The Fastest Response Burst-mode Transmission Scheme Using Small Redundant Scrambler and AC-coupled Receiver with Fast Baseline Response

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Abstract: The fastest 10-nsec response with 21.5-dBm dynamic-range burst-mode transmission for 10G-PONs without any reset scheme is demonstrated using newly proposed small redundant scrambler and low-cost AC-coupled receiver. Efficient bandwidth is improved to 97% for 512-ONUs.

OCIS codes: (060.4510) Optical communications, (060.2360) Fiber optics links and subsystems, (060.4263) Networks, star

Introduction

Worldwide Internet traffic has been growing continuously, and larger bandwidth is required for access networks. Fiber-to-the-home (FTTH) is a promising solution for large-bandwidth access network services. A passive optical network (PON) is the most suitable access network architecture due to its cost effectiveness. This is because the trunk line fiber and central office equipment are shared by all users in a PON. Video distribution services have been provided on G-EPON [1], and high-resolution real-time video conference or surveillance systems will be utilized in the next step. Thus, bandwidth that is several-times larger than available in current systems will be required not only for downstream, but also for upstream traffic. Therefore, two 10G-PON standardizations are being discussed; 10G-EPON, which was standardized by IEEE [2], and XG-PON, which is being discussed in ITU-T/FSAN [3]. Both of the standardizations have 10G- symmetrical systems.

On the other hand, cost reduction is the first priority for universal access services. Sufficient bandwidth of the 10G-PONs will be available for an even lower cost per user by multiplying the number of users in a PON. However, degradation of the effective upstream bandwidth can occur by multiplying the number of users, because degradation is caused by the burst overhead length.

In this paper, we propose a novel low cost burst transmission scheme using a novel small redundant scrambler and a simple AC-coupled receiver to reduce the burst-mode receiver (BM-Rx) cost for large number of PON subscribers.

Issue of a low cost AC-coupled fast response burst-mode receiver

A fast settling BM-Rx is required to reduce the preamble length of the overhead. There are two types of BM-Rx. One is a DC-coupled receiver that controls the gain and offset of an amplifier quickly by the reset pulse input [4]. In many cases, the reset pulse is served from the media access controller (MAC) to the BM-Rx in the physical layer (PHY). Therefore, the crossing boundary between the layers of the reset signal causes timing accuracy and interoperability issues. To resolve these issues, a self-reset type receiver that has fast settling capability within 30 nsec was developed [5]. The receiver generates the reset pulse internally from consequent 0s in the discriminated signal. However, the reset pulse generation sequence has difficulty for a mis-operation by inaccurate gain setting.

In contrast, an AC-coupled BM-Rx does not require a control signal [6,7]. The AC-coupled receiver is suitable for low-cost service due to its simple circuit architecture. A fast AC-coupled receiver that can settle the baseline within 100 nsec has been reported [8]. To shorten the settling time, time-constant of a high-pass-filter (HPF) consisting the AC-coupled circuit has to be reduced. However, the fast settling capability and receiving power penalty are incompatible. Nonuniform patterns; such as long consecutive identical digits (CIDs) and/or mark-rate deflections, are converted to baseline deflections in the AC-coupled BM-Rx, and they trigger bit errors.

Low baseline deflection and low redundant line code for the AC-coupled fast burst-mode receiver

There are many line-code encoders listed in Table 1 to reduce the baseline deflection; such as scrambled NRZ, 64B66B and 8B10B. However, some problems exist on these scramblers when applied to the BM-Rx. Scrambled data using the scrambled NRZ without redundancy or the 64B66B require

Table 1. Characteristics of line codes

	Scrambled NRZ	64B66B	8B10B	**Proposed**
Baseline deflection	Not good	Not good	Excellent	**Good**
Maximum CID length	> 72	66	5	**(16)**
Rate increasing ratio	1	1.03125	1.25	**1.032**

small redundancy, however, they still have the baseline deflection. On the other hand, the 8B10B encoded data constrains bit patterns rigidly with a high redundancy. However, it requires 25 % rate increasing.

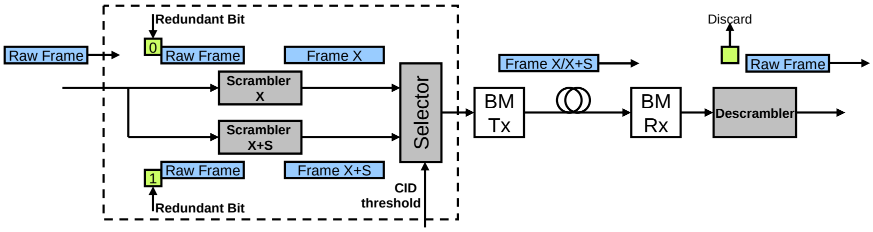

Figure 1. Configuration of the redundant scrambler and descrambler

We propose a line code with multiple scramblers as depicted in Figure 1. While line codes like 8B10B encoding make sequences satisfy predetermined constraints rigidly with a high redundancy, our scheme aims at a less occurrence of bad bit patterns with a low redundancy. In our scheme, scrambling is applied by a frame. The selector in Figure 1 evaluates maximum CID lengths and/or mark rates of the two scrambled frames and determines the better one. A redundant bit is placed in the head of a frame and indicates the selection. We can also build the scheme essentially with a single appropriate self-synchronizing scrambler, which can provide a much different bit pattern for a frame by the header bit. In this scheme, the procedure of a receiver is quite simple: descramble the sequence with the scrambler and discard the header bits.

We evaluated the deflection reduction effects of the proposed scrambler by simulation, where the frame length with the header bit is 32, and the self-synchronizing scrambler has a generator polynomial $g(x) = x^{21} + x^{19} + 1$. For the header bit 1, the sequence S = "1010 1010 1010 1010 1010 1110 1110 1110" is added to the scrambled sequence X of the frame generated with the header bit 0. The selector in Figure 1 determines the header bit in the following manner:

a) Examine the maximum CID lengths in X and $X + S$.
b) If only one of them is less than or equal to a CID threshold which is determined from the required settling time, then select the one and exit.
c) Examine mark rates of the last $(n - 1)$ frames and X or $X + S$.
d) Select the one so that the resulting mark rate is better.

By this rule, we can improve not only the number of CID longer than the threshold but also mark rates. The graph in Figure 2 shows mark rates of consecutive $n = 4$ frames for the CID threshold 12 or 16 with 10^6 frames of random input data. Figure 3 shows the probability of bit sequence which has each CID length in the selected frame. It depicts clear limitation for the maximum CID. The proposed scheme achieves better mark rates than the conventional scrambler, and the probability of occurrence is reduced by 1/100 at 12% deflection. The redundancy is only 32/31 = 1.032. The effective CID threshold was determined to be 16 through this analysis.

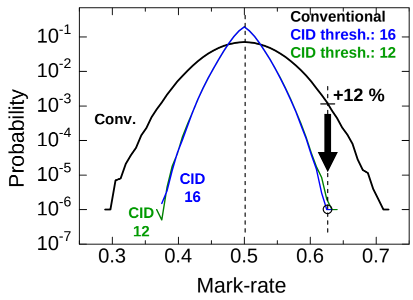

Figure 2. The deflection reducing effect by the scrambler

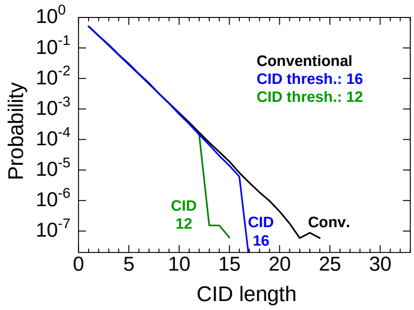

Figure 3. The maximum CID limitation effect by the scrambler

Experiment

The effect of the proposed scrambler was evaluated through experiments. Figure 4 shows a block diagram of the experimental setup. The scrambled data, which were 66 Mbit long and generated by software, were downloaded into memory in both a pulse pattern generator (PPG) and an error detector (ED). Figure 5 shows bit error rate (BER) characteristics that were measured using continuous-mode transmission. There is not only a large power penalty, but also an error floor for the conventional PRBS pattern. In particular, the forward error correction (FEC) scheme does not achieve sufficient performance for the error floor due to errors localized around baseline deflected region. In contrast, obvious improvement can be observed for the proposed scrambled signal. There is still a power penalty, however, the error

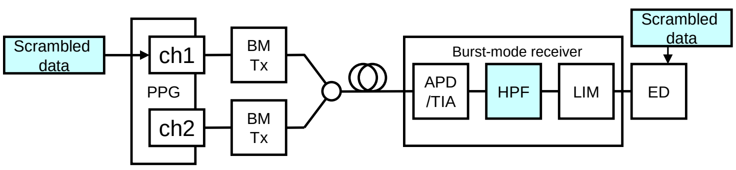

Figure 4. Block diagram of the experimental setup

floor is significantly suppressed, and the error rate monotonically decreases in proportion to the increasing power. The BER improvement also indicates that the proposed scrambler can be applied to another PON system that has a valid/invalid FEC option. A PON that has a low loss budget can select low overhead transmission without FEC.

Finally, settling time was evaluated using burst mode transmission. Figure 6 depicts the example of received waveforms after the HPF. Each 2-usec signal frame and dummy frame are alternately are received interleaving guard time for 2-nsec LD turn-off/on time. The baseline settling is indicated by the dashed line in the lower waveform. It shows that about 10-nsec preamble is sufficient to receive the signal frame. The relationship between preamble length and burst power penalty is plotted in Figure 7. The power penalty is measured at a BER of 10^{-3}, which can be improved to BER of 10^{-12} applying a high-gain FEC scheme such as RS(255,223) [2]. The preamble length can be reduced to 10 nsec with 1.5 dB power penalty from continuous-mode sensitivity which preamble length can improve the effective bandwidth to 97 % for 1:512-system. The settling speed is accelerated about ten times from previous AC-coupled receiver [8]. The receiver dynamic range is 21.5 dB due to a -6 dBm dummy burst was used for the experiment.

Summary

A novel low cost burst transmission scheme is proposed for a PON with a large number of subscribers without effective bandwidth degradation caused by burst overhead length. The transmission scheme, which is constructed from a small redundant scrambler and a simple AC-coupled BM-Rx without any reset scheme, settles in 10 nsec with 1.5 dB power penalty from conventional optical receiver using FEC scheme. The scrambler reduces the mark-rate deflection of the transmission signal to 1/1000 with a minimal increase in overhead. Therefore, the fast response AC-coupled BM-Rx is applicable to receive the scrambled signal with fast response. Through experiments, the improved bandwidth efficiency for a large number of subscribers in a PON was demonstrated using the proposed transmission scheme with 21.5-dB dynamic range. The proposed burst transmission scheme has an additional advantage. The scheme can be applied to a PON that has a low loss budget, with a selectable option for low overhead transmission without FEC.

Acknowledgement

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Reference

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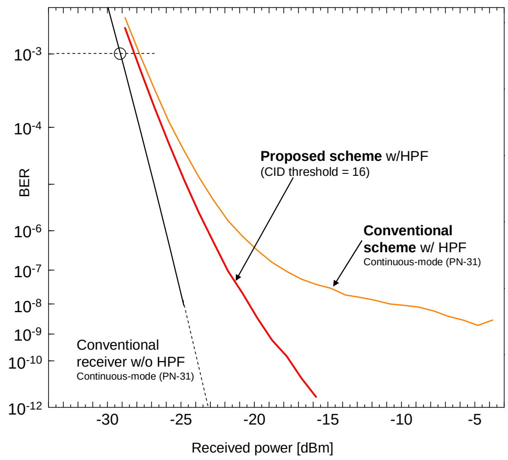

Figure 5. Bit error rate for continuous signal

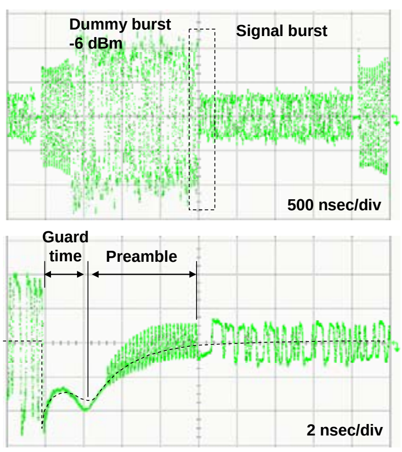

Figure 6. Example of received burst frame waveform observed after the HPF

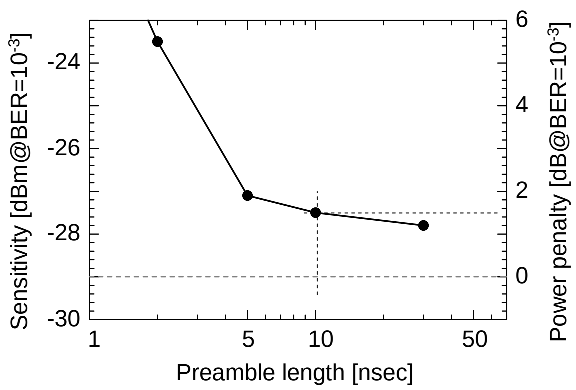

Figure 7. Burst power penalty for normal receiver sensitivity

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