BER Penalty of Burst-Mode Receiver in Optical Multiaccess Network

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Recently there is a lot of interest in high bit-rate burst-mode receivers [1] - [4]. These receivers are intended for the future broadband all optical multiaccess and multimedia networks in which various nodes communicate with one another via short bursts (or packets) of data. It is important to understand the system performance of such receivers since they are considerably different from conventional receivers [3]. A previous attempt [2] only gave an understanding of the BER penalty due to the length of the preamble field of the packet.

It was recently shown [3] that the decay time constant of the adaptive threshold control circuit in the receiver can contribute significantly to the system penalty. However, the previous framework only provides an upper bound of the BER performance or when the data are encoded with a line code (e.g. 4B5B or 5B6B). In this paper we provide a more complete framework for the computation of BER penalty, which can be applied to unencoded NRZ data as well as line coded data.The theoretical model can be used to explain the observed power penalty of previously reported burst-mode receivers [4]. We believe this is the first attempt to quantitatively explain the observed power penalty.

We shall use the same burst-mode receiver model as that of Ref. [1] or [3]. A peak detection circuit is employed by the receiver to detect the amplitude of the incoming signal for adaptively setting the detection threshold. It is understood that the holding time constant of the peak detection circuit (τ_f) is much larger than the rising time constant (τ_r), i.e., $\tau_f >> \tau_r$. Assuming $\tau_r < 1/B$, where B is the bit rate of the data link, the BER caused by erroneous "0"s should be the same as that of the conventional receivers. That is, $P_{e1} = P_{e1c}$, where the subscript c denotes the BER of a conventional receiver.

However, $P_{e0} \neq P_{e0c}$. This is because the detection threshold depends on the holding time constant τ_f of the peak detection circuit. When there is a large number of consecutive "0"s in the input data, the threshold will decay rapidly, reducing the signal to noise ratio (SNR) of the receiver [3]. Thus, a power penalty is introduced, i.e., $P_{e0} > P_{e0c}$.

The threshold of a burst-mode receiver is determined by a Markov process $V_{th}[m, t]$ [3], where m is the relative position of the bit under consideration in a sequence of consecutive "0"s, and t is the time reference within the bit interval. For a long string of consecutive "0"s appearing in the input signal, the average threshold for the $m-th$ bit is given by:

$$\bar{V}_{th}[m] = \frac{1}{T}\int_{(m-1)T}^{mT} V_{th}[m,t]dt = \frac{(e^{-(m-1)K} - e^{-mK})V_c}{K}, \qquad (1)$$

where $K = T/\tau_f$, and V_c is the optimal threshold for a conventional receiver. The decay parameter K has been redefined. It is related to the decay parameter k introduced in Ref. [3] by the relation $k = M \times K$, where M is the maximum number of consecutive "0"s in an encoded data pattern.

Assume the network operates with a good extinction ratio, i.e., $V_{on} >> V_{off}$, the Q-factor of the $m-th$ bit in a consecutive string of "0"s is:

$$Q[m] = \frac{\bar{V}_{th}[m] - V_{off}}{\sigma_0} = \frac{(e^{-(m-1)K} - e^{-mK}) \times Q}{K}, \qquad (2)$$

where Q and $Q[m]$ are the Q-factors for conventional and burst-mode receiver respectively, and σ_0 is the rms noise voltage for "0"s.

For a pseudo-random input signal with $N = 2^n - 1$, where N is the length of the pseudo-random number sequence (PRNS), the ratio of "0"-bits contained in strings of i consecutive "0"s relative to N is $\frac{1}{2^i+1}$. The average BER can thus be expressed as:

$$P_e = P(1)P_{e1} + P(0)P_{e0} = P(1)P_{e1} + \sum_{i=1}^{n}\frac{1}{2^{i+1}}\frac{1}{i}\sum_{j=1}^{i}P_{e0j}, \qquad (3)$$

Assume the bit rate B in the data link is $1Gb/s$, the input impedance and the noise figure F_n of the pre-amplifier are $1K\Omega$ and $1.7dB$, the responsivity R of the photo-detector is $1A/W$, the BER P_e versus the optical received power P_r for uncoded data is shown in Fig. 1. The BER performance of the receiver depends on the length of the PRNS N. For $N = 2^{15} - 1$ and $K = 0.05$, the power penalty is $1\ dB$ at a BER of 10^{-9}. From Fig. 1, the BER preformance will approach the worst case when $n \geq 15$.

For a typical 4B5B or 5B6B encoded data format (such as that provided by Am 7968 IC from AMD), statistical distributions for consecutive "0"s are obtained by simulation and results are shown in

Table 1. The BER for these encoded data is

$$P_e = P(1)P_{e1}+P_1 P_{e01}+P_2 \sum_{i=1}^{2} P_{e0i}/2+P_3 \sum_{i=1}^{3} P_{e0i}/3, \quad (4)$$

The relationship between the decay parameter K and P_e is shown in Fig. 2. Here, we compare the simulation results shown in Ref. [3] with the present theoretical results for different data format under the same SNR ($Q = 6$ which corresponds to a BER of 10^{-9} for conventional receivers). The theoretical curves agree with the simulation results very well. In the simulation, we use $N = 2^{23} - 1$ pesudo-random signal generator to produce an uncoded NRZ data stream, thus the simulation result for the uncoded data approaches the upper boundary.

We can use the above equations to evaluate the power penalty versus K and the results are shown in Fig. 3. For a power penalty of 1 dB at a BER of 10^{-9}, K must be ≤ 0.05, 0.1, and 0.12 for uncoded data (PRNS $N = 2^7 - 1$), 4B5B and 5B6B respectively. The decay parameter k for the 4B5B encoded data is $k = mK = 0.3$ (since $m = 3$) which agrees with the result shown in Ref. [3]. We can also use Fig. 3 to predict the K parameter from the power penalty of a recently published burst-mode receiver [4]. K should be ≈ 0.06 for a penalty of 1.5 dB (PRNS $N = 2^9 - 1$).

In conclusion, we have proposed a more complete theoretical model for the BER penalty calculation of digital optical burst-mode receivers employed in a multiaccess TDMA network. This model can be applied to unencoded (NRZ) data as well as line coded (mBnB) data. The theoretical results agree well with the simulation results and it can be used to explain the observed power penalty of previously reported burst-mode receivers [4].

References

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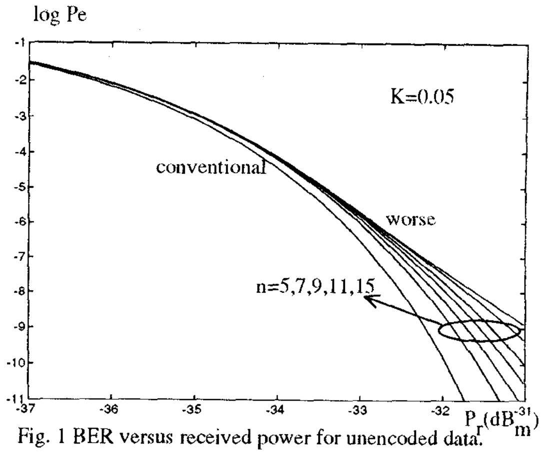

Fig. 1 BER versus received power for unencoded data.

Table 1 The distribution of consecutive "0"s in 4B5B and 5B6B

	4B5B	5B6B
P1("0")	0.21	0.18
P2("00")	0.079	0.071
P3("000")	0.008	0.02

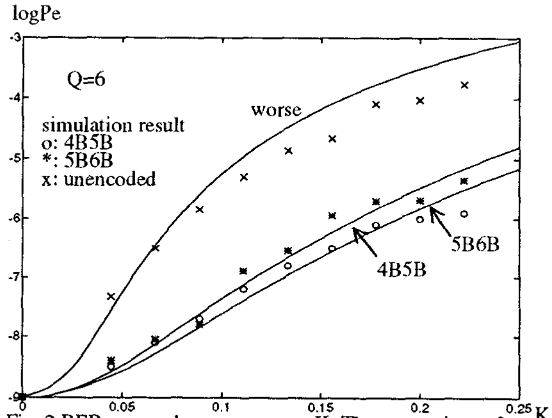

Fig. 2 BER versus decay parameter K. The comparison of simulation results and theoretical results (solid line)

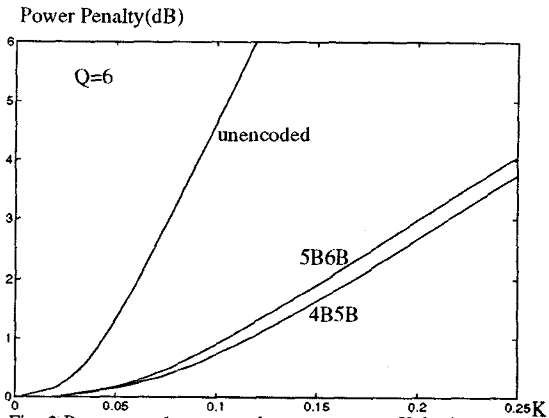

Fig. 3 Power penalty versus decay parameter K for input data.