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Using Fiber Grating to Compensate Differential Delay in a WDMA/TDMA ”Switchless” Optical Network

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Abstract— **Differential delays due to fiber dispersion represent the ultimate limitation on achievable guard-times and packet durations for WDMA/TDMA ”switchless” optical transport networks. A delay compensator based on fiber gratings is proposed to decrease such delays**

Keywords—**”Switchless” Optical Network, Delay Compensation**

I. WDMA/TDMA ”SWITCHLESS” OPTICAL NETWORK

The European Union ACTS project SONATA has shown the feasibility of a PON-based (passive optical network), 200 Tbit/s ”switchless” optical network transport architecture on a national scale [1] serving up to 20 million terminals, capable of transporting and switching multiple client layers (eg ATM, PSTN) within a single optical technology layer, with common control for all client layers. No electronic switches or cross-connects are required within the national-scale network. A WDMA/TDMA, burst-mode optical packet format is employed, using time-slots within frames on each wavelength. A time-slot of 10 ms and a frame duration of 10 ms are envisaged, i.e. 1,000 time-slots per frame. For a national-scale network, up to 800 wavelength channels are employed with 0.05 nm channel spacing within each PON, using heterodyne detection. Signalling is required between end terminals and a network controller, to request and allocate time-slots (optical packets) on appropriate wavelength channels to prevent packet collisions and output contentions at the receiving terminals.

The ”switchless” optical network [1] is intended to perform the concentration/distribution, switching and routeing functions within a single network layer by providing end-to-end optical connections between a large number of terminals, over a large geographical area extending to 1,000 km from terminal to terminal. The structure is shown in figure 1.

The fast tunable terminals are attached to amplified passive optical network (PON) infrastructures directly connected to a single passive wavelength router with N input and N output ports, i.e. an N´N wavelength multiplexer. Any terminal wishing to communicate with another terminal simply tunes its transmitter and receiver, in the allocated time slots, to a wavelength channel carrying multiplexed traffic through the wavelength router between the pair of PONs to which the transmitting and receiving terminals are attached.

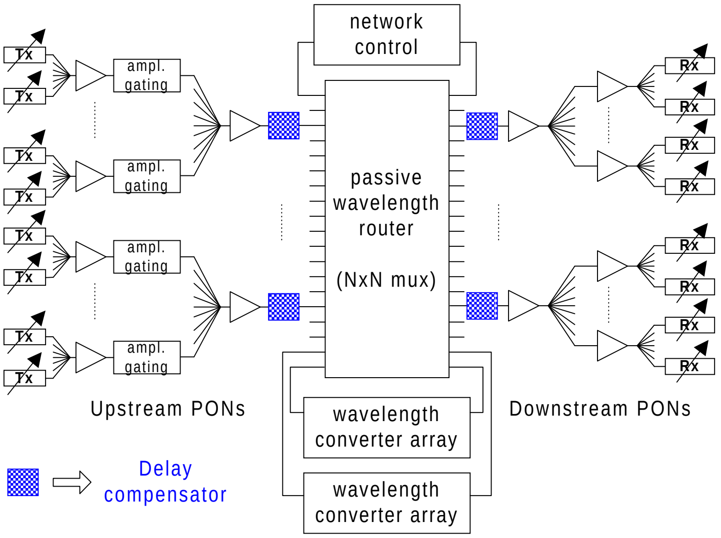

Fig. 1. Reference structure of the WDMA/TDMA ”switchless” optical transport network architecture.

II. PACKETISATION ISSUES

A guard-time is necessary between packets in order to accommodate three forms of delay; i) tuning delays, ii) any differences in propagation delay between packets passing straight through the wavelength router to their destination PONs and those going via wavelength converters and also iii) any differential propagation delays between different wavelengths resulting in packets of different wavelengths colliding at the receivers. The total guard-time required in SONATA is in the 1-2 ms range, which forces the time-slot duration to be 10 ms to ensure reasonable transmission efficiency. At an operational bit-rate of 622 Mbit/s this leads to packet sizes of around 5,000 bits. Such sizes are perfectly acceptable for high bit-rate applications such as switched video, but are very inefficient for low bit-rate information sources with delay constraints, such as telephony. If we assume a 20 ms packetization delay is acceptable for telephony, this requires only 160 bytes or 1,280 bits per packet, lasting 1,280/622=2.06 ms. To achieve 90% packet efficiency for telephony, shorter guard-times around 230 ns and time-slots around 2.29 ms would therefore be desirable.

Tuning delays can be eliminated simply by the use of two tunable lasers in parallel, where one is tuned in readiness for the next packet (time-slot) while the other one is still transmitting its packet. Additional propagation delay for packets going via a wavelength router can be eliminated by unfolding the topol-

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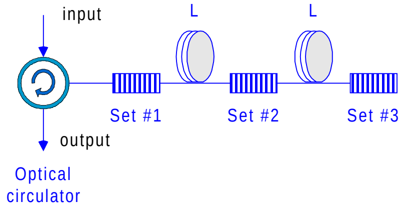

Fig. 2. The differential propagation delay compensator.

ogy of figure 1 using two stages of wavelength routers through which all packets must propagate. But differential delays due to fiber dispersion represent the ultimate limitation on achievable guard-times and packet (slot) durations. We cannot simply use dispersion-shifted fiber to reduce the differential delay, because the strong effects of fiber non-linearities on transmission performance would greatly reduce the potential number of wavelength channels deployable [1]. The method adopted here is to provide discrete differential delay compensators located in the input and output ports of the wavelength router. The differential delay compensators are highly shared by all the terminals on a PON, ensuring a low-cost solution. The degree of dispersion compensation within each compensator would be matched to the length of the PON in which it is used.

III. DIFFERENTIAL PROPAGATION DELAY COMPENSATOR

This section describes the experimental setup used to compensate the differential propagation delay across the 40nm-wide Er C-band, over 1,000 km of standard single-mode fiber, down to a residual value suitable as the packet guard-time for efficiently transporting telephony. The compensator is illustrated in figure 2. It consists of a three port optical circulator and three broadband fiber gratings [2]. Light coming from the fiber enters the circulator and is reflected by the gratings. Each of three wavelength bands is reflected by a different grating, so the delay imposed by the compensator can be used to compensate the fiber's differential propagation delay. Each band of wavelengths is designed to be 13 nm wide (with a 1 nm spectral guard-band), to cover the Er C - band with just three filters.

The fiber's differential propagation delay between two signals traveling at different wavelengths is a function of the fiber dispersion and the wavelength spacing and it is defined as [3]

$$\Delta\tau = L\Delta\lambda.D\left(\lambda_c\right) \tag{1}$$

where L is the fiber length, $\Delta\lambda$ the separation between wavelengths, $D(\lambda)$ the fiber dispersion, and λ_c the central wavelength. For a "switchless" optical network having L = 1,000 km maximum span between terminals, using standard fiber with D = 17 ps/nm/km, the differential delay across 40 nm is 680 ns. But across the 13 nm passband of each fiber grating it is just 221 ns, which is within the required guard-time of 230 ns. The delay provided by the compensator is defined by the separation between the gratings. The wavelength spacing between the fiber-grating passbands is designed to be 14 nm, and so, because there are two compensators, one on each side of the wavelength converter, the round-trip fiber delay required between the fiber gratings should be 1,000x14x17/2 ps = 238/2 ns =119 ns (approx. 11.9 m of fiber).

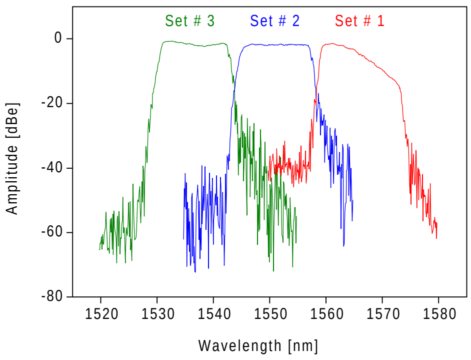

Fig. 3. Measured amplitude response of the fiber gratings.

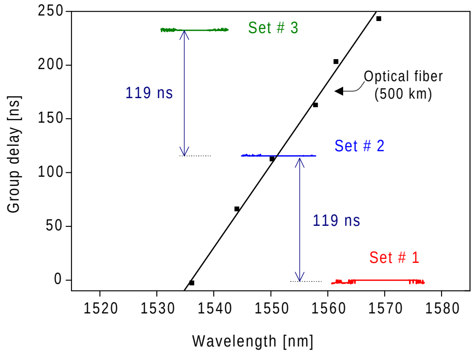

Fig. 4. Measured delay for the compensator and for 500 km of SMF.

3-mm long gratings were designed to have flat amplitude response and constant group delay inside the reflection bandwidth. The phase-shift technique [2] was used to measure the amplitude and group delay characteristics of each individual grating. The amplitude response is illustrated in figure 3. The gratings were separated by approximately 11.9 m of Standard Single Mode Fiber (SMF). The relative delay imposed by the compensator and the fiber's differential delay for 500 km of SMF were measured using a time domain technique. Figure 4 shows the measured group delay for both cases. The delay imposed by the gratings is 119 ns between Set #1 and Set #2 and between Set #2 and Set #3. The total delay after the compensator is shown in figure 5.

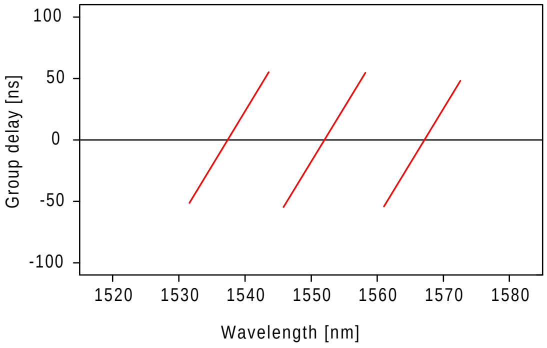

Fig. 5. The group delay after 500 km of fiber plus the compensator.

IV. CONCLUSIONS

Differential delay compensators based on fiber-grating filters have been shown to provide reduced guard-times and packet (slot) durations in a WDMA/TDMA ”switchless” optical transport network. This will enable such networks to provide efficient transport of low bit-rate applications such as telephony, as well as broadband applications such as switched video.

REFERENCES

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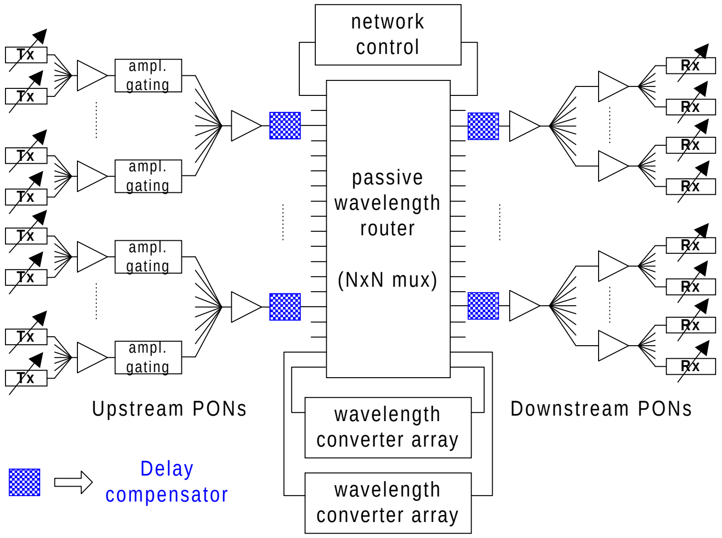

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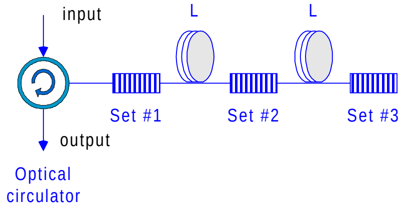

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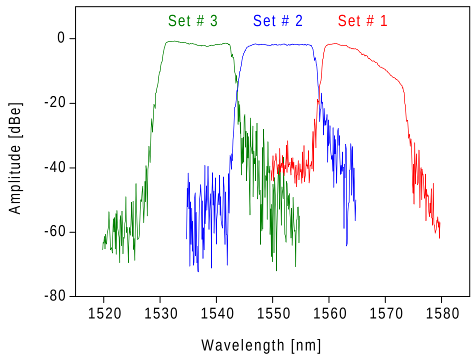

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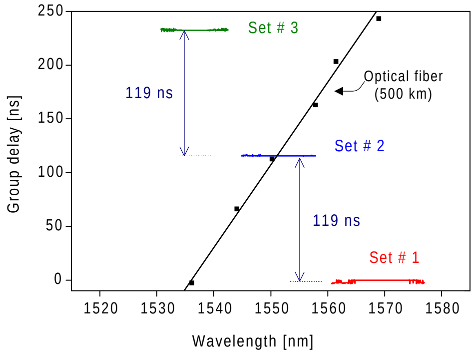

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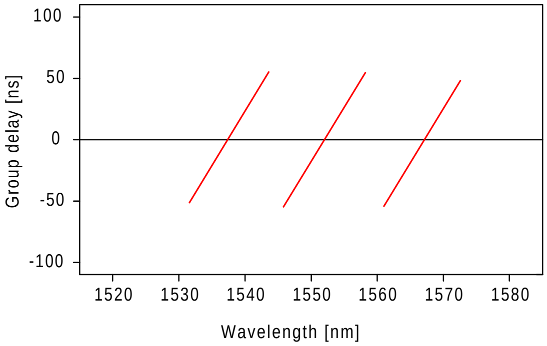

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