

STUDY PAPER

ON

**AUTOMATICALLY SWITCHED OPTICAL
NETWORK(ASON)**

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Automatically Switched Optical Network (ASON)

ABSTRACT

This paper gives an overview of the automatically switched optical network (ASON), concentrating on its control plane. The ASON architecture, based on transport, control, and management planes, types of connections supported by ASON including permanent, switched, and soft permanent connections and drivers to automatically switched optical networks have been described. Different kinds of internal and external interfaces and various issues related to the ASON control plane, such as control plane requirements, modeling, and functions have also been presented and discussed. 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.

1.0 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.

The purpose of the automatic switched optical network (ASON) control plane is to: – facilitate fast and efficient configuration of connections within a transport layer network to support both switched and soft permanent connections; – reconfigure or modify connections that support calls that have previously been set up; – perform a restoration function.

The Automatic Switched Optical Network (ASON) is both a framework and a technology capability. As a framework, it describes a control and management architecture for an automatic switched optical transport network. As a technology, it refers to routing and signaling protocols applied to an optical network which enables dynamic path setup.

2.0 OPTICAL NETWORK ARCHITECTURES: Optical network architectures not only provide transmission capacities to higher transport levels, such as inter-router connectivity in an IP-centric infrastructure, but also provide the intelligence required for efficient routing and fast failure recovery in core networks. This is possible due to the emergence of optical network elements that have the intelligence required to efficiently manage networks such as GMPLS and ASON.

2.1 GENERALIZED MULTI-PROTOCOL LABEL SWITCHING (GMPLS): Present data and transmission networks consist of elements such as routers, switches, Dense Wavelength Division Multiplexing (DWDM) systems, Add-Drop Multiplexors (ADMs), photonic cross-connects(PXCs), optical cross-connects (OXCs), etc. that will use Generalized

Multi-Protocol Label Switching (GMPLS) to dynamically provision resources and to provide network survivability using protection and restoration techniques. The MPLS architecture was defined to support the forwarding of data based on a label. In this architecture, Label Switching Routers (LSRs) were assumed to have a forwarding plane that is capable of (a) recognizing either packet or cell boundaries, and (b) being able to process either packet headers (for LSRs capable of recognizing packet boundaries) or cell headers (for LSRs capable of recognizing cell boundaries). The original MPLS architecture has been extended to include LSRs whose forwarding plane recognizes neither packet, nor cell boundaries, and therefore, cannot forward data based on the information carried in either packet or cell headers. Specifically, such LSRs include devices where the switching decision is based on time slots, wavelengths, or physical ports. GMPLS extends MPLS to encompass time-division (e.g., SONET/SDH, PDH, G.709), wavelength (lambdas), and spatial switching (e.g., incoming port or fiber to outgoing port or fiber). So, the new set of LSRs, or more precisely interfaces on these LSRs, can be subdivided into the following classes: i) Packet Switch Capable (PSC) interfaces, ii) Layer-2 Switch Capable (L2SC) interfaces, iii) Time-Division Multiplex Capable (TDM) interfaces, iv) Lambda Switch Capable (LSC) interfaces and Fiber-Switch Capable (FSC) interfaces.

2.2 ASON (Automatically switched optical network): An Automatic Switched Optical Network (ASON) is basically a DWDM-based network designed to provide Client Networks and Customers with very flexible transport services, called permanent, soft permanent and switched optical connections. Apart from permanent connections, also known as leased lines, the other two innovative optical transport services are based on distributed network intelligence (i.e., Control Plane) and signaling. A switched connection is set up and released directly either by Client Network or by Customer equipment by means of a User Network Interface (UNI), in case of a soft permanent optical connection, it is the Management System that triggers the Control Plane (CP) of the head-end node. Both kinds of connections are then established via Network Node Interface (NNI) signaling and Control Plane processing (fig 1).

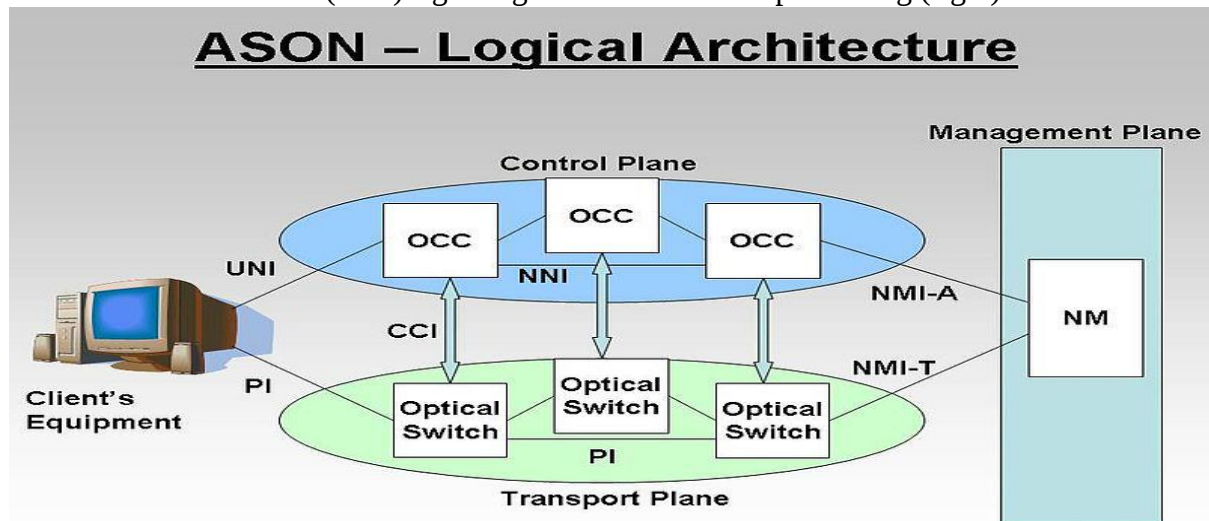


Fig 1. Automatically switched optical network Architecture

3.0 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

- i. Manual error-prone provisioning,
- ii. Long provisioning times,
- iii. Inefficient resource utilization,
- iv. Difficult interoperability between the packet client networks and the circuit-switched optical networks.
- v. Complex network management,
- vi. Difficult interoperability between networks belonging to different operators,
- vii. Lack of protection in mesh-type optical network

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

- i. Fast provisioning,
- ii. Easier network operation,
- iii. Higher network reliability,
- iv. Scalability,
- v. 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.

4.0 ASON ARCHITECTURE

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

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. The general relationships between the three ASON planes are shown in Fig. 3. The following interactions can be distinguished:

- i.Management - transport interaction,
- ii.Control - transport interaction, and
- iii.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.

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. **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.

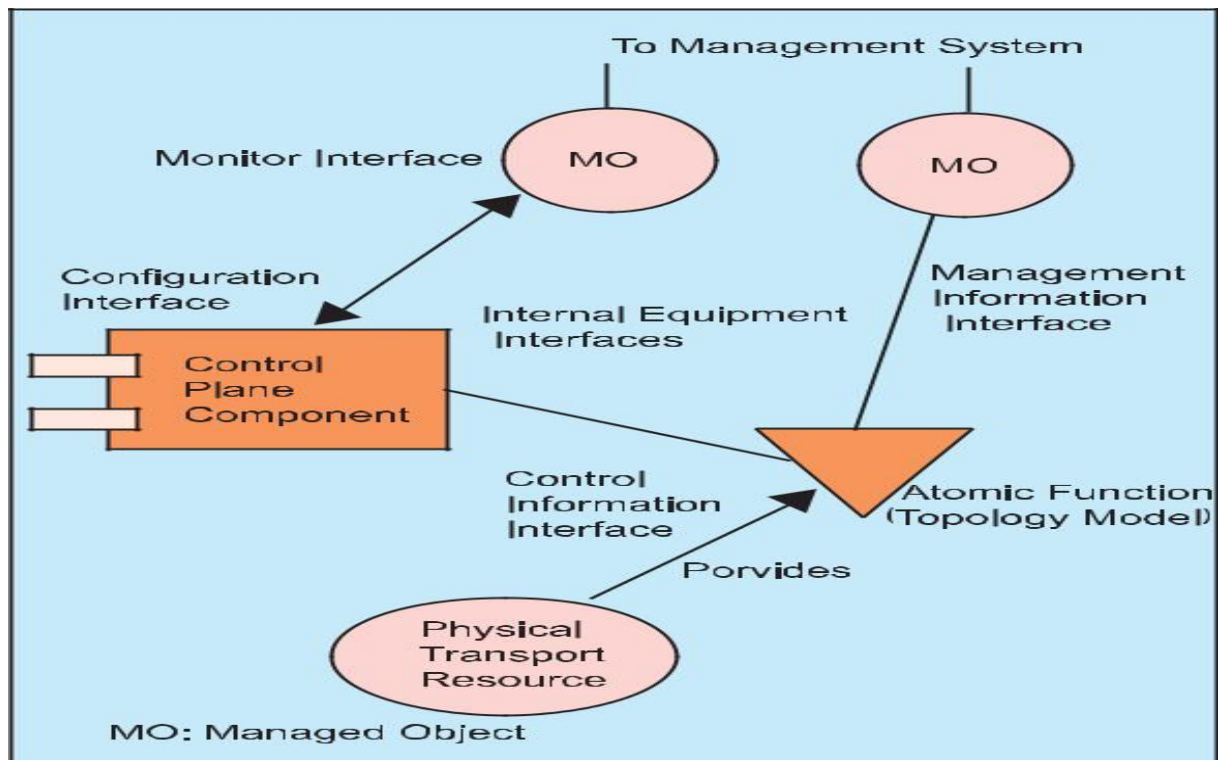


Fig.2. Interactions between ASON planes

4.1 Optical Connections

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

- i. Uni-directional point-to-point connection,
- ii. Bi-directional point-to-point connection,
- iii. 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:

- i. Permanent,
- ii. Switched,
- iii. 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.

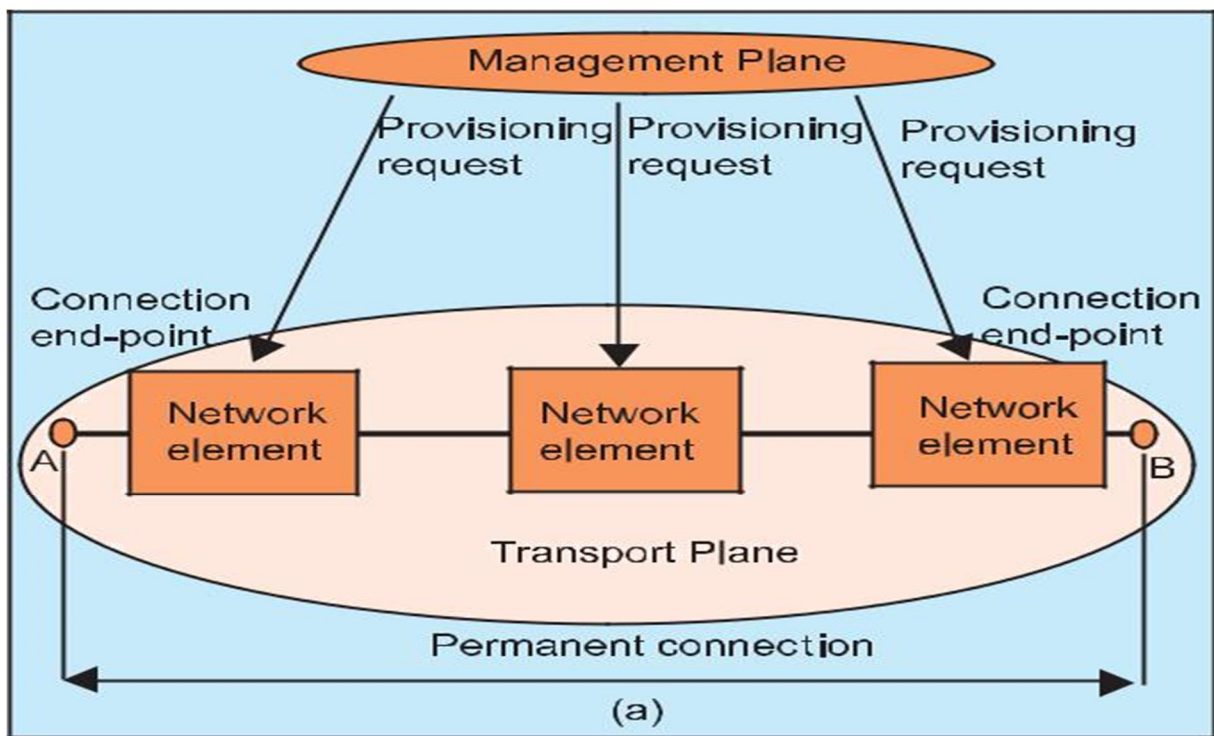


Fig. 3a. Examples of transport connections in ASON; permanent connection,

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).

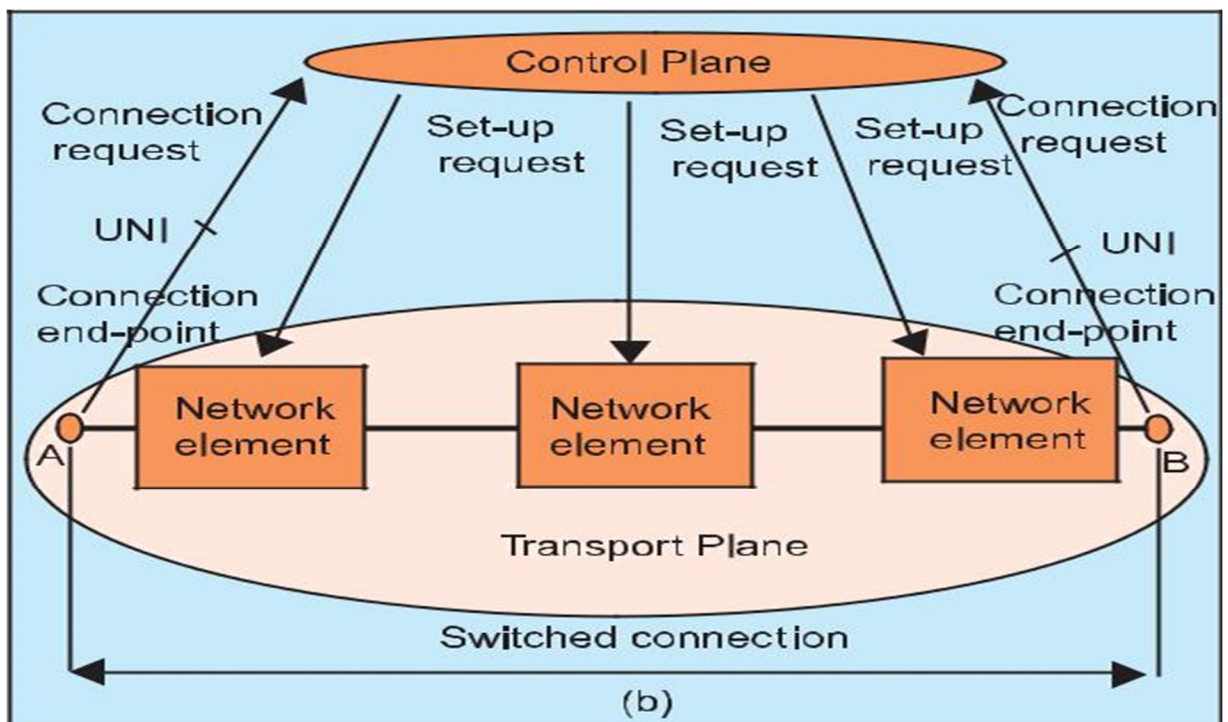


Fig. 3b. Examples of transport connections in ASON; , switched connection

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.

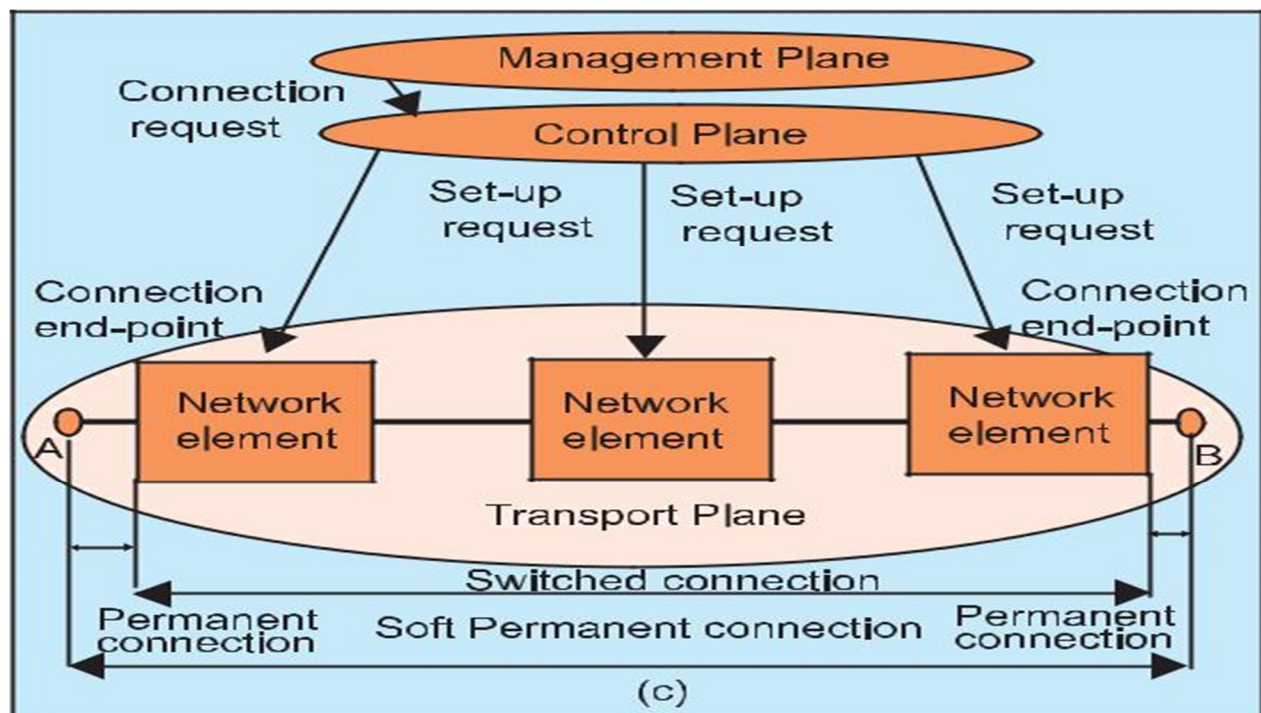


Fig. 3c. Examples of transport connections in ASON soft permanent connection

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.

4.2 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:

- *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.

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

- Connection service messages (UNI, E-NNI, I-NNI);
- Authentication and connection admission control (UNI, E-NNI);
- End-point name and address (UNI);
- Reach ability 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, reach ability 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.

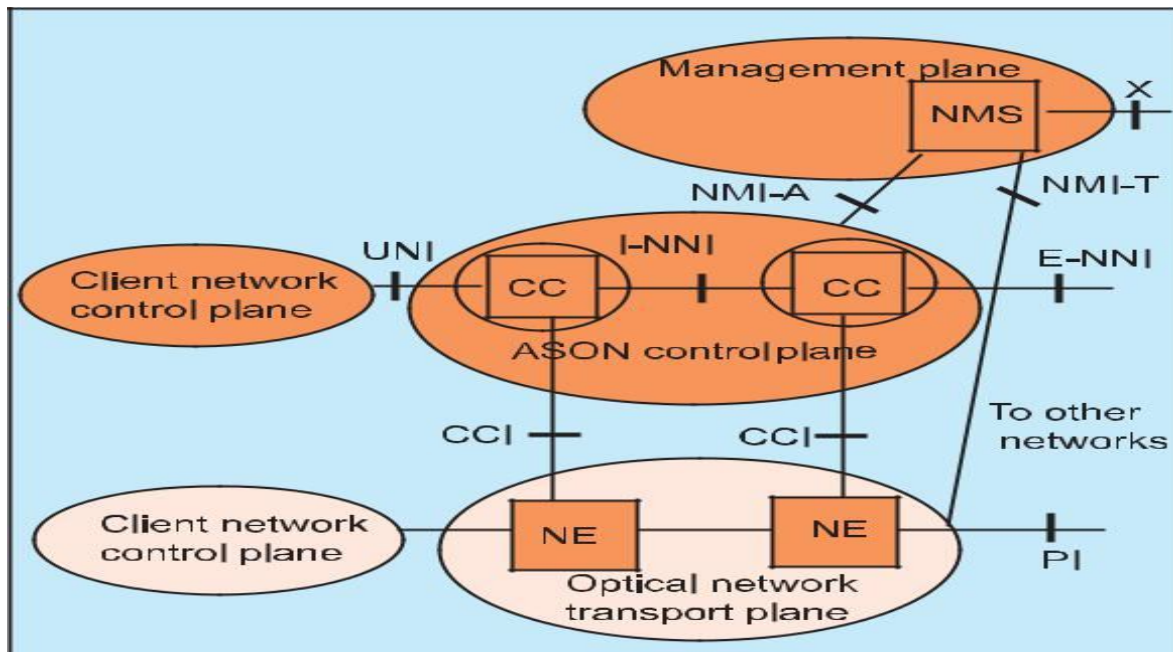


Fig.4. Logical view of ASON architecture
CC: Connection Controller
CCI: Connection Control Interface
E-NNI: External Network-Network Interface

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

Some other interfaces are shown in Fig. 5. 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 cross connect, 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. 6. 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 sub networks belonging to different carriers.

The external network-network interface may also be used to connect optical sub networks belonging to the same carrier but located in different control domains. In principle, selection of either I-NNI or E-NNI between sub networks 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. There are several possible reasons that a single carrier decides to distinguish several optical sub networks. 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, sub networking may reflect a hierarchical structure of large networks or is a result of business mergers and acquisitions.

5.0 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.

5.1 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. 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:

- i. Automatic network neighbor, resource and service discovery,
- ii. Address assignment and resolution,
- iii. Signaling,
- iv. Routing.
- v. A variety of requirements related to the control plane can be listed as follows:
- vi. Fast and reliable call setup,
- vii. Ability to control admission of calls and connections,
- viii. Reliability, scalability, and efficiency of the control plane,
- ix. Support for transport network survivability,
- x. Support of various transport network technologies,
- xi. Support for supplementary services,
- xii. Applicability regardless of the particular choice of control protocols,
- xiii. Applicability regardless of the distribution of connection control functions,
- xiv. Support for multi-homing,
- xv. Support of diverse connections,
- xvi. 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. 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. The reasons for such divisions may include geographical arguments, vendor requirements, routing constraints, etc.

5.2 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. Each component of control plane contains a set of interfaces used for monitoring of its operation, setting policies and affecting internal behavior. Along with the components shown in Table1, 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, 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.

5.3 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.

5.3.1 Discovery

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

- i. Neighbor discovery,
- ii. Resource discovery,
- iii. 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.

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.

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.

Recommendation G.7714 discusses the following two discovery methods:

- i. Trace identifier method, and
- ii. 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 sub network 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. 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.

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. 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.

5.3.2 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 . 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 sub network knows only its own topology but has no knowledge of the topology of other sub networks at any hierarchical level. Path selection starts at the top of the hierarchy and define a sequence of sub networks in a lower level through which a path can be found between a given source and destination node. 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.

5.3.3 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. 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**. It also describes signaling exchange that allows support for hierarchical, source and **step-by-step routing**. Recommendations G.7713.1/Y.1704.1, G.7713.2/Y.1704.2, and G.7713.3/Y.1704.3 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.

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.

5.3.4 Call and connection control

Call and connection control are separated in the ASON architecture. A call is an association between endpoints that supports an instance of service, while a connection is a concatenation of link connections and sub network connections that allows transport of user information. 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. 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.

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).

5.3.5 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. 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.

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. 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. 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.

6.0 ASON versus GMPLS

6.1 GMPLS: GMPLS switches are seen as operating in a GMPLS-only cloud of peer network elements. Nodes at the edge of the cloud are capable of accepting non-GMPLS protocol data and tunneling it across the GMPLS cloud to other edge nodes (figure 6). All the nodes and links that constitute the GMPLS network share the same IP address space and information is shared freely between nodes. In other words, GMPLS implies a trusted environment. When full data plane interoperability is achieved, any of the network elements in the cloud may be swapped for a different vendor's network element. Until then, GMPLS can be used to interface between groups of network elements from different vendors.

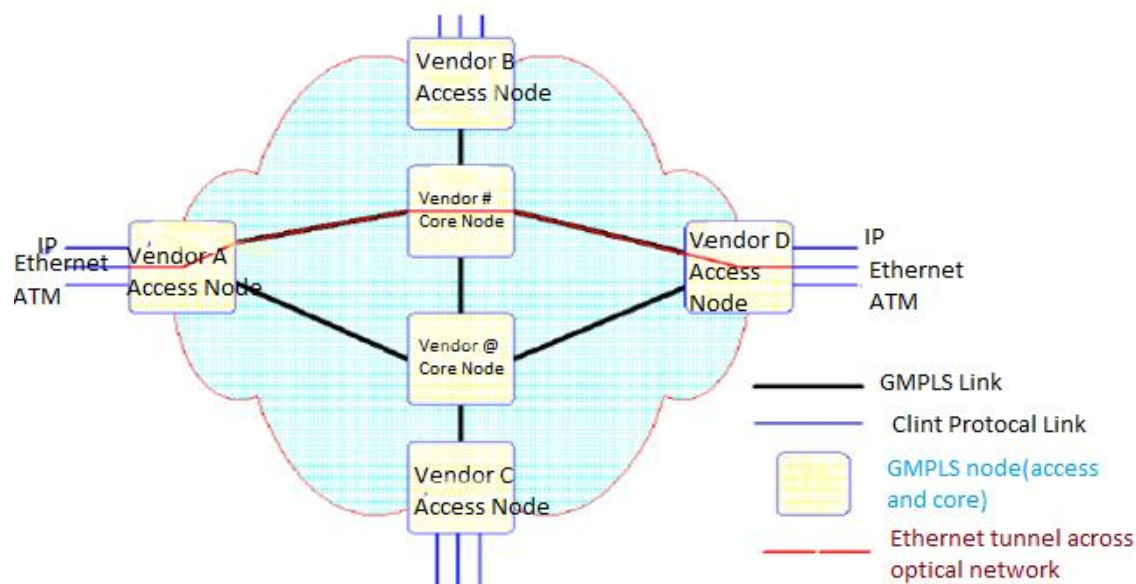


Figure 6 - Simple GMPLS network showing Ethernet tunnel

6.2 ASON: By contrast with the “GMPLS everywhere” approach, a key principle of ASON is to build in support for legacy network devices explicitly into the architecture. Full multi-vendor

interoperability is seen both as a low priority and unrealistic to achieve in the near term, not least because of data plane compatibility issues.

ASON views the network as composed of domains which interact with other domains in a standardized way, but whose internal operation is protocol-independent and not subject to standardization (figure-7). The interface between such domains is known as the exterior node-to-node interface, or E-NNI. E-NNIs can also be usefully classified into “intra-operator” and “inter-operator”.

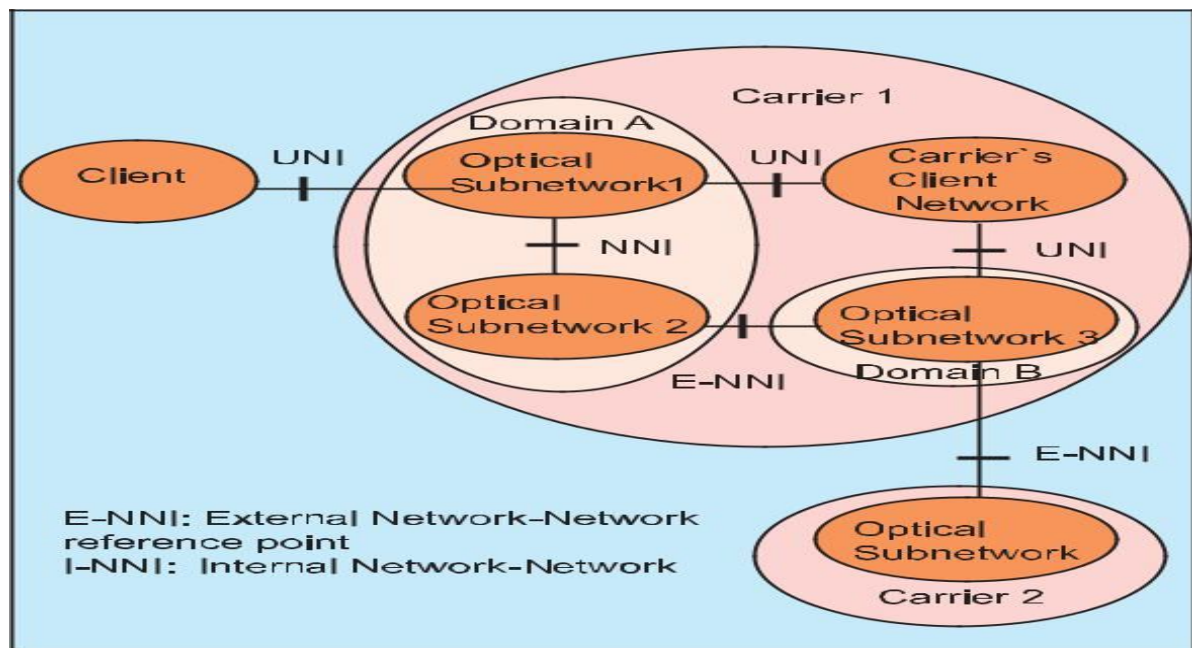


Fig.7. Generic ASON network reference model

The I-NNI (interior NNI) is the vendor-specific, proprietary interface used within a single-vendor domain.

The conception of the network is also extended more widely than in GMPLS, to allow users to participate in the automated control plane. Here, the “user” is an endpoint device that requests the services of the transport network rather than provides them. In ASON, users can request connection services dynamically over a user-network interface, or UNI. In GMPLS, the closest thing to an ASON user is simply a GMPLS edge node, but this is not an exact mapping of the ASON concept.

The ASON way of looking at the network is not all that different from the GMPLS, this can be understood from the GMPLS analogy -

- i. Relax the definition of a GMPLS “node” so that it does not always correspond to a single network element, but can instead be a group of network elements, or a proxy operating on their behalf
- ii. Redraw the boundaries of the network clouds to illustrate UNI, I-NNI and E-NNI interfaces.

The UNI, E-NNI and I-NNI are known as “reference points”, and the UNI and E-NNI indicate the locations in the network where standardized protocols will need to be used. Each reference point has different requirements on the degree of information hiding that occurs at that reference point.

- i. The UNI is an un-trusted reference point, and hides all routing and addressing information pertaining to the interior of the network from the user. ASON is very clear on the fact that users should belong to a different address space from internal network nodes, and this means that when GMPLS is mapped onto the ASON UNI reference point, the usual IP address cannot represent a user.
- ii. The I-NNI is a trusted reference point. Full routing information can be flooded.
- iii. The inter-operator E-NNI is a semi-trusted reference point. Some degree of routing information is exchanged to allow routes to be calculated across the network, but network internals are hidden to avoid leakage of confidential information between operators.
- iv. The intra-operator E-NNI is either trusted or semi-trusted, depending on the administrative structure of the particular operator.

6.3 Where do the conflicts arise?

The UNI requires new features that are not provided in core GMPLS. First, new addresses need to be assigned to users of the network in order to maintain complete separation of the user and the network addressing spaces. This is a security requirement of the operators who are supporting ASON. Next, because no routing information is allowed to flow across the UNI, the user cannot calculate suitable routes itself. Instead, it must pass its requirements across to its neighbour in the network. Finally, the user needs to have an expectation of what requirements the network can actually satisfy in advance, which creates the need for a start-of-day service discovery process.

The initial work to define the UNI profile of GMPLS has been done by the OIF in the UNI 1.0 specification mentioned earlier. This involves creating a profile of the two GMPLS signalling protocols that satisfies the signalling requirements above, and also enhancing the LMP protocol to include service discovery. ITU has both influenced and drawn heavily on the OIF work in this area.

Another issue between the ASON architecture and the current GMPLS protocol definition is the ASON requirement to allow call setup signalling, as distinct from connection setup. An ASON “call” is an association between two user endpoints. The concept of a call, which is inherited from telephony protocols, is problematic to map onto GMPLS because

- i. GMPLS does not have “users” in the ASON sense of the term
- ii. GMPLS signalling already has a built-in association between endpoints, so an ASON call looks like duplication of function.

There are proposals on the table to extend GMPLS signalling to include ASON call setup, which will give the IT users support they need, but are likely to meet resistance from pure GMPLS vendors who perceive them as unnecessary.

Moving onto routing, it is clear from the above that an ASON network will have a requirement to flood user address reach ability that will not be supported by unmodified GMPLS routing protocols. Apart from that, to a casual observer, it might look as if trusted E-NNI routing requirements can be met by intra-area protocols such as OSPF-TE, and semi-trusted E-NNI routing requirements can be met by an inter-area protocol such as BGP.

7.0 Future trends and challenges in ASON implementation:

i) Bandwidth-on-demand (BOD) and optical virtual private network (OVPN).

The introduction of ASON to optical networks brings with it several added benefits such as providing fast service and expansion, dynamic optimization of network resources, and quick

recovery of optical layer services. Other added advantages in providing new service types would include: bandwidth-on-demand (BOD), wavelength services, and the creation of an optical virtual private network (OVPN). ASON has many advantages over traditional optical networks. It can provide fast network services, and furnish profit growth points such as, OVPN, triple play, and other new services. It can also greatly enhance the survivability of services, effectively remove defects in the network at multiple points, and actually attain a carrier-class of over 99.999%.

The adoption of standard protocols and interfaces also makes it easier for the interworking of equipment from different operators, which operate under a variety of environments. In addition to this, ASON offers a range of services for the diversified needs of its customers. For instance, it makes service self-protection and topology discovery a realization and also reduces the workload of manual configuration and maintenance difficulties.

ii). Optical Transport Networks & Technologies (OTNT) & ITU-T Study Group-15 Standardization Work Plan

The transmission of information over optical media in a systematic manner is an optical transport network. The optical transport network consists of the networking capabilities and the technologies required to support them. For the purposes of standardization and work plan of ITU-T, all new optical transport networking functionality and the related other transport technologies have been considered as part of the OTNT Standardization Work Plan. The focus has been the transport and networking of digital client payloads over fiber optic cables. Though established optical transport mechanisms in transport plane such as synchronous Digital Hierarchy(SDH), Optical Transport Network (OTN), Ethernet frames over Transport (EoT), Multi-protocol label switching-transport profile(MPLS-TP) fall within the broad definition, only standardization efforts relating to new networking functionality of OTN, EoT and MPLS-TP have been actively considered as part of lead study group activity.

ASON in control plane and related equipment management aspects are also within this scope. Synchronization and time distribution aspects in the above transport network technologies are also included in the definition.

iii). Wavelength switched optical network (WSO) and automatically switched optical networks (ASON):

A WSO consist of two planes: the data and the control planes. The data plane comprises wavelength-division multiplexing(WDM) fiber links connecting optical cross-connect (OXC)s through a comb of several tens of wavelength channels, with typical data rates of 10 or 40 Gb/s. Optical end-to-end connections (i.e., light-paths) are established in the optical domain and switched by OXC)s at the wavelength granularity.

In WSO)s the optical signal is switched at the wavelength granularity, therefore the wavelength assignment process, selecting the carrier of each established light-path, plays a crucial role in dynamic network operation.

The dynamic provisioning and maintenance of light-paths is managed by the control plane. The control plane is implemented on a separate network and typically employs one network controller for each node in the data plane.

iv). Network switching evolution: The possible further stages in the network switching evolution illustrated in the figure 8 to be studied to understand the future of Network switching has taken shape. These are:

- Initially, we move to a more data-centric and dynamic switching model using an ASON architecture, which would allow automated light-path provisioning and supports NG-SDH/SONET with DXC or OXC (OEO) switching in the data plane and possible move to IP/MPLS (i.e., IP routers) or GMPLS with optical-electrical-optical (OEO) or optical-optical-optical(OOO) wavelength switches) architectures is foreseen, which provides an enhanced dynamic capability GMPLS to allow all transport modes, circuits, burst, and packets to be supported and can be deployed in either a centralized or a distributed mode. This represents one of the options to build a “converged network,” where the backbone is a multi-technology IP/GMPLS/OEO/OOO network supporting all services (voice, data, video), which may overtake the ASON architecture.
- It is also the case that in recent times carrier Ethernet based on native Ethernet or MPLS looks increasingly attractive across all layers of the network. Indeed, some network providers already operate national converged networks with Ethernet switching elements. The move toward 100 GbE standards illustrates the importance of this technology and hints of future major roles in NG networks.
- Then move to a user-centric design based on Optical burst Switching (OBS) with GMPLS (OBS/GMPLS); this technology provides sub-wavelength granularity and is also of interest to future optical grid networks.
- Finally, move to an Optical Packet Switching (OPS) network, where MPLS provides a common (across electrical/ optical domains) control plane. OPS offers the finest granularity and is still seen as the ultimate switching technique, but its success will depend on many technological advances;

v). ITU-T recommendations and IETF standards on ASON:

The creation and evolution of the ASON/GMPLS control plane is a collaborative effort among several standards bodies and industry players. The ITU-T has defined the ASON suite of Recommendations (ITU-T Recommendations ITU-T G.8080, G.807, G.805, G.7712/Y.1703, G.7713/Y.1704, G.7714/Y.1705 & G.7715/Y.1706), which focuses on transport control plane requirements, architecture and management. The ITU-T brings expertise in multi domain, multilayer transport network and equipment architecture, operations and forwarding plane specifications.

The protocols used for GMPLS have been defined by the IETF as a generalization or extension of Multiprotocol Label Switching (MPLS) for applicability to optical switching. The foundation for GMPLS standards matured in the early to mid-2000s and is supported by vendors across a broad segment of service and transport products. The IETF brings expertise in packet networks and Internet evolution to the ASON/GMPLS collaboration, and focuses on defining protocols for signaling and routing.

The Optical Interworking Forum (OIF) promotes the development and deployment of interoperable networking solutions. Its focus is on creating implementation agreements (IAs) based on requirements developed by the end-user, service provider and equipment-vendor communities. Key activities for IA development are bench mark creation and periodic interoperability testing using multivendor networks that connect service provider labs globally.

vi). Key challenges on ASON implementation:- A key challenge being faced by service providers is how to offer innovative, value-added services while maintaining efficient,

low cost-per-bit transport. This imperative is getting addressed with the Converged Backbone Transformation solution, which features close integration of IP and optical core transport networks. The ASON/GMPLS control plane is a key component of this solution, and the High Leverage Network architecture, providing:

- A control plane for a converged network to handle large traffic volumes at the lowest cost per bit
- Cross-layer automation between service and transport layers for maximum resource use
- Network resilience and flexibility, QoS and cross-layer management for integrated network visibility and operational troubleshooting

The ASON/GMPLS intelligent control plane spans the opto/electrical (Ethernet, SDH/SONET and sub-lambda OTN) and photonic (lambda OTN) layers to groom and forward traffic at the most economical layer, minimizing transport costs. It provides network reliability and resilience, is scalable, supports multiple services and lowers OPEX. Innovative network transformation solutions enable service providers to build on advances in IP and optical transport, and to leverage advances in transport network control and management, allowing providers to further improve QoS and network efficiency while reducing costs. We need to understand innovations happening in the field of ASON so as to accept challenges likely to come in the near future shall require to study ASON as part of yearly plan so as to develop the standards as part of deployment strategy in the near future. Although being a significant advancement towards flexible and easy-to-maintain transport network architectures, the ASON/GMPLS paradigm still presents the following open issues:

1. First, due to the coarse granularity offered by the WDM transport technology, established connections remain underused when sub-wavelength client flows must be transmitted. In light of this, a multi-layer approach, where different higher level data flows are aggregated in the IP layer and transmitted over the same optical path, appears as the most valid solution.
2. Second, even though pure optical transmission enabled by WDM provides high bandwidth in a cost-effective way, it is also very sensitive to the physical layer impairments that affect to the transmitted optical signal and, thus, to the transported data. Hence, a control plane capable of managing physical layer information to provide feasible light paths becomes a must.
3. Third, as transport network infrastructures grow, they are typically segmented into domains due to administrative, technological, or scalability reasons. The interconnection of network infrastructures managed by different operators is mandated by the need to provide long distance connectivity. Hence, confidentiality and reliability concerns become of paramount importance.

8.0 NETWORK APPLICATIONS: Network applications of an ASON Envisaged and the potential Customers of such transport services are:

- i). Optical Virtual Private Networks (OVPNs) for corporate connectivity are being recognised as a service that can be provided through ASON. Basically the OVPN service unit is an optical connection between a pair of customer/client devices.
- ii). Some recent studies showed an increased usage of streaming media in corporate applications. The extent to which streaming media will reach a mass market is highly dependent on the network infrastructures carrying it: from this perspective, ASONs are likely to fulfil such network requirements.

iii). Another need that is being faced today by companies is to access and retrieve data and information assets from huge data repositories or servers. This, together with corporate disaster recovery needs, may be satisfied with ASON infrastructures.

iv). The banking sector is likely to be one of the potential customer areas that might benefit from the provisioning of dynamic transport services.

v). Tele-medicine is another potential application, a lot of different information might be dynamically sent between remote centres (including high-resolution video streaming and on-line data from medical equipment) during surgery. Hence, the need for high capacity automatic switched connections emerges. The Quality of Service must be very high, since cutting off the channel during surgery may have fatal consequences.

vi). Other potential applications that might use ASON transport services are:

- i. Interactive collaboration environments,
- ii. Common access to remote resources,
- iii. Network-wide computation and data services (e.g., Grid)
- iv. Display of information through virtual reality environments.

vii) Current network infrastructures are supported on a layered model whereby heterogeneous data traffic can be seamlessly transported. In this architecture, where client/server relationships are established between adjacent layers, there exists an IP layer on top, two intermediate Asynchronous Transfer Mode (ATM) and Synchronous Digital Hierarchy (SDH) layers, and a Wavelength Division Mode (WDM) layer at the bottom. Despite the benefits provided by the intermediate ATM and SDH layer (i.e. QoS and resilience), the complex interaction between them and introduced overhead motivate an evolution towards a lighter model, where IP flows are directly sent through the WDM layer. In this new IP/WDM model the functionalities formerly provided by the ATM and SDH layer are moved to the optical domain.

viii) The static nature of current transport networks, which leads to long service provisioning times (i.e., hours or days), becomes incompatible with the dynamic patterns associated to the prevalent IP traffic. To overcome these limitations, the ITU-T proposed the Automatically Switched Optical Network (ASON) architecture, which utilizes a control plane to provide fast and reliable light paths within the optical transport network. In addition, the Generalized Multi-Protocol Label Switching (GMPLS) model defined by the IETF appears as the most promising technology to implement the functionalities of the ASON control plane. Therefore, future infrastructure for supporting public telecommunication networks will be based on optical networks, which will have to be data centric focused. Such an infrastructure will not be just the pure replacement of current SDH/SONET infrastructure; it is being required to include some intelligence in the network, which will be provided by a Control Plane.

9.0 RECOMMENDATIONS:

- a. DoT/TEC can further study on provisioning of new service such as BOD and OVPN through ASON.
- b. National Working Group- 15 of TEC may contribute towards ITU-T study group-15 (Standardization Work Plan on optical and other Transport Networks & Technologies(OTNT) for formulation of ITU-T recommendations & IETF standards (RFC 6827) on ASON.

- c. TEC may further take-up study of wavelength switched optical network (WSO), which is a related Extension of automatically switched optical networks (ASON).
- d. GR/IR on ASON may be formulated by Transmission division of Telecom Engineering center (TEC).
- e. Key challenges in implementation of ASON in Indian Networks can be studied in joint collaboration of TEC and Telecom industry and a white paper can be prepared.
- f. DoT/TEC may further study and develop ASON model for provisioning of dynamic transport services for banking sector.

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Abbreviation

ADMs	Add-Drop Multiplexors
ASON	Automatically switched optical network
ASTN	Automatic Switched Transport Network
CAC	Call Admission Control
CC	Connection Controller
CCI	Connection Controller Interface
CoS	Class of service
DCN	Data communication network
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
FCAPS	Fault Configuration Accounting Performance Security
FSC	Fiber-Switch Capable
FTTH	Fiber- to- the- home
FTTB	Fiber- to- the-building
FTTC	Fiber- to- the-curb
FTTCab	Fiber- to- the-Cabinet
E-NNI	External Network-Network Interface
FEC	Forward Error Correction
GLIF	Global Lambda Integrated Facility
GMPLS	Generalized Multiprotocol Label Switching
GoS	Grade of Service
HD	High Definition
IP & OC	IP and Optical Convergence
IP o DWDM	IP over DWDM (colored interfaces in router)
IPTV	IP television
I-NNI	Internal Network-Network Interface
LDP	Label Distribution Protocol
LFIB	Label Forwarding Information Base
LSC	Lambda Switch Capable
L2SC	Layer-2 Switch Capable
LSR	Label Switching Routers
MO	Management Object
MPLS	Multiprotocol Label Switching
MSA	Measurement Systems Analysis
NE	Network element
NFV	Network Functions Virtualization
NMI-A	Network Management Interface-ASON control plane
NMI-T	Network Management Interface-Transport control plane
NMS	Network Management System
OAM	Operations, Administration and Management
OADM	Optical Add Drop Multiplexers
OCH	Optical Channel
ORI	Optical Receiver Interface
OSC	Optical Supervisory Channel
OTI	Optical Transmitter Interface
OTN	Optical Transport Network

OXC	Optical Cross-connect
PI	Physical Interface
PON	Passive Optical Network
POTN	Portable OTN
PSC	Packet Switch Capable
PXC	Photonic Cross-connects
QoS	Quality of Service
RA	Routing Area
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RSVP	Resource-Reservation Protocol
SAN	Storage Area Network
SCC	Set of control component
SDN	Software Defined Networking
SLA	Service-Level Agreement
SONET	Synchronous optical networking
TCO	Total Cost of Ownership
TDM	Time Division Multiplex Capable
TDP	Tag Distribution Protocol
TP	Traffic Policing
UNI	User-network signaling interface
VLC	Visible light communication
VPNs	virtual private networks
VRS	Vendor related sub-domain
WDM	Wavelength Division Multiplexing
XFP	10 Gigabit Small Form Factor Pluggable