Architecture and Functional Requirements of Control Planes for Automatic Switched Optical Networks: Experience of the IST Project LION

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Abstract

This article focuses on architecture and functional requirements for control planes of automatic switched optical networks. Specifically, four different approaches for triggering the setup of optical connections have been reported. Furthermore, the article describes the testbed of the IST Project LION: the testbed, aimed at demonstrating some ASON functionalities, is composed by optical network elements (OADM and OXC provided by Siemens, Tellium, and Telecom Italia Lab) and IP routers (provided by Cisco).

Introduction

The growing trend of data traffic and new emerging requirements are driving the need to migrate from current time-division multiplexed (TDM) networks, mainly designed for voice and leased line services, toward a more flexible and dynamic optical infrastructure enabling the transport of larger channels for data, video, and voice. In this context, automatic switched optical networks (ASONs) are currently the object of deep investigation within international projects. Furthermore, there is a significant effort in the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Study Group 15 (SG15) to standardize the requirements of such networks. In other activities, Optical Internetworking Forum (OIF) is standardizing specifications for a user–network interface (UNI) between transport network elements and their client equipment to achieve network control by the customer. The Internet Engineering Task Force (IETF) has specified the control plane of the network from the viewpoint of generalized multiprotocol label switching (GMPLS). GMPLS will be able to achieve seamless integration of conventional MPLS networks and circuit-based transport networks.

Basically, an ASON is an optical network supporting permanent, soft-permanent, and switched optical connections. To achieve such functionalities, an ASON is equipped with a control plane that is responsible for setting up, releasing, and restoring a connection. In principle, an ASON seems to fulfill many of the emerging requirements, such as high-capacity links, fast and automatic end-to-end provisioning, optical rerouting and restoration, support of multiple clients, deployment of optical virtual private networks (OVPNs), interworking functionality with client networks, and multidomain interconnections. The main objective of the article is to describe the architectural principles and functional requirements of the control plane for ASONs.

Basically, the requirements described in this article should be applicable to both synchronous digital hierarchy (SDH) transport networks, as defined in ITU-T Recommendation G.803 [1], and optical transport networks (OTNs), as defined in ITU-T Recommendation G.872 [2].

The article also reports control plane implementation and demonstration activities being carried out within the Information Society Technologies Project (IST) [3] LION, Layers Interworking in Optical Networks [4]. LION is a three-year-long project funded by the European Commission and led by Telecom Italia Lab (TILAB) with the main objectives of studying, designing, and demonstrating a network scenario based on ASONs. Specifically, an IP/MPLS over ASON/GMPLS testbed is being developed at TILAB integrating equipment from TILAB, Tellium, Siemens, and Cisco, and two network management systems realized by T-Systems Nova and TILAB.

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AUTOMATIC SWITCHED OPTICAL NETWORKS

As mentioned, an ASON is an optical network supporting three types of optical connections: permanent, soft-permanent, and switched.

A **permanent connection** is a connection established by configuring every network element along the path with the required parameters to establish an end-to-end connection. Such provisioning is done by either management systems or manual intervention [5].

A **soft-permanent connection** is a connection whereby a management system configures the head-end node while network generated signaling and routing protocols are used to establish the end-to-end connection along the path. The establishment of such connections depends on the definition of a network–node interface (NNI).

A **switched connection** is a connection set up by a customer/client network and established using signaling and routing protocols [5]. The establishment of such connections depends on the definition of an NNI and a UNI.

Three planes characterize an ASON: the control, management, and transport planes.

The **control plane** supports connection setup/teardown as a result of a customer/client network request (switched connection) and a management request (soft-permanent connection). In addition, a control plane may support reestablishment of a failed connection (e.g., restoration) by carrying link status (e.g., adjacency, available capacity, and failure) information.

The **management plane** is responsible for fault, performance, configuration, accounting, and security management functions for the transport and control planes.

The **transport plane** provides bidirectional or unidirectional information flow transfer between users and detects connection state information (e.g., fault and signal quality).

In particular, some of the main purposes of the control plane are:

- Facilitate fast and efficient configuration of switched and soft-permanent connections.
- Reconfigure or modify connections to automatically optimize usage of network resources.
- Perform a restoration to enhance robustness of the network.

CONTROL PLANE ARCHITECTURE

The introduction of a control plane in transport networks is likely to bring some new advantages:

- Traffic engineering for dynamic allocation of resources to routes
- Connection control in a multivendor environment/multidomain
- Rapid and flexible service provision
- Introduction of supplementary and flexible optical transport services
- Automatic optical rerouting and restoration

ITU-T Recommendation G.8080 [5] describes the set of control plane components that are used to manipulate transport network resources in order to provide the functionality of setting up, maintaining, and releasing connections.

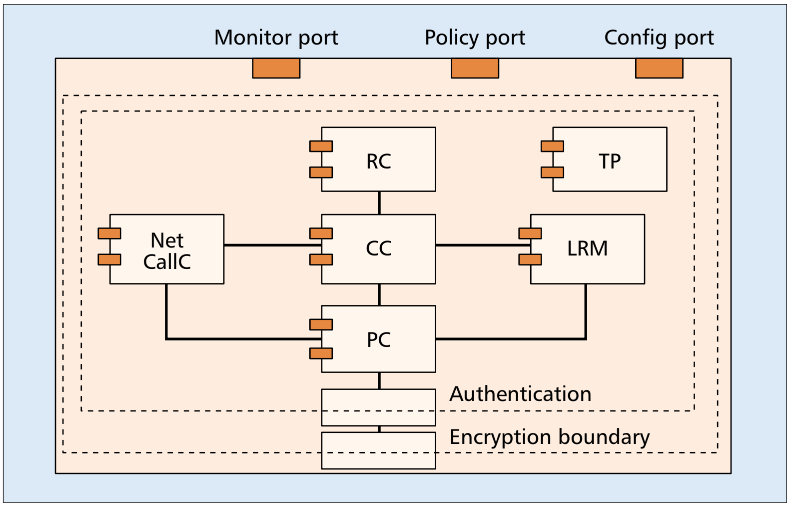


Figure 1. *Control plane components.*

The control plane architecture is described in terms of components that represent abstract entities. Generically, every component has a set of interfaces to support a collection of operations that specify a provided or used service of that component.

Figure 1 shows the control plane architecture according to ITU-T Recommendation G.8080, mainly highlighting the functional flows among the different components, disregarding a formal representation with all the interfaces.

Following are brief descriptions of each component:

CC — Connection controller component: manages and supervises connection setups and releases, and modification of connection parameters for existing connections. Moreover, it is responsible for coordination among the link resource manager, routing controller, and both peer and subordinate CCs.

RC — Routing controller component: responds to requests from CCs for path information needed to set up connections and respond to requests for topology information for network management purposes.

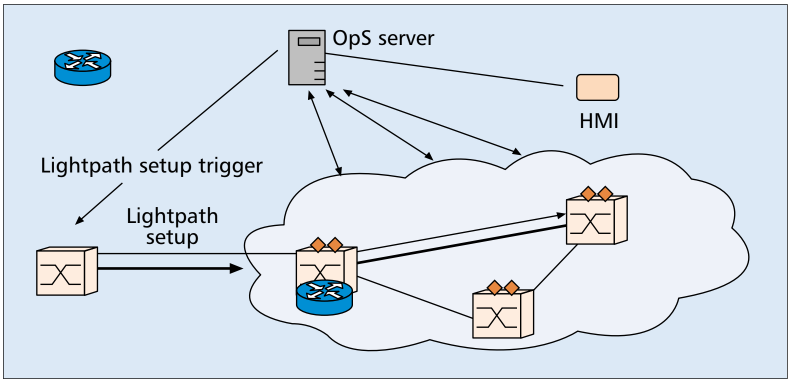
LRM — Link resource manager components: responsible for the management of a subnetwork point pool (SNPP) link, including the allocation and deallocation of link connections, providing topology and status information.

TP — Traffic policing component: responsible for checking that the incoming user connection is sending traffic according to the parameters.

NetCallC — Network call controller component: accepts (after verifying user rights and resource policy) and processes incoming call requests from a client network, processes and generates call termination requests toward a client network, and validates call parameters.

PC — Protocol controller component: provides the function of mapping the parameters of the abstract interfaces of the control components into messages that are carried by a protocol to support interconnection via an interface. Proper interaction between a certain number of components is necessary to control a connection.

Three approaches to dynamic path control can be identified: hierarchical, source routing,



■ **Figure 2.** *Lightpath setup when installing a new system or equipment.*

and step-by-step routing.

Hierarchical routing is based on decomposition of a layer network into a hierarchy of subnetworks, each having its own dynamic connection control. A node contains a routing controller, connection controllers, and link resource managers for a single level in a subnetwork hierarchy.

In the case of source routing, in which the route of the connection is determined at a source node, a federation of distributed CCs and RCs implements the connection control process. The operators can specify the exact route of the path for the purpose of traffic engineering.

Step-by-step routing differs from the previous case in a reduction of routing information so that each RC provides information only about the next step. In this case, the operator cannot know the route of the paths before execution of the path setup command, but they can easily establish new paths due to avoidance of complicated path configurations.

Triggering Lightpath Setup

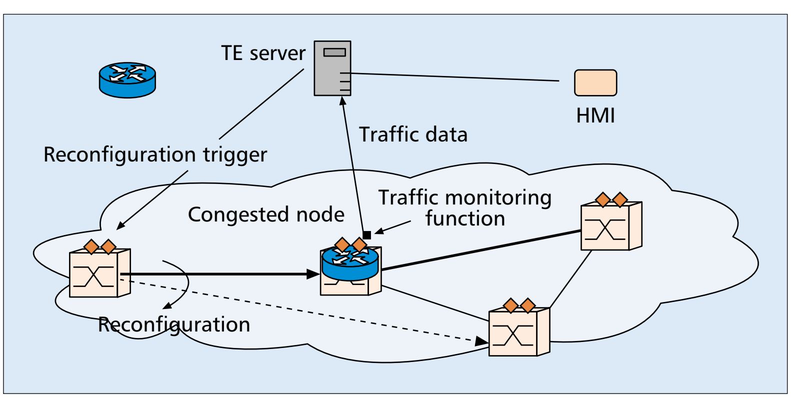
There are two types of triggers for lightpath setup: one is an initiation command for the lightpath setup procedure intentionally input by an operator; the other is an automatically initiated command sent by the equipment itself. There are at least four cases during manual operation where the initiation command is sent:

- In the first case (Fig. 2), an initiation command for lightpath setup is sent when a new system or equipment is installed. In this case, an operator can establish a lightpath after required procedures (e.g., configuration and initialization) are completed. This is the most typical example of lightpath setup intentionally executed by an operator initiation command.
- In the second case (Fig. 3), such initiation commands may be sent by a traffic engineering (TE) server, which collects information such as traffic volume and available resources in each node.
  This is to allow a network operator to make the best use of its resources by reconfiguring the topology of its lightpaths with changes in the traffic pattern. For instance, even on a day scale, there can be a situation in which the commute of a large population between a metropolitan area and its suburban areas may cause a significant change in the traffic pattern. Another case in which a sudden change in the traffic pattern may occur is if there are a huge number of users accessing a particular Internet Web site containing a short period event such as the Olympic games or booking or preordering of popular products/tickets.
  Another possibility is that a network has sufficient intelligence (e.g., traffic monitoring in the routers) to estimate traffic for triggering additional lightpaths. Single or plural TE servers, which collect such information, may request additional lightpath setup triggers.
- In the third case (Fig. 4), such initiation commands may also be sent in order to establish new VPNs or modify existing VPN attributes. This is somewhat different from the previous two cases as to whether or not the lightpath setup comes from the network operator.

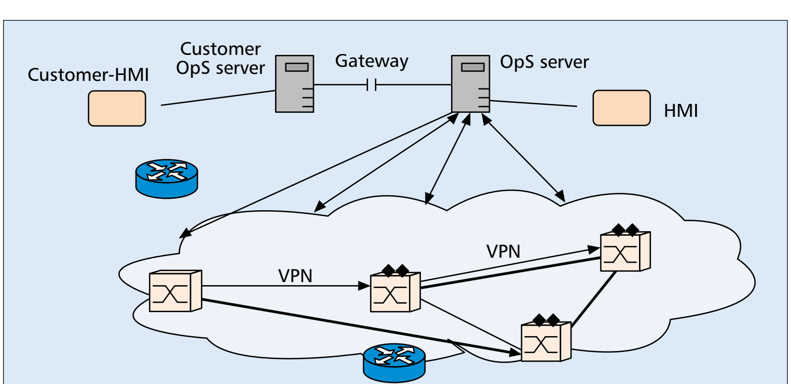
For VPN related lightpath setup, there may be a case where the customer him/herself is allowed to operate his/her VPN accordingly to the contract between the service provider and customer. In fact, it is desirable that some portion of the operator's signaling capability be opened to its customers in order to allow for advanced VPN services.

The ASON Testbed Developed in the IST Project LION

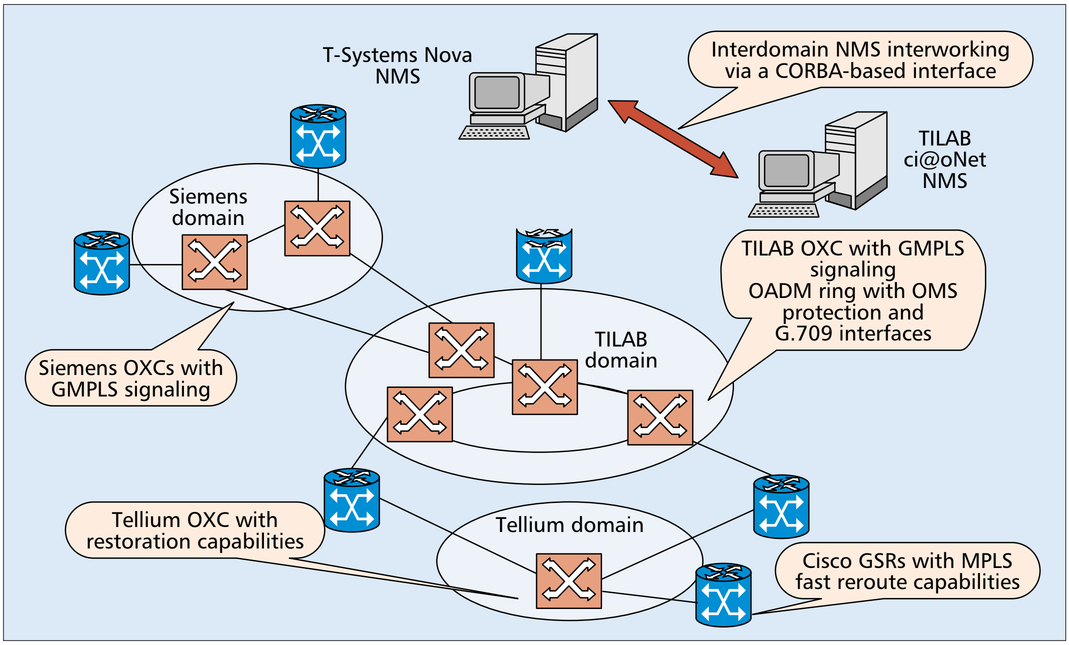
The IST Project LION is a three-year project funded by the European Commission with the main objectives of studying, designing, and demonstrating a network scenario based on ASON/GMPLS:



■ **Figure 3.** *Lightpath setup initiated by traffic engineering server.*



■ **Figure 4.** *Lightpath setup for the creation or modification of a VPN.*



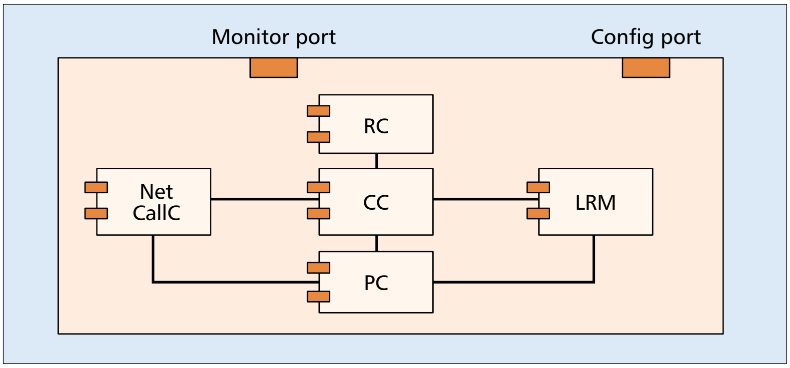
■ **Figure 5.** *Testbed of the IST Project LION.*

specifically, this network infrastructure is aimed at carrying multiple clients (e.g., SDH, IP-based) with interworking and interconnection between layer transport networks and domains.

The testbed is being developed to assess some innovative ASON/GMPLS functionality carrying IP clients. Particularly, the demonstrations and assessment will be focused on the setup and teardown of soft-permanent optical connections and the activation of multilayer resilience strategies and protection. Figure 5 shows the testbed architecture based on an ASON network partitioned in three vendor domains, respectively Siemens, TILAB and Tellium domains. TILAB's domain includes a ring of three optical add-drop multiplexers (OADMs) with a single hub traffic pattern. The TILAB's domain is completed by an optical cross-connect (OXC) connected to the Siemens' domain that includes two OXCs. A third domain is based on a Tellium OXC that can be partitioned in three or four virtual switches. The client network is based on IP Giga Switch Routers provided by Cisco. Two interworking (via Corba-based interface) network management systems (developed by T-Systems Nova and TILAB) provide an end-to-end management of connections.

In this context, among the main objectives of the project is the development of CP and NNI signaling based on RSVP-TE. Particularly, the control plane being developed for the OXC of the TILAB's domain is in line with ITU-T Recommendation G.8080 from which it differs for the absence of minor functionalities, not related to the project objectives (i.e., mechanisms of authentication and encryption and the traffic policing component).

Figure 6 shows a high-level sketch of TILAB's control plane highlighting the relationships among different components. Figure 7 introduces the TILAB's control plane implementation showing the different PC component's interfaces described below:

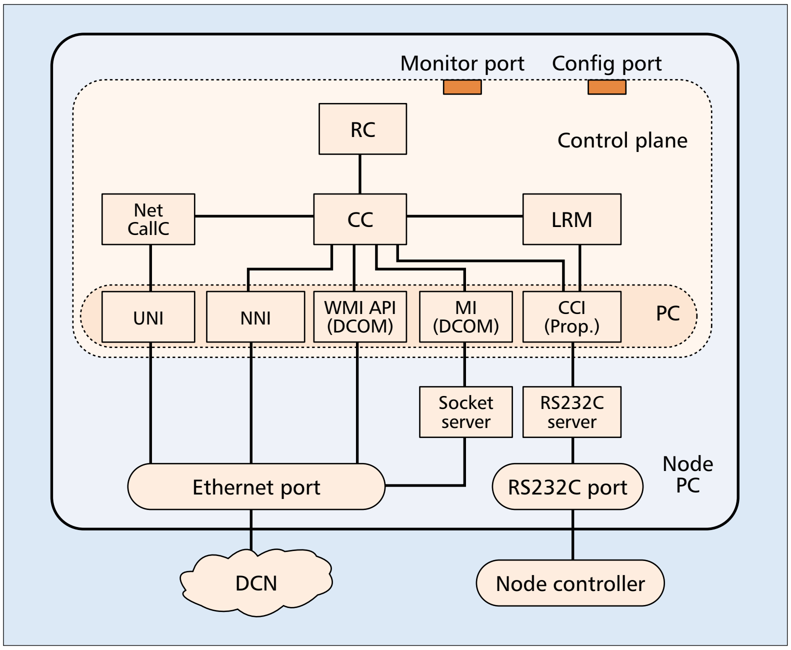


■ **Figure 6.** *TILAB's control plane components and their relationships.*

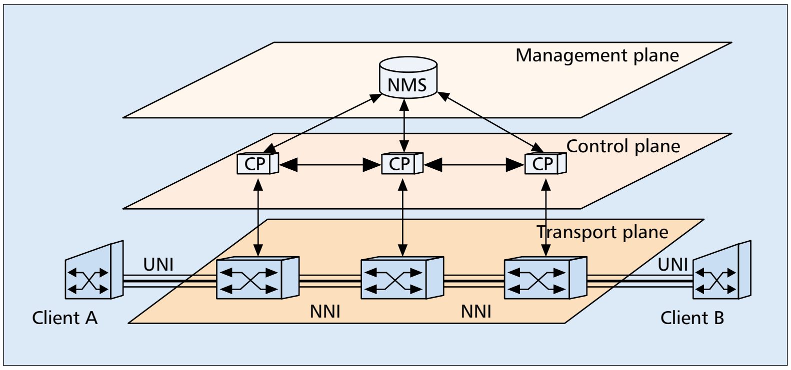
- UNI and NNI interfaces support the information flows for call control, resource discovery, connection control, connection selection, and connection routing (only NNI) functions. Such interfaces are being developed in line with the emerging OIF standards and IETF drafts and RFCs. More in detail, the RSVP-TE approach has been adopted.
- The management interface (MI) is the interface through which the signaling between the control plane and NMS is exchanged.
- The Windows Management Instrumentation (WMI) application programming interface (API) is the interface control plane uses for updating the information model.
- The Connection Controller Interface (CCI) is the interface between the control plane and the node controller (transport plane) used for the creation, modification, and deletion of subnetwork connections (SNCs).

A Connection Setup Example

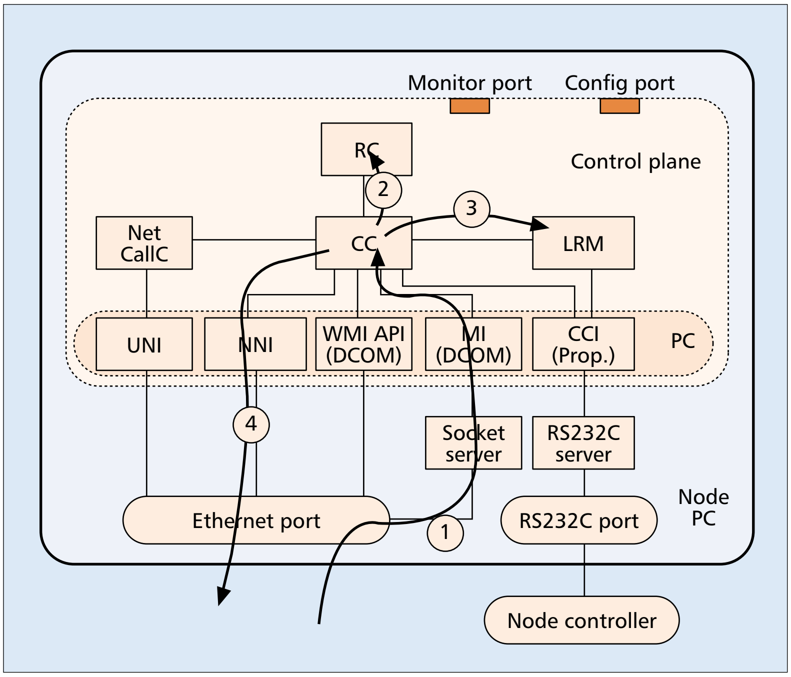
As an example, a typical network scenario could be based on a server transport network with optical network elements (ONEs) and a client net-



■ **Figure 7.** *TILAB's control plane implementation.*



■ **Figure 8.** *Network scenario.*



■ **Figure 9.** *Controller A receives a connection create request from NMS.*

work with IP routers as shown in Fig. 8. ONEs A, B, and C are connected each other by NNI interfaces. At the transport network edge, ONEs (A and C) are also equipped with UNI interfaces.

This section shows an example of soft-permanent connection setup (therefore, no UNI interface is involved) where the management system configures head-end node A, while network-generated signaling and routing protocols are used to establish the end-to-end connection between the nodes. For simplicity, the description will refer to the TILAB's control plane implementation scheme.

The detailed sequence of operations involved in setting up a connection is described in Figs. 9–11. The steps involved are listed below:

- The NMS sends a connection create request to *CP A* with all required information such as destination node, data rate, and protection requirement. MI gathers it and forwards it to CC component as showed in Fig. 9, step 1.
- The CC queries the RC to obtain routing information (Fig. 9, step 2) in the form of a set of next hops (route).
- LRM provides the CC with the information of link availability (Fig. 9, step 3) and, if available, reserves it.
- The request, containing the remainder of the route, is forwarded to *CP B* by the NNI interface (Fig. 9, step 4).
- *ONE B*'s CC receives the connection create request through the NNI (Fig. 10, step 1)
- The LRM controls the availability of a link toward the next hop and reserves the resources (Fig. 10, step 2).
- The request, containing the remainder of the route is forwarded to *CP C* by the NNI interface (Fig. 10, step 3).
- *ONE C*'s CC receives the connection create request through the NNI (Fig. 11, step 1).
- LRM controls the availability of a link toward the next hop and reserves the resources (Fig. 11, step 2).
- The CC recognizes it is the end node and asks *node controller C* to set up cross-connections on the local fabric (provisioning) (Fig. 11, step 3).
- The CC sends the Connection Create Response to the previous hop, *CP B*, by the NNI (Fig. 11, step 4), enabling previous hops for provisioning.
- At last, CC updates the distributed information model by WMI API (Fig. 11, step 5).

The Connection Create Response will be propagated to the first node following the same path utilized from the Connection Create Request. At each intermediate node the CCs will set up local cross-connections, in the same manner described above, resulting in the provisioning of a path along the ASON network.

Conclusions

This article reports on the architectural principles and the functional requirements of control planes for ASONs. Basically, such requirements should be applicable to both SDH transport networks, as defined in ITU-T G.803, and optical transport networks, as defined in ITU-T G.872. The article also covers the control plane implementation as a subset of ITU-T G.8080 specifications and demonstration activities being carried out within the IST project LION, where a specific testbed is being developed at Telecom Italia Lab premises integrating equipment from TILAB, Tellium, Siemens, and Cisco and two interworking network managers from T-Systems Nova and TILAB. The testbed will show the feasibility of network functionalities, such as multilayer resilience and dynamic setup/teardown of optical connections, in an IP/MPLS over ASON/GMPLS environment.

Acknowledgments

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References

[1] ITU-T Rec. G.803, "Architecture of Transport Network Based on the Synchronous Digital Hierarchy (SDH)."
[2] ITU-T Rec. G.872, "Architecture of Optical Transport Networks."
[3] http://www.cordis.lu/ist/
[4] http://www.telecom.ntua.gr/lion
[5] ITU-T Rec. G.8080, "Architecture for the Automatic Switched Optical Network (ASON)."

Additional Readings

[1] ITU-T Rec. G.8070, "Requirements for the Automatic Switched Transport Network (ASTN)."
[2] ITU-T Rec. G.709, "Interface for the Optical Transport Network (OTN)."

Biographies

ANTONIO MANZALINI (antonio.manzalini@tilab.com) received a Dr. Ing. degree in electronic engineering in 1988 from the Politecnico of Turin, Italy. He joined Telecom Italia Lab (formerly CSELT), that is, Telecom Italia Group's Company for study, research, experimentation, and qualification in the field of telecommunications and information technology. He is currently project manager in the Transport Network Area of the Wireline Networks Department. His current activities are in the area of optical transport networks, with particular reference to architectural and functional issues for advanced optical networking such as automatic switched optical networks and GMPLS. He is active in the ITU standardization for transport networks: from 1997 to 2000, he was chair of ITU SG13 Question 19, "Transport network architecture and interworking principles"; he was also chair of ITU SG15 Question 12, "Technology Specific Transport Network Architectures." He was involved in several EURESCOM and European Project (ACTS and IST) on optical networking issues; since January 2000 he is project leader of IST Project LION, whose main goal is to study, design, and experimentally demonstrate an automatic switched optical network carrying multiple clients (IP/MPLS over ASON/GMPLS).

ALESSANDRO D'ALESSANDRO (alessandro.dalessandro@tilab.com) received a Dr. Ing. degree in electronic engineering from Politecnico of Turin, Italy, in 1999 with a thesis on optical waveguides. In the same year, he started a stage at CSELT to work on the upgrade of passive optical networks with WDM systems. Afterward he joined Marconi Communications as a customer engineer dealing with SDH and DWDM systems. Since 2001 he has been working at Telecom Italia Lab (formerly CSELT), where he has been involved in IST Project LION, specifically in the development of Control Plane and GMPLS signaling for an IP/MPLS over ASON/GMPLS testbed.

CARLO CAVAZZONI (carlo.cavazzoni@tilab.com) received a Dr. Ing. degree in electronic engineering from Politecnico of Turin. In 1993 he started a stage at Telecom Italia Lab (formerly CSELT) to work on simulations of optical communication systems with EDFA. Since 1994 he has been working at Telecom Italia Lab. He has been involved in several European projects on optical networking: RACE 2028 MWTN, ACTS projects METON and DEMON and EURESCOM Project EUP918. He has also been involved in the realization of an optical transport network testbed in activities regarding the definition of the architecture, OA&M, and management of optical transport networks. Currently he is involved in IST Project LION. In particular, he is working on the design and realization of a multivendor and multidomain IP/MPLS over ASON/GMPLS testbed.

KATSUHIRO SHIMANO (shimano@exa.onlab.ntt.co.jp) received B.S. degrees from Waseda University, Tokyo, Japan, in 1991, and M.S. degree form University of Tokyo in 1993. He joined NTT in 1993, and has been engaged in research on the architecture and operation of optical networks, and integration of multilayer networks. He has been a member of the development team for a photonic MPLS router prototype which is NTT's GMPLS prototype. He is involved in IST Project LION.

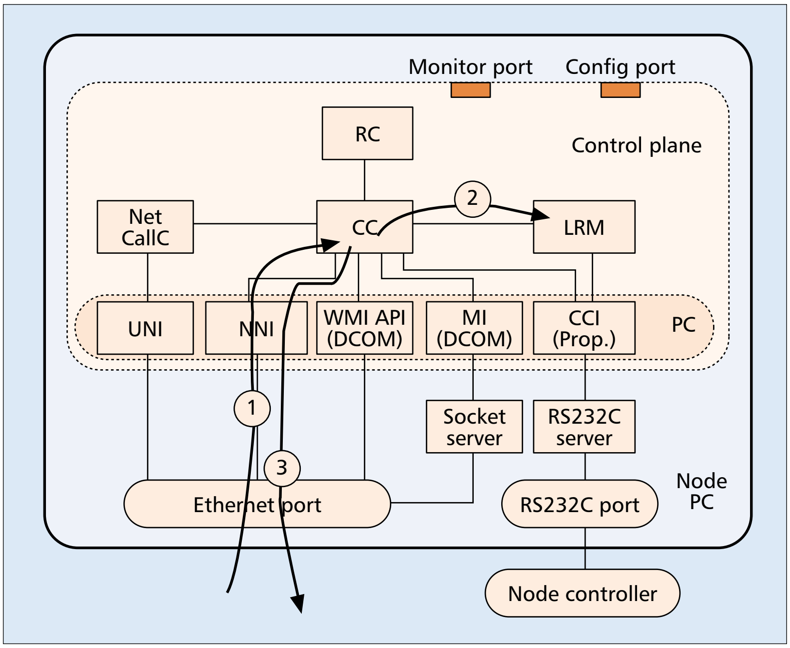

Figure 10. *Controller B receives a connection create request from adjacent node.*

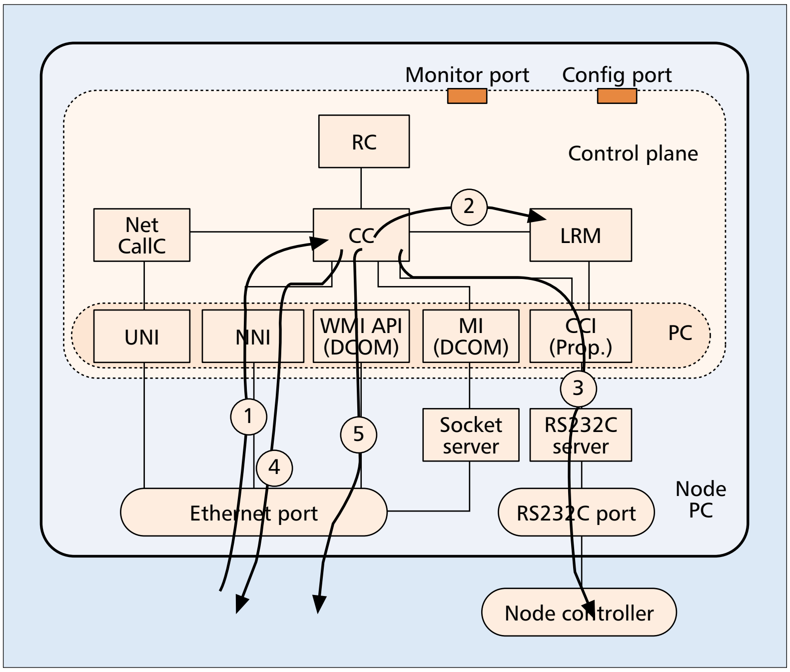

Figure 11. *Controller C receives a connection create request from adjacent node and sends a connection create response.*