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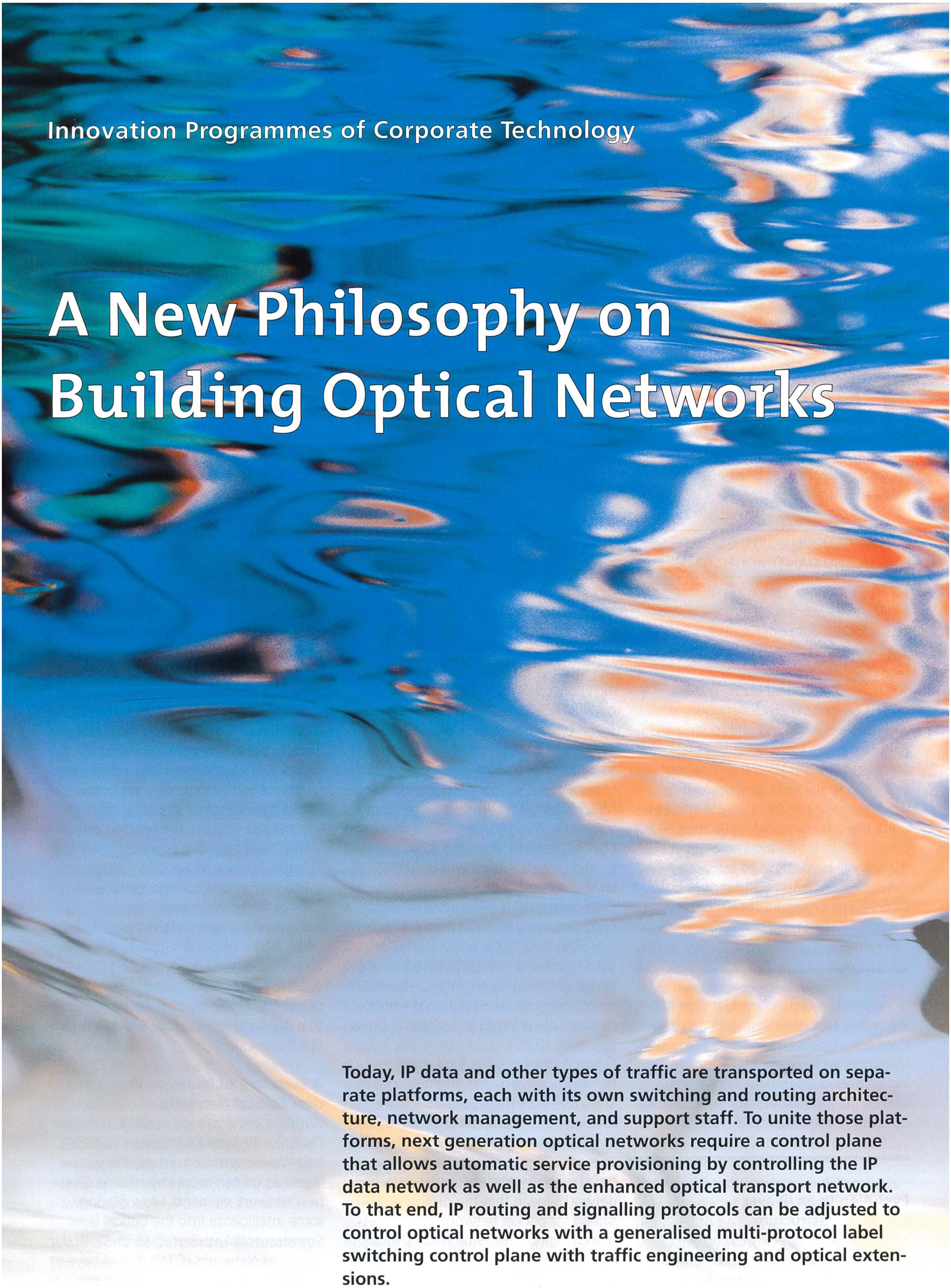

A New Philosophy on Building Optical Networks

Today, IP data and other types of traffic are transported on separate platforms, each with its own switching and routing architecture, network management, and support staff. To unite those platforms, next generation optical networks require a control plane that allows automatic service provisioning by controlling the IP data network as well as the enhanced optical transport network. To that end, IP routing and signalling protocols can be adjusted to control optical networks with a generalised multi-protocol label switching control plane with traffic engineering and optical extensions.

The programme "Future Network Services" explores future network technologies enabling wired and wireless, fix and mobile broadband services. Novel broadband wireless technologies, such as WLAN, will strongly affect mobile and fixed network operators. Moreover, new wireless access technologies will support voice services, leading to threats for traditional, and opportunities for new voice services. Supporting such services requires a very flexible, economically operated, IP-based backbone network.
With its Innovation Programmes, Corporate Technology follows the objective of recognising early on the impact of technological developments, finding new business opportunities, promoting technical synergies, and developing concrete innovation proposals. Further, the expertise built up enables active engineering support of business innovation projects.

The application of an IP-based control plane to optical networks has opened up new opportunities and challenges for network designers. Although much work has been done on standardisation of protocols for IP networks, the applicability of these protocols to controlling optical networks and the overall reliability of optical networks need further investigation.

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Today, voice and data traffic is transported on two separate networks, each with its own switching and routing architecture, network management platform, and support staff. With the imminent evolution to the next generation networks, service providers are striving to unite these separate infrastructures to a single network over a common packet core. It will be possible to build simplified network architectures and reduce both OPerational EXpenditures (OPEX) and CAPital EXpenditures (CAPEX).

Generalised multi-protocol label switching with traffic engineering makes efficient use of data and transport network resources, while at the same time reducing plant and equipment investment as well as the amount of maintenance and operations needed.

Evolution to an IP over GMPLS Infrastructure

Multi-Protocol Label Switching (MPLS) is a versatile protocol that has emerged in response to the need for bandwidth management in next generation, IP-based backbone networks. It addresses the problems faced by present day IP networks – those of speed, scalability, QoS management, and traffic engineering. MPLS also supports multiple transport options and can be supported over several layer-2 transport protocols.
MPLS performs the forwarding of data packets based on a "label" that is added to each IP packet. *Label Switched Routers* (LSR) forward packets according to the attached labels along a *Label Switched Path* (LSP).
The Internet Engineering Task Force (IETF) is extending IP-based protocols originally designed for MPLS to support a range of transport technologies including optical transport networks. The resulting protocols form the basis of the control plane within the Generalised MPLS (GMPLS) architecture. The Optical Internetworking Forum (OIF) is defining a *User to Network Interface* (UNI) based on the protocols used within GMPLS.
GMPLS extends MPLS to encompass time-division multiplexed, wavelength-switched, and fibre-switched technologies. The term "optical networks" is used to refer to networks based on these circuit-switched technologies. The circuit-switching nodes used within the optical network are referred to as Optical Cross-Connects (OXC).
Figure 1 illustrates the logical relationship between control plane and data plane. The lower part shows the data plane topology and the upper part the logical control plane topology.
The differences between packet-switched networks and circuit-switched networks mean that the protocols designed for packet networks (like IP networks) cannot simply be re-used in an optical network control plane (circuit-switched). Careful analysis of the optical network control plane requirements is necessary, with a solution designed to address these requirements.

Models for IP using MPLS over Optical Transport Networks

There are currently three identified models for IP using MPLS over optical transport networks, called Overlay Model, Augmented Model, and Peer Model.
The three models are characterised by the extent of information exchanged between the control planes of IP networks and optical transport networks. In the data plane, all three models are similar and may be characterised as overlay models.

- In the *Overlay Model,* the optical network and the IP and MPLS layer are considered as two separate domains. The optical domain provides a limited set of services to its client – the IP layer – across the UNI, mainly to set up and tear down connections. The two domains utilise independent instances of routing, topology distribution, and signalling protocols. This model is conceptually similar to IP over ATM.
- The *Augmented Model,* like the Overlay Model, separates routing, topology distribution and signalling in the optical domain from those in the IP domain, but augments the routing instance of each domain to pass routing information from its domain to the routing instance of the other domain.
- In the *Peer Model,* the optical network and the IP layer act as peers, utilising a single instance of a routing protocol. This implies one common address space for both domains.

It is important to highlight that the GMPLS control plane supports the three above mentioned models. GMPLS is very suitable for controlling each layer independently. This is an elegant approach that will facilitate the future deployment of other models.

A Summary of Issues on IP over Optical Networks

With the development of OXC, tuneable Optical Add-Drop Multiplexers (OADM), and Wavelength Converters, the optical layer has gained more importance. These new network elements allow placing some intelligence into the optical layer. Some essential attributes which Optical Transport Networks (OTN) should have to provide to dynamic, protocol indepen-

dent and protected connections are listed below:
- real-time provisioning of light paths through the network,
- interoperability functionality in multi-vendor networks,
- protection and restoration capabilities, to enhance survivability.

Figure 2 shows the assumed network model for GMPLS that is used to describe the extensions of MPLS for optical networks.

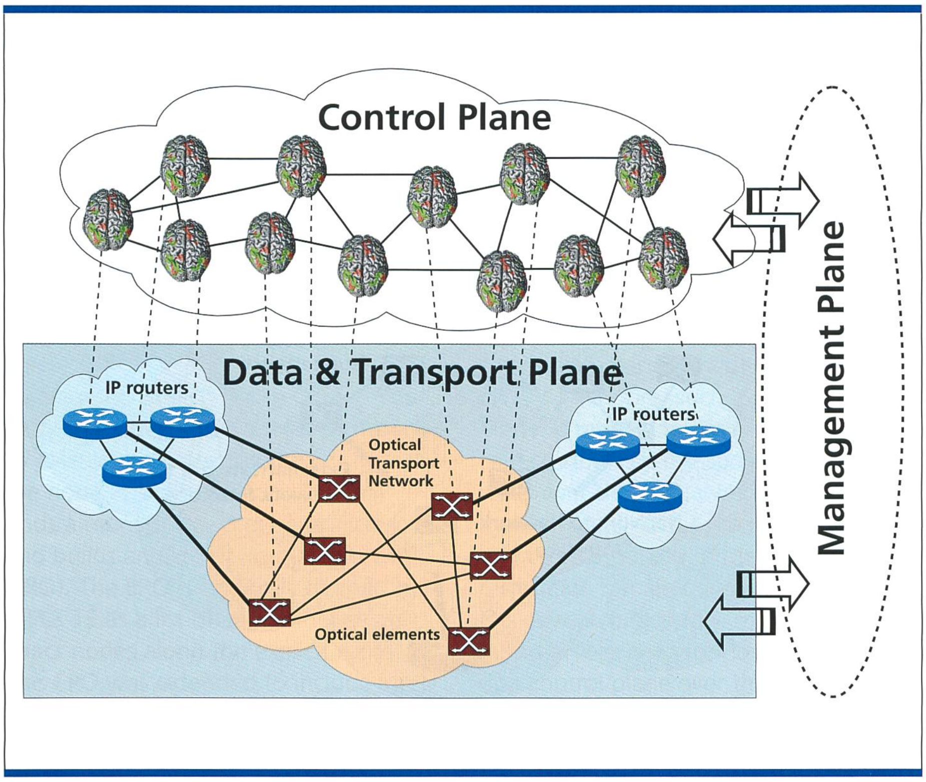

Fig. 1. Logical relationship between the control plane and the data & transport plane. The architecture is divided into three functional network planes: the data & transport, the control and the management planes. The control plane is responsible for routing and signalling. The data & transport plane, separated from the control plane, treats subjects related to the transmission. Finally the management plane is responsible for fault management, performance and billing.

The Extension of MPLS to Optical Networks

The above mentioned attributes could be achieved by putting IP-related features into the optical layer. Optical channel provisioning could be driven by IP data paths and traffic engineering mechanisms. This would mean a tight operation of routing and resource management protocols at the two layers.

Comparing the IP and the optical layers, the OXC and the LSR show some similarities. They both base their switching decision on labels. The OXC uses the wavelength as forwarding information; the LSR reads the label directly in the data layer, as shown in figure 2. Unlike the LSR, the OXC is not able to access the data plane and to perform packet level processing.

GMPLS is an extension of the IP-layer-based MPLS and supports the following features:
- A network can consist of both LSRs and OXCs which do not recognise data carried in packets or in headers
- Bi-directional paths can be established (unlike MPLS)
- Rapid failure notification
- Termination of a path on a specific egress port,
- The supported label formats are: time slots, optical wavelengths, space switching, *MPLS labels.* The IETF has proposed to design the OXC control plane based on the MPLS-TE (Traffic Engineering) control plane. Some extensions are required primary to support TDM (Time Division Multiplexing), LSC (Lambda Switch Capable) and FSC (Fibre Switch Capable) traffic. Five Interfaces switching capabilities have been defined: *PSC* (Packet Switch Capable), *L2SC* (Layer 2 Switch Capable), *TDM, LSC,* and *FSC.*

Work done at Corporate Technology

This study is based on the scanning of the IETF drafts and the follow-up of several Eurescom projects dealing with this matter. A deep analysis has been made to extract the most relevant parameters and protocols that could be of interest for the IP and optical networks of Swisscom.

Adjustments Needed to Expand the Control Plane from MPLS to GMPLS

As an extension of the MPLS-TE control plane, the GMPLS control plane is made of several building blocks. These building blocks are well-known routing and signalling protocols that have been extended and modified. Only one new specialised protocol was required to support the operation of GMPLS, a signalling protocol for link management (LMP). Most of the extensions have already been defined for PSC traffic engineering with MPLS. GMPLS mainly adds additional extensions for TDM, LSC and FSC traffic engineering.

Routing Extensions for GMPLS

GMPLS is based on IP routing and addressing models. The traffic related to the different switching capabilities introduces new constraints to the IP routing protocols, like *OSPF* (Open Shortest Path First) and IS-IS (Intermediate System – Intermediate System).

With technologies like DWDM (Dense Wavelength Division Multiplexing) several hundred links can connect two nodes. It is impractical to associate each end of each link to an IP address and to bring up adjacency for these links. To solve this problem, new mechanisms like link bundling and unnumbered links have been developed. The end points of an unnumbered link have no IP address, so no routing adjacency can be brought up and the traditional routing protocols will not work.

Non-PSC links may have TE properties. Routing adjacency cannot be brought up on such links.

The concept of *Forwarding Adjacencies* (FA) allows that an advertised link does not need to be between two IGP (Interior Gateway Protocol) direct neighbours. FA gives the possibility to aggregate multiple LSPs inside a bigger LSP. The advan-

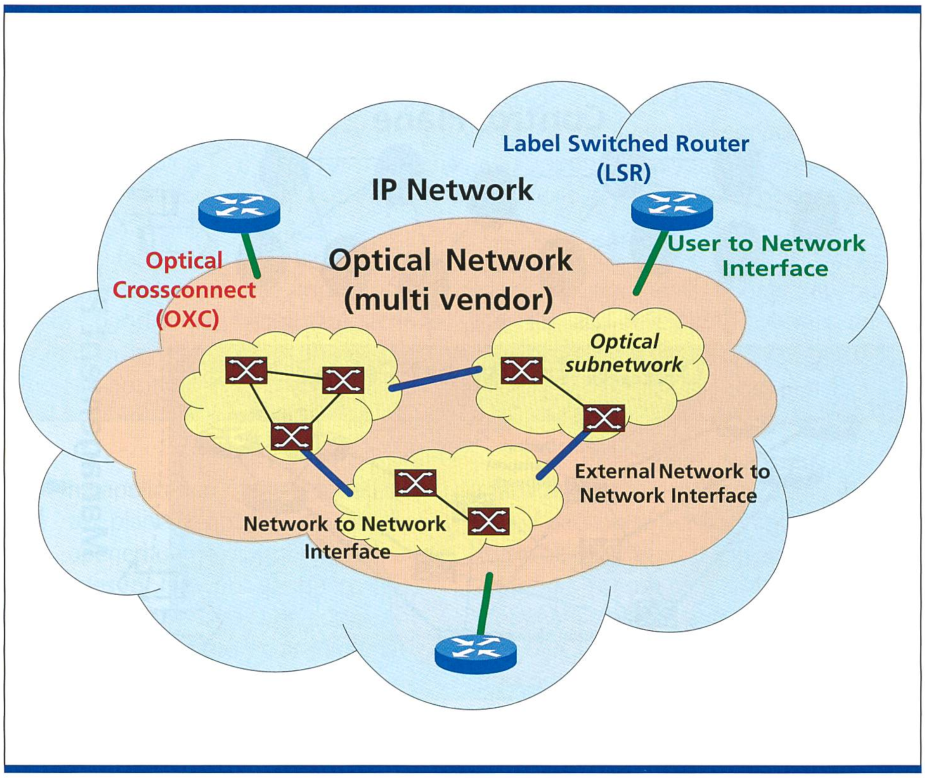

Fig. 2. Assumed Network Model for Generalised Multi-Protocol Label Switching. The Label Switched Routers (LSR) forward packets based on a label added to each IP packet. The switching nodes used within the optical network are referred to as Optical Cross-Connects (OXC). In a GMPLS network model different types of interfaces can be identified. The interface between IP and optical networks is referred to as the User-Network Interface. Interfaces between the optical sub-networks and interfaces between optical network elements are referred to as Network-Network Interface. Interfaces are called Private (or Internal) if they belong to the same administrative domain and Public (or External) if they belong to the different administrative domains.

tage is that intermediate nodes only see the external LSP, and so less signalling messages are sent and also fewer labels are needed. As nodes connected by a FA would usually not have routing adjacency, the traditional IGPs are not able to treat such links.

The constraints defined above induce extensions to the traditional routing protocols. The necessary enhancements are listed below.

- An *unnumbered link* is a link that does not have an IP address. The LSRs, at both ends of the link, assign an identifier to this link. They will then see a local and a remote identifier for each link. Both these values have to be carried by the routing protocols.
- The *link protection* type is a new information that routing protocols have to transport, representing the protection capability for a link. This information is used by the path calculation algorithm. A minimum acceptable protection is specified at the path instantiation and the path selection algorithm finds a path that satisfies this minimum acceptable protection. Six protection types have been defined.
- A *Shared Routing Link Group* (SRLG) is a set of links that share a resource whose failure may affect all links in the set. This information is used for restoration purposes. For example, if an LSR is required to have diversely routed LSPs to another LSR, the path computation algorithm shall route the paths so that they have no links in common and such that the path SRLGs are disjoint.
- A link is connected to a node by an interface that supports different encoding types. The *Interface Switching Capabilities Descriptor* lists the switching capabilities (supported encoding type) of an interface. This descriptor is a new constraint for the path computation algorithm. A unidirectional link is required to have the same interface switching capabilities at both ends. A bi-directional link with different switching capabilities at its two ends is allowed.

The information is of the form TLV (Type, Length, and Value). The type field indicates the type family. The length field indicates the number of bytes in the value field. The value field is the information; it can be composed of sub-TLVs recurrently.

The four above mentioned enhancements are transported in new sub-TLV triplets of the link TLV for OSPF. In IS-IS, the extended IS-IS reachability TLV is enhanced to support the unnumbered link, the protection type and the interface switching capability descriptor. Two new TLVs are added: the TE LSA carrying the SRLG information and the Hello PDU transporting a link identifier.

Signalling Extensions for GMPLS

As already mentioned extensions to signalling protocols, like *RSVP-TE* (Resource ReSerVation Protocol with Traffic Engineering extensions) and *CR-LDP* (Constraint-based Routing using Label Distribution Protocol) are under study to support GMPLS. These additions impact on basic LSP properties, on how labels are requested and communicated, on the unidirectional nature of LSPs, on how errors are propagated, and on the procedure for synchronising the ingress and egress LSRs.

The Generalised Label Request is a new TLV to be added in a Path/Label Request message instead of the regular Label Request TLV. The Generalised Label Request TLV gives some major characteristics (parameters) required to support the LSP being requested, such as the LSP encoding type, the LSP payload type and the desired link protection. The Generalised Label extends the traditional label by allowing the representation of not only labels that travel in-band with associated data packets, but also labels that identify time-slots, wavelengths, or space division multiplexer positions. Four types of labels are defined corresponding to the four switching layers:

- SDH and SONET each define a multiplexing structure. These multiplexing structures are used as naming trees to create unique labels. Such a label will

identify the type of a particular signal (time slot) and its exact position in a multiplexing structure. The same label format can be used for SDH and SONET.
- Some configurations of FSC and LSC use multiple data channels/links controlled by a single control channel. In such cases the label indicates the data channel/link to be used for the LSP. It's important to see that this case is not the same as when bundling is being used. The label indicates a port or a lambda to be used, from the sender's perspective. It only has significance between two neighbours, and the receiver may need to convert the received value into a value that has local significance. Values may be configured or dynamically determined using a protocol such as LMP.
- A special case of lambda switching is waveband switching. A waveband represents a set of contiguous wavelengths which can be switched together to a new waveband. This may reduce the distortion of the individual wavelengths and may allow a tighter separation of the individual wavelengths. Waveband switching uses the same format as the Generalised Label.
- A Generalised Label only carries a single level of label, i.e., it is non-hierarchical. When multiple levels of label are required, each LSP must be established separately.

GMPLS allows for a label to be suggested by an upstream node. This suggestion may be overridden by a downstream node. This permits the upstream node to start configuring its hardware with the proposed label before the downstream node communicates the label. Such early configuration can reduce set-up latency, and may be important for restoration purposes where alternative LSPs must be rapidly established as a result of network failures.

Label set is used to restrict label ranges that may be used for a particular LSP between two peers. The receiver of a label set must restrict its choice of labels to one that is in the label set. Each node generates its own outgoing label set, possibly based on the incoming label set and the node's hardware capabilities.

Bi-directional LSPs: With bi-directional LSPs both the downstream and upstream data paths are established using a single set of signalling messages. This reduces the set-up latency and limits the control overhead to the same number of messages as a unidirectional LSP. For bi-directional LSPs, two labels must be allocated. Bi-directional LSP set-up is indicated by the presence of an upstream label TLV in the appropriate signalling message. An upstream label has the same format as the Generalised Label.

Generalised Explicit Route Object: The path taken by an LSP can be controlled by calculating an explicit route. Typically, the node at the head-end of an LSP finds a more or less precise explicit route and builds an *Explicit Route Object* (ERO). The ERO is originally defined by MPLS-TE as a list of strict or loose abstract nodes along the explicit route. This ERO was extended to include interface numbers as abstract nodes to support unnumbered interfaces. GMPLS also includes labels as abstract nodes. Having labels in an explicit route is an important feature that enables the placement of an LSP with a very fine granularity.

Rapid Notification of Failures: GMPLS defines signalling extensions for RSVP-TE to enable expedited notification of failures to nodes responsible for restoring failed LSPs, and modify error handling. For CR-LDP there is currently no similar mechanism.

Dynamic Trunking

A TE link needs to be configured with switching capability types assigned before it can be used. Of course it is inefficient to statically configure each interface with a given switching class. The solution is to create dynamically a link driven by the need, for example when a set-up message arrives. Therefore the concept of dynamic trunk has been developed. A dynamic trunk is associated with an available bandwidth and a set of switching capabilities. But it is incapable of carrying LSP directly; TE links have to be created dynamically using the resources associated with the dynamic trunk. After its creation the dynamic link is treated as a normal link.

The LMP, enhanced to support the dynamic trunking capability, can be used to create dynamic TE links. New messages are exchanged to create a dynamic trunk, to add link and to delete link.

Conclusions

The rapid growth of the Internet and new services are driving the demand for huge bandwidth. The optical network is an ideal Internet transport infrastructure in core and metro networks due to its enormous bandwidth availability. Although optical networks are already in use to provide point-to-point connections for a multilayer architecture to transport IP traffic, Carriers have experienced high management cost and complexity. Therefore, such a multilayer model is moving towards a two-layer architecture which transports IP traffic directly over the optical network. Nevertheless, issues such as rapid and effective service provisioning, protection and restoration remain quite challenging with this new architecture.

In this article, the work on the proposal of a control plane over the IP and optical networks has been presented. There have been many ongoing research activities in this area, and today there is a consensus that the IP routing and signalling protocols can be adapted for the optical network control. In particular, the Multi-Protocol Label Switching (MPLS) control plane with optical extensions has been proposed for this purpose. Generalised Multi-Protocol Label Switching (GMPLS) has been proposed to further extend MPLS to support multiple switching types, for example, packet switching (PSC), time-division multiplexed (TDM) switching, lambda switching (LSC), and fibre switching (FSC). In the GMPLS control plane, Open Shortest Path First (OSPF) or Intermediate System to Intermediate System (IS-IS), with Traffic Engineering extensions, is used as the interior gateway protocol (IGP), and Resource Reservation Protocol with Traffic Engineering (RSVP-TE) or Constraint-Based Routing Label Distribution Protocol (CR-LDP) is used as the signalling protocol.

The final objective of this work is to adopt and integrate existing IP protocols to design a flexible, scalable, and resilient control plane. The conceptual and functional requirements and mechanisms have been presented. Therefore, a careful examination is made within the Innovation Programmes at Swisscom Corporate Technology to determine necessary aspects to be taken into account when introducing such philosophy on building optical networks.

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Zusammenfassung

In diesem Beitrag wird die Arbeit an einem Vorschlag für eine Kontrollebene, die gleichzeitig das IP- und das optische Netzwerk umfasst, vorgestellt. Die IP-Routing- und Signalling-Protokolle können für die Kontrolle von optischen Netzwerken angepasst werden. Zu diesem Zweck wurde die Multi-Protocol-Label-Switching-Traffic-Engineering (MPLS-TE)-Kontrollebene mit optischen Erweiterungen vorgeschlagen.
Um mehrere Switchingarten, wie beispielsweise Packet Switching, Zeitmultiplexing, Lambda Switching oder Faser Switching unterstützen zu können, wird Generalised Multi-Protocol Label Switching (GMPLS) vorgeschlagen. In der GMPLS-Kontrollebene wird OSPF oder IS-IS mit Traffic-Engineering-Erweiterungen als Interior Gateway Protocol und RSVP-TE oder CR-LDP als Signalling Protocol benützt. Es sind drei Modelle vorgesehen, um die möglichen Kombinationen von IP über optische Netzwerke untersuchen zu können: das Overlay-Modell, das Augmented-Modell und das Peer-Modell. Diese unterscheiden sich nur durch das Ausmass der ausgetauschten Informationen zwischen den Kontrollebenen des IP- und des optischen Netzwerks.

Abbreviations

CR-LDP	Constraint-based Routing using Label Distribution Protocol
ERO	Explicit Route Object
FA	Forwarding Adjacencies
FSC	Fibre Switch Capable
GMPLS	Generalised Multi-Protocol Label Switching
IETF	Internet Engineering Task Force
IS-IS	Intermediate System – Intermediate System
LMP	Link Management Protocol
LSC	Lambda Switch Capable
LSP	Label Switched Path
LSR	Label Switched Router
MPLS	Multi-Protocol Label Switching
OADM	Optical Add-Drop Multiplexers
OSPF	Open Shortest Path First
OXC	Optical Cross-Connect
PSC	Packet Switch Capable
RSVP-TE	Resource ReSerVation Protocol with Traffic Engineering extensions
SRLG	Shared Routing Link Group
TDM	Time Division Multiplexing
TE	Traffic Engineering
TLV	Type-Length-Value
UNI	User to Network Interface
WDM	Wavelength Division Multiplexing

Acknowledgements

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Further Reading:

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