maximum reach of 2, 4 and 8 subscribers are 90.6, 61.5 and 21.25 km, while the use of 10-GHz LPF reduces the maximum reaches of 2 and 4 subscribers to 77 and 35.5 km, respectively.

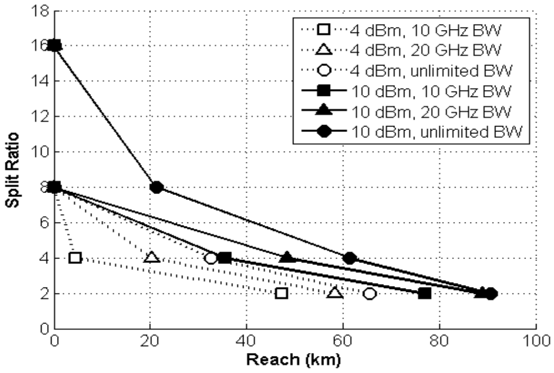

Fig. 6: Maximum reaches of OCDMA-PON for 2, 4, 8 and 16 subscribers with transmitted powers of 4 and 10 dBm, and the LPF bandwidth of unlimited, 20, and 10 GHz.

VI. CONCLUSIONS

In this paper, we have investigated, by computer simulation, the feasibility of applying OCDMA scheme incorporated with inline dispersion compensation on PON. The OCDMA signals were en/decoded in optical domain by a programmable coherent time-spreading en/decoder. The simulation results of 1.25 Gbps/subscriber OCDMA-PON have shown that, at BER = 10^{-9}, the maximum reaches of OCDMA-PON were, respectively, around 90.6, 61.5, and 21.25 km for 2, 4, and 8 subscribers; however, with the use of unlimited bandwidth of receiver LPF. The performance of the OCDMA-PON was found to be dependent of the transmitted power, the bandwidth of LPF at receiver, and the amount of MAI.

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