Experimental demonstration of a simple, optically transparent, add/drop multiplexer at 2.5 Gb/s without local optical source.

J.M. Rijnders[1], M.O. van Deventer[2], and A.C. van Bochove[1,2],
[1] Dept. of Electrical Engineering, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands.
[2] Royal PTT Nederland N.V., KPN Research, P.O. Box 421, 2260 AK Leidschendam, The Netherlands.

Abstract

We present a novel add/drop multiplexer and experimentally demonstrate its operation at 2.5 Gb/s. No local laser is needed since the wavelength- and modulation format transparent 'add' is accomplished by using optical switches, delay lines and the 'dropped' input. Applications are found in flexible, high capacity WDM networks.

Introduction

The use of add/drop multiplexers (ADMs) in, for example, ring network architectures can be employed to conveniently add local user data to the ring, or to receive the data sent by other nodes in the ring. Optical transparency of these nodes to the signal's wavelength and modulation format would be very desirable since it can be used to avoid opto-electrical and electro-optical conversions, commonly referred to as the 'electronic bottleneck'[1]. Besides, transparent WDM networks can accommodate to high capacities while preserving the network's flexibility and granularity.

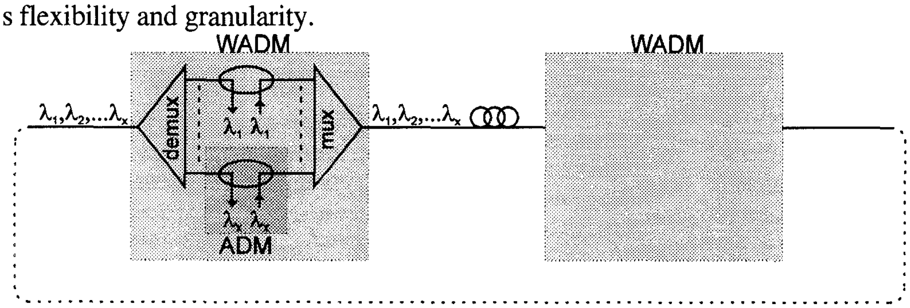

Figure 1: Situation of WADM and ADM in a ring network topology.

Figure 1 depicts a general structure of a ADM in a WDM ring network environment. Since multiple wavelengths can be dropped and added, each node is designated as a Wavelength-ADM (WADM). A common characteristic of WADMs is the ability to select a certain wavelength of which the data is subsequently detected by the ADM. This wavelength demultiplexing function is common to WADM structures and can be achieved with, e.g., a combination of an optical circulator and filter [2] or with Arrayed Waveguide Gratings [3]. In our concept we concentrate on the ADM operation at one single wavelength, irrespective of this wavelength. Consequently, extension to a multi-wavelength situation will only require an extra wavelength multiplex and demultiplex stage.

Optical ADMs generally have the drawback that a locally (wavelength) controlled source is required for the 'add' function [2], [3]. Other designs rely on the availability of dummy packets at their input, consisting of a CW burst, which is modulated by the ADM according to its demand [4]. As a matter of fact, these ADMs do not need a local laser and operation is transparent for the optical wavelength. However, dummy packets might not be available due to heavy load operation in previous nodes, thereby seriously degrading the performance of the network. Moreover, these packets can only be used once.

In the following, we will first briefly outline the processing concept behind this novel ADM [5]. Then we will show the experimental demonstration and operation at 2.5 Gb/s. Finally, we will discuss the measurements and the performance.

ADM operation.

Figure 2 illustrates the framework of the wavelength- and modulation format independent ADM. The input of this ADM consists of a line-code which is constructed to avoid long runs of '0s' or '1s'. A possible candidate of such a line-code is the Manchester line-code in which a logical '0' is encoded as '10' and a logical '1' as '01'. By definition the maximum runlength, $L_{\max}$, of this line-code is limited to $L_{\max,0} = L_{\max,1} = 2$, which occurs on the boundaries of a logical '1' and '0' or vice versa (0110 or 1001).

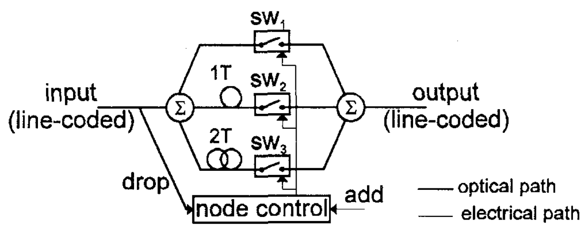

Figure 2: wavelength- and modulation format independent ADM

It will be clear that the first stage of the ADM, which consists of an alignment delay and an optical $1 \rightarrow 3$ splitter having 0T, 1T and 2T delay loops, acts as a serial to parallel converter for the optical input signal if T equals one bit-period. In case of a Manchester line-code input, serial to parallel conversion means that in every time-slot *at least* one '1' **and** one '0' are available at the input of the electro-optic switches (sw_1-sw_3) for the period of the sequence [6]. Appropriate control of these switches by the control electronics, which operate on basis of the signals 'add' and 'drop', allows the construction of each arbitrary output by closing one of the switches in each time-slot. Since signal consistency is required, e.g. to enable cascadability of ADMs, the output should also consist of a Manchester line-code. Finally, it should be noted that input bits are only gated by the switches, making the ADM operation modulation format transparent (OOK, FSK, PSK, etc.).

In Figure 3 the hardware configuration has been depicted which is required if we restrict ourselves to the most widely used modulation format, being On-Off Keying (OOK). Compared to Figure 2 we obtain some simplification because '0s' need not be available in each time-slot. They can be created by interruption of the signal path (i.e. opening both switches). ADM operation is now guaranteed because an '1'-bit is now available in every time-slot in one of the branches. In terms of runlength requirements this means for this ADM that $L_{\max,0}$ should be limited and $L_{max,1}$ can be left unconstrained. For the ADM in Figure 3, it can easily be deduced that $L_{max,0} = 1$ [6].

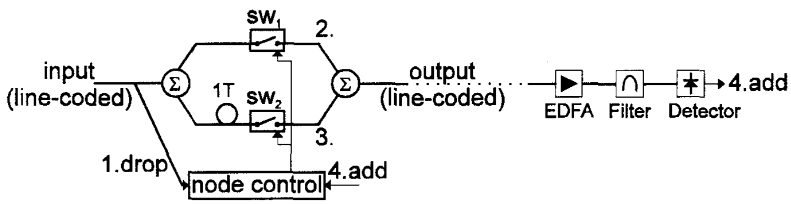

Figure 3: minimal ADM configuration for OOK operation.

An example of such a line-code could be to encode a logical '1' as '11' and a logical '0' as '10'. Since each logical bit is represented by two physical bits the code rate, R, of this example and the Manchester encoding, is given by $R = 0.5$. Runlength Limited (RLL) line-codes, having a code rate $R \geq 0.5$, are widely used in magnetic and optical recording and can be assembled according to the desired runlength constraints. For the ADM shown in Figure 3 the maximum value of R, also termed as capacity, can be as high as $R_{max} \cong 0.694$.

Measurements.

An experimental set-up of the ADM, similar to Figure 3, has been built to demonstrate operation for the OOK case. The ADM's input consists of a 2.5 Gb/s RLL sequence of 10 bits, constraint by $L_{max,0} = 1$. Furthermore, a 3dB coupler was used to perform the copy operation and an 8 cm fibre pigtail in the second branch to obtain a time delay of exactly one bit period. For the electro-optic switches we used Mach-Zehnder modulators. The bit streams of both switch outputs were merged with another 3 dB coupler to yield the RLL 'add' output. Finally, this signal was pre-amplified by an EDFA, optically filtered (FWHM=0.6 nm) and subsequently detected by a broadband PIN photodiode.

The Mach-Zehnder modulators have a fibre-to-fibre loss of about 4 dB and an extinction ratio of over 30 dB. They were DC-biased to minimal intensity output and, according to the 'add' protocol, switched to maximum intensity output by the control node. This 'add' protocol is surprisingly simple and reads:

$$control\_sw_1 = add \wedge drop$$

$$control\_sw_2 = add \wedge \overline{drop}$$

add	1	1	0	1	0	1	1	1	0	1
drop	1	0	1	1	1	0	1	0	1	0
$\overline{drop}$	0	1	0	0	0	1	0	1	0	1
$control\_sw_1$	1	0	0	1	0	0	1	0	0	0
$control\_sw_2$	0	1	0	0	0	1	0	1	0	1

Table 1: add, drop and control sequences of the experiment.

Table 1 gives the 'add' and 'drop' as well as the derived switch control sequences, that we used in the experiment. Figure 4a shows the real-time measured data at 2.5 Gb/s.

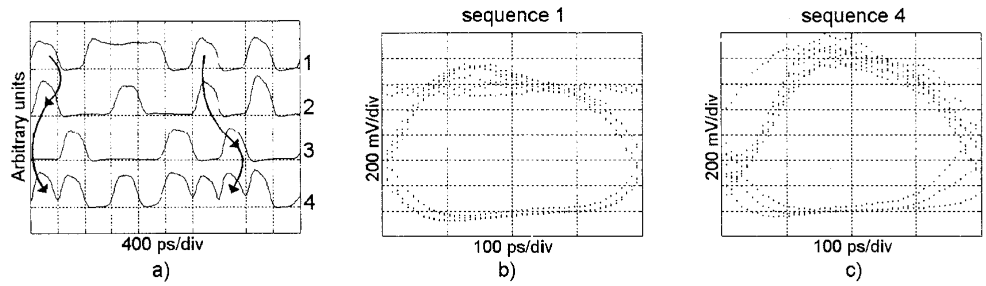

Figure 4: **a.)** 1. the 'drop' sequence; 2. the output of switch-1; 3. the output of switch-2; 4. the 'add' sequence (numbers refer to Figure 3). **b.)** eye diagram of sequence 1 (@ -32 dBm). **c.)** eye diagram of sequence 4 (@ -32 dBm).

Discussion.

Interpretation of the traces has been elucidated by means of the arrows shown in Figure 4a (note: for both branches only one example has been given). Trace 2 consists of the undelayed input bits, whereas trace 3 shows the 1T delayed input bits which were switched to the output.

Figure 4b and 4c depict the eye diagrams for the back-to-back situation (drop) and when including the ADM (add), respectively. Clearly visible is the larger vertical eye opening of the ADM output, compared to the back-to-back situation. This extinction ratio improvement is caused by the electro-optic switches in the ADM. On the other hand, the horizontal eye opening has been reduced as a result of inaccuracy of the delay loop and timing jitter in the switch control circuitry. Some initial measurements have shown that a clear eye diagram can be obtained at a receiver power level of ~ -48 dBm. Finally, it should be noted that other optical switches, like, e.g., semiconductor electro-optic switches, may be used to combat signal losses.

Conclusions.

We have shown a new technique to achieve an optically transparent ADM. The method, which exploits special features of the Runlength-Limited line-coding, does not need a local optical source for its 'add' function and is transparent to wavelength and, in principle, modulation format.

Furthermore, we have experimentally demonstrated extinction ratio improvement for OOK operation at 2.5 Gb/s. As a result, this ADM could be an excellent candidate to be cascaded in transparent optical WDM networks.

References.

[1] D. Boettle, ATM Optical Switching - System perspective, Telekom 1995.

[2] K. Oda, H. Toba, An Optical FDM-Add/Drop Multiplexing Ring Network Utilizing Fiber Fabry-Perot Filters and Optical Circulators, IEEE Photonics Technology Letters, Vol. 5, No. 7, July 1993.

[3] K. Okamoto, K. Takiguchi, Y. Ohmori, 16-Channel Optical Add/Drop Multiplexer Using Silica-based Arrayed-Waveguide Gratings, Electronics Letters, Vol. 31, No. 9, 1995.

[4] Y. Cai, R. M. Fortenberry, R. S. Tucker, Demonstration of Photonic Packet-Switched Ring Network with Optically Transparent Nodes, IEEE Photonics Technology Letters, Vol. 6, No. 9, 1994.

[5] J.M. Rijnders, A.C. van Bochove, A novel optically transparent add/drop node for use in high-speed packet-switched networks, Proc. of the OFC, paper WM9, 1996.

[6] J.M. Rijnders, A.C. van Bochove, Signalprocessor, NL pat. appl. NL1000682, 1995.

[7] K.A. Schouhamer Immink, Runlength-Limited Sequences, Proc. of the IEEE, Vol. 78, No. 11, 1990.