Performance Degradation in Coherent OCDMA due to Receivers' Bandwidth Limit and Improvement by using optical Thresholding

Xu Wang[1], Naoya Wada[1], and Ken-ichi Kitayama[2]

1. Information and Network System Division, National Institute of Information and Communication Technology, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795 Japan. xwang@nict.go.jp
2. Department of Electronics and Information Systems, Osaka University, 565-0871 Osaka, Japan.

BACKGROUND Optical code division multiple access (OCDMA) is one of the promising candidates for the next-generation broadband access networks other than TDMA and WDMA owing to its unique features of all optical processing, full asynchronous transmission, low latency, soft capacity on demand, protocol transparency, simplified network control, increased flexibility of QoS control as well as robust information security [1].

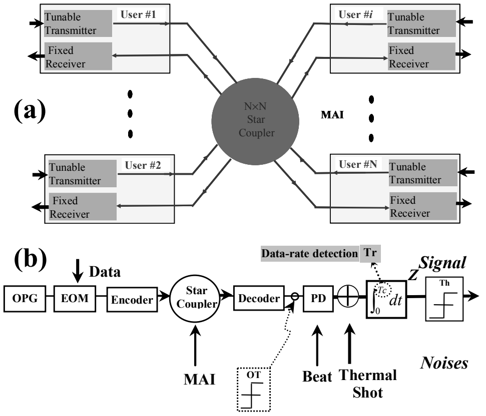


Fig. 1. (a) Basic N×N OCDMA network architecture
(b) System model

Figure 1(a) shows a basic N × N broadcast OCDMA network architecture, where signal from each transmitter is delivered to every receiver. Figure 1(b) is a simplified system model of an asynchronous coherent time-spreading (TS) OCDMA network [2]. The transmitter consists of an optical pulse generator (OPG), electro-optic modulator (EOM) and OCDMA encoder. After transmitting through the network, the encoded signals will be decoded by the decoder at the receiver. For the target user, the decoder recovers the original optical pulse, while for improper users, the output will be psudorandom noise, namely, multiple access interference (MAI) noise. The decoded signal will be detected by the square low photo-detector (PD), where the mixing of the signal and interferences will result in the arising of beat noise [2]. The receiver noise such as thermal, dark current and shot noise will arise in the receiver as well. Assuming that the PD is fast enough and the electrical bandwidth of the receiver is larger than chip-rate, the receiver is equivalent to an integrator over one chip interval (Tc) followed by thresholder. Previous theoretical analyses are mostly based on this chip-rate detection model.

However, in practical, the receiver's bandwidth is preferred to be in the order of the data-rate instead of chip-rate. This bandwidth limitation will result in severe performance degradation in, particularly, TS OCDMA system. It could be crucial to make the system work with a receiver that performs data-rate detection. In this paper, we will theoretically and experimentally investigate the performance degradation due to the receiver's bandwidth and the improvement by using optical thresholding technique in coherent TS OCDMA system.

THEORY Assume that the receiver's bandwidth is B$_{\mathrm{Rev}}$, the corresponding integration time of the integrator is $T_r \approx (B_{\mathrm{Rev}})^{-1}$. Similar as the analysis in [2], the output signal Z from the integrator becomes:

$$\begin{aligned} Z &= \int_0^{Tr} \Re \cdot (E \cdot E^*)dt + \int_0^{Tr} n_0(t)dt \\ &= T_c \Re P_d + T_r \Re \sum_{i=1}^{m} P_i + 2\Re \sum_{i=1}^{m} \sqrt{P_d P_i} \int_0^{Tc} \cos((\omega_i - \omega_d)t - \omega_i \tau_i + \phi_i(t-\tau_i) - \phi_d(t))dt + 2\Re \sum_{j=i+1}^{m} \sum_{i=1}^{m-1} \sqrt{P_i P_j} \int_0^{Tr} \cos((\omega_i - \omega_j)t - \omega_i \tau_i + \omega_j \tau_j + \phi_i(t-\tau_i) - \phi_j(t-\tau_j))dt + \int_0^{Tr} n_0(t)dt \end{aligned} \qquad (1)$$

The notations are same as those in [2]. Compared to the case with chip-rate detection, the variances of MAI and secondary beat noise change to:

$$\sigma_{MAI}^2 = rm\sigma_{MAI-0}^2; \quad \sigma_{beat-0}^2 = rm(m-1)\xi^2 P_d^2; \quad where \quad r = T_r / T_C$$

Figure 3(a) shows the calculated BER performance of the system with four different B_{Rev} using this model. Here, data-rate is 1.25 Gbit/s, the interferer level ξ≈-24 dB. The performance degradation due to the receiver's bandwidth limitation is clearly shown from the BER curves. It will be crucial to improve the system performance with a receiver that performs data-rate detection.

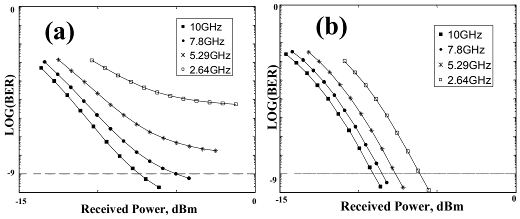


Fig. 2. Calculated BER performance with different B_{Rev}
(a) without optical thresholder (b) with optical thresholder

Therefore, applying optical thresholding technique in the system to eliminate the MAI noise is necessary [3-6]. The optical thresholder could be inserted after the decoder as shown in Fig. 1(b) to perform this function. With an ideal optical thresholder, the MAI and secondary beat noise could be eliminated completely: $\sigma_{MAI}^2 = \sigma_{beat-0}^2 = 0$. Therefore, the BER performance could be improve significantly as shown in Fig. 2(b). By applying optical thresholder in the system, error free (BER<10^{-9}) could be achieve with all receiver bandwidth.

EXPERIMENT Figure 3 shows the experiment setup to investigate the impairment of receiver's bandwidth limitation using superstructure FBG (SSFBG) en/decoder.

The mode-locked laser diode (MLLD) generates the 2 ps optical pulses at a repetition rate of 10 GHz with a central wavelength of 1550 nm. This signal is then modulated by the first Lithium Niobate Intensity Modulator (LN-IM) into 1.25 Gb/s. The second LN-IM further modulates the signal by 2^{23}-1 pseudo-random binary sequence (PRBS). The data signal is then split into two arms, each with a different time delay, and encoded by encoders 1 and 2 via circulators, respectively. The en/decoders are 511-chip SSFBGs [6]. The signal from encoder 2 is used as the interfere signal. The interferer's level (ξ) could be adjusted by the tunable attenuator (TATT).

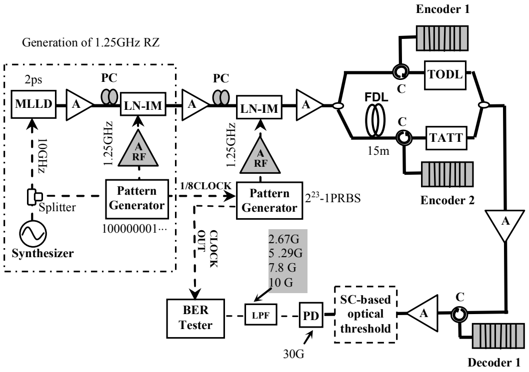
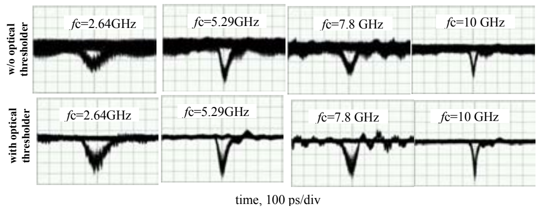


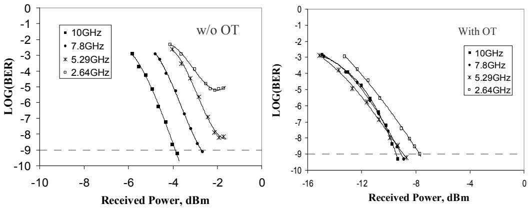
Fig. 3. Experimental setup

At the receiver, the multiplexed signals are recognized by the decoder 1 and received by a PD with 30GHz bandwidth. To evaluate the performance degradation due to the receiver's bandwidth limitation, we employed low-pass filters (LPFs) with four different cutoff frequencies (fc) after the PD. The optical threshoder is based on super-continuum (SC) generation in dispersion flattened fiber (DFF) [6].

The measured eye diagrams and BERs are shown in Fig. 4 (a) and (b), respectively. In the case of without optical thresholder, the raising of BER floor with lower fc agree with theoretical predictions done in last section very well. This degradation will severely restrict the application of the coherent TS OCDMA, even if the SSFBG en/decoder with chip-rate as high as 640 Gchip/s. By using the optical thresholding, the error free BER curves verify that the MAI noise has been removed significantly in the experiment. Therefore, the system performance could be free of receiver's bandwidth limitation to be able to work with data-rate detection. The performance improvement by using the optical thresholding technique again agrees with the theoretical prediction very well.



(a) Eye diagrams



(b) BER performances

Fig. 4. Experimental result with and w/o optical thrtesholder

CONCLUSION The limitation of the receiver's bandwidth in coherent TS OCDMA system has been investigated theoretically and experimentally. The receiver's bandwidth limitation will result in severe performance degradation due to the accumulation of the MAI and secondary beat noise. Applying optical thresholding technique in the system could eliminate the out-of-peak MAI and secondary beat noise to improve the performance significantly. The experimental results agree with the theoretical predictions very well. Therefore, it is essential to employ optical thresholder in practical coherent TS OCDMA system with a receiver that performs data-rate detection.

REFERENCES:

[1] A. Stock and E. H. Sargent, *IEEE Communication Magazine*, pp.83-87, Sept. 2002.
[2] X. Wang and K. Kitayama, J. Lightwave Technol, vol. 22, pp.2226-2235, 2004.
[3] H. P. Sardesai, and A. M. Weiner, Electron. Lett. 33, pp. 610-611, 1997.
[4] Z. Jiang et al., OFC'04, PDP29, 2004.
[5] R. P. Scott, et al., IEEE Photonics Technol. Lett., vol. 16, pp. 2186-2188, 2004.
[6] X. Wang et al., OFC'05, PDP33, 2005.