Evolution towards an all-optically switched packet network: the LASAGNE viewpoint

(Invited)

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All-optical packet-switching networks form a logical step in the evolution of packet-switched networks. Nevertheless, research now focuses on the migration path towards these all-optical packet-switching networks. This paper paints a picture of different migration strategies from the viewpoint of disaster recovery and from business point of view.

1. Introduction

The IST-LASAGNE project [1], investigates all-optical label swapping employing optical logic gates in network nodes: in other words, the intention is not only to switch the payload of a burst or packet optically, but also to process the accompanying header in the optical domain. All-optical packet-switching forms in that way the logical evolution of optical packet-switched (OPS) networks. It overcomes the speed limitations that are posed by costly and difficult optical/electronic/optical conversions of the packet’s header and payload. Notwithstanding the research efforts that are done in the fields of all-optical networking and the progress that is made towards a feasible design of an all-optical label swapping router, truly all-optical networks are still considered to be a distant future. The main focus now lies with the design of a migration path from current networking technologies towards (all-optical) packet switching networks. Which migration strategy to follow and how the future networks will look like, depends on the requirements posed by different drivers as business, disaster recovery, user-services...

This paper categorizes different migration scenarios and identifies their special requirements. Section 2 describes the migration strategies in more detail. Section 3 and 4 give the viewpoint of disaster recovery and business operators (two important stakeholders in network design) on the scenarios. Section 5 concludes this paper.

2. Migration strategies

This section explains in more detail the migration paths under study.
2.1 Node per node

Migration from an existing network to an (all-) optical packet-switched network, following this approach, implies a gradual replacement of the original nodes by the new (all-) optical packet-switching nodes. Both nodes coexist and the intermediate network forms as such a parallel multi-technology hybrid optical network. In this strategy, two scenarios can be distinguished:

- **OPS nodes are introduced in an OCS network, Figure 1 (circuit to packet migration):** this scenario consists of an optical circuit-switched (OCS) network with optical cross-connects (OXC) in which some OPS nodes are introduced dispersed through the network. To permit the migration, OPS nodes should have the capability of OXC underlying.

- **LASAGNE nodes are introduced in an existing OPS network, Figure 1 (packet to packet migration):** this scenario consists of an optical packet-switched network with electronic header processing and LASAGNE nodes with all-optical header processing are introduced.

![Figure 1 Node per node migration](image)

2.2 Island based

This scenario is an extension of the previous migration strategy. In this case, multiple nodes, which form a sub-network, are introduced in the existing network architecture. Also in this migration strategy, two scenarios can be distinguished:

- **Island based introduction of OPS nodes, Figure 2 (circuit to packet migration):** this scenario consists of an OCS network with OXC and in which an island of OPS nodes is introduced. To guarantee the migration to packet-switched networks, additional hardware should be added in the edge OPS nodes to form the correct interface to the OCS network.

- **Island based on LASAGNE nodes, Figure 2 (packet to packet migration):** this scenario consists of an optical packet-switched network in which an island of LASAGNE nodes is introduced. The main difference between the existing OPS nodes and the LASAGNE nodes is the processing of the header.

![Figure 2 Island based migration](image)
2.3 Mixed network: OCS + OPS/AOLS

This migration scenario, Figure 3, is based on two network layers, and forms as such a client server hybrid optical network. The original optical circuit layer still exists but the network architecture is extended with an optical packet layer. Optical packet-switched nodes are then connected using optical Wavelength Division Multiplexed (WDM) circuits provided by the circuit layer. Even if the OPS/AOLS network is supposed to carry every type of client traffic, the connection of client equipment to OPS/AOLS edge routers would need certain time to evolve and the definition of a migration policy. In this transient phase, some clients may use the OPS network, while others are still connected through a circuit based backbone.

Figure 3 Mixed network scenario

2.4 ORION

The last migration strategy to be studied in the LASAGNE project is the concept of “Overspill Routing In Optical Networks”, ORION, [2], Figure 4. The ORION concept makes use of the idle periods on optical WDM circuits to insert optical packets. This is an example of integrated multi technology optical networks in which multiple technologies, e.g., OPS and OCS make use of the same wavelengths.

3. Protection/restoration issues

3.1 Introduction

Communications networks are subject to a wide variety of unintentional failures that may cause a large amount of data loss. Therefore, the survivability of network is a critical issue and it is thus imperative to provide a high level of network availability by means of recovery schemes.

The network recovery mechanisms are classified in several ways: on a local or end-to-end basis, by protection or restoration and pre-planned or in real time [3].

3.2 Resilience in optical circuit-switched networks

Until recently, protection was the only realistic choice for a network operator to make a meshed Optical Transport Network (OTN) resilience against failures. With protection, back-up paths are calculated before the failure occurs and cross-connects on the back-up route are switched beforehand. Applying a protection scheme requires much more installed capacity (wavelength) in the network than applying restoration, where back-up routes are calculated the moment of failure. In fact, typically more than 50% of the capacity installed in the network with a
dedicated protection scheme is spare wavelength capacity, [3]. This is because in almost all cases the back-up path is longer than the working path, and thus uses more wavelengths. Regarding link or path recovery, the former requires typically more capacity because path recovery has a larger view on the network allowing more opportunities to optimize the spare capacity needed in the network.

Concluding, the protection suffers from capacity inefficiency and shows little flexibility in dealing with unexpected failures. Also, path recovery is preferred over link recovery. Therefore, path restoration is the preferable recovery scheme in OTN.

3.3 Resilience in optical label swapping networks

Which resilience scheme to choose in all-optical networks depends highly on the effect they have on the dimensions of the all-optical nodes, [4]. Because the protection scheme uses pre-defined paths, the infrastructure needed must be available and configured as if all LSPs were to pass through the back-up link at the same time. Due to this the total number of correlators needed in the back-up node is the sum over all correlators needed for individual failures. On the other hand, the restoration scheme sets up back-up paths at the time the failure occurs. Figure 5 depicts that restoration needs less capacity on the back-up link because it re-uses the same components (i.e. correlators, incoming ODL, outgoing ODL) for different LSPs in the case of different link failures. In terms of AOLS node dimensions, Figure 6 depicts that the protection scheme is worse than the restoration scheme and link recovery needs more capacity than path recovery. As the flexibility of an all-optical network is defined by the components available in the node, restoration - with the re-use of components - is not as flexible as it is in the case of packet-switching networks with electronic header processing. Therefore, the most suitable recovery scheme for all-optical label swapping is thus path protection.

3.4 Resilience in migration scenarios

As there will be a long time of co-existence of current and future networks, it is important to study the migration scenarios regarding disaster recovery strategies.

Node per node

- **OPS node based**: the network consists of different nodes, OXC and OPS nodes with OXC capability underlyng. Therefore, an interface that sends packets to OPS node and the non-packets to the OXC is needed. The resilience mechanisms are the same as the circuit-switched networks (section 3.2).
- **LASAGNE node based**: in a packet-switched network, protection increases the recovery speed whereas restoration optimizes the flexibility and lowers the
required amount of spare capacity. The introduction of all-optical nodes increases the throughput of the network. But, in all-optical packet-switched networks, the flexibility is related to the dimensions of back-up nodes. Due to this, restoration is not as flexible and thus protection is preferred. On the other hand, link recovery needs more capacity than path recovery. Therefore, the choice for the appropriate recovery scheme, path protection/path restoration, is a trade-off between the dimensions of the nodes and the throughput.

**Island based**

- **Island of OPS nodes in OCS network**: as for the node per node strategy, additional hardware is needed in OPS nodes. In the edge nodes of the packet sub-network, the data traffic should be accommodated in the payload of optical packets. Therefore a mapping procedure should be defined. The incoming wavelength thus should be mapped onto a label. Recovery schemes depend on the part of the network where the failure occurs and which elements are affected.

- **Island of LASAGNE nodes in an OPS network**: in this environment, two cases can be distinguished:
  - The link failure only affects LSPs inside one network, leaving the other intact. From the point of view of resilience, the two networks can be managed independently and the most appropriate scheme can be applied in each network. Thus, path protection for LASAGNE and path restoration for OPS.
  - The link failure affects LSPs in both networks. Then, back-up LSPs can pass through two different nodes (OPS/LASAGNE). As all-optical networks are the critical factor in terms of flexibility, to obtain a more flexible solution, path protection can be chosen as recovery scheme.

**Mixed network: OCS + OPS**

In this scenario the connections are established in the circuit layer. Therefore, the recovery schemes typical for OCS networks are applied (section 3.2).

**ORION**

The integration of different network technologies into a multilayer network creates challenges with respect to network survivability. In different network layers, recovery mechanisms that are active can be exploited jointly, but interworking is also indispensable in order to overcome the failures that can occur. There are three approaches in multilayer scenario: single-layer recovery, static multilayer recovery and dynamic multilayer recovery [5].

4. **Evolution towards AOPS from an operator’s point of view**

After the rather general considerations of the previous sections, this paper now focuses on a more concrete, very specific example, i.e., the Telecom Italia optical packet backbone network. It is an example of trying to forecast a practical way of introducing an OPS network on an existing situation.

4.1 **Present network - the TelecomItalia example**

A topological / geographical representation of the Italian IP/MPLS network is shown in Figure 7. It consists of a core section surrounded by access segments. The inner links are equipped with DWDM line systems carrying SDH high capacity frames for the transport of encapsulated layer 3 IP packets. Both optical and SDH layers are
terminated at any edge node, where IP packets are separately switched by electronic matrixes, according to their destinations.

The topology of the core network is organised around four hubs, with a few tens of core PoPs (Point of Presence) connected to them in dual homing, distributed around the country to serve different access areas. The hubs are interconnected via STM-64 links, which form with them the inner core of the IP/MPLS network (Figure 9). Since STM-64 containers carry IP packets encapsulated, all the SDH links involved are terminated with Packet over SDH interfaces. The inner core has thus a ring topology, whose shortest sides contain also separated 10GBe links, carrying IP packets. Their main function is to guarantee a correct balancing of the overall traffic between the longest sides of the inner core. The traffic distribution is dimensioned all over the optical packet backbone in such a way that a 50% maximum capacity is effectively used per link, assuring a 1 + 1 protection against a single link failure. To give an estimate of the core PoPs throughputs in the IP/MPLS backbone of Telecom Italia, it can be recalled that the whole core network is based on the Cisco technology of the series 12000 routers with switching capacities comprised between 80 and 320 Gbit/s.

4.2 Present node structure

From the viewpoint of node architectures, the most important feature is that resource duplication for inner core protection at the link level is further doubled at the hub level. There, each of the four PoPs consists of a small, meshed network of four routers. Two of them (CS nodes on Figure 9) are respectively connected to a four-sided ring. This obviously depends on the choice of extending the 1 + 1 protection. The introduction of two additional routers (E routers on Figure 9) per PoP originates from separating the paths of the transit traffic and the traffic related to the IP access side over the double ring core. Again this is for resilience purposes. Hub duplication (dual homing), besides ensuring protection against single link faults, provides disaster recovery for each hub.

In analogy to the inner core, also the architecture of the outer core PoPs in the above model of IP/MPLS network is characterised by a little meshed network. The meshed network interconnects four routers; two (directly connected to the four hubs via STM-16 links) are called core routers, while the remaining two on the access side are edge routers. These node architectures that are characterised by the use of 4 (6 in some cases) routers in each core PoP, are motivated by resilience requirements. This has obviously economic disadvantages: more operation resources, more fibre plant, more footprint space and more power are needed to maintain these sub-networks of routers within IP/MPLS core networks.

4.3 Future OPS network and future node structure

It is commonly agreed that future networks will have a meshed topology. There are clear advantages in this configuration: a shortest mean length of the links; resilience to multiple link failures; a better redistribution of the traffic load, etc. On the other hand, a meshed structure is more expensive, due to the higher number of interfaces that are necessary per node. Even before the deployment of an all-optically switched packet network, however, it is likely that the network will evolve towards a meshed topology, with switching capabilities implemented also at the wavelength level by means of OXC.
Although previous forecasts of the IP traffic constantly doubling every year have been somewhat reduced, the ongoing growth of the Internet remains the first driver for the evolution of PoPs’ schemes. Especially for the components related to the most demanding services, voice and video streaming. Until now, the majority of service providers and operators have increased the number of routers in their IP/MPLS network to cope with the increased traffic volume. This simple solution, however, is becoming more and more critical for economic reasons. Actually, the installation of a new router in an (almost) fully meshed sub-network, like that interconnecting the routers of core PoPs, makes architectural complexity and capital costs for additional resources needed (e.g., interfaces to be added on old routers, fibre links, etc.) to increase very rapidly. A continuous increase at the same rate as recently experienced would lead to a saturation of presently installed routers. This, in its turn would require a drastic PoPs’ architecture simplification with respect to
present models. This need is being taken into serious consideration by routers constructors, who are moving towards unified structures like the one shown in Figure 8.

4.4 Possible migration strategy

As far as a migration strategy towards OPS is concerned, the LASAGNE viewpoint is essentially in agreement with the views expressed in the IST project NOBEL [6]. A smooth migration of services and/or traffic to the new network could be realized, for instance, by first deploying a small network of interconnected OPS nodes in some of the geographical locations where present PoPs of the outer core are installed. Since the lion’s share of traffic in the present network is routed through the inner core, it would be preferable to locate the first nodes of the new network not far from inner core nodes. Also some gateways for interworking between the old and the new network are necessary. They are clearly best located at the inner core PoPs of the old network. Their main functionality would be to assemble LASAGNE packets starting from IP packets (and other client data) that were previously embedded in SDH frames. The LASAGNE packets would then be routed through the OPS network up to an edge node. There they are de-assembled into client data and sent to the final client equipment or to another interface gateway were they are again embedded in an SDH stream (not necessarily being first de-assembled into IP packets).

5. Conclusion

This paper presented different migration scenarios and addresses rather generally how resilience can be provided to them. It showed that depending on the migration path chosen, other disaster recovery schemes must be deployed. The paper also addressed the business operator’s point of view concerning migration for a very concrete situation, the Telecom Italia network. It proves the need for reliable and optimized migration paths.

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