Complexity and Performance Comparisons between Optical OOK-CDMA Chip-Level Receivers and Double-Optical-Hardlimiters Correlation Receivers

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I. INTRODUCTION

Optical code-division multiple-access (CDMA) techniques can be utilized in fiber-optic local area networks because of the great advantages resulting from employing high-bandwidth optical components [1]–[7]. When compared to time-division multiple-access (TDMA) technique, optical CDMA technique does not require time synchronization and provides flexibility in the network design and security against interception. Optical CDMA, on the other hand, suffers from the multiple-user interference, which degrades its performance as the number of users increases. Further, it exhibits an error probability floor, which cannot be reduced without the use of interference cancelation subsystems [7].

The traditional method to recover the data at the receiving end is to use an optical correlator followed by a photodetector and a decision device [2]. To enhance the performance of the correlation receiver, Salehi and Brackett have added an optical hardlimiter before the correlator at the receiver side [2]. Although the performance of their receiver (which involved an ideal photodetector) was improved, Kwon [3] has shown that such improvement becomes insignificant for more realistic systems, e.g., with avalanche photodiodes (APDs). With the implementation of double optical hardlimiters before and after the correlator at the receiving end, Ohtsuki [4],[6] was able to improve the performance even with real photodetectors.

Although many authors have adopted the optical hardlimiter in their system design, the problem with this device is that its technology is not yet mature. The characteristics of this device was first proposed in [8] as one of the future needs for digital optical computing but it does not practically exist yet. Recently we have proposed a new receiver model, called chip-level receiver [5]. This receiver does not require the optical hardlimiter or the correlator in its implementation. So it is much more practical than the correlation receiver with hardlimiters.

Our aim in this paper is to compare between the chip-level receiver and the double-optical-hardlimiters correlation receiver in terms of their hardware complexity and bit error probabilities.

II. OPTICAL OOK-CDMA RECEIVER MODELS AND HARDWARE COMPLEXITY

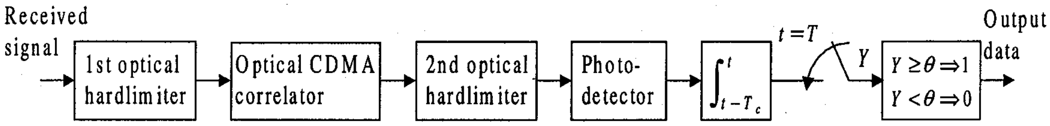

Fig. 1. Optical OOK-CDMA correlation receiver with double optical hardlimiters.

The block diagrams for both the double-optical-hardlimiters correlation receiver and the chip-level receiver are shown in Figs. 1 and 2, respectively. It can be seen from Fig. 1 that three threshold settings are needed for the double-hardlimiters correlation receiver; two for the optical hardlimiters and one for the OOK decoder. These thresholds are generally dependent on the received optical power and the number of simultaneous users, hence it is required to dynamically provide information about these parameters. Further, optical hardlimiters with variable thresholds do not exist in practice. The optical CDMA correlator in Fig. 1 usually splits the received optical signal into a number of branches which is equal to the code weight w and then combines these branches after properly delaying (in accordance to the signature code) the split optical pulses. This splitting process wastes most of the received optical signal. the electronic switch in Fig. 1 samples at a rate that is equal to the data bit rate R_b. This rate is much less than the optical processing rate (or the chip rate R_c). In fact $R_b = R_c/L$, where L is the code length.

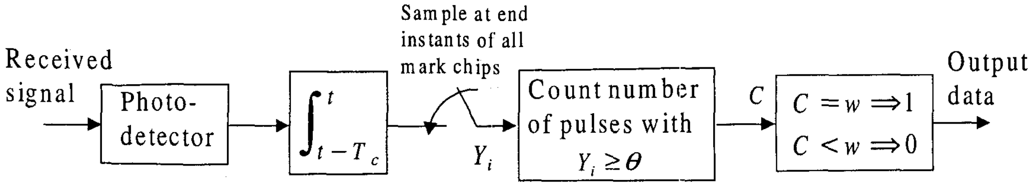

Fig. 2. Optical OOK-CDMA chip-level receiver.

From Fig. 2 we can see that the chip-level receiver does not require the optical correlator and hence it does not waste the received optical power as in the correlation receivers. The information about the signature code is provided in the electronic switch, which samples only at the instants of the mark chips. The average sampling rate of this electronic switch is still very low compared to the optical processing rate. In fact it samples at an average rate of wR_b. Further the chip-level receiver does not involve optical hardlimiters and only one threshold is required for the decision system. It turned out that for a shot-noise-limited system, this threshold is even independent of the system parameters, whereas for a more general system, this threshold depends on both the received optical power and the number of simultaneous users.

From the above discussion, it turns out that the chip-level receiver is much more practical than the double-hardlimiter correlator. Next we compare between their performance.

III. BIT ERROR PROBABILITIES AND NUMERICAL RESULTS

In this section we compare between the performance (in terms of the bit error rates) of both chip-level and double-hardlimiters correlation receivers. We consider two cases: (1) Poisson shot-noise-limited photodetectors and (2) avalanche photodetectors with thermal noise.

A. Poisson Shot-Noise-Limited Photodetectors

The bit error probability for the double-hardlimiters correlation receiver can be found in [4] and that for the Poisson chip-level receiver can be found in [5]. It should be emphasized that the error probability for the chip-level receiver from [5] was derived under the assumption of a constant threshold $\theta = 1$. This threshold is independent of the number of users and the average optical power, which adds to the advantages of chip-level receivers.

The error probabilities for both receivers are plotted in Fig. 3, versus the average received photons/nat, for different system parameters. An optimum threshold has been used for the hardlimiter correlation receiver, whereas a suboptimum threshold $\theta = 1$ has been used for the chip-level receiver. From this figure we can see that the bit error rate of the hardlimiter correlation receiver is slightly better than that of the chip-level receiver for very low optical power. Soon they coincide with each other (by increasing the average optical power) and reach the probability error floor. It should be emphasized that although the performance of the hardlimiter correlator is slightly better, it is expected to be worse than that of the chip-level receiver in practice since the properties of the ideal *sharp* hardlimiter is impossible to be practically realized. The error probabilities for the optimum receiver, correlation receivers without hardlimiters and with a single hardlimiter are also plotted in the same figure for convenience.

B. Avalanche Photodetectors and Thermal Noise

The bit error probability for the double-hardlimiters correlation receiver, when using an APD and taking into account the effect of the thermal noise can be found in [6]. We have derived the corresponding bit error

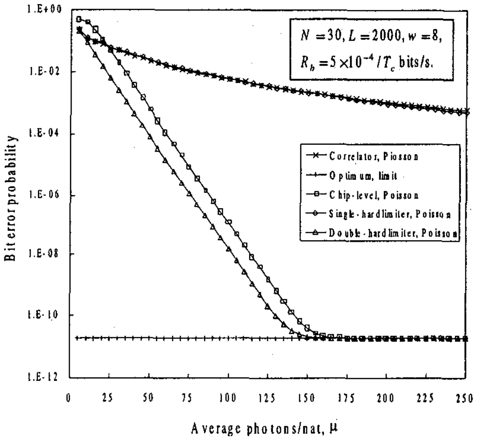

Fig. 3. Bit error probabilities for OOK-CDMA receivers, under a Poisson shot-noise limited assumption, versus average photons/nat.

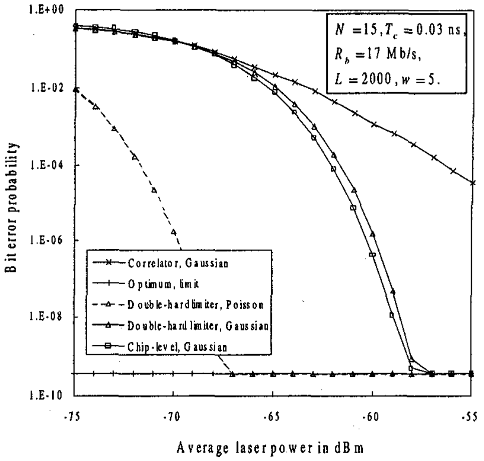

Fig. 4. Bit error probabilities for OOK-CDMA receivers, with thermal noise and APD noise, versus the average laser power.

rate for the chip-level receiver (the derivation has been omitted here for the lack of space) and found that.

$$P_b = \frac{1}{2} + \frac{1}{2} \sum_{l_1, l_2, \ldots, l_w} \Pr\{\kappa_1 = l_1, \kappa_2 = l_2, \ldots, \kappa_w = l_w\} \sum_{i=1}^{w} (-1)^i \binom{w}{i} \left[\prod_{j=1}^{i} Q\Big(\frac{m_{0j} - \theta}{\sigma_{0j}}\Big) - \prod_{j=1}^{i} Q\Big(\frac{m_{1j} - \theta}{\sigma_{1j}}\Big) \right],$$

where the function $Q(x)$ is the normalized Gaussian tail probability, m_{rj} and σ_{rj}^2 are the conditional mean and variance, respectively, of the decision (sampled) variable Y_j, $j \in \{1, 2, \ldots, w\}$, given data bit $r \in \{0, 1\}$ and interference pattern $\{\kappa_1 = l_1, \kappa_2 = l_2, \ldots, \kappa_w = l_w\}$.

The error probabilities for both receivers in this case are plotted in Fig. 4, versus the average received laser power, for different system parameters. Optimum thresholds have been used for both receivers. The error probabilities for the optimum receiver, correlation receivers without hardlimiters, and Poisson shot-noise-limited double-hardlimiter correlation receiver are also plotted in the same figure for convenience. The following system parameters are used in our calculations. The laser pulsewidth $T_c = 0.03$ ns, its wavelength $\lambda = 1.3\mu$m, the average APD gain $G = 100$, its efficiency $\eta = 0.8$, its effective ionization ratio $k_{eff} = 0.02$, its dark current $I_d = 1$nA, the receiver load resistor $R_L = 50\Omega$, and the receiver noise temperature $T^\circ = 300^\circ$K. From Fig. 4, we can see that the chip-level receiver performs slightly better than the double-hardlimiter correlation receiver. It fact we have found that for low thermal noise the double-hardlimiter correlation receiver performs slightly better than the chip-level receiver, whereas for high thermal noise the chip-level receiver performs better.

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