On the Evolution of the Optical Infrastructure — COST 266 Views —

**T. Cinkler†, S. Bjornstad, D. Careglio, D. Colle,
Ch. Gauger, M. Karasek, A. Kuchar, S. de Maesschalck,
F. Matera, C. Mauz, M. Settembre**

†cinkler@ttt-atm.ttt.bme.hu, http://www.hsnlab.hu/~cinkler
Department of Telecommunications and Telematics
Budapest University of Technology and Economics

Abstract

This paper discusses the evolution of optical systems starting from WDM links to Optical Packet Switching Networks via some stages as Switched Optical Networks, Multilayer Networks with either traffic or wavelength grooming, Optical VPNs and Optical Burst Switching. We discuss the advantages and drawbacks of certain approaches since the future developments of optical networking technology might influence this evolution. We also draw our near-term and long-term visions of optical networking.

1. Introduction

There is no dubt, the near future infocommunications will be based upon optical networking. However, as the amount of traffic grows the technology enabling optical networking develops as well. Therefore, an evolution is expected in this field, not a revolution. In this paper we discuss this step-by step development roadmap, by analyzing the advantages and drawbacks of certaion approaches and by drawing a likely evolution scenario.

As seen in Figure 1 in the early phases of WDM employment the capacity of point-to-point links has been extended by carrying multiple signals over a single fiber by different wavelengths. The next step was adding Add-Drop multiplexers to that link to be able to add and drop signals of certain wavelengts. This was followed by forming rings of OADMs, and interconnecting these rings by Optical Cross-Connects. In these rings, the protection was trivial, however, when traffic had to be routed over multiple rings, the routing was not trivial, and resource usage, particularly in csae of protection was not optimal. Furthermore, there was a large amount of "pass-through traffic" at inter-ring junctions.

The next step was to build mesh networks, i.e., networks of general topology. with arbitrary density and arbitrary constraints on maximal shortest cycles. To carry out various investigations (e.g., configuration algorithms) and to compare them, we have defined a 30-node, 39-link fictive European reference mesh network, and four variants of it: a sparser, a denser, a smaller and a larger one. This network is described in details in [1]. Not only the topology, but

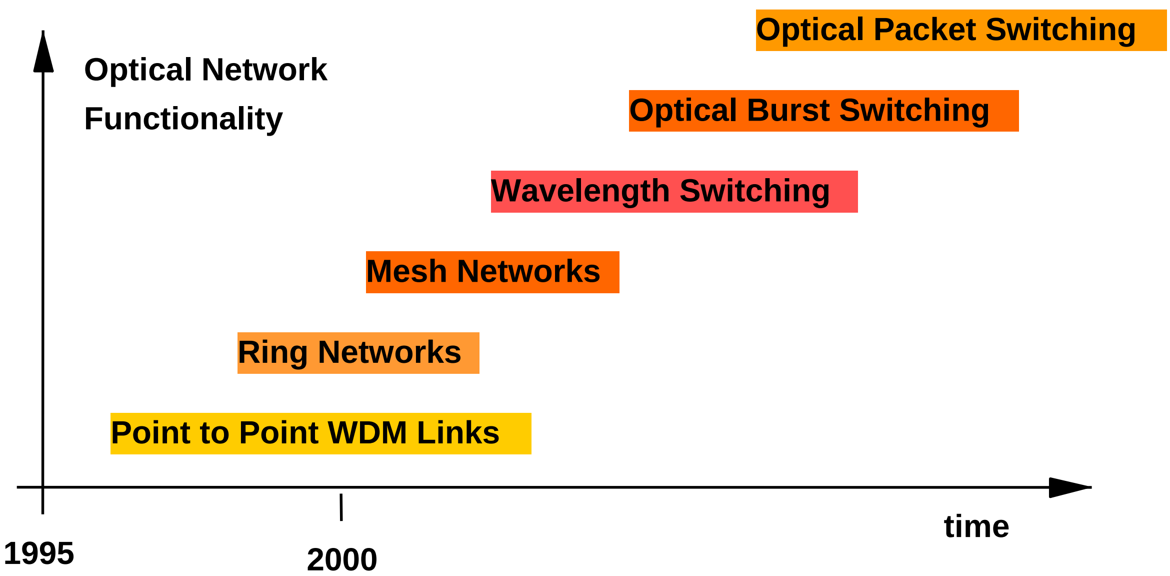

Figure 1: The Optical Networking Evolution Road Map

estimated traffic matrices are given over a 5 year time scale.

First static configuration will be discussed, then dynamic routing followd by various protection alternatives and problems related to multilayer networks. Thereafter Optical Time Division Multiplexing will be discussed, as well as various grooming strategies.

2. Shell the physical limitations be taken into account?

There has been a discussion whether the networking layer should be completely independently designed of the physical layer? Theoretically, the answer is positive. However, then it is required that the physical layer equalises different levels of signal, regenerates them all, and performs reshaping and retiming as well.

However, all optical 3R (Regeneration + Reshaping + Retiming) is not yet commercially available and will not be affordable soon, therefore, some effects should be considered. Since G.652 fibres are most widely used in Europe, effects like four wave mixing *(FWM),* cross-phase modulation *(XPM)* and *chromatic dispersion* should be mentioned.

Transmission of nx40 Gb/s per fibre is now mature by using:

- ***dispersion management*** (DM): In this case the dispersion of a section is compensated by a short section having characteristics inverse to the section being compensated. In this case distance of 900 km can be overbridged in G.652 fibres.
- ***DM plus prechirp***: In this case a part of the compensating section is put before the section that is being compensated. By this approach a distance of 1200 km can be overbridged in G.652 fibres.
- ***hybrid Raman/EDFA plus DM***: In this case Raman amplification jointly with EDFA (Erbium Doped Fibre Amplifier) shell be used with DM. This approach allows overbridging distances of 2000 km in G.652 fibres.
- ***optical 3R regeneration plus DM***: This approach allows overbridging distances of even 4500 km. However, this is still not enough for a world-wide network.

Wavelength conversion at 40 Gb/s is also ready! Either Periodically poled Lithium Niobate (PPLN) should be used or the FWM effect in semiconductor optical amplifiers (SOA).

In Figure 2 obtained by simulations it can be seen for the above mentioned European optical network that the worst performance was that of the optimal WDM system with dispersion managent without prechirp, with longer pulses, denoted by b) in the figure. This means that the largest number of wavelength channels per fiber were needed for carrying the required amount of traffic in an statically optimally configured network. The next curve denoted by a)

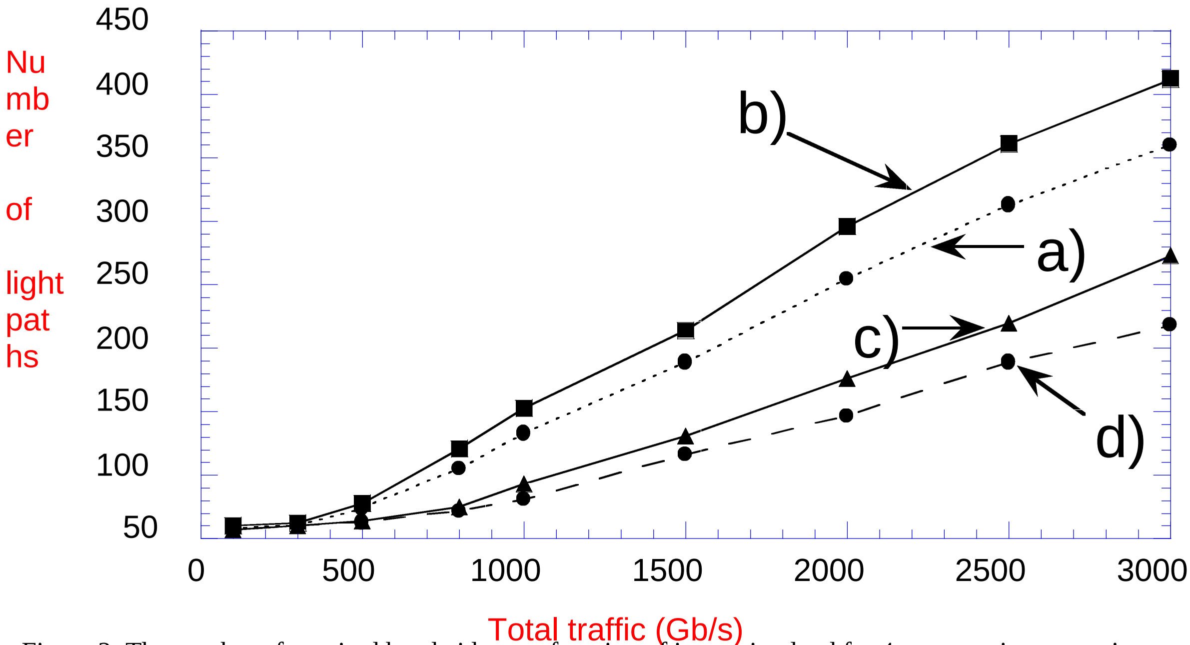

Figure 2: The number of required bandwidts as a function of increasing load for 4 regeneration strategies

corresponds to the case of optimum single channel transmission with dispersion managent with prechirp. Case c) corresponds to the case analogous to that of b) but with exploring the Raman effect and with EDFA. The last case (curve denoted by d) assumes use of optical 3R regeneration. Case c) is here the most promissing, since it provides only slightly worse than d) while realisable by available and affordable components. In this case the required number of wavelengths is significantly lower than either in case a) or b) for the same amount of traffic.

This was the static configuration of the mesh networks, by taking physical limitations into account.

3. Switched or Dedicated (Leased-Line-like) Connections?

There are networks of both types. SDH/SONET is for example a typical "leased" network with dedicated connections, while ATM for example can be switched as well. While in networks with leased connections the network operator sets up and tears down the connections in days or weeks, in switched networks the connections are set up in a few seconds through user signalling, and the resources are released imediately, whenever not needed anymore. This leads to more efficient resource usage, however, it needs a complex signalling system. Furthermore, routing must be fast enough even in large networks, therefore, the state information of network elements has to be spred (flod, advertised) through the network and source routing should be used. In [2] an overview of switched WR-DWDM networks is given.

There are two problems with switched networks. First, if *shared* protection is chosen to save a significant amount of resources, source routing becomes very complex. Namely, the source must "know" not only the network topology and link states, but also the pairs of working and protection paths for all other demands! This calls for extending existing link-state advertisment or flooding protocols which results in very havy signalling load.

The other drawback of switched networks is that there is no traffic matrix given in advance, but a steadily changing traffic pattern, which is not known in advance. There might appear some sequences in the traffic pattern, which lead to suboptimal network state significantly reducing the throughput.

Typically, for a steadier traffic, e.g., in long-distance transport networks, that carry a huge amount of aggregated traffic, the static configuration seems to be advantageous, while in access and metro part per-connection based dynamically switched approach is more promissing.

4. Single or Multi-Layer Networks?

In case of single layer switched WR-DWDM networks, we assume, that as the demand arrives the source destination pair is connected by two uni-directional lightpaths (typically along the same path) either without or with wavelength conversion, however, without any interaction with upper layers. As examples four specifications can be mentioned:

- ODSI UNI: Optical Domain Service Interconnect (www.odsi-coalition.com)
- OIF UNI: Optical Interworking Forum (www.oiforum.com)
- IETF MPLambdaS Multiprotocol Lambda Switching by Internet Engineering Task Force (www.ietf.org)
- ITU-T ASON, Automatic Switched Optical Network by International Telecommunications Union - Telecommunication Standardisation Sector (www.itu.int)

Examples of Multi-layer networks are:

- GMPLS (Generalised MultiProtocol Label Switching) proposed by IETF
- ASTN (Automatic Switched Transport Network) proposed by ITU-T.

The idea of these activities is not only to build multiple layers one over the other, but also to define standard interfaces, protocols and signaling system for building up connections on demand with required traffic and quality parameters as well as for tearing them down.

For example in case of GMPLS five networking layers are identified, namely

1. Packet Switching capable one which can handle packets or cells (e.g., IP, ATM, MPLS),
2. Time Division Multiplexing layer capable which handles larger TDM frames (e.g., SDH STM-1,4,16),
3. λ-switching capable layer, either WR-DWDM or MPλS,
4. Waveband switching capable layer which handles jointly more λs of a wavelength band and
5. Fiber switching capable layer, which handles fibers with all the traffic over them.

There are 3 models regarding interoperation of these layers:

- Overlay model, where the layers operate independently. The upper layer can "see" the underlying network as it is configured, without having any influence onto it.

- Peer model, where the layers operate jointly, i.e., any demand can be satisfied by the network layers jointly. When a routing decision has to be made the whole multilayer network is considered as one.
- Hybrid model is something between the two above mentioned models.

To be able to carry the exponentially increasing amount of traffic all fibers of cables and all wavelengths of fibers are needed. However, we still have to be thrifty, and not to assign a wavelength channel of capacity of, e.g., 10 Gb/s to a mobile phone call with bandwidth requirement of, e.g., 14 kb/s, but to offer " Sub-Lambda Bandwidth Granularity". Multiple layers are definitely needed, however, the number of these layers should be minimised as much as possible.

5. Is Grooming needed at all?

Although there are numerous aspects, the answer is positive [3,4].

We distinguish two kinds of grooming. First, when the traffic streams are groomed using electrical TDM, and second, when the wavelengths are groomed into fibres and handled jointly. These approaches are referred to as traffic grooming and Lambda grooming, respectively.

As mentioned in last section the lack of wavelength channels calls for traffic grooming. However, then the network looses its transparency. The most significant drawback is that the whole network has to use a unique upper, electrical layer which will perform traffic grooming, i.e., re-multiplexing in time and space. This upper layer must support all services with their various traffic and quality requirements, while in case of transparent networks we can dedicate an own end-to-end wavelength channel to different services. Then the protocol established over that channel will take care of special requirements for that service. Furthermore, in case of grooming, the bit rates, encoding and protocolls should all be well defined and interoperable (if not unique) for the whole network.

The advantage of traffic grooming is that it has better resource utilisation through arbitrary sub-lambda bandwidth granularity of upper, electrical layers. The physical length of paths will be shorter in average as well, but due to buffering needed where remultiplexing is performed to total latence will still be larger than in case of transparent solution.

From the network design and configuration aspect, although both are NP-hard the case of transparent networks is easier to handle, since one layer has to be optimised at time only instead of two or more in case of grooming.

The considerations are analogous for the lambda grooming case as well. As an example the MEMS (Micro Electro-Mechanical Systems) should be mentioned. In case with no grooming all the wavelength channels of all fibers are demultiplexed. Let W be number of wavelengths per fiber, while F the number of fibers per cable. Now at a node with four neighbours (4 cables connected) a switch with 4WF ports is needed, i.e., a 4WF by 4WF switch. That switch is typically either not available or extremely expensive. However, the routing protocol through such a switch will be simpler and the wavelength blocking probability will be typically lower.

In contrast to the above described case without Lambda grooming, Lambda grooming can switch a whole fiber with all the wavelengths it carries saving w-1 switching elements. Assuming, that only a part (e.g., a quarter) of the fibers should be demultiplexed into wavelengths a (WF+3F) by (WF+3F) switching matrix is sufficient. It will be roughly 1/16 of the size, and will have price by an order of magnitude lower than the case without grooming. Lambda grooming will result in a more complex routing protocol, particularly if protection is needed, the resource usage will be slightly worse, however, as seen a considerably smaller switch will be satisfactory.

6. How to build oVPNs?

The idea of traffic grooming and wavelength (lambda) grooming can be reused to build Optical Virtual Private Networks (oVPN). Typically a VPN will consist of as few wavelength paths as possible, while numerous traffic streams belonging to that VPN will share these wavelength paths. There are two other possibilities as well. First, when two or more VPNs may share a single wavelength channel. Second, when a demand should use a wavelength path exclusively, i.e., this wavelength path will be dedicated to the considered demand.

7. Wavelength- or Time-Division Multiplexing?

Wavelength division multiplexing (WDM or DWDM) is analogous to circuit switching with a unit (but a very large amount, e.g., 10 Gb/s) of capacity. Optical time division multiplexing (OTDM) is analogous to TDM, particularly asynchronous TDM, i.e., packet switching. Therefore, the advantage of WDM is that a connection with dedicated resources is allocated guaranteeing Quality of Service (QoS). In case of switched networks this connection is torn down when it is not needed any more, and re-established if needed again [5]. This is useful for connections of constant bit rates close to the optical channel capacity. However, the trafficcharacteristic is increasingly bursty, and therefore it might not be justified to build up a connection for sending a few bytes only. Therefore, variants of OTDM are promising where the labeled information is sent, and forwarded to the destination hop-by-hop.

There are 3 approaches to OTDM according to the time scale considered:

- Optical Flow Switching (OFS)
- Optical Burst Switching (OBS)
- Optical Packet Switching (OPS)

Since the switching speed of optical switching elements is still low, a significant guard time has to be left between certain information elements and between the header and payload of each information element. Therefore, OPS is of limited interest nowadays, however, bursts of packets, or whole flows can be switched together saving all those guard times between [6].

The OBS is of particular interest in short term, while OPS in long term.

Optical burst switching is a tradeoff between OPS and WDM.

According to the knowledge of burst lengths and resource reservation strategies the OBS strategies can be classified into 4 groups as illustrated in Figure 3. The one pass reservation sends a control message over a common control channel, and then sends the payload over a chosen wavelength channel without waiting for the answer from the end point, that the burst may be sent as in case of end-to-end reservation. It is clear that although it has weaker QoS guaranties the one pass reservation approach is preferable to the end-to-end resrvation, since it introduces less delay, and has larger throughput. Among OBS strategies we will deal with the one pass reservation with known burst lengths.

Although the header processing is performed electronically, the payload stays in the optical domain along the whole path. If a burst can not be transmitted due to a collision, there are two alternatives. First, if the burst just enters an optical burst switching domain it can be sent over another wavelength, where collision is not experienced, or if the network is equipped with wavelength conversion capability it can be converted to another wavelength. The second alternative is that if the collision within the control channel is experienced, the burst is being resent from the electrical layer, since optical buffering with random access is not yet solved.

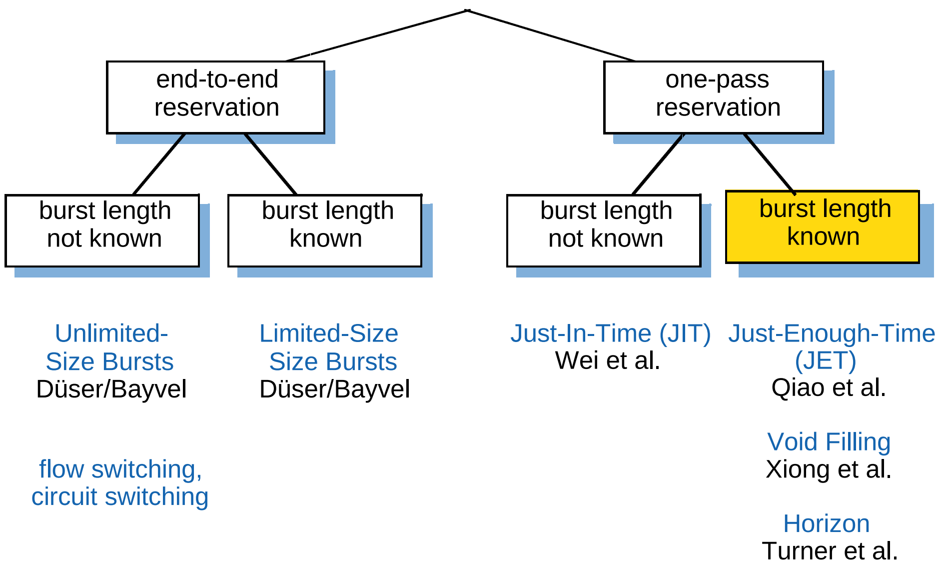

Figure 3: Different OBS Definitions

Optical Packet Switching has lower throughput due to the relatively small size of packets compared to guard time. However, if the packet length is fixed, then switched delay lines can be used to delay the packets. Wavelength conversion or deflection to a predefined deflection destination or path can be used as well. In case of OPS the header and payload are not separated, typically they are using the same channel. When combining a label switching approach, the labels should be swapped in the optical domain, that further complicates the approach.

As described there are three obstacles to employing all-optical packet switching:

The optical processing capabilities are poor, the switching speed is too low and lack of optical RAMs. Therefore, some hybrid solution is being used, where the payload typically uses optical layer, while the header is converted to the electrical domain and signal processing and the control of the switch is performed electronically.

As mentioned OBS and OPS can be used jointly with WDM, i.e., a pool of different wavelengths is available to the bursts or packets, and if one is busy, it just chooses another wavelength. However, traffic grooming can be performed here as well, by sending all the packets or bursts having common or similar destination over a single wavelength. This leads to similar advantages and drawbacks as already discussed in Section 5.

8. Conclusion

In short-term future the networks will be based likely upon a switched metropolitan WDM network while the transport part is expected to be statically configured in the beginning, and made automatically switched later.

Future network will likely consist of 3 layers under the IP layer: Packet Switching Capable (PSC), Wavelength Switching Capable (WSC) and Fibre Switching Capable (FSC). In the near future the PSC layer will be only electrical, based probably on OBS, since the functionality of the electrical and optical layers differs significantly. Later it can be OPS based, with electronic control, later on the all-optical alternative is viable as well.

In the beginning the overlay model is applicable only, while the peer model seems to be more promising later. Probably the transport part will remain of overlay type, while the metropolitan part will start to evolve to the peer model. However, the network will have to be partitioned into smaller peer domains, since this model is more complex by orders of magnitude. Also some kind of aggregation of the topology and link state information is uesful.

From the MPLS/MPLambdaS/GMPLS point of view instead of swapping labels, the labels cen be stacked. Label stacking refers to forming hyerarchical LSPs (Label Switched Paths). These LSPs can be even at different layers of networks. This assumes hierarchical grooming as well. For example MPLS units are groomed into wavelengths, and then wavelengths are groomed into fibers, fibers groomed into cables.

The electronics shall be substituted by optics slowly, from bottom up as the technology allows.

A slow evolution from circuit switching to packet switching is expected as well, particularly in the access and metropolitan part of the networks, while the transport part will likely remain circuit switched, i.e., based upon WR-DWDM.

9. References

[1] S. De Maesschalck et al.: ***Pan-European Optical Transport Networks: an availability-based comparison***, WAOR, Workshop on all Optical Routing, Warsaw, April 2002

[2] K. Bala, D. Saha: ***Towards End-to-End Internet Protocol-centric Network Control and Signaling***, World Markets Series - Business Briefing, Wireless Technology 2001, World Markets Research Center

[3] S. Subramaniam, A.K. Somani: ***Design and Architectural Considerations in WDM All-optical Networks***, World Markets Series Business Briefing: Global Optical Communications (www.wmrc.com), 2001, ISBN 1-903150-48-5

[4] T. Cinkler: ***Towards Switched Wavelengt-routed DWDM Networks - Design Considerations***, World Markets Series - Business Briefing: Global Optical Communications (www.wmrc.com), 2001, ISBN 1-903150-48-5

[5] A. Manzalini: ***Roadmap to Automatic Switched Optical Networks for Metropolitan Areas***, World Markets Series Business Briefing: Global Optical Communications (www.wmrc.com), 2001, ISBN 1-903150-48-5

[6] David K. Hunter: ***Issues in Optical Packet Switching***, World Markets Series Business Briefing: Global Optical Communications (www.wmrc.com), 2001, ISBN 1-903150-48-5