Advanced infrastructure for photonic networks - state of the art and prospects

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Key words: networks, optical systems, WDM, wavelength, 40 Gb/s

Abstract:

We report the main results from the IST ATLAS project on the transmission techniques for new network infrastructures. We show how future transport networks can be based on the nx40 Gbit/s transmission with wavelength conversion and we report an example for European network.

1. Introduction.

Future telecommunication networks operating on wide areas will have to support a total traffic of the order of some Tbit/s. Such a huge capacity will be transmitted by means of the Wavelength Division Multiplexing (WDM) technique, or better with Dense WDM (DWDM) [5-6] and processed at the nodes by means of devices as Optical Cross Connects (OXC) [1] and Optical Add Drop Multiplexers (OADM) [1]. Due to the traffic increasing and to the fact that transmission at 40 Gbit/s seems to be close to field testing, we believe that future telecommunication transport networks, especially if operating on wide geographical areas, will be based on the Nx40 Gbit/s transmission systems [6], even though the network design in this environment requires many ingenious contrivances [7-8]. Furthermore it is well known that the All Optical Wavelength Conversion (AOWC) is a fundamental requirement for future networks [1] and in the current literature many works consider such a process as already commercially available; this scenario is particularly evident in papers dealing with novel switching techniques as the optical packet switching and the optical burst switching. However, also for networks that do not consider a too much deep innovation, and in particular for network still based on a circuit switching operation, the wavelength conversion could strongly improve the network performance. Two are the main advantages of the wavelength conversion: the dynamic allocation of the resources and the restoration. As far as the first advantage is concerning we can simply say that the wavelength conversion permits to carry the information using suitable regions of the fibre bandwidth according to the evolution of the traffic requirements along the time. Wavelength conversion can be considered as a fundamental recipe for networks based on the bandwidth-on-demand.

In this paper we report the experience of the IST ATLAS project in the field of the advanced infrastructure of transport networks. In particular we show the high performance of the nx40 Gbit/s transmission also in links encompassing G.652 fibres and in the presence of AOWC based on Periodical Poled Litium Niobate (PPLN) devices. We also show how to implement future transport networks based on the nx40 Gbit/s transmission.

2. An overview of the IST ATLAS project

The aim of the ATLAS (All-optical Terabit per second LAmbda Switched transmission) project was to investigate transmission techniques at very high capacity over long distances (500-1000 km), taking into account the behaviour of some fundamental devices that will be used in future Terabit/s networks, such as the optical wavelength converters that should perform routing operations in the network nodes.

In the ATLAS project fibre-optic WDM transmission over 500 –1000 km with an aggregate capacity of 1 Tbit/s was pursued by adopting return-to-zero signal format and the dispersion management technique. 40 Gbit/s and 80 Gbit/s in-line optical wavelength converters were experimented to investigate the role of the wavelength converters in optical transport networks.

The main experiment of the ATLAS project was the field demonstration of the transmission of four channels at 40 Gbit/s in a link 500 km long with an amplifier spacing of 100 km by adopting both G.652 and G.655 fibres. One of the channel was also converted in frequency along the line, simulating in this way the signal behaviour in a future transport network. Theoretical studies showed how extend such performance to a Tbit/s transmission over distances of the order of some thousands of kilometres.

In table 1 we report the list of the ATLAS participants. More details can be found in www.fub.it/atlas/:

Fondazione Ugo Bordoni	ITALY
Pirelli LABS	ITALY
United Monolithic Semiconductors	FRANCE
Opto Speed SA	SWITZERLAND
Thales	FRANCE
University of Ljubljana	SLOVENIA
Instituto de Telecomunicações	PORTUGAL
University of Paderborn	GERMANY
Consorzio Padova Ricerche	ITALY
University College of London	UNITED KINGDOM
Istituto Superiore delle Comunicazioni	ITALY
Optospeed Italia	ITALY

Table 1: ATLAS participants

3. Transmission experimental results

In this Section we report some results on the 4x40 Gbit/s transmission performed in the PIRELLI LABS laboratories. Results on the field trial performed in Rome during summer 2002 will be reported at next OFC2003 conference.
In fig. 1 we report the scheme of our 40 Gbit/s transmitter based on the electrical 4x10 to 1x 40 Gbit/s multiplexing.

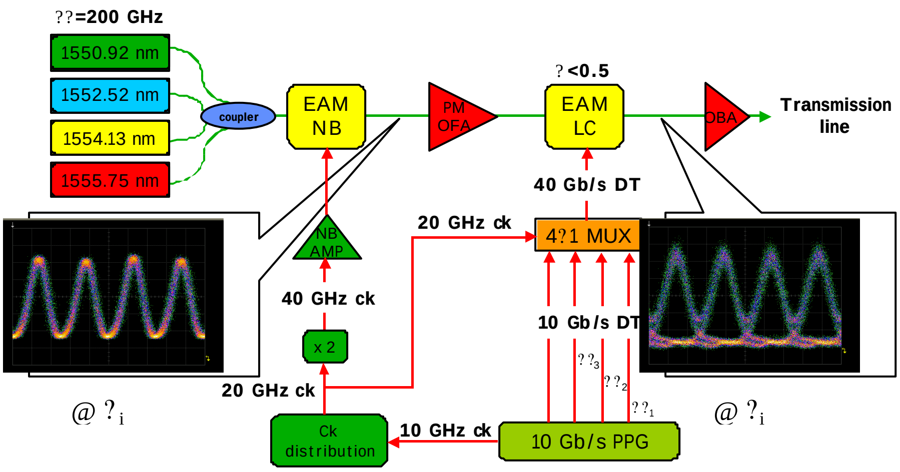
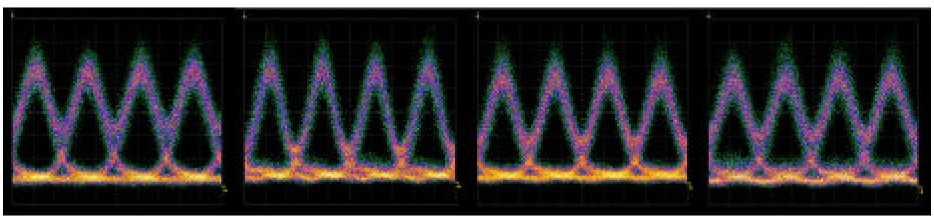


Fig. 1: scheme of the 40 Gbit/s transmitter. By means of the 4 CW laser four 40 Gbit/s channels are obtained.

In fig. 2 we report the eye diagrams of the four channels after the transmission in a link 500 km long encompassing G.652 fibres with an amplifier spacing of 100 km. The transmission was obtained by compensating the chromatic dispersion at each fibre span by means of Dispersion Compensating Fibres (DCF).



Ch 1 (1550.92 nm) **Ch 2** (1552.52 nm) **Ch 3** (1554.13 nm) **Ch 4** (1555.73

Fig. 2: eye diagram of the four channel after the transmission in a G.652 link.

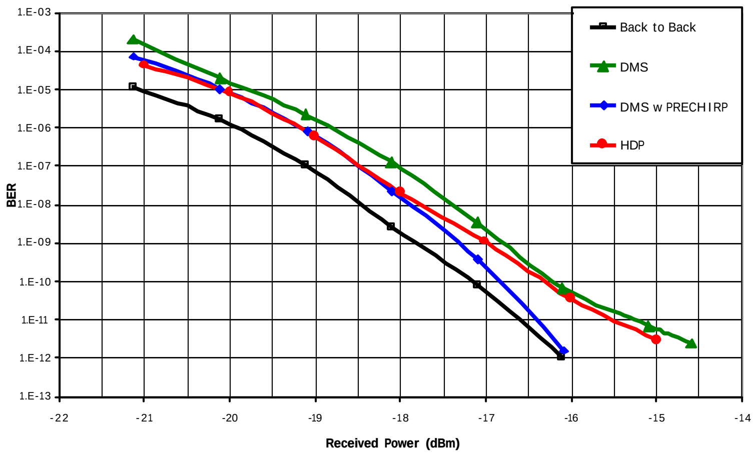


Figure 3: 4 channels 40 Gb/s transmission performance over 5 x 100 km G.652. Channel 2 BER curves with different compensating map: DM and DM with –78 ps/nm pre-chirp (14 dBm/span, 4 dBm/DCU), and HDP (12 dBm/span, 10 dBm/DCU). OSNR is 17 dB for all cases.

In fig. 3 we report the BER measurements on channel 2 considering different dispersion schemes: DMS means periodically compensation of the chromatic dispersion at each amplifier position, DMSPRECHIP is as DMS but with a prechirp at the link input [7] and HDP high dispersive pulse means a scheme in which all the compensation is performed at the end.

As shown in figure 3, where BER curves versus received power are reported for the same channel with the different schemes, DMSPRECHIRP (the prechirp was –78 ps/nm) is confirmed as the best choice: no power penalty is noticeable with respect to back to back at 10^{-12} BER, with 14 dBm/span and 4 dBm at DCF. With the same power levels and OSNR (17 dB) but without pre-chirp, the penalty increases and a slope decline is evident too. With HDP scheme we had to slightly decrease the power level per span (12 dBm), increasing the power levels on the DCF modules (10 dBm) instead: the performance is quite similar to straight periodic post-compensation.

The results shown in fig. 3 illustrate that the multichannel transmission at 40 Gbit/s can be obtained with negligible degradation (especially by using suitable dispersion management) also in long links with strong impairments as high chromatic dispersion and long amplifier spacing.

4. All Optical Wavelength Conversion

One of the objective of IST ATLAS project was the development of all-optical wavelength converters based on three different methods: (I) quasi phasematched (QPM-) cascaded ? (2):? (2)-difference frequency generation (cDFG) in Ti-diffused, periodically poled $LiNbO_3$ (Ti:PPLN) waveguides, (II) four-wave mixing in semiconductor optical amplifiers, and (III) non-linear switching in semiconductor quantum well structures. These techniques have different advantages, disadvantages and degrees of technological maturity. It was therefore decided to develop the three techniques and then select the most suitable one for use in the ATLAS field experiments. After several experiments we have verified that the PPLN device, with polarisation independent scheme, is the one that can be assumed as almost ideal device.

In fig. 4 we report the PPNL AOWC [9].

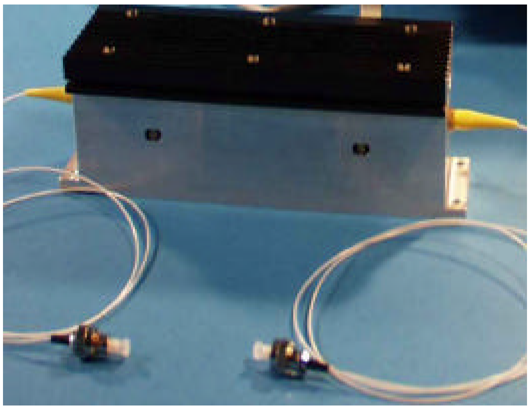


Fig. 4: The PPLN AOWC.

In fig. 5 we report the eye diagram after the conversion with PPLN (on the left) and after the transmission in a G.655 link 500 km long. Also the 10 Gbit/s demultiplexed signal is reported.

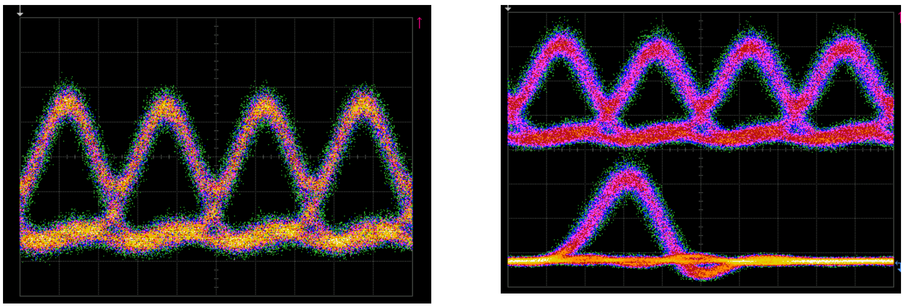


Fig. 5: eye diagram after the conversion with PPLN (on the left) and after the transmission in a G.655 link 500 km long.

As shown by figure 5, and also by BER measurements [9], no relevant penalty was observed after conversion and transmission.

5 Performance of nx40 Gbit/s

The results on the performance of WDM systems based on the 40 Gbit/s channel are summarised in fig.(6), where we report the maximum number of channels versus distance for (a) transmission with the DMS-PRECHIRP technique with a T_{FWHM} pulse duration of 5 ps and a frequency spacing among the channels of 200 GHz by using EDFA, and (b) transmission with the DMS technique with a T_{FWHM} pulse duration of 8.5 ps and a frequency spacing among the channels of 100 GHz by using both EDFA and of Raman/EDFA amplification [10].

The different time duration of the pulses corresponds two the best propagation regime that can be achieved in the DMS and DMSPRECHIRP scheme. In particular the 5 ps duration does not permit a frequency spacing narrower than 200 GHz, conversely the 8.5ps allows us to reach a minimum frequency spacing of 100 GHz. The worst impact of the 100 GHz spacing is a limitation in terms of maximum propagation distance for each channel. Conversely the narrow frequency spacing permits to have more channels, and this is due to a less impact of the Raman Crosstalk.

The presence of Raman amplification deeply permits to increase the WDM system performance, both in terms of maximum propagation distance and number of channels.

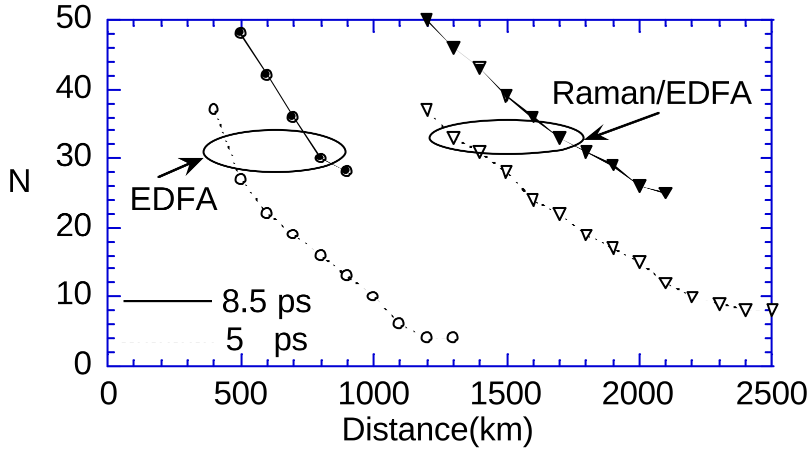


Fig. 6: Maximum number of 40 Gbit/s channels vs distance in links encompassing G.652 fibres with an amplifier spacing of 100 km, by using both EDFA amplifiers and hybrid Raman/EDFA. Dotted line refers to the DMSPRECHIRP technique with a T_{FWHM} pulse duration of 5 ps and a frequency spacing among the channels of 200 GHz and solid line to DMS technique with T_{FWHM} pulse duration of 8.5 ps and a frequency spacing among the channels of 100 GHz.

6 Optical Transport Networks based on the 40 Gbit/s transmission

From this numerical analysis we have obtained the results that permit the design of a wide geographical transport network and as example we have taken into consideration a model for a European network proposed within of the European COST 266 project, assuming 26 nodes (fig. 7) [12].

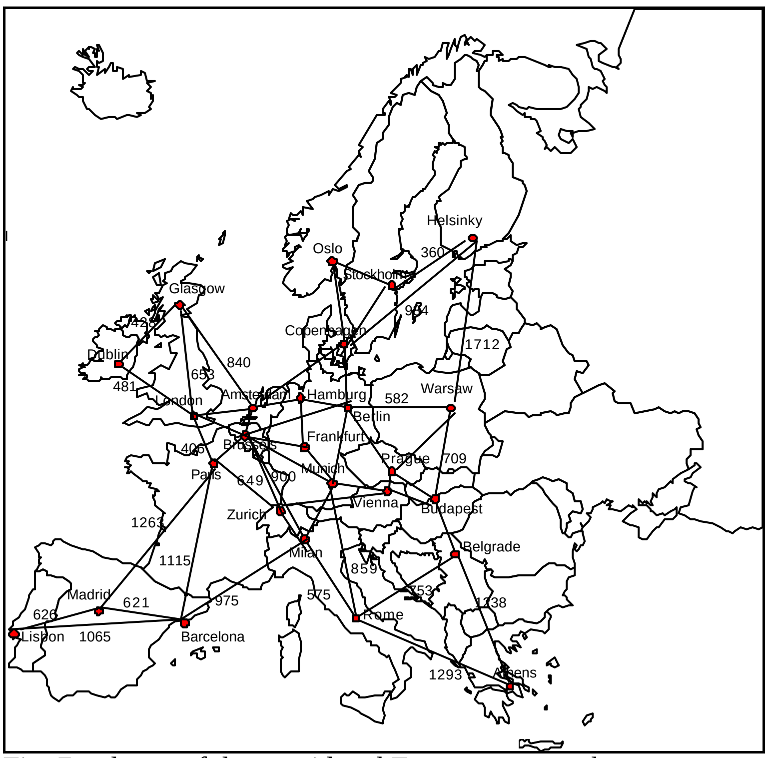


Fig. 7: scheme of the considered European network.

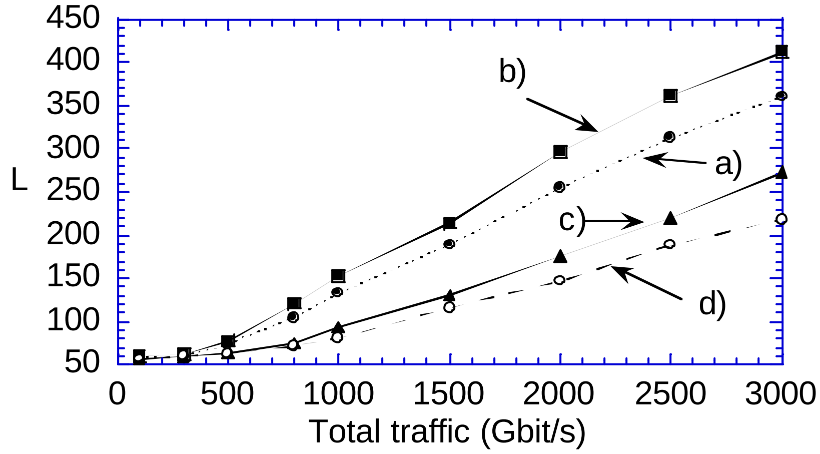


Fig. 8: Number of 40 Gbit/s lightpaths vs distance in links encompassing G.652 fibres, by using: a) transmission with the POC-PRE technique with a T_{FWHM}=5 ps, ?f=200 GHz and EDFA, b) POC technique with T_{FWHM}=8.5 ps, ?f=100 GHz and EDFA, c) POC technique with T_{FWHM}=8.5 ps, ?f=100 GHz and Raman/EDFA, d) ideal propagation.

In fig. (8) we report the number of lightpaths versus the total traffic by using different nx40 Gbit/s transmission techniques:

(a) transmission with the DMSPRECHIRP technique with a T_{FWHM} pulse duration of 5 ps and a frequency spacing among the channels of 200 GHz by using EDFA;

(b) transmission with the DMS technique with a T_{FWHM} pulse duration of 8.5 ps and a frequency spacing among the channels of 100 GHz by using EDFA;

(c) transmission with the DMS technique with a T_{FWHM} pulse duration of 8.5 ps and a frequency spacing among the channels of 100 GHz by using hybrid Raman/EDFA amplification;

(d) represents the case of ideal propagation and it means that the lightpaths can have any length.

Practically the case (d) could be achieved by means of either optical or electrical 3R regenerators. A preliminary numerical investigation on the 40 Gbit/s optical 3R regeneration, based on the semiconductor optical amplifiers, was also carried out and it showed that by locating the optical 3R regenerators every 500 km, a maximum propagation distance of 4500 km can be reached.

The (b) technique is the simplest to be achieved since the chromatic dispersion control is less severe (absence of prechirp) but it is the one that requires more lightpaths since the signal can propagate on shorter distances. In case (c) the number of lightpaths can be much less than in (a) and (b) since the scheme Raman/EDFA allows the signal to propagate on longer distances. The advantage of (d) with respect to (c), in terms of lightpaths, is not so relevant since, in the European network scheme, the paths longer than 2000 km, that should carry heavy traffic, are not so many. Furthermore in case (d) the network complexity could increase very much due to the presence of the optical 3R regenerator that is a device that still requires several contrivances.

For a correct interpretation of the results, it is clear that in case (c) it is not necessary the presence of Raman/EDFA amplifiers in all the links of the networks, but only in the links containing lightpaths that require a distance longer than 900 km. At the same way, in case (d) the presence of the 3R regeneration it is required only in links containing lightpaths longer than 900 km.

7. CONCLUSIONS

The ATLAS project has demonstrated that future reconfigurable transport telecommunication networks, also in very wide terrestrial applications, can be based on the RZ transmission at 40 Gbit/s by using the DWDM technique in combination with all-optical wavelength conversion to enable blocking free routing in the nodes. The experience made in the fabrication of electronics devices shows that 40 Gbit/s transmitter and receivers will be integrated in small devices with a predicted cost that will be comparable with those for components for 10 Gbit/s WDM networks.
The results which we achieved, together with the recent market research reports on the growth of data traffic, show that the 40 Gbit/s WDM techniques are a correct promising solution for future networks since they can reduce the number of optical components needed in the core switches. In fact, the number and the size of switching matrices and the number of filters is reduced since only a quarter of channels is required.

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