

40 GBIT/S OPTICAL-TDMA LAN OVER 300 METRES INSTALLED BLOWN FIBRE

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Abstract: We demonstrate an optical TDMA LAN with 40 Gbit/s capacity that interconnects computer workstations over installed blown fibre. The LAN is 300 metres long and uses separate fibres within the same cable for clock and data.

Introduction: We have previously demonstrated an optical-TDMA¹ LAN prototype² (SynchroLan) that had a polarisation maintaining (pm) fibre backbone. The LAN used a distributed optical clock: clock and data were distinguished using polarisation by sending them along the slow and fast axis of the pm fibre respectively. However, a more practical solution is to use standard (non-pm) fibre so that existing blown fibre infrastructure³ can be exploited. This also avoids the need for expensive polarisation maintaining components. In this paper we demonstrate a new version of SynchroLan that uses 300 metres of standard installed blown fibre. This achievement was possible for two reasons:

- (i) We have discovered that when optical pulses are sent along separate fibre strands within the same blown fibre cable, the relative jitter at the output due to environmental effects is negligible (see later). This means that rather than using the two polarisation axes of pm fibre to distribute clock and data, separate fibres within the same cable can be used instead.
- (ii) We now have electro-absorption (EA) modulators that have a unique combination of high modulation depth (>30 dB) and low polarisation sensitivity (<1dB). These allow the required time channel to be selected and the other channels rejected at the READ section of each node regardless of the polarisation of the incoming channels.

Experiment: Figure 1 shows a schematic of the LAN. It has a re-entrant bus topology: the CLOCK and DATA fibres pass through the WRITE side of each node before doubling back and passing through the READ side of each node. An optical pulse source generates a continuous 2.5 GHz train of 4 ps optical pulses. This acts as the optical clock for the LAN, and is sent down the CLOCK bus. At the WRITE side of each node (figure 2), a copy of the clock is tapped from the CLOCK bus, is modulated with data using a polarisation-insensitive (<1dB) EA modulator having a 30 dB modulation depth and is added onto the DATA bus. In principle, the output of the EA modulator could be precision-spliced to the DATA bus to ensure that the data channel is inserted into the correct time-slot. In practice, a commercial variable optical delay line is used to achieve this. Having passed through the WRITE side of each node, the DATA bus contains three channels, one from each node, each separated by 25 ps. These are passively split and recombined in such a way as to create six independent channels separated by 25 ps as shown in the inset of figure 1. At the READ side of each node, a copy of the optical clock is tapped from the

CLOCK bus, and a copy of the data channels is tapped from the DATA bus. The data channels pass onto an EA modulator of the same type used in the WRITE sections of the nodes. The optical clock signal is received and filtered to generate a 2.5 GHz electrical clock in the form of a sine-wave. From this a suitable signal is derived to drive the EA modulator so that only one data channel reaches the receiver. A different method is used in each node to achieve this. In node 3, a new scheme is used in which the 2.5 GHz electrical clock is used to drive two 5 V impulse generators, the outputs of which are applied in phase to an EA modulator with 10 V reverse bias. This arrangement is shown in figure 3. In node 2, the 2.5 GHz electrical clock is used to drive a single 5 V impulse generator, the output of which is applied to an EA modulator with 6 V reverse bias. In node 1, a 10 GHz sine-wave is derived from the 2.5 GHz electrical clock, and the 2.5 GHz and 10 GHz signals are applied to an EA modulator with 10V reverse bias. In each node, switching between channels is accomplished by changing the phase of the electrical clock signal using a continuously variable microwave phase shifter, which is capable of switching in 100 ns. In order to test the LAN, synchronous modulation at 2.5 Gbit/s was applied to the WRITE side of each node. Figure 4 shows each channel being selected in turn at the READ side of each node. Figure 5 shows bit-error ratio measurements taken at the output of the READ side of each node. The results for nodes 1 and 3 show a small penalty of less than 1 dB. The results for node 2 show a penalty of 2 dB, because the 5V output from a single impulse generator is insufficient to allow the required combination of high modulation depth (30 dB) and narrow transmission window (15 ps) to be achieved simultaneously with the EA modulator.

We have performed measurements to assess the relative jitter between clock and data at the READ section of node 1: the 2.5 GHz electrical clock from the node was used to trigger a sampling oscilloscope on which the output of the DATA fibre was displayed on infinite persistence for several hours. The results indicated that if there is any relative jitter/drift between clock and data due to the 300m blown fibre path and the microwave components in the READ section of the node, it is less than 600 fs rms.

Each workstation has a 155 Mbit/s network interface card, the output of which drives the EA modulator within the WRITE side of its node. In this way, the data from the network interface card is over-sampled by the 2.5 GHz optical pulse-train. The output of the receiver within the READ side of the node is connected to the input of the network interface card. 2.5 Gbit/s network cards are not available at present for workstations, but it is reasonable to assume that these will be available in the near future because even today the backplane bandwidth of a high-end workstation is 1.6 GByte/s (= 12.8 Gbit/s). A fixed time-slot assignment is used at the WRITE side of each node, so connections between workstations are created by having each workstation tune to the appropriate time-slot at the READ side of its node. This is accomplished by using a digital to analogue converter within the workstation to control the microwave phase shifter, thus allowing the workstation to switch between channels. An access protocol is required to avoid contention. This is implemented by having a central controller that holds a dynamic connection table. Signals are sent between workstations and the central controller in order to set up connections between workstations. These signals are carried out-of-band over ethernet, although in principle they could be carried in-band.

In summary, we have successfully demonstrated a 40 Gbit/s optical-TDMA LAN called SynchroLan that runs over standard installed blown fibre and uses polarisation insensitive electro-absorption modulators within the WRITE and READ sections of the nodes. The LAN is logically equivalent to an $N \times N$ cross-bar switch, where N is the number of nodes. However, in contrast to the cross-bar switch, the LAN scales as N instead of N^2 , has a natural broadcast/multicast capability and merges the transmission and switching into one. The use of optical-TDMA means that in order to extend the reach, the entire contents of the LAN backbone could be digitally regenerated using a *single* 40 Gbit/s all-optical regenerator⁴.

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¹ A.P. Perrier and P.R. Prucnal, "High-dimensionality shared-medium photonic switch", *IEEE Transactions on Communications*, **41**, 224, (1993)

² J.K.Lucek, P.Gunning, D.G.Moodie, K.Smith, A.D.Ellis and D.Pitcher, "40 Gbit/s optical TDMA LAN", *ECOC '96 post-deadline paper* THC.3.5

³ S.A.Cassidy and M.H.Reeve, "A radically new approach to the installation of optical fibre using the viscous flow of air", *BT Technology Journal*, **2**, 56 (1984)

⁴ J.K. Lucek and K. Smith, "All-optical signal regenerator", *Optics Letters*, **18**, 1226 (1993)

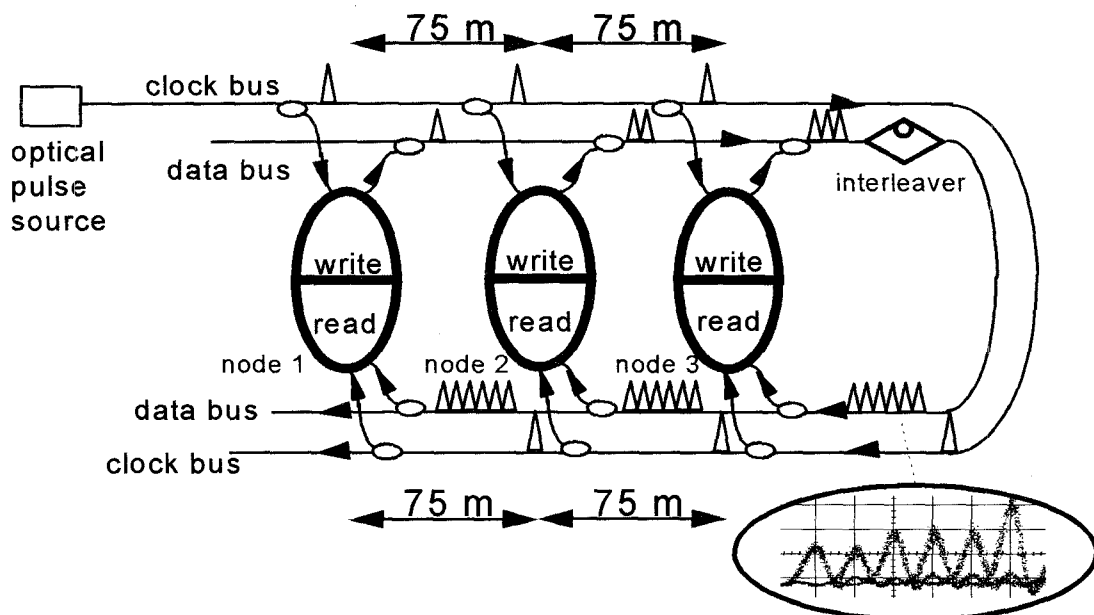


Figure 1: schematic of SynchroLan prototype. Inset shows sampling oscilloscope trace of the six bit-interleaved channels (scale=25 ps/division)

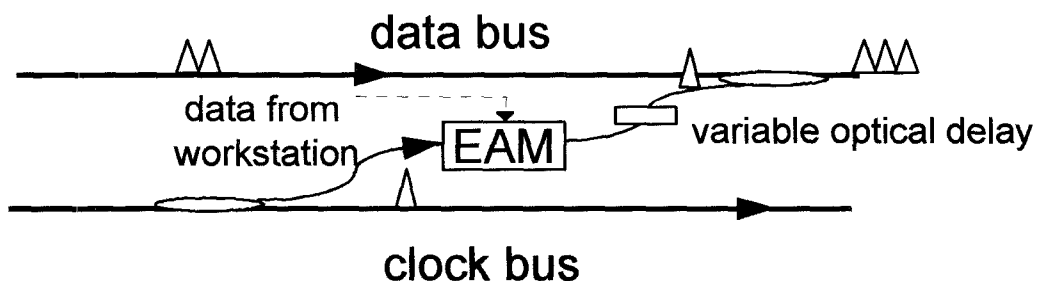


Figure 2: WRITE section of node. EAM=electroabsorption modulator

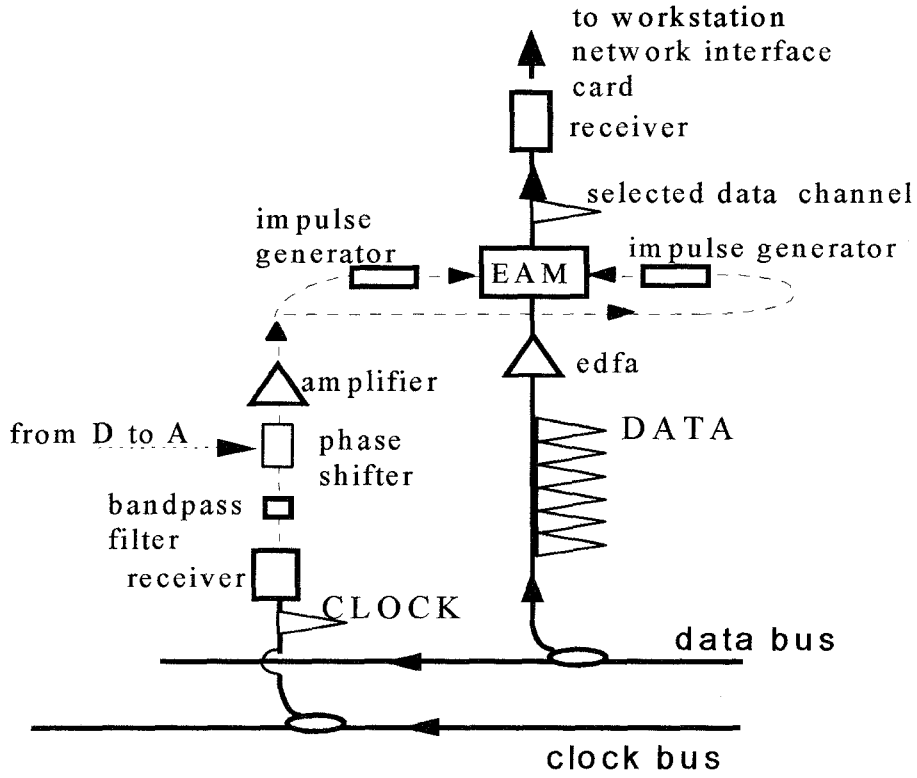


Figure 3: READ section of node 3. EAM=electroabsorption modulator

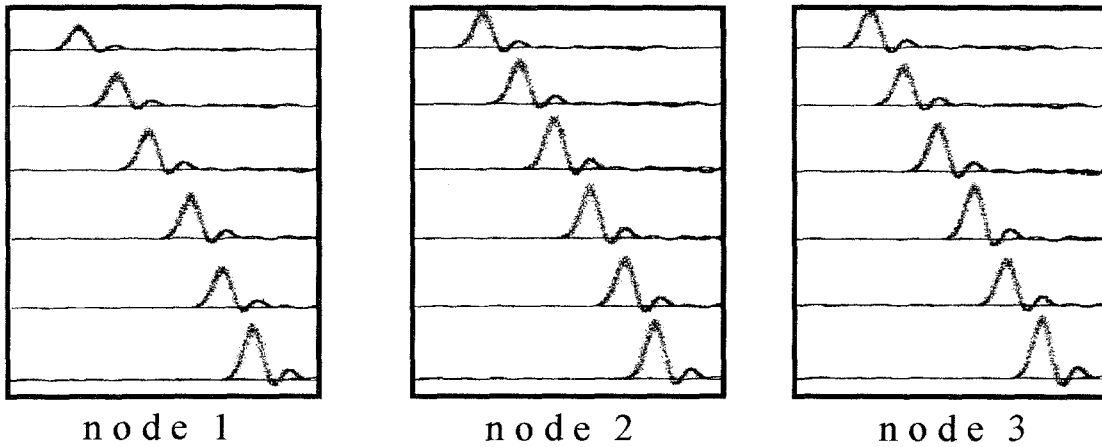


Figure 4: Output from READ section of each node

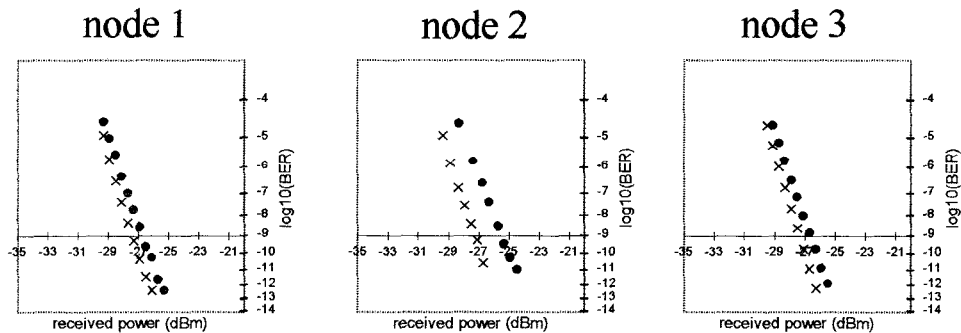


Figure 5: Bit-error ratio plots. Crosses=back-to-back, circles= output of READ section of node. 2^{15} -1 patterns were used.