

Performance Analysis for Optimizing Threshold Level Control of a Receiver in Asynchronous 2.5 Gbps/1.2 Gbps Optical Subscriber Network with Inverse Return to Zero(RZ) Coded Downstream and NRZ Upstream Re-modulation

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We propose the performance enhancing method optimization of an asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ (Return to Zero) coded downstream and NRZ (Non Return to Zero) upstream re-modulation by adjusting threshold level control of a receiver. We theoretically analyze the BER (Bit Error Rate) performance by modeling the occurrence of BER by simulation with MATLAB according to the types of downstream data. The results have shown that the normalized threshold level in an optical receiver could be saturated at 1/3 as the SNR (Signal to Noise Ratio) increases. The needed SNR for obtaining the BER 10^{-9} can be reduced by ~5 dB by optimizing the normalized threshold level at 1/3 instead of by using the conventional receiver with threshold level of 0.5. The proposed system can be a useful technology for asynchronous optical access networks with asymmetric upstream and downstream data rates, because the improved minimum receiving power could replace a light source with a source with lower power and lower cost in an OLT (Optical Line Termination).

Keywords : Fiber-to-the-home (FTTH), Optical subscriber network, Inverse return to zero code, Optical Network Unit (ONU), Optical Line Termination (OLT)

OCIS codes : (060.0060) Fiber optics and optical communications; (060.2380) Fiber optics sources and detectors; (060.2330) Fiber optics communications

I. INTRODUCTION

A present subscriber access system needs a broadband transmission link that offers interactive multimedia services such as voice, high quality video-on-demand, high speed data, and so on. Fiber-optic transmission systems such as the FTTH (Fiber-To-The-Home) have been introduced into subscriber access networks to improve the characteristics of transmission. A FTTH-based passive optical network (PON) is shown in Fig. 1, where several ONUs (Optical Network Units) are connected to an OLT (Optical Line Termination) by

using an optical fiber and a routing node (RN) [1-4].

A PON is an effective technology for an optical subscriber network because of ease of installation and low operational costs through sharing the optical fiber and an OLT. However, the conventional WDM-PON system needs complex circuits such as wavelength and power controllers. Wavelength and power controllers and light sources were removed at ONU in order to simplify the circuit and reduce the cost. The re-modulation scheme is one of the methods for removing an optical source at the ONU and the use of centralized light source at OLT. The re-modulation schemes reusing downstream light for upstream data transmission have been proposed and studied in optical access

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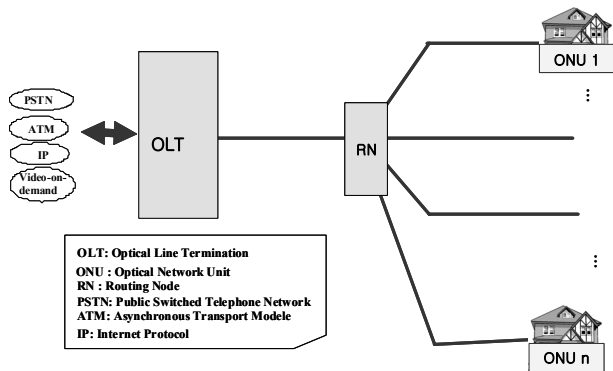


FIG. 1. FTTH-based passive optical network(PON).

networks [5-17]. There are various re-modulation schemes depending on the downstream data formats. Among many re-modulation schemes, Manchester and inverse return-to-zero (RZ) coded re-modulation schemes have been proposed in order to provide asynchronous full duplex operations [13-17].

In this paper, we propose the performance enhancing method of asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ (Non Return to Zero) upstream re-modulation by adjusting the threshold level of a receiver. We theoretically analyze BER (Bit Error Rate) performance by modeling the occurrence of BER by simulation with MATLAB according to the types of downstream data.

II. ASYNCHRONOUS 2.5 GBPS/1.25 GBPS OPTICAL SUBSCRIBER NETWORK WITH INVERSE RZ CODED DOWNSTREAM AND NRZ UPSTREAM RE-MODULATION

An asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation is shown in Fig. 2. The output of a laser diode (LD) is encoded by inverse RZ code for 2.5 Gbps downstream data using an inverse RZ code generator at the OLT, where they are converted into '01' and '11' when downstream data are '1' and '0', respectively. Downstream data modulated with inverse RZ coded downstream are shown in Fig. 3. At the ONU, the encoded light is split by a 50:50 fiber coupler. One output of the coupler is connected to a photodiode (PD) and inverse RZ coded downstream data are detected. The other output is fed into a Mach-Zehnder interferometric intensity modulator (MZI) for the upstream data transmission. The latter is re-modulated by an MZI driven by a 1.25 Gbps NRZ data and transmitted back to the OLT. The re-modulated upstream data are detected at a receiver which consists of a PD, low pass filter (LPF), and a limiting amplifier

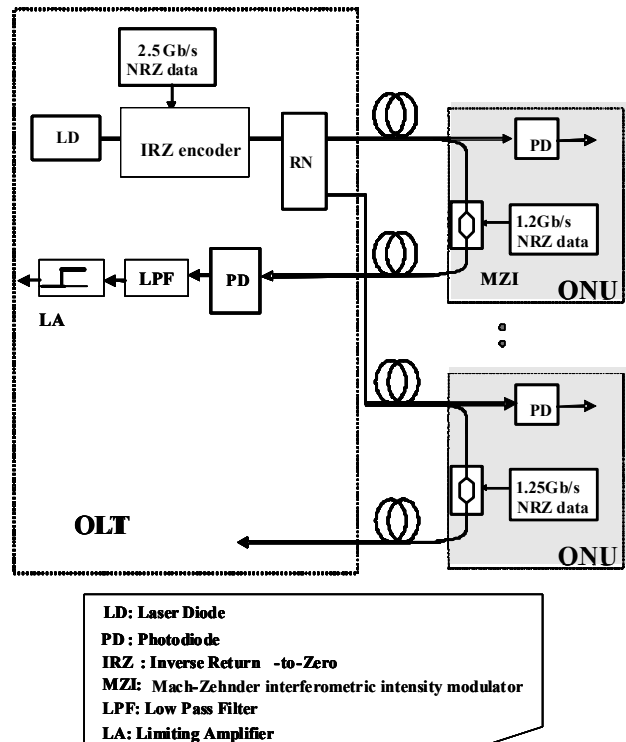


FIG. 2. An asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation.

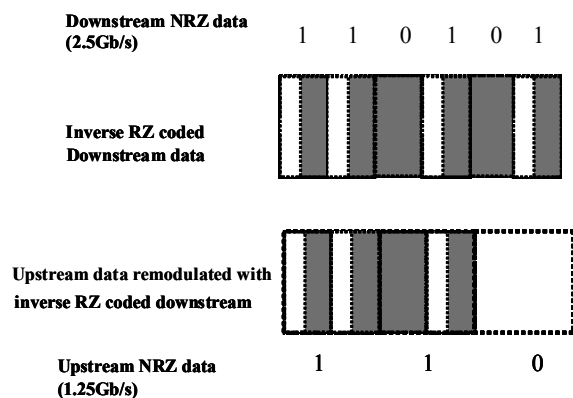


FIG. 3. Downstream data modulated with inverse RZ coded downstream.

(LA). The threshold level of the limiting amplifier is controlled by adjusting the offset voltage.

We analyze NRZ upstream re-modulation data modulated by inverse RZ coded downstream by dividing one period of 1.25 Gbps into four sectors. Two bits of upstream data exist during one bit of downstream data. As downstream inverse RZ coded signals are '01' and '11' for data bits of '1' and '0', one pulse and two pulses exist in one bit of upstream data, respectively. When the clock synchronization between downstream and upstream data is kept, there are two, three, four

TABLE 1. NRZ upstream re-modulated data with inverse RZ coded downstream according to three bits of downstream data

Type	downstream 3bits A B C	Probability	No. of pulses in bit '1' of upstream
a	1 1 1	$P_{1a}=1/8$	2
b	0 1 1 1 1 0	$P_{1b}=1/4$	2~3
c	0 1 0 1 0 1	$P_{1c}=1/4$	3
d	0 0 1 1 0 0	$P_{1d}=1/4$	3~4
e	0 0 0	$P_{1e}=1/8$	4

pulses in one bit of upstream data according to downstream data. However clock synchronization circuits are needed to keep the clock synchronization between downstream and upstream data. We adopt asynchronous communication between downstream and upstream data for simple structure of ONU with low cost.

In this paper, we analyze BER performance and propose the performance enhancing method by controlling the threshold level of a receiver for asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation. When the clock synchronization between downstream and upstream data is not kept, the number of pulses is between two and four in one bit of upstream data according to downstream data. We can classify NRZ upstream re-modulated data with inverse RZ coded downstream according to three bits of downstream data as shown in Table 1. The number of pulses varies between two and four in one bit of upstream data according to three bits of downstream data and the probability for each case is shown in Table 1.

III. ANALYSIS OF BER PERFORMANCE USING MODELING OF BER OCCURRENCE

The power component at the output of the LPF at a receiver in OLT is the sum of signal power and noise power. The noise power at the output of LPF is assumed to be a zero-mean Gaussian distributed function. Assuming that the data bits 1 and 0 are transmitted with a probability of 0.5, the BER is given by

$$BER = \frac{1}{2}[P(0/1) + P(1/0)] \quad (1),$$

where $P(0/1)$ and $P(1/0)$ are error probabilities when detected data are '0' and '1' for '1' and '0' of upstream

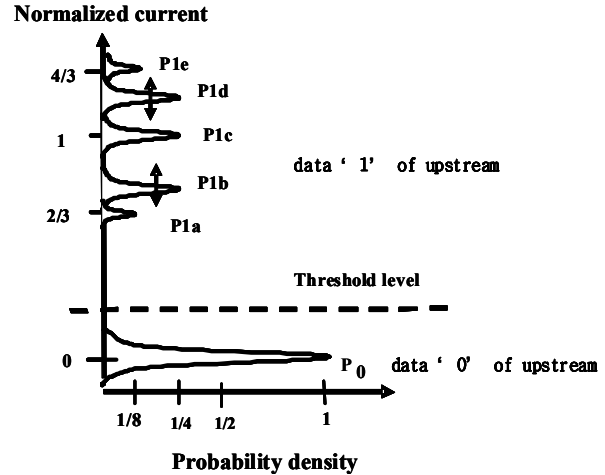


FIG. 4. Power density function of remodulated upstream with inverse RZ coded downstream according to downstream data.

data, respectively.

When upstream data is '0', the signal power is zero. So the error probability, $P(1/0)$ at the output of an LA is given by

$$P(1/0) = \frac{1}{2} \operatorname{erfc} \left(\frac{I_D - I_0}{\sigma_0 \sqrt{2}} \right) \quad (2),$$

where I_0 and I_D are the mean current for the data bit '0' and the threshold current, respectively, and σ_0 is the current standard deviation of the noise current for the data bit of '0' [18].

However, when upstream data is '1', the signal power varies according to downstream data. We consider the mean current for the data bit '1' by classifying it into five cases as shown in Table 1. When upstream data is '1', the mean number of pulses transmitted at a receiver in OLT is three. So when the number of pulses is three, the normalized current at the output of LPF is defined as 1. In the cases of type a, type c and type e defined as Table 1, the normalized currents are $2/3$, 1 and $4/3$ and the probability densities are P_{1a} , P_{1c} , and P_{1e} , respectively as shown in Fig. 4. In the cases of type b, the normalized current varies from $2/3$ to 1 and the probability density is P_{1b} . In the cases of type d, the normalized current varies from 1 to $4/3$ and the probability density is P_{1d} .

When upstream data is '1', the error probability, $P(0/1)$ at the output of an LA is given by

$$P(0/1) = P_a(0/1) + P_b(0/1) + P_c(0/1) + P_d(0/1) + P_e(0/1) \quad (3),$$

where $P_a(0/1)$, $P_b(0/1)$, $P_c(0/1)$, $P_d(0/1)$ and $P_e(0/1)$ are error probabilities for type a, type b, type c, type

d and type e in the case upstream data is '1', respectively. As the noise power is random variables, we can assume noise at the output of an LPF is a zero-mean Gaussian distributed function.

$P_a(0/1)$, $P_b(0/1)$, $P_c(0/1)$, $P_d(0/1)$ and $P_e(0/1)$ are expressed as

$$P_a(0/1) = P_a \frac{1}{2} \operatorname{erfc} \left(\frac{2/3 - I_D}{\sigma_1 \sqrt{2}} \right) \quad (4),$$

$$P_b(0/1) = \int_{I=2/3}^1 P_{1b}' \frac{1}{2} \operatorname{erfc} \left(\frac{I - I_D}{\sigma_1 \sqrt{2}} \right) dI \quad (5),$$

$$P_c(0/1) = P_{1c} \frac{1}{2} \operatorname{erfc} \left(\frac{1 - I_D}{\sigma_1 \sqrt{2}} \right) \quad (6),$$

$$P_d(0/1) = \int_{I=1}^{4/3} P_{1d}' \frac{1}{2} \operatorname{erfc} \left(\frac{I - I_D}{\sigma_1 \sqrt{2}} \right) dI \quad (7),$$

$$P_e(0/1) = P_{1e} \frac{1}{2} \operatorname{erfc} \left(\frac{4/3 - I_D}{\sigma_1 \sqrt{2}} \right) \quad (8),$$

where P_{1b} and P_{1d} are given by

$$\int_{I=2/3}^1 P_{1b}' dI = 1/4 \quad (9),$$

$$\int_{I=1}^{4/3} P_{1d}' dI = 1/4 \quad (10),$$

and σ_1 is the current standard deviation of the noise current for the data bit of '1' [18]. The signal power and the noise power at the output of the LPF for the data bit of '1' are given by

$$S = I_1^2 \quad (11),$$

$$N = \sigma_1^2 \quad (12),$$

where I_1 is the normalized currents for the data bit '1'. The noise power ratio (SNR) is given by

$$\text{SNR} = \frac{S}{N} \quad (13),$$

IV. PERFORMANCE ANALYSIS FOR PROPOSED SYSTEM USING SIMULATION

In this section, simulations are performed with MATLAB on the basis of theoretical analysis on BER performances completed in previous section and some numerical results are shown and discussed. Here we

assume that the receiver is designed with the PIN (Positive Intrinsic Negative) detector whose noise is dominated by the thermal noise at low receiving optical power and is independent of the average current ($\sigma_0 = \sigma_1$). [18]

Figure 5 shows BER performances as a function of normalized threshold level at the SNR of 27 dB for asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation. When upstream data is '0', BER $P(1/0)$ is improved as the normalized threshold level increases. When upstream data is '1', the BER $P(0/1)$ is the sum of error probabilities for type a, type b, type c, type d and type e and it deteriorates as the normalized threshold level increases. Considering the signal power, it is seen that the BER $P(0/1)$ is more dominated by $P(1/0)$ than by error probabilities for type c, type d and type e. As the total BER is the sum of $P(1/0)$ and $P(0/1)$, the BER performance is mainly determined by $P(1/0)$ and $P_a(0/1)$. Namely when the normalized threshold level is low, the total BER is dominated by $P(1/0)$. As the normalized threshold level increases, the total BER is dominated by $P_a(0/1)$ out of error probabilities for type a, type b, type c, type d and type e. So the receiver threshold level for the best BER performance is optimized at the near point of intersection between $P(1/0)$ and $P_a(0/1)$, the optimal normalized threshold level would be gained between 0 and 2/3 which are the average normalized currents of the data '0' and type 'a' cases ($P_a(0/1)$). because the total BER is limited by $P_a(0/1)$ as the normalized threshold level increases. When the SNR is 27 dB, the best BER performance of 3×10^{-16} is achieved at the normalized threshold level of 1/3.

Figure 6 shows relationships among the best BER, the optimal normalized threshold level, and the SNR. When the SNR is lower than 25 dB, the total BER is more dominated by $P(1/0)$ than $P_a(0/1)$. As the SNR increases more than ~25 dB, the total BER is more dominated by $P_a(0/1)$ than $P(1/0)$. Namely when the

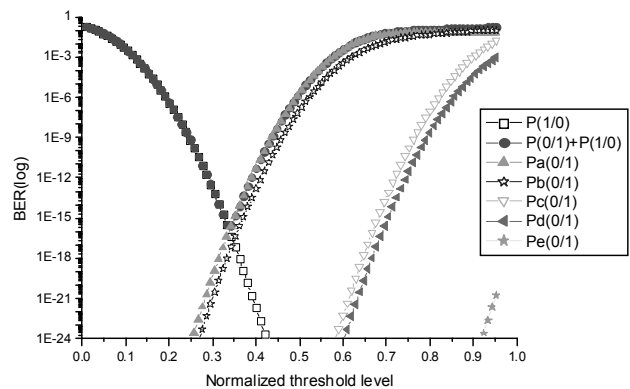


FIG. 5. BER performances as a function of normalized threshold level at the SNR of 27dB.

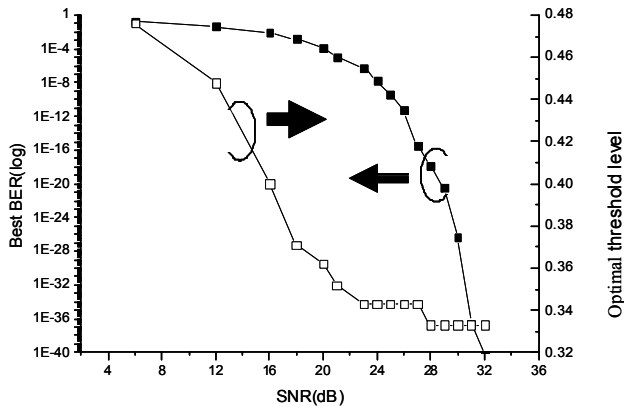


FIG. 6. Relationships among the best BER, the optimal normalized threshold level and the SNR.

SNR is low, the best BER is dominated by $P(1/0)$. As the SNR increases, the best BER is dominated by $P_a(0/1)$ out of error probabilities for type a, type b, type c, type d and type e. We assume we are using the PIN detector whose noise is dominated by the thermal noise and is independent of the average current.[19] When the SNR increases, the best BER is limited by $P_a(0/1)$ and the optimal normalized threshold level comes to 1/3, the mean between 0 and 2/3. It is seen that the optimal normalized threshold level becomes saturated at 1/3 as the SNR increases. The best BER performance can be gained by using the fixed normalized threshold level without controlling the threshold level of a receiver if the SNR attained is more than 25 dB. Note that the optical threshold level Especially for obtaining the better BER than 10^{-9} 10^{-6} is between 0.33~0.35. the needed SNR is larger than ~25 dB. So, This means that the receiver having the fixed threshold level of 1/3 is very useful for real PON systems.

Figure 7 shows BER performances as a function of SNR in the cases of the fixed threshold level at 1/3 and the conventional threshold level at 0.5 for asynchronous 2.5 Gbps/1.25 Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation. As the SNR increases more than 25 dB, the BER is more dominated by $P_a(0/1)$ than $P(1/0)$ and the optimal normalized threshold level (TL) becomes saturated at 1/3. As the SNR increases, BER performance can be improved more by using the fixed threshold level at 1/3 than by the general receiver with threshold level of 0.5. In the case of the fixed threshold level of 1/3, the BER of 5.6×10^{-10} is gained at the SNR of 25 dB. In the case of the general receiver with threshold level of 0.5, the BER of 1.8×10^{-10} is gained at the SNR of 31 dB. The threshold level is fixed optimized by adjusting the offset of an LA. The SNR necessary for obtaining BER 10^{-9} can be reduced by ~5 dB by fixing the normalized threshold level at 1/3

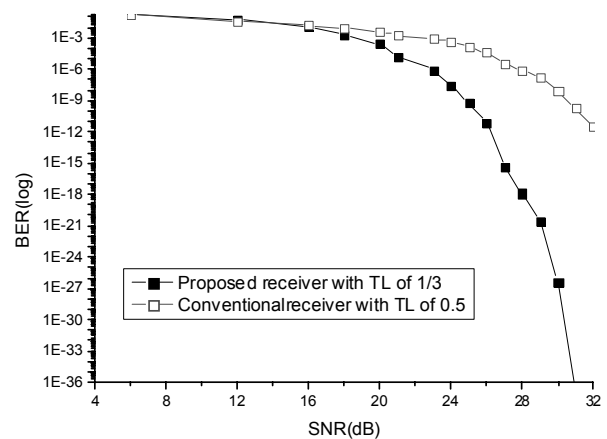


FIG. 7. BER performances as a function of SNR in the cases of the fixed threshold level at 1/3 and the conventional threshold level at 0.5.

instead of using the general receiver with threshold level of 0.5. It means that the minimum receiving power of a receiver can be improved and a low power and low cost light source can be used in this proposed system.

V. CONCLUSION

In this paper, we have proposed the performance enhancing method optimization of asynchronous 2.5 Gbps/1.25Gbps optical subscriber network with inverse RZ coded downstream and NRZ upstream re-modulation by the threshold level control adjusting the threshold level of a limiting amplifier at a receiver. We have theoretically analyzed BER performance by modeling the occurrence of BER by simulation with MATLAB. The SNR necessary for obtaining BER 10^{-9} can be reduced by ~5 dB by optimizing the normalized threshold level at 1/3 instead of using the conventional receiver with threshold level of 0.5.

The results have shown that the re-modulation scheme with inverse RZ coded downstream could be a useful technology for asynchronous optical access networks with asymmetric upstream and downstream data rates because the reduced minimum receiving power could replace a light source with a low power and low cost light source in an OLT.

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