Experimental BER performance of 2D λ-t OCDMA with recovered clock

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The BER performance of a 2D λ-t OCDMA system is compared experimentally with optimum sampling (global clock) and non-optimum sampling (recovered clock from an OCDMA receiver). The power and BER penalties of the receiver are quantified, and the impact of interferers on its performance is determined.

Introduction: The theoretical performance of networks based on optical code-division multiple-access (OCDMA) has been studied extensively. A number of OCDMA systems have been demonstrated experimentally, but they all used a global clock (optimum sampling) to perform bit error rate (BER) measurements [1, 2]. Any practical OCDMA system will require clock and data recovery (CDR). The OCDMA receiver reported in [3] performs CDR on OCDMA data and converts the OCDMA signal to an NRZ signal, thus enabling interoperability with standard digital circuits. In this Letter, we extend these previous results by comparing experimentally the BER performance of an OCDMA system with optimum sampling (global clock) and non-optimum sampling (recovered clock). We performed BER measurements on a four-user 2D λ-t OCDMA system, quantifying not only the power and BER penalties of the OCDMA receiver, but also determining the impact of interferers on the receiver performance. These results will help refine theoretical models of OCDMA systems, and provide input for establishing realistic power budgets.

Table 1: OCDMA system parameter

Parameter	Value
Code length	29
Code weight	8
Channel spacing	50 GHz
Each optical wavelength bandwidth	20 GHz
Data rate	155.52 Mbit/s (OC-3)
Chip rate	1.24416 Gbit/s (OC-24)

System: The OCDMA system test bed is described in detail in [2]; the main parameters are listed in Table 1 and the block diagram is shown in Fig. 1. A broadband incoherent signal is passed through an electro-absorption modulator driven by a $2^{15}-1$ PRBS RZ signal. The single train of optical pulses is amplified by an EDFA before being split and sent to four encoders, each with a delay line sufficiently long to decorrelate the pulses. The encoders are fibre Bragg gratings (FBGs) written in series, the passbands of which and physical position on the fibre determine the 2D λ-t codes. The OCDMA signals are recombined and amplified by an EDFA before entering the decoder for the desired user. A photodiode, followed by a 933 MHz Bessel-Thompson filter, converts the decoded signal to an electrical signal. In the global clock case, the BER tester (BERT) is triggered by the transmitter's clock. In the recovered clock case, the clock and data recovery unit is inserted after the electrical filter and the recovered clock and data are used as inputs to the BERT.

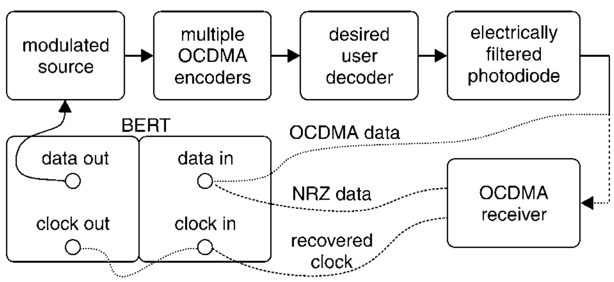

Fig. 1 *Block diagram of experimental setup*

Dashed and dotted lines show connections for global and recovered clock configurations, respectively

BER measurements were made for up to four simultaneous users: the desired user and three interferers. The three interferers each share two common wavelengths with the desired user (the other wavelengths are filtered out by the decoder). For the first interferer, both wavelengths appear under the autocorrelation peak (or inside the detection window) of the desired user (Fig. 2*b*) – this represents a worst-case interferer. For the other two interferers, only one of the two wavelengths appears inside the detection window (Figs. 2*c* and *d*).

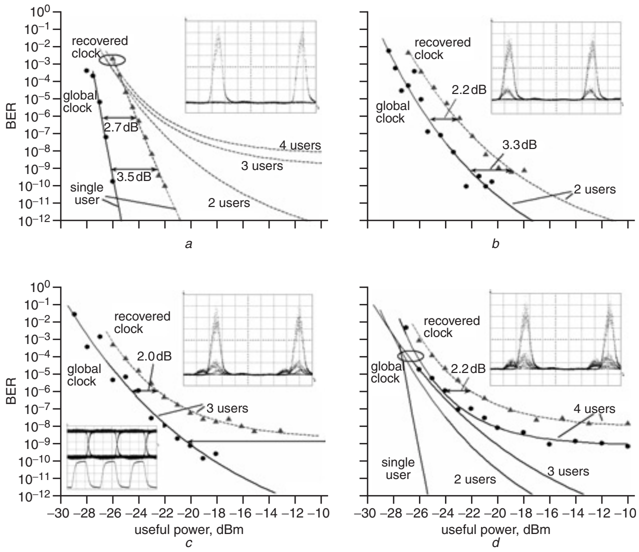

Fig. 2 *BER performance of four-user OCDMA system with global clock (solid curves) and recovered clock (dashed curves)*

Markers represent measurements, curves are fitted
a 1 user
b 2 users
c 3 users
d 4 users
Insets are oscilloscope traces

Clock and data recovery: As described in [3], the CDR is made of four building blocks: a quantiser, an OC-48 SONET CDR, a 1:16 deserialiser, and a controller. The quantiser filters out multi-access interference (MAI) by thresholding the incoming OCDMA data, both inside and outside the detection window. In the global clock case, only the MAI falling inside the detection window affects the system performance; MAI falling outside the detection window is filtered out by the global clock sampling at the bit rate. As the OCDMA receiver has no *a priori* information on where sampling should occur, the quantiser must eliminate the energy outside the detection window to help the CDR lock on the correct data edges. MAI outside the detection window and above the quantiser threshold creates spurious edges and usually prevents the CDR from locking.

The CDR recovers the clock at twice the chip rate (2.48832 Gbit/s) in order to accommodate the 1:16 deserialiser (2.48832 Gbit/s/16 = 155.52 Mbit/s). Each OCDMA autocorrelation peak is therefore sampled twice in this configuration. Using the thresholded signal and the recovered clock, the 1:16 deserialiser performs an RZ to NRZ conversion and divides the clock frequency by 16. The deserialiser outputs NRZ data at the bit rate, together with its associated clock. When the link is first established, the controller sends realignment/reframing signals to the deserialiser to steer the data to the correct output port.

Results and discussion: The performance of the OCDMA system with global clock (solid curves) and recovered clock (dashed curves) is shown in Figs. 2*a*–*d*. Each Figure presents the power penalty of the receiver for a different case (one, two, three or four users). Note that the abscissa is the useful power, i.e. the optical power contributed by the desired user at the photodiode. Oscilloscope traces of the OCDMA signal, after O/E conversion and filtering, are shown as insets in each Figure. The bottom left inset in Fig. 2*c* shows the OCDMA receiver outputs (clock and data).

For the single user case (Fig. 2*a*), the power penalty due to clock extraction is 2.7 dB (BER$\sim10^{-6}$) or 3.5 dB (BER$\sim10^{-9}$). As users are added on the network, the power penalty stays relatively constant. For a BER of 10^{-6}, there is a power penalty difference of 0.7 dB between the worst case and the best case. For a BER of 10^{-9}, the power penalty difference between the one and two user cases is 0.2 dB. We could not measure power penalties for the three and four user cases due to BER floors, which were observed with three or more users in the recovered clock case, and after the fourth user in the global clock case. The BER floors are mainly due to the intensity noise of the source [4]. For all cases with no BER floor, we obtained error-free operation for over 1 min at 155.52 Mbit/s (BER$<10^{-10}$).

Another way of assessing the performance of the receiver is to measure the power penalty due to interferers. In the global clock case (Fig. 2*d*), the addition of one, two and three interferers causes power penalties of 1.3, 2.2 and 2.6 dB, respectively (BER$\sim 10^{-6}$). In the recovered clock case (Fig. 2*a*), the power penalties are 0.9, 1.6 and 2.1 dB, respectively (BER$\sim 10^{-6}$). These numbers suggest that the addition of interferers causes similar power penalties for the global and recovered clock cases.

Conclusion: We have found that practical CDR for λ-t OCDMA provides an acceptable BER penalty as compared to optimum sampling with a global clock. Moreover, our results show that MAI (the major source of impairment in OCDMA) is not detrimental to practical CDR. Performance could be enhanced by including a windowing function over the autocorrelation peaks, effectively filtering out MAI outside the detection window and thereby facilitating CDR. This is the subject of future work.

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