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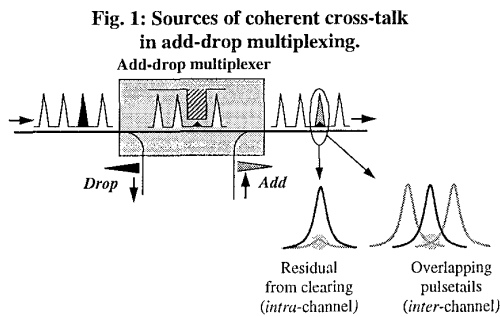
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Abstract: The influence of coherent cross-talk on the cascadability of add-drop multiplexers in OTDM systems is analysed theoretically using moment generating functions. Calculations are validated by experiments.

Introduction

All-optical add-drop multiplexing is a key function in OTDM systems and constitutes an important step in making OTDM a practical technology. The first demonstration of high-speed OTDM LAN systems employing add-drop multiplexers (ADMs) has recently been shown [1]. The aim of this work is to analyse system requirements for cascaded add-drop multiplexers in OTDM systems, as set by coherent cross-talk [2]. As illustrated in Fig. 1, add-drop multiplexing gives rise to *intra*-channel coherent cross-talk if the add timeslot is not adequately cleared by the ADM prior to inserting the add signal [3]. Additionally, the tails of the added pulses leak into the neighbouring timeslots, resulting in *inter*-channel coherent cross-talk which is a feature specific to OTDM. In addition to the calculated results, we present experimental validation of the applied model for a 10 Gb/s RZ signal with cross-talk terms from up to three independent sources.

Fig. 1: Sources of coherent cross-talk in add-drop multiplexing.

Add-drop multiplexer

Drop ↓   ↑ Add

Residual from clearing (*intra*-channel)   Overlapping pulsetails (*inter*-channel)

Theoretical model and experimental verification

The theoretical framework is the method of moment generating functions (MGF) [4]. The coherent cross-talk modifies the MGF to include additional product terms of the form

$I_0(2\sqrt{P_{sig}P_j} \cdot other\ terms)$, where I_0 is the modified Bessel function, for all the interfering channels j. The system BER is evaluated by applying the saddle-point approximation [5] to the MGF for calculating the probability in the tails of the probability distributions.

Experimentally, the influence of coherent cross-talk on the receiver sensitivity is analysed in a simple experiment: The 10 Gb/s RZ signal is obtained by externally modulating pulses from a 10 GHz gain-switched DFB laser (λ=1556nm, FWHM~8ps, $\Delta t \Delta B$~0.8). External cavity lasers provide up to three independent CW signals (λ=1556nm) for introduc-

ing coherent cross-talk in the signal. The signal is received in an optically pre-amplified 10 Gb/s receiver, and the resulting power penalty for 1, 2 and 3 cross-talk signals (identical power and polarisation) is shown in Fig. 2. The experiments simulate the influence of overlapping pulse tails due to pedestals (characterised by the pulse-tail extinction ratio relative to the pulse peak, *PTER*) in an OTDM signal. Calculations simulating the above experiment are also shown in the figure. The agreement between measurements and calculations is very good both in terms of trends and absolute values and the validity of the model is verified.

Fig. 2: Experimental and calculated power penalty vs. PTER in the case of 1 (o), 2 (Δ) and 3 (ổ) CW interferers.

Pulse tail extinction ratio (dB)
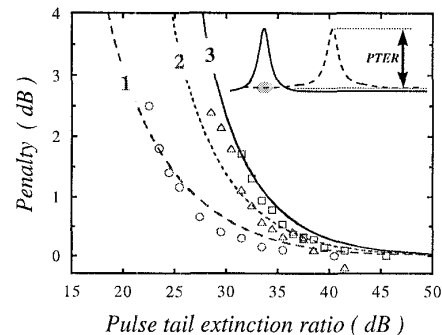
Cascadabilty of add-drop multiplexers

Calculations are carried out using the following system parameters: The OTDM signal is passively multiplexed from N independent 10 Gb/s RZ signals (R_{ext} = 13 dB). The $sech^2$ pulses have a FWHM equal to ¼ of the timeslot of the aggregate bit-rate. The pulses are further characterised by a pedestal, as described above. In the add-drop multiplexer the add timeslot is suppressed by 25 dB (termed the intra-timeslot suppression ratio, *ITSR*) across the entire width of the time slot and a new channel is added into the cleared timeslot. At the receiver the signal is demultiplexed to 10 Gb/s and the sensitivity is calculated.

In the first set of calculations the add-signals are repeatedly inserted into the same timeslot (Fig. 3). As illustrated in the figure, each successive clearing further suppresses the previous signals, and as a result the total cross-talk power is effectively bounded. Therefore, no limitation to the cascadability is expected for the add channel. Calculated power penalties versus number of cascaded ADMs are shown in Fig. 3 with the PTER as parameter and for both 4x10 and

8x10 Gb/s signals. Several distinctive features are seen: First, the results for the add channel and neighbouring channels are qualitatively different. The add channel suffers an initial multiplexing penalty (zero cascaded nodes) followed by a constant penalty for add-drop multiplexing, as described above. In contrast, the neighbouring channels suffer from an increasing number of cross-talk terms due to the pulse tails from the add signals. The most severely affected channels are the two nearest neighbours since they are affected by the flanks of the add pulses while the other neighbours are only affected by the pedestals. Further, the calculations show that the PTER is a key parameter for cascading ADMs; a major improvement in the cascadability is seen for just 5 dB improvement of the pulse pedestals. The last figure indicates that although the penalty is a little higher for the 80 Gb/s signal than for the 40 Gb/s signal, the requirements to the pulse pedestals are only moderately affected by increasing the level of aggregation.

Fig. 3: Cascading of ADMs, adding repeatedly into same timeslot. a.) Previous signals in add timeslot are further suppressed on each clear/add. b.) Calculated power penalty for 4x10 Gb/s and 8x10 Gb/s OTDM signals with PTER as parameter. Clearing efficiency by ADM is 25 dB.
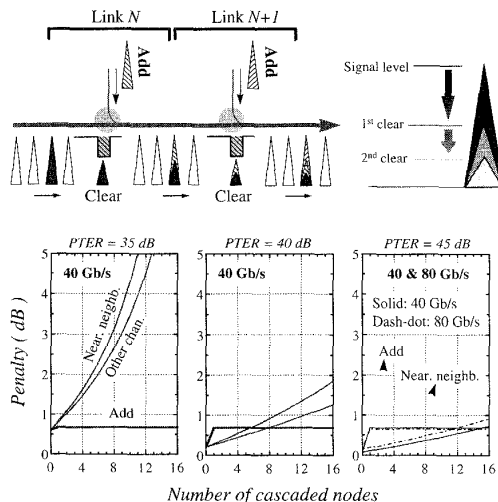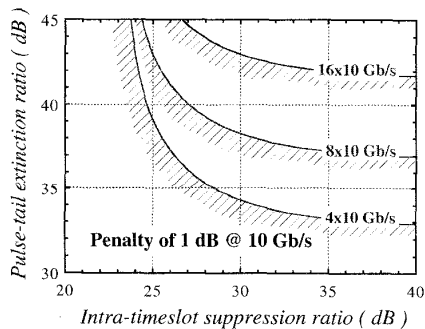

Number of cascaded nodes

Fig. 5: Combined requirements to PTER and ITSR for worst case node in circular add-drop for N = 4, 8 and 16.

Intra-timeslot suppression ratio (dB)

In most circumstances, the add-drop multiplexing actually plays an important role in reducing the coherent noise build-up due to pulse tail overlap. As an example of this, Fig. 4

shows the evolution of power penalty for one of the channels in the case of 'circular' add and drop (add-drop channel shifted by one timeslot for every add) for a 4x10 Gb/s signal. The penalty is basically reset to the level of the 'add-penalty' by the clear/add process at the beginning of each cycle, after which the penalty increases, before once again being reset. The cross-talk terms for the worst case node essentially consist of one residual pulse from the most recent 'clearing' and $N-1$ pulse tails from the other channels. Thus, this worst-case penalty depends both on the PTER and on the ITSR, as illustrated in Fig. 5. The figure shows the combined requirements for circular add-drop multiplexing (penalty <1 dB) to the pulse quality and the clearing efficiency, in terms of PTER and ITSR of the ADM. Results for a 4x10, 8x10 and 16x10 Gb/s signal (N = 4, 8, 16) are shown. As an example, for a ring where 4 nodes communicate mutually (one timeslot allocated for each connection), N=6. Add-drop experiments at 4x10 Gb/s with a single ADM [6] clearly show that adequate pulse quality and clearing of the add timeslot can be obtained, so that cascading of ADMs is feasible for at least 4x10 Gb/s signals, e.g., in a ring configuration as described above.

Fig. 4: Calculated power penalty in the case of 40 Gb/s 'circular' add-drop (add-drop channel shifted by one timeslot for every add).

Number of cascaded nodes
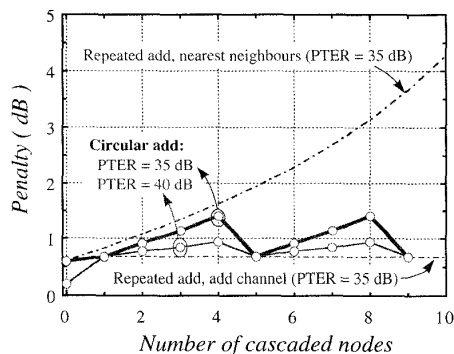
Conclusion

The cascadability of add-drop multiplexers in OTDM systems has been investigated theoretically. The calculations show that the residual power level in the pulse-tails is a crucial parameter and that the clearing of the add timeslot plays an important role in extending the cascadability of add-drop multiplexers.

Acknowledgement

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