Control Plane for Optical Networks: The ASON Approach

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ABSTRACT

The paper gives a tutorial overview of the automatically switched optical network (ASON), concentrating on its control plane. Drivers to automatically switched optical networks are briefly presented. The ASON architecture, based on transport, control, and management planes is discussed. Types of connections supported by ASON are described, including permanent, switched, and soft permanent connections. Different kinds of internal and external interfaces are presented and discussed. Various issues related to the ASON control plane, such as control plane requirements, modeling, and functions are covered. These functions include: discovery, routing, signaling, call and connection control, as well as survivability mechanisms.

Keywords: Automatically switched optical network (ASON), optical networks, control plane

INTRODUCTION

Optical backbone networks, based on SDH/SONET and WDM technologies, and designed mainly for voice applications, do not match current needs triggered by rapid growth of data traffic. Available resources often cannot be properly allocated due to inherent inflexibility of manually provisioned large-scale optical networks. This problem may be solved by using a control plane that performs the call and connection control functions in real time. One of the most promising solutions is based on the concept of automatically switched optical networks.

Automatically switched optical network (ASON) is an optical transport network that has dynamic connection capability. This capability is accomplished by using a control plane that performs the call and connection control functions [1]. A related, but more generic, term is *automatic switched transport network* (ASTN) [2]. ASTN is technology independent, i.e., it concerns not only optical networks.

In this paper we give an overview of ASON, concentrating on its control plane. The overview is based on current standardization activities, mainly those of ITU-T. First, drivers to automatically switched optical networks are briefly presented. In Section 3 the ASON architecture, based on transport, control, and management planes is discussed. Types of connections supported by ASON are described, including permanent, switched, and soft permanent connections. Different kinds of internal and external interfaces are presented and discussed. Section 4 covers various issues related to the ASON control plane, such as control plane requirements, modeling, and functions. These functions include: discovery, routing, signaling, call and connection control, as well as survivability mechanisms.

DRIVERS TO ASON

Current optical networks, although offering enormous capacity, are quite inflexible, comparing to their IP counterparts. Most of their limitations are due to the fact that they are operated manually or via complex and slow network management systems. Major drawbacks of such optical networks can be enumerated as follows [3]:

- manual error-prone provisioning,
- long provisioning times,
- inefficient resource utilization,
- difficult interoperability between the packet client networks and the circuit-switched optical networks.
- complex network management,
- difficult interoperability between networks belonging to different operators,
- lack of protection in mesh-type optical networks.

The major features of an automatically switched optical network, expected by network operators, can be listed as follows:

- fast provisioning,
- easier network operation,
- higher network reliability,
- scalability,
- simpler planning and design.

Provisioning of optical channels in minutes or even seconds would open new opportunities related to better resource utilization, creation of new services, such as bandwidth on demand, and a range of traffic engineering mechanisms. Optical network resources can be automatically linked to data traffic patterns in client networks.

Creation of a separate control plane will significantly impact the network operation and management. Connections can be set up in a multi-vendor and multi-carrier environment without relying on interoperability between different management systems. Such systems will be also relieved from route selection and the need to manually update the network topology. This, in turn, will increase scalability which is essential to support switched connections on a global scale.

New protection and restoration schemes for mesh-type optical transport networks will improve the reliability performance measures offered to customers. Such measures are especially important if we take into account very high bit data rates switched in optical networks. The control plane rapidly reacting to failures in the optical network will make it possible to reallocate traffic to reserve paths in real time.

Large-scale transport networks are difficult to plan and design. Lack of reliable traffic data, uncertainty of future service needs predictions, a large variety of available protocols and interfaces make the network design process a real challenge. The standardized control plane will enable the reuse of existing protocols and will reduce the need to develop operational support systems for configuration management. Moreover, the possibility to dynamically allocate optical network resources to changing traffic patterns, will facilitate network planning in contrast to statically configured networks.

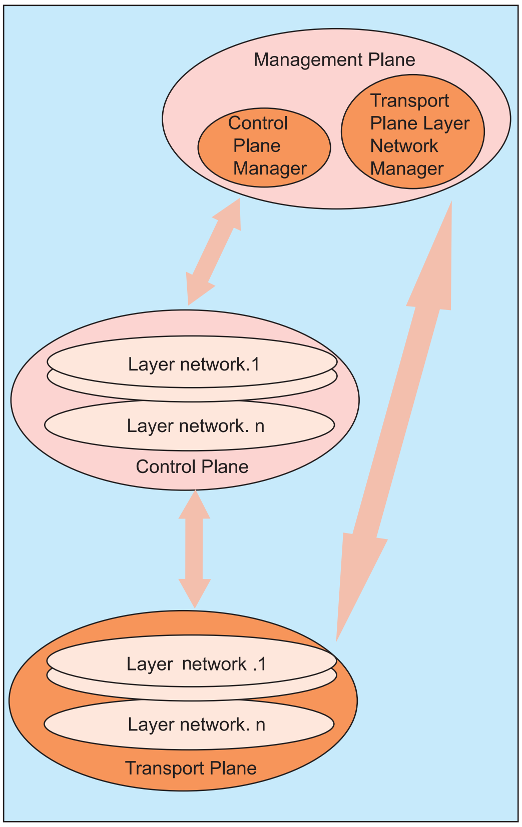


Fig. 1. *Transport, control, and management planes in ASON*

ASON Architecture

Functional Planes

Functional planes of ASON and their relationship are shown in Fig. 1 [1]. The layered transport plane, referred also to as data plane, represents the functional resources of the network which convey user information between locations. Transfer of information is either bi-directional or unidirectional. The transport plane can also provide transfer of some control and network management information.

A layer network within the transport plane is a topological component that includes both transport entities and transport processing functions that describe the generation, transport and termination of signals with a specific format (called *characteristic information*) which are transferred on network connections. The topology of a layer network is described by access groups, subnetworks and links between them. IP, ATM, SDH, or OTN are examples of layer networks.

The control plane performs the call control and connection control functions. The functions of the ASON control plane are automated, based on networking intelligence that include automatic discovery, routing and signaling. The management plane performs management functions for the

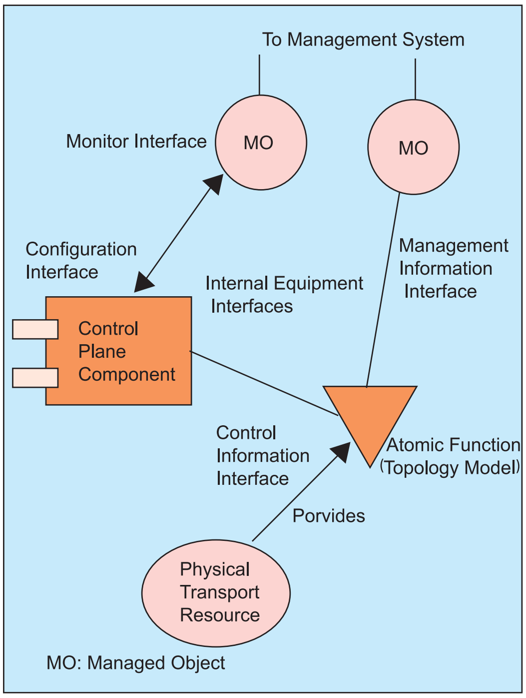


Fig. 2. *Interactions between ASON planes*

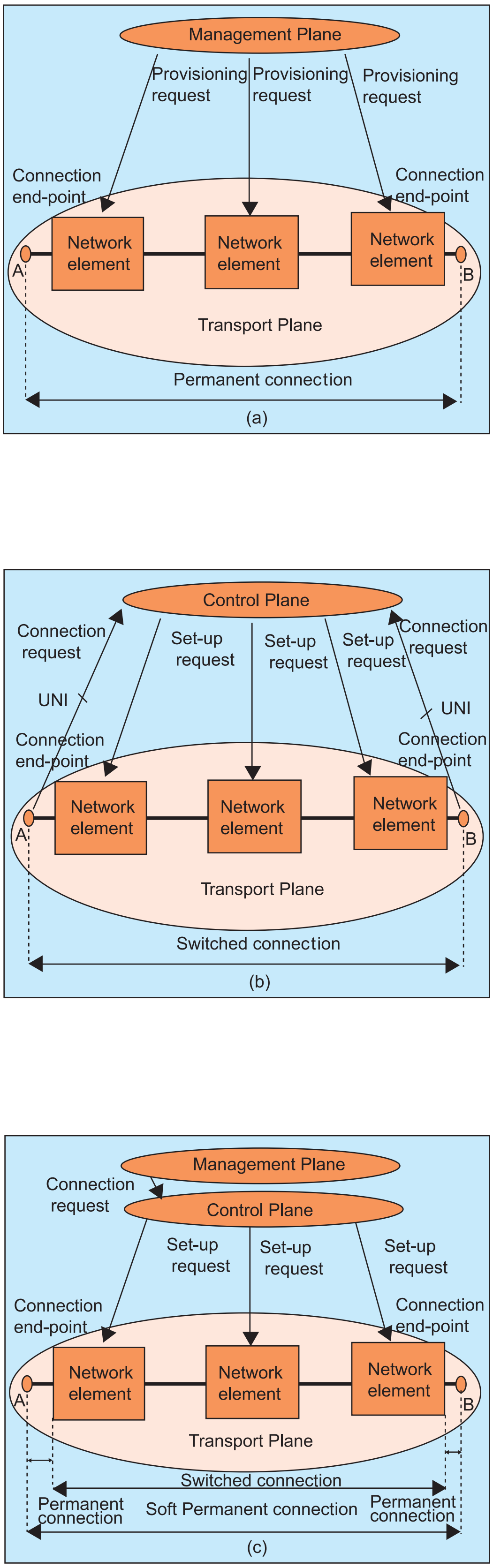


Fig. 3. *Examples of transport connections in ASON; (a) permanent connection, (b) switched connection, (c) soft permanent connection [2]*

transport plane, the control plane and the system as a whole, as well as coordinates operation of all the planes [1]. These management functions are related to network elements, networks and services and, usually, they are less automated than those of the control plane [4].

Although each plane is autonomous, some interactions occur because the planes operate on a common underlying resource. It can be seen as the transport, control and management planes intersect at this resource [5]. The general relationships between the three ASON planes are shown in Fig. 2 [1]. The following interactions can be distinguished:

- management - transport interaction,
- control - transport interaction, and
- management -control interaction.

The management plane operates on an appropriate information model of transport resources. Such a model reflects an external management view of the equipment. Its managed objects (MO) interact with the functional model, represented by G.805 atomic functions, via the management information interfaces. Atomic functions represent functionality of transport processing functions within network elements. An atomic function cannot be divided into simpler functions. Both the management objects and management information interfaces are physically contained within the transport resource. Control plane operation appears autonomous to the operation of the management plane, and vice versa, that is both planes are unaware of each other's existence, and see only resource behavior. The information presented to the control plane is similar to that presented to the management plane. In fact, the control plane information overlaps some but not all management information [1].

Every control plane component has a set of interfaces used for its monitoring as well as setting policies and affecting internal behavior. These interfaces are employed by a management system. It should be noted that the management plane does not access resources via control plane components but only manages these components themselves [5]. The management plane interacts with control plane components by operating on a suitable information model. The objects of this model are physically located with a control component [1].

Optical Connections

The optical network offers primarily fixed bandwidth connections between two clients [4]. Three main connection capability types are defined in G.807:

- uni-directional point-to-point connection,
- bi-directional point-to-point connection,
- uni-directional point-to-multipoint connection.

An asymmetric connection can also be considered, being either a special case of bi-directional connection or a set of two uni-directional connections.

The following three kinds of connections, differing in connection establishment type, can be distinguished in ASON [2]:

- permanent,
- switched,
- soft permanent.

The permanent connection is set up either by a management system (Fig. 3a) or by manual intervention and is also referred to as a provisioned connection. Therefore, such a connection does not require any intervention of the control plane and does not involve automatic routing or signaling. Usually, this is a static connection lasting for a relatively long time, such as months or years. The switched connection is established on demand by the communicating end-points by using routing and signaling capabilities of the control plane (Fig. 3b). In this case we refer to signaled connection set up. The switched connection requires a user-network signaling interface (UNI) and its set up may be the responsibility of the end user (the client network) [2]. The soft permanent connection is established by specifying two permanent connections at the edge of the network and setting up a switched connection between the permanent connections within the network (Fig. 3c). The relevant connection establishment is referred to as a hybrid connection set up. In this case no UNI is needed.

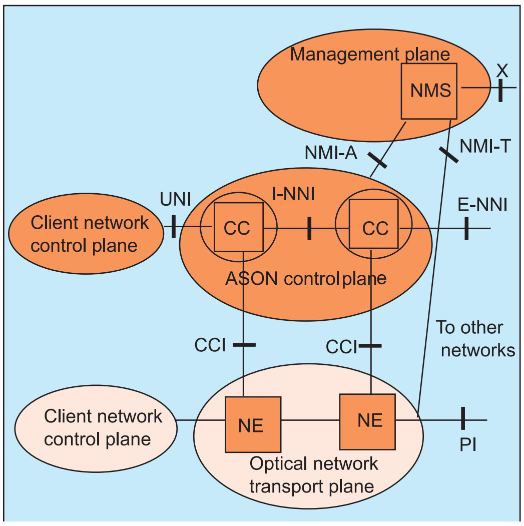
The permanent connection is set up by the network operator via the management plane and is an equivalent to a traditional leased line. The switched connections, involving the control plane, are set up within seconds. They enable such a service as bandwidth on demand. The soft permanent connections, triggered by the management plane, but set up within the network by the control plane, may support traffic engineering or dynamic re-establishing of failed connections.

Ason Reference Model and Interfaces

According to G.8080 ITU-T Recommendation, the interconnection between domains, routing areas, and in some cases, also sets of control components is described in terms of reference points. A reference point represents a collection of services provided via interfaces on one or more pairs of components. The exchange of information across these reference points is described by the multiple abstract interfaces between control components. The physical interconnection is provided by one or more of these interfaces. A physical interface is provided by mapping an abstract interface to a protocol.

A logical view of ASON architecture is shown in Fig. 4. Along with the transport, control, and management planes, a variety of ASON and non-ASON interfaces is shown. The ASTN/ASON standardization defines the following three logical interfaces and relevant reference points in the control plane [1], [2]:

- *User-Network Interface* (UNI): a bi-directional signaling interface between service requester and service provider control plane entities.
- *Internal Network-Network Interface* (I-NNI): a bi-directional signaling interface between control plane entities belonging to one or more domains having a trusted relationship.
- *External Network-Network Interface* (E-NNI): a bi-directional signaling interface between control plane entities belonging to different domains.



CC: Connection Controller
CCI: Connection Control Interface
E-NNI: External Network-Network Interface
I-NNI: Internal Network-Network Interface
NE: Network Element
NMI-A: Network Management Interface-ASON control plane
NMI-T: Network Management Interface-Transport control plane
NMS: Network Management System
PI: Physical Interface

Fig. 4. *Logical view of ASON architecture*

The interfaces are defined by the information flow between control plane entities. The following information elements have to be supported by the interfaces [2]:

- connection service messages (UNI, E-NNI, I-NNI);
- authentication and connection admission control (UNI, E-NNI);
- end-point name and address (UNI);
- reachability information (E-NNI);
- topology information (I-NNI);
- network resource control information (I-NNI).

The connection service messages involve call control (UNI and E-NNI only), connection control, and connection selection. The end-point name and address, reachability information (summarized network address information), and topology information are related to resource discovery processes and routing of connections. We can note that no routing function is associated with the UNI interface. Network resource control information (I-NNI only) may be used to optional control of network resources. Signaling specification for UNI can be found in [6].

Some other interfaces are shown in Fig. 4. They include the physical interface (PI) in the transport plane, the connection control interfaces between components of the control and transport planes (CCI) as well as two kinds of network management interfaces (NMI) between the management plane and two other planes. CCI instructs the network element, e.g., an optical crossconnect, to set up connections between selected ports. This interface is vendor specific. Network management interfaces are used between network management systems (e.g., TMN based) and the control (NMI-A) and transport (NMI-T) planes.

A generic ASON network reference model, presenting the discussed reference points, is shown in Fig. 5 [4]. UNI reference points are located between client networks, for example IP or ATM based, and an optical transport network. Such client networks may belong to the same carrier that owns the transport network or they may be separate business entities. E-NNI reference points are between optical subnetworks belonging to different carriers. The external network-network interface may also be used to connect optical subnetworks belonging to

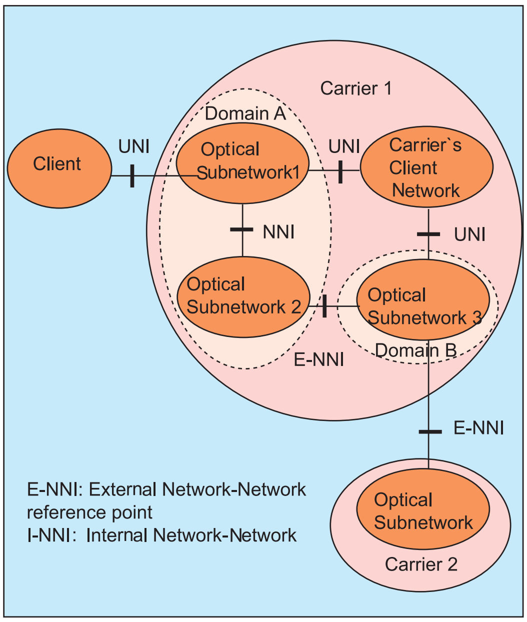
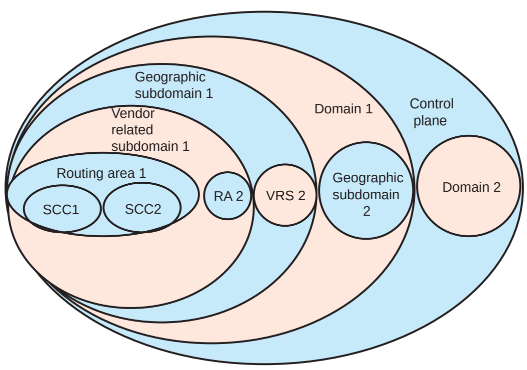


Fig. 5. *Generic ASON network reference model*



RA: Routing Area

SCC: Set of Control Components

VRS: Vendor related Subdomain

Fig. 6. *Possible divisions of the control plane*

the same carrier but located in different control domains. In principle, selection of either I-NNI or E-NNI between subnetworks is based on the trust relationship for security and access control purposes. If this relationship is fully trusted, the control information exchange across the interface may be unlimited and the I-NNI interface is used (even between different domains). If not, the administrative policy should impose strict constraints, especially related to network topology and resource control, on information flowing across E-NNI.

ASON standardization allows multi-homing, i.e., support of more than one link between a user or a client network and the optical network (see, for example, carrier's client network in Fig. 5 connected to two different optical subnetworks). Such an arrangement is used to enhance resilience or to facilitate load balancing, and can involve a single or multiple carriers [2].

There are several possible reasons that a single carrier decides to distinguish several optical subnetworks. They include separation between metro and long distance networks or could be a result of incremental optical network deployment using different vendors or technologies. In some cases, subnetworking may reflect a hierarchical structure of large networks or is a result of business mergers and acquisitions [4].

ASON Control Plane

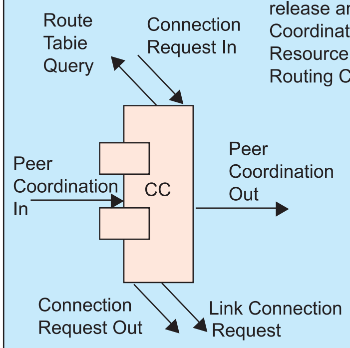
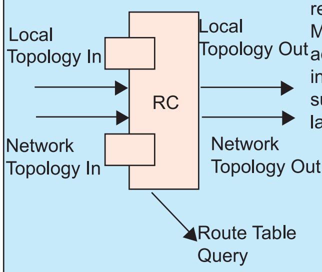
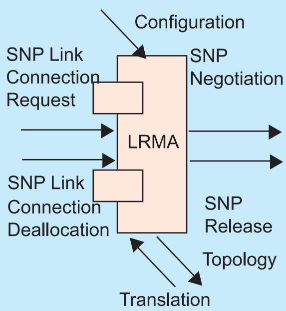
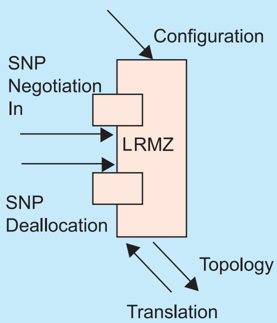
The control plane is a set of communicating entities that are responsible for setup of end-to-end connections, their release, and maintenance. These capabilities are supported by signaling.

The Systemic Composition of the Future

The control plane in ASON is responsible for the call and connection control. A call is an association between endpoints that support an instance of service, while a connection is a transport entity capable of transferring information between its inputs and outputs. An important feature of ASON is separation of call and connection control functions. The call control is responsible for the end-to-end session negotiation, call admission control and call state maintenance [4]. The connection control is related to setup and release of connections as well as maintenance of their states. A call can be supported by zero, one, or a multiplicity of connections. Connections can be released and re-established while their associated call session is up. The separation of call and connection control allows to reduce call control information at intermediate connection control nodes, since the call control is provided only at UNI (an ingress port) and E-NNI (network boundaries), and not at I-NNI.

The principal functions of the control plane to support the call and connection control are as follows:

- automatic network neighbor, resource and service

Component	Description
Connection Controller (CC) 	Manages and supervises connection setup, release and modification. Coordinates operation of Link Resource Manager(LMR)and Routing Controller(RC)
Routing Controller (RC) 	Provides routes within the domain of its responsibility. Maintains addressing information about other subnetworks at the same layer
Link Resource Manager A (LRMA) 	Allocates and deallocates SNP(subnetwork point) link connections.Provides topology and status information.LRMA is responsible for the management of the A end of the SNPP link.
Link Resource Manager Z (LRMZ) 	Manages the Z end of the SNPP link, providing topology information

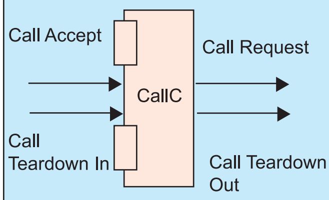
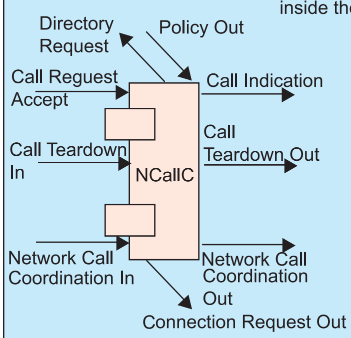
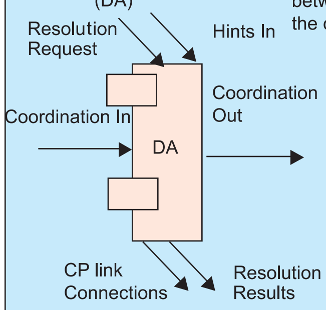
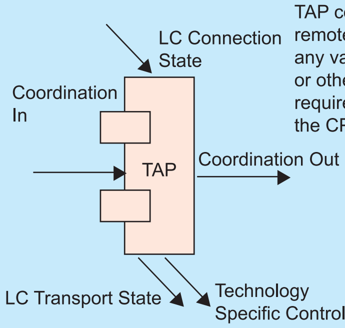
Component	Description
Call Controller(CallC) 	Calling/Called Party Call Controller is associated with an end of a call and generates and processes call requests.
Network Call Controller (NCallC) 	Network Call Controller is responsible for call control inside the network
Discovery Agent (DA) 	Provides for separation between the transport and the control plane names
Termination and Adaptation Performer(TAP) 	Responsible for holding SNP-CP binding.A local TAP cooperates with a remote TAP to coordinate any variable adaptation or other coordination required when forming the CP link connections

Table 1. Components of the control plane

discovery,
- address assignment and resolution,
- signaling,
- routing.

A variety of requirements related to the control plane can be listed as follows [1]:
- fast and reliable call setup,
- ability to control admission of calls and connections,
- reliability, scalability, and efficiency of the control plane,
- support for transport network survivability,
- support of various transport network technologies,
- support for supplementary services,
- applicability regardless of the particular choice of control protocols,
- applicability regardless of the distribution of connection control functions,
- support for multi-homing,
- support of diverse connections,
- possibility of division into domains and routing areas.

The call admission function at the originating node is responsible for authentication of the user and checking the requested service parameters against a Service Level Specification. These parameters may be renegotiated, if necessary. At the terminating node, the call admission function has to check if the called user is entitled to accept the call. The connection admission control checks if there are sufficient resources to admit a connection. In the case of circuit switched networks, availability of physical resources (e.g., wavelengths, TDM channels, etc.) is checked. For packet networks, the connection admission function has to ensure that admission of a new packet flow will not jeopardize quality of service contracts of the existing connections.

The control plane has to be reliable, scalable and efficient. The reliability means that even in case of failures of the control plane the existing transport connections are maintained. The separation of the call and connection control facilitates support for transport network survivability. The impact of failures affecting connections in the transport plane can be minimized by using appropriate protection and restoration schemes. During the relevant procedures the associated calls are maintained.

Along with bearer services, such as SONET/SDH, OTN, Ethernet, and others, the control plane should support supplementary services independent of the bearer service. An example of such a service is a closed user group [2]. ASON defines functionality of the control plane independent of a particular choice of control protocols. Therefore, a variety of such protocols can be used in real networks, including those from the MPLS family, like RSVP-TE, or coming from the ATM world, like PNNI. Elementary control functions can be packaged differently by different vendors. They can have also diverse approaches concerning either centralization or distribution of control functions.

The control plane has to support multi-homing, allowing multiple links between a user and one or more transport networks. Such an approach facilitates load balancing and resilience. A user can request diversely routed connections, i.e., connections using disjoint sets of network resources.

The control plane can be subdivided into domains that match the administrative domains of the network. These domains can be further divided, and so on, as shown in Fig. 6 [1]. The reasons for such divisions may include geographical arguments, vendor requirements, routing constraints, etc.

Control Plane Modeling

The architecture of the control plane is modeled by defining its key functional components and their interactions. Components are used to represent abstract entities and are used to construct scenarios explaining the operation of the architecture [1]. Control plane components, as defined in [1] are listed in Tab. 1. Each component contains a set of interfaces used for monitoring of its operation, setting policies and affecting internal behavior. Along with the components shown in Tab. 1, some additional components can be defined. They include Protocol Controllers and Port Controllers. Protocol Controllers map the parameters of the abstract interfaces of the control components into messages that are carried by a protocol. Port Controllers are used to implement policy, defined as a set of rules applied to interfaces at the system boundary, as well as to monitor and configure system components. Call admission control or traffic policing are examples of policy functions implemented by Port Controllers. Call Admission Control (CAC) and Traffic Policing (TP) components are subclasses of Policy Port.

Controllers in different domains have to co-operate. Two types of such a co-operation were defined by ITU-T in G.8080 [1], i.e., the joint federation model and the co-operative model. In the first model, the highest-level controller acts as the coordinator by dividing the responsibilities between the next-level controllers, where each of them is responsible for its part of the connection. The second model does not involve any higher-level co-ordination. In large networks both models can be combined.

Control Plane Functions

To offer features discussed in the previous sections several enabling mechanisms are necessary. They include discovery functions, routing, signaling as well as protection and restoration schemes.

Discovery

Automatic discovery eliminates the need for explicit configuration activity. The following three groups of discovery functions can be distinguished:
- neighbor discovery,
- resource discovery,
- service discovery.

The neighbor discovery is responsible for determining the state of local links connecting to all neighbors. This kind of discovery is used to detect and maintain node adjacencies. It is essential to keep track of connectivity between adjacent network elements. Without it, it would be necessary to manually configure the interconnection information in management systems or network elements. The neighbor discovery usually requires some manual initial configuration and automated procedures running between adjacent nodes when the nodes are in operation. Three instances of neighbor discovery are defined in ASON, that is: physical media adjacency discovery, layer adjacency discovery, and control entity logical adjacency establishment [7]. Physical media discovery has to be done first to verify the physical connectivity between two ports. This is followed by checking the layer adjacency which defines the associations between the end points that terminate a logical link at a given layer. The control adjacency involves two control entities associated with neighboring transport plane network elements. The layer adjacency discovery is used for building layer network topology to support routing, creating logical adjacencies between control entities, and for identifying link connection endpoints that are needed for connection management [7].

Discovery processes involve exchange of messages containing identity attributes. Relevant protocols may operate in either an acknowledged or unacknowledged mode. In the first case, the discovery messages can contain the near end attributes and the acknowledgment can contain the far end identity attributes. The service capability information can be also contained in the acknowledgment message. In the unacknowledged mode both ends send their identity attributes [7].

Recommendation G.7714 discusses the following two discovery methods [7]:

- trace identifier method, and
- test signal method.

In the trace identifier method trail termination point associations are first discovered, and then link connections are inferred. This method is especially useful if the server layer network topology is sparse compared to the client layer network. It also does not require any test signal generators and receivers. In the test signal method test signals are used to directly find associations between subnetwork termination points without discovering any server layer trails. The two presented discovery methods are related to methods described in G.7714.1, i.e., *in-service discovery* and *out-of-service discovery* [8]. In the in-service discovery process termination connection points are discovered by using the server layer overhead, while the out-of-service discovery process uses test signals. The latter process can only be used if the link connection is not carrying any client traffic.

The resource discovery has a wider scope than the neighbor discovery. It allows every node to discover network topology and resources. Some details of the complete topology can be hidden to the nodes located in other network domains. This kind of discovery determines what resources are available, what are the capabilities of various network elements, how the resources are protected. It improves inventory management as well as detects configuration mismatches. Resource discovery can be achieved through either manual provisioning or automated procedures [4].

The service discovery is responsible for verifying and exchanging service capabilities of the network, for example, services supported over a trail or link. Such capabilities may include the class of service (CoS), the grade of service (GoS) supported by different administrative domains, the ability to support flexible adaptation at either end of the connection, and the ability to support diverse routing [7]. Service capability exchange reduces the amount of in-band events that are required to perform discovery. Discovery of trails at a server level allows for automatic identification of the link connections that are supported by these trails.

Protocols for automatic discovery in SDH and OTN networks are specified in ITU-T Recommendation G.7714.1/Y.1705.1 [8].

Routing

Routing is used to select paths for establishment of connections through the network. Although some of the well known routing protocols developed for the IP networks can be adopted, it has to be noted that optical technology is essentially an analog rather than digital technology and, therefore, transmission impairments accumulated along the optical paths have to be taken into account while calculating the route. Another constraint influencing routing mechanisms, related to ASON, but also to any operator being an ISP or a bandwidth service provider, is the fact that carriers do not allow other carriers or private domains visibility of their internal network topologies. Because of the large scale of the considered networks the routing protocols should minimize global information as much as possible.

Architecture and requirements for routing in ASON have been described in ITU-T Recommendation G.7715/Y.1706 [9]. This recommendation covers the following areas: ASON routing architecture, functional components including path selection, routing attributes, abstract messages and state diagrams.

ASON supports hierarchical, source-based and step-by-step routing resulting in a different distribution of components between nodes and their mutual relationships. In the first case, connection controllers are related to one another in a hierarchical manner. Each subnetwork knows only its own topology but has no knowledge of the topology of other subnetworks at any hierarchical level. Path selection starts at the top of the hierarchy and define a sequence of subnetworks in a lower level through which a path can be found between a given source and destination node [9]. The process continues the same way at all levels. Source routing is based on a federation of distributed connection and routing controllers. The path is selected by the first connection controller in the routing area. This component is supported by a routing controller that provides routes within the domain of its responsibility. Step-by-step routing requires less routing information in the nodes than the previous methods. In such a case path selection is invoked at each node to obtain the next link on a path to a destination [9].

Signaling

Signaling involves transporting control messages between all entities communicating through a network's control plane. Signaling protocols are used to create, maintain, restore, and release connections. Such protocols are essential to enable fast provisioning or fast recovery after failures. According to G.807, the signaling network in ASTN should be based on common channel signaling which involves separation of the signaling network from the transport network. Such a solution, in turn, supports scalability, a high degree of resilience, efficiency in using signaling links, as well as flexibility in extending message sets [2]. It is important that a variety of different signaling protocols can inter-operate within a multi-domain network and the inter-domain signaling protocols shall be agnostic to their intra-domain counterparts.

Several recommendations concerning signaling issues in ASTN were developed by ITU-T. G.7713/Y.1704 specifies operations for call setup and release [10]. It also describes signaling exchange that allows support for hierarchical, source and step-by-step routing. Recommendations G.7713.1/Y.1704.1 [11], G.7713.2/Y.1704.2 [12], and G.7713.3/Y.1704.3 [13] provide the signaling mechanisms and protocol specifications based on PNNI/Q.2931, GMPLS RSVP-TE, and GMPLS CR-LDP, respectively. Transport of signaling messages is via a data communication network (DCN), such as that described in ITU-T Recommendation G.7712/Y.1703 [14].

Automatic discovery and routing, supported by signaling schemes, are sometimes referred to as self-management since they relieve the management system from time-consuming tasks concerned with manual updates of topology changes and path selection.

Call and connection control

Call and connection control are separated in the ASON architecture [10]. A call is an association between endpoints that supports an instance of service, while a connection is a concatenation of link connections and subnetwork connections that allows transport of user information [2]. A call may embody any number of underlying connections, including zero. Benefits of this separation include supporting such optical services as scheduled bandwidth on demand, diverse circuit provisioning, or bundled connection, for example in the case where the call involves multimedia applications, including voice, video, and data [4]. The call and connection control separation makes also sense for restoration after faults. In such a case the call can be maintained (i.e., it is not released) while restoration procedures are underway [15].

The call control must support co-ordination of connections in a multi-connection call and the co-ordination of parties in a multiparty call. It is responsible for negotiation of end-to-end sessions, call admission control, and maintenance of the call state. The connection control is responsible for the overall control of individual connections, including set-up and release procedures and the maintenance of the state of the connections. The connection control involves connection admission control, i.e., a process that determines if there are sufficient resources to admit or maintain a connection (the latter case is related to re-negotiation of resources during a call) [1].

Survivability mechanisms

The higher network reliability in ASON is achieved by using various survivability schemes. Survivability is a network capability to continue its operation under the condition of failures within the network. Survivability can be supported by either protection or restoration mechanisms. The former is based on replacement of a failed resource (e.g., a link or a path) with a pre-assigned standby resource, while the latter, on re-routing using spare capacity. Typically, protection actions are completed within tens of milliseconds while restoration takes from hundreds of milliseconds to up to a few seconds. Both mechanisms can support the class of service (CoS) requested by a customer [1]. Since protection or restoration may be applied at different layers (e.g., the IP and optical layers), they have to appropriately coordinated.

Survivability in ASON involves all three functional planes. In the case of transport plane protection, the configuration of protection is the responsibility of the management plane. However, the transport plane should inform the control plane about all failures of transport resources as well as their additions or removals. Unsuccessful transport plane protection actions may trigger restoration supported by the control plane. In the case of control plane protection, the control plane creates both a working connection and a protection connection. For this kind of protection only the source and destination connection controllers are involved [1].

Control plane restoration is based on rerouting of calls using spare capacity. Such a rerouting service is performed on a per rerouting domain basis, i.e., the rerouting operation takes place between the edges of the rerouting domain and is entirely contained within it [1]. This assumption does not exclude requests for an end-to-end rerouting service. Hard and soft rerouting services can be distinguished. The first one is a failure recovery mechanism and is always triggered by a failure event. Soft rerouting is associated with such operations as: path optimization, network maintenance, or planned engineering works, and is usually activated by the management plane. In soft rerouting the original connection is removed after creation of the rerouting connection, while in hard rerouting the original connection segment is released prior to creation of a new alternative segment.

Amendment 1 to G.8080 defines resilience as the ability of the control plane to continue operation under failure conditions [1]. An important principle is that the existing connections in the transport plane should not be affected by failures in the control plane. However, new connection requests may not be processed by the failed control plane. In this case the management plane can be used to respond to new connection requests.

CONCLUSIONS

The ASON-based approach to the control plane for optical networks is relatively mature. The key standards are already available, although considerable work still has to be done to fill all gaps. The strength of the ASON concept is the fact that it employs well developed concepts of the IP world, such as automatic discovery or routing, and allows reuse of some of its protocols, in the circuit switched environment of optical networks. Implementation of ASON enables fast provisioning, easier network operation, increases network reliability and scalability as well as simplifies planning and design. This, in turn, may be translated into direct benefits to operators and their clients. It should be noted, however, that along with ASON, there exist alternative approaches to the implementation of the control plane for optical networks, such as those based on generalized multiprotocol label switching (GMPLS).

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