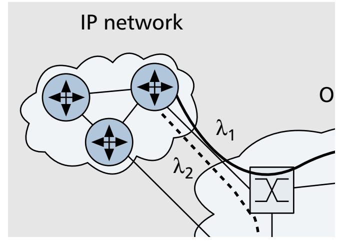

Automatically Switched Optical Networks: Benefits and Requirements

Andrzej Jajszczyk, AGH University of Science and Technology

Abstract

The article summarizes driving forces that are behind automatically switched optical networks. It discusses potential features of ASONs as well as benefits this concept may offer to carriers and their clients. The article begins with a brief discussion on limitations of existing optical networks, followed by a description of benefits of ASONs and their requirements. A numerical example illustrating the benefits of fast provisioning to the banking sector is given. Major features of ASONs are enumerated and enabling mechanisms are presented. The enabling mechanisms include discovery functions, routing, signaling, as well as protection and restoration schemes. The proposed taxonomy may facilitate understanding of a plethora of features of ASONs and their mutual relations.

Introduction

In recent years transport network carriers have built an impressive optical network infrastructure spanning five continents. Although in many areas such networks have excessive capacity, at the same time the available resources cannot be properly allocated due to inherent inflexibility of manually provisioned large-scale optical networks. In this article we overview limitations of the existing networks, and discuss potential features of automatically switched optical networks (ASONs) as well as benefits they may offer to carriers and their clients. An ASON is an optical transport network (OTN) that has dynamic connection capability [1]. This capability is accomplished by using a control plane that performs the call and connection control functions. A related but more generic term is automatic switched transport network (ASTN) [2]. The requirements concerning ASTN are technology-independent (i.e., they are valid not only for optical networks). Operators introducing the ASON control plane may expect increased revenue generating capabilities, reduced operational cost, and increased return on capital [3]. Mechanisms that will make the ASON possible are presented, along with relevant requirements.

Current optical networks, although offering enormous capacity, are quite inflexible compared 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:

- Manual error-prone provisioning
- Long provisioning time
- Inefficient resource utilization
- Difficult interoperability between packet client networks and circuit-switched optical networks
- Complex network management
- Difficult interoperability between networks belonging to different operators
- Lack of protection in mesh-type optical networks

Provisioning of leased optical paths, especially in a multi-operator environment, can take several weeks and requires considerable effort by well paid staff. Although such leased connections are usually set up for a long period of time (i.e., months or even years), fast provisioning within minutes or seconds would open new opportunities for both transport network operators and their clients. Such a shortening of the provisioning time would make more efficient utilization of available resources possible, allowing dynamic allocation of links and nodes, matching rapidly changing needs of client networks.

Large-scale OTNs require complex and costly network management systems. This, in turn, affects network scalability. Each change in the network structure, for example, adding a new crossconnect, usually results in a manual error-prone update in the management databases to reflect the current network topology. Keeping track of changes in the connectivity between network elements in large networks is usually very complex. Interoperability between different network operators is even more difficult. Although standardized interfaces between network management systems, such as the X interface in the telecommunication management network (TMN), were defined by the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) and other standardization bodies, they are practically not used since operators are not ready to allow access to their management systems to their competitors.

Network management systems can be used for relatively slow restoration in case of failures in networks. Real-time protection mechanisms are currently limited to ring-type optical networks. The target is to achieve control-plane-driven recovery mechanisms to replace resource-inefficient data-plane-driven mechanisms (in particular, 1+1 and Simple Network Control Protocol, SNCP) and time-inefficient management-plane-driven recovery mechanisms. Fast protection schemes

0163-6804/05/$20.00 © 2005 IEEE

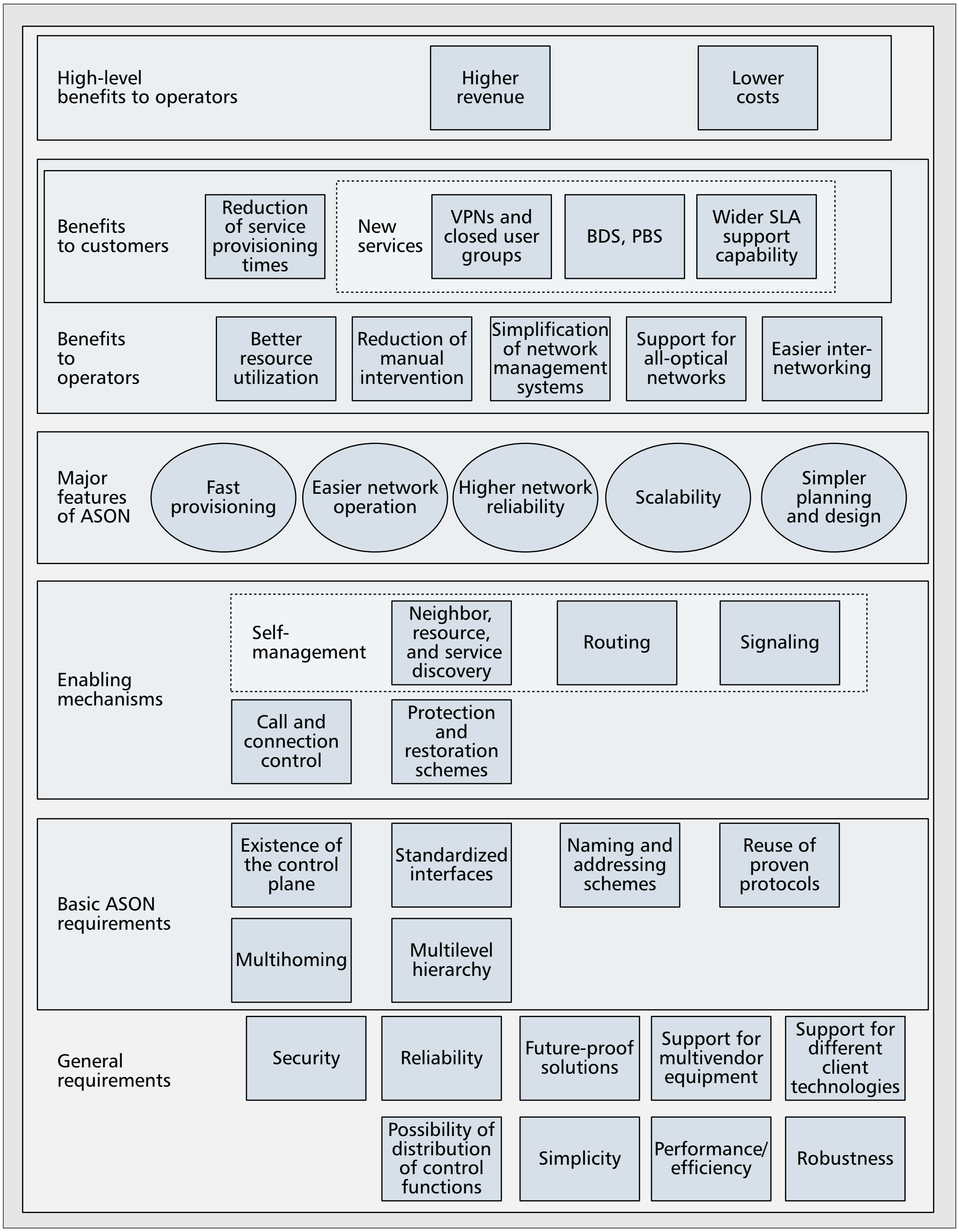

FIGURE 1. Major features, benefits, and requirements of ASONs.

for mesh-type networks would considerably enhance the reliability of the transport layer, offering new quality levels to clients.

BENEFITS AND REQUIREMENTS

In this section we discuss a variety of benefits and features associated with ASONs. The division into benefits, major features, enabling mechanisms, as well as basic and general requirements, shown in Fig. 1, is informal and subjective. Its aim is to facilitate understanding of a plethora of features of ASONs and their mutual relations. Obviously, some of the items can easily be moved to some other category if we decide to change our emphasis. The assumption is that the ASON concept is implemented by network operators to achieve higher revenue and lower costs of network deployment and operation. Other features hierarchically support these aims.

MAJOR FEATURES OF ASONS

The major features of an ASON 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

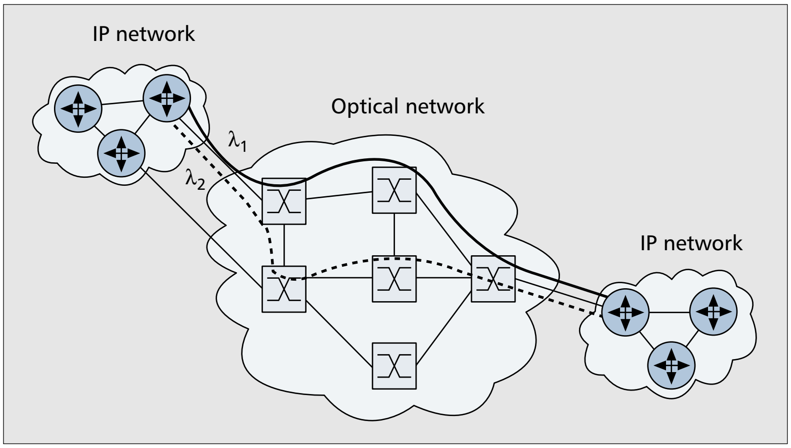

FIGURE 2. An example of fast provisioning.

resources can be linked automatically to data traffic patterns in client networks. An example of dynamic wavelength allocation to relieve congestion is shown in Fig. 2. Routers in IP networks can request an additional wavelength from an optical network for a relatively short period of time. The optical crossconnects dynamically add a new path (λ_2). When the traffic between the routers decreases, λ_2 can be released. Resources of the optical network can also be requested by a traffic engineering application based on measured statistics.

New protection and restoration schemes for mesh-type 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 switch traffic to reserved paths in real time, as shown in Fig. 3.

Large-scale transport networks are difficult to plan and design. Lack of reliable traffic data, uncertainty of future service needs predictions, and a large variety of available protocols and interfaces make the network design process a real challenge. A standardized control plane will enable reuse of existing protocols and reduce the need to develop operational support systems for configuration management [3]. Moreover, the possibility to dynamically allocate optical network resources to changing traffic patterns will facilitate network planning in contrast to statically configured networks.

Benefits to Operators and Customers

The major features of ASONs discussed in the previous section are directly linked to benefits that can be expected by carriers and their clients. Fast provisioning can result in better resource utilization, allowing for efficient bandwidth management. The scale of savings that may be achieved can be illustrated by the following simple example.

Example 1 — Let us estimate the number of STM-1 (OC-3) synchronous digital hierarchy/synchronous optical network (SDH/SONET) lines needed to exchange data between $S = 40$ bank headquarters located in a business capital and their branch offices in a distant city. Let us assume that, on average, there are $b = 4$ branch offices/bank, and that each branch office holds $L = 5000$ user accounts. Data volume associated with a single account is $D = 250$ kbytes (= 2000 kb = 2 Mb). This amount of data has to be transferred every day to the database of the relevant bank headquarters within $T = 3$ h after bank closing. For the nonswitched leased lines case each branch office needs a separate line, say, a single STM-1 (OC-3). Therefore, for all banks 160 lines are needed (Fig. 4a). To calculate the number of switched lines we have to estimate the average traffic carried between the bank headquarters and all the branch offices.

The mean holding time h related to information transfer between a single bank headquarters and its single branch office can be calculated as follows:

$$h = \frac{L \times D}{R} = \frac{5000 \times 2}{155} \approx 64.5 \text{ s.}$$

The mean interarrival time on links between all bank headquarters and their branch offices is

$$t = \frac{T}{S \times b} = \frac{3}{40 \times 4} = 0.01875 \text{ h} = 67.5 \text{ s.}$$

The average traffic intensity between the two cities is therefore

$$A = \frac{h}{t} = \frac{64.5}{67.5} \approx 0.96 \text{ Erlangs.}$$

By using the Erlang-B formula, and assuming the allowable probability of blocking of 0.002, the number of STM-1 links needed to carry all the traffic calculated above is equal to 6 (Fig. 4b). Therefore, the saving ratio between the nonswitched and switched solutions is: $160/6 \approx 26.7$. This figure gives us a rough view of the possible increase in bandwidth utilization efficiency by using the ASON concept.

Better resource utilization can be accomplished via either new services, such as bandwidth on demand, or traffic engineering performed by an appropriate application. The bandwidth on demand service (BDS) is real-time and requires a signaled connection request via a user-network interface (UNI) [4]. Provisioning of optical bandwidth can be done upon direct request of IP routers. This feature will extend the possibilities of IP-over-wavelength-division multiplexing (WDM) networks in terms of dynamic behavior and service flexibility.

One of the most important benefits to operators achieved using ASON functionality is considerable reduction of manual intervention required to operate and maintain the network. This intervention includes operator-assisted configuration of leased connections and manual updating of databases in network management systems. Moving manual operations to the automatic control plane reduces the number of

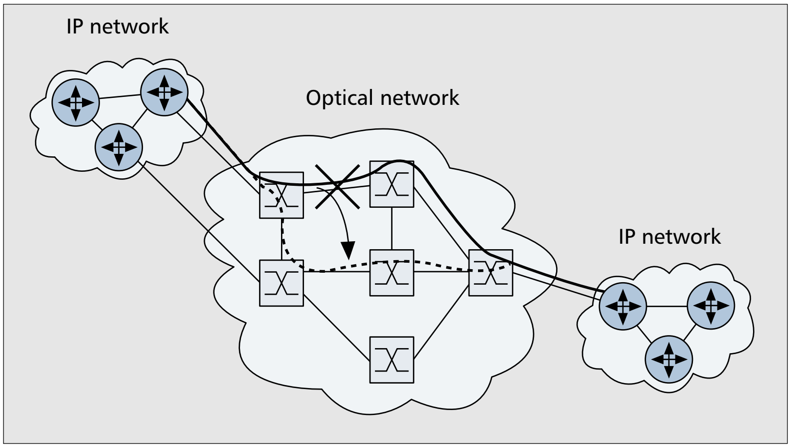

FIGURE 3. An example of fault recovery.

errors, considerably shortens provisioning time, and increases overall reliability. The self-managed control plane relieves the network management system from many time-consuming tasks, such as resource discovery and route selection as well as enables more accurate inventory. Therefore, the network management system can be simpler and the software development needs can be reduced. On the other hand, we have to remember that the newly created control plane will require its own management functionality located in the management plane.

It is clear that ASON is capable of considerably enhancing functionalities of existing networks such as SDH/SONET, WDM, or OTN. These enhancements can include more efficient protection and restoration schemes, and better interoperability in multivendor and multicarrier environments. However, the greatest expectations for ASONs are related to their support for all-optical networks. The cost of optical-electrical-optical conversions significantly influences investments of telecommunication operators. Introduction of intelligent optical crossconnects will make it possible to create end-to-end optical channels in transparent transmission all-optical subnetworks. We have to note, however, that ASON control plane capabilities defined in current specifications do not support such an all-optical transport plane.

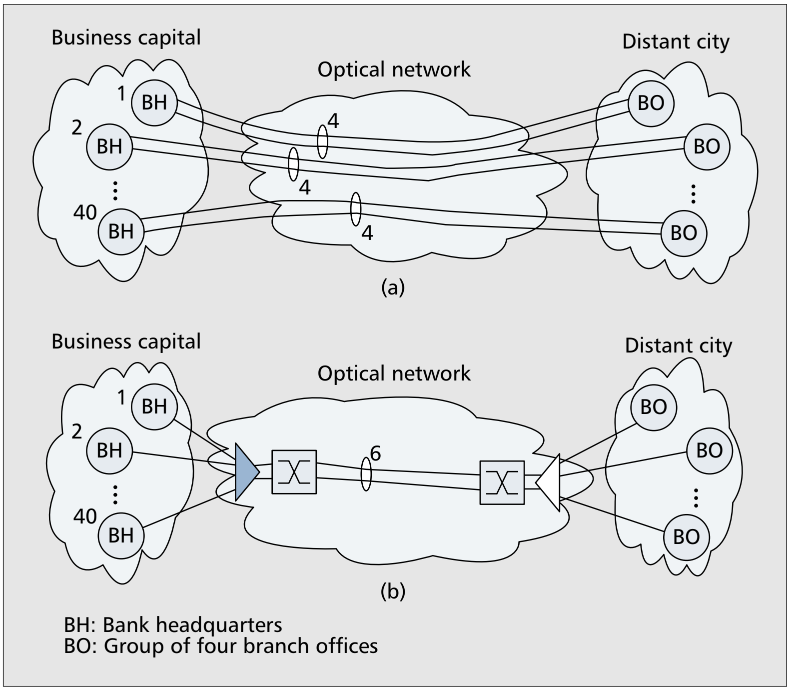

FIGURE 4. An example of interconnection between bank headquarters and branch offices: a) permanent connections; b) switched connections.

Standardized interoperator network-to-network interfaces between control planes will simplify internetworking, supporting end-to-end switched connections on a global scale. One of the important features of such interfaces should be strict limits on sharing topology-related information between operators.

The ASON offers new opportunities to customers. They include reduction of service provisioning times as well as a range of new services. Fast provisioning enables bandwidth-on-demand service (BDS), where a user or its proxy can directly request a connection by using appropriate signaling via the user-network interface. As mentioned above, the user (client network) has no or limited server network visibility. BDS can be used, for example, for a short-term bandwidth adjustment in the optical network to match changing data traffic patterns, or for high-data-volume overnight backups (see also Example 1). It should be noted, however, that very little has been done in the data-driven domain today. Most of the approaches are control/topology-driven. The provisioned bandwidth service (PBS) enhances the functionality of leased line services and, in contrast to BDS, connection requests go through the management interface, although the connections set up may also involve the control plane. PBS is especially attractive to support long-term high and steady bandwidth.

The ASON control plane functionality makes it possible to offer customers a wide variety of service level agreements (SLAs). Such SLAs may differ in the existence of resilience mechanisms leading to higher reliability or the applied security measures. In addition to virtual private networks (VPNs) realized in higher layers, the introduction of automatically switched networks allows provision of VPNs at the optical layer [5]. Such private networks can identify sets of network resources, including optical connection ports and wavelengths. As in normal VPNs, the closed user group (CUG) concept can also be supported.

ENABLING MECHANISMS

To offer features discussed in the previous sections several enabling mechanisms are necessary (Fig. 1). They include discovery functions, routing, and signaling as well as protection and restoration schemes.

Discovery — The following three groups of discovery functions can be distinguished:
- Neighbor discovery
- Resource discovery
- Service discovery

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. Neighbor discovery usually requires some initial manual configuration and automated procedures running between adjacent nodes when the nodes are in operation. Three instances of neighbor discovery are defined in the ASON: physical media adjacency discovery, layer adjacency discovery, and control entity logical adjacency establishment [6]. Physical media discovery has to be done first to verify the physical connectivity between two ports. This is followed by checking layer adjacency, which defines the associations between the endpoints that terminate a logical link at a given layer. Control adjacency involves two control entities associated with neighboring transport plane network elements.

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

Service discovery is responsible for verifying and exchanging service capabilities of the network (e.g., 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 [6].

Routing — Routing is used to select paths for establishment of connections through the network. Although some well-known routing protocols developed for IP networks can be adopted, it has to be noted that optical technology is essentially an analog rather than digital technology, so transmission impairments accumulated along the optical paths must be taken into account while calculating the route. Another constraint influencing routing mechanisms, related to ASON but also to any operator whether an Internet service provider (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 ASONs are described in ITU-T Recommendation G.7715/Y.1706 [7]. This covers the following areas: ASON routing architecture, and functional components including path selection, routing attributes, abstract messages, and state diagrams. Routing requirements for ASON have also been studied by the Internet Engineering Task Force (IETF) [8].

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 an 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 interoperate within a multidomain network, and the interdomain signaling protocols shall be agnostic to their intradomain counterparts.

Several recommendations concerning signaling issues in ASTN were developed by ITU-T. G.7713/Y.1704 specifies operations for call setup and release [9]. It also describes signaling exchange that allows support for hierarchical, source and step-by-step routing. Recommendations G.7713.1/Y.1704.1 [10], G.7713.2/Y.1704.2 [11], and G.7713.3/Y.1704.3 [12] provide the signaling mechanisms and protocol specifications based on PNNI/Q.2931, generalized multiprotocol label switching (GMPLS) Resource Reservation Protocol with traffic engineering (RSVP-TE), and GMPLS constraint-based routing Label Distribution Protocol (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 [13]. Signaling issues in ASONs are also studied by the IETF [14, 15].

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 [9]. 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 [1]. 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, where the call involves multimedia applications including voice, video, and data. Call and connection control separation also makes sense for restoration after faults. In such a case the call can be maintained (i.e., not released) while restoration procedures are underway.

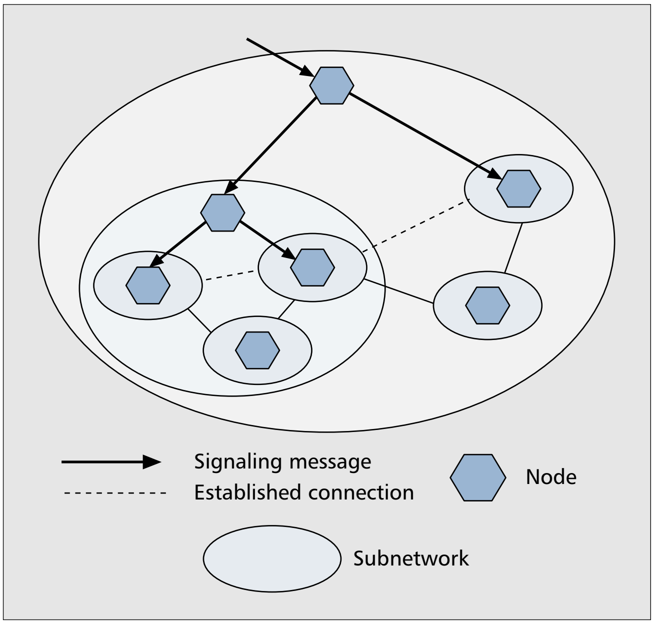

FIGURE 5. An example of multilevel hierarchy [1].

Call control must support coordination of connections in a multiconnection call and coordination of parties in a multiparty call. It is responsible for negotiation of end-to-end sessions, call admission control, and maintenance of call state. Connection control is responsible for the overall control of individual connections, including setup and release procedures, and maintenance of the state of connections. Connection control involves connection admission control, a process that determines if there are sufficient resources to admit or maintain a connection (the latter case is related to renegotiation of resources during a call) [1].

Protection and Restoration — The higher network reliability in ASONs is achieved by using various resiliency schemes. Resiliency is a network's capability to continue operation under failures within the network. Resiliency can be supported by either protection or restoration mechanisms. The former is based on replacement of a failed resource (e.g., a link or path) with a preassigned standby resource, the latter on rerouting using spare capacity. Both mechanisms can support the CoS requested by a customer [1]. Since protection or restoration may be applied at different layers (e.g., the IP and optical layers), the layers should be appropriately coordinated.

BASIC ASON REQUIREMENTS

Several basic requirements can be identified to support operation of ASONs (Fig. 1). The most visible is the existence of a separate control plane. The control plane refers to intelligence for performing the call control and connection control functions. These functions are supported by such enabling mechanisms as discovery, routing, and signaling. The control plane interoperates with the two remaining planes (transport and management) through a set of standardized interfaces. Another set of interfaces must be defined between control planes belonging to different domains of either the same or different carriers, and between the user and control planes.

To allow global connectivity, ASONs must have a scalable naming and addressing scheme. According to G.807 [2], a name, or identifier, is a location-independent string with respect to both source and destination. If a string is the name of a destination, it remains unchanged if the destination moves. An address is a string of symbols that is valid regardless of the location of the source but changes if the destination moves, in contrast to the string representing the name. Addresses must be globally unique within a layer network.

One important feature of ASONs facilitating their smooth deployment is reuse of proven protocols as much as possible. They include routing, signaling, and discovery protocols, mostly from the IP/MPLS/GMPLS family. The same sets of control plane protocols can be used for different transport technologies.

To support protection or load balancing via diverse routes, multihoming (usually dual homing) may be used in ASONs (i.e., multiple links between a client and one or more transport networks) [2]. This may involve the same or different nodes, the same or different access networks, the same or different core networks, and the same or different carriers. Dual homing shall not require the use of multiple addresses for the same client device.

ASONs should support a multilevel hierarchy (e.g., core, metro, and access networks), as shown in Fig. 5 [1].

General Requirements

Along with the ASON related requirements discussed earlier, there are a number of general requirements common to any large-scale newly designed optical network. They can be listed as follows:
- Security
- Reliability
- Future-proof solutions
- Support for multivendor equipment
- Support for different client technologies
- Possibility of distribution of control functions
- Simplicity
- Performance/efficiency
- Robustness

The importance of security in automatically controlled high-capacity transport networks cannot be overestimated. We can easily imagine disastrous effects of a possible hacker or terrorist attack on a network carrying traffic related to gigabit- or even terabit-per-second flows. Therefore, various security mechanisms must be implemented in the control plane, especially related to the signaling network. It is important that only those signaling messages that are allowed to pass between two administrative domains be able to cross relevant interfaces, while other messages should be prevented from crossing these interfaces [13]. All unauthorized access should be blocked, and network information shall not be advertised across external interfaces.

Reliability was mentioned earlier in the context of the major features of ASONs. As such, it was supported by appropriate protection and restoration schemes. However, any large-scale network has to be sufficiently reliable to offer reliable services to its clients. This is especially true of the control plane. Its failure should not affect the existing connections in the transport plane.

Implementations of ASONs should enable continuous enhancement and improvement of transport networks triggered by changes in technology and changing client needs. This means that architectural and functional solutions of ASONs should be future-proof. It is also essential that such networks may contain equipment and software from a variety of vendors and support different client technologies, such as SDH/SONET, IP, ATM, Ethernet, and Frame Relay.

Although, in principle, the control plane can be fully centralized (especially the connection control functions), its scalability and reliability usually require that control functions are geographically distributed. This also reflects the fact that the transport resources can be partitioned into subnetworks, and the control plane divided into domains and routing areas [1].

It is obvious that the system should be as simple as possible, and its performance should be satisfactory. Another important feature of any technology is its robustness.

Conclusion

A general view of the driving forces behind automatically switched optical networks was given. Carriers, to improve their competitiveness, have to make their existing OTNs more flexible, efficient, and easier to manage. Implementation of ASONs enables fast provisioning, eases network operation, increases network reliability and scalability, and simplifies planning and design. This, in turn, may be translated into direct benefits to operators and their clients.

The most important mechanisms to make the ASON possible are briefly presented. They include automatic discovery, routing, signaling, along with call and connection control functionality, and new protection and restoration schemes. Various features, either ASON-specific or general, required of switched transport networks are enumerated and briefly described.

Acknowledgment

This work was supported by the Polish Ministry of Scientific Research and Information technology under grant 4 T11D 012 25.

References

[1] ITU-T Rec. G.8080/Y.1304, "Architecture for the Automatically Switched Optical Networks," Nov. 2001, and Amendment 1, Mar. 2003.

[2] ITU-T Rec. G.807/Y.1302, "Requirements for Automatic Transport Networks (ASTN)," July 2001.

[3] C. Brownmiller *et al.*, "Switched Connection Services — The ITU-T ASTN Standards Framework," *Opt. Net. Mag.*, vol. 4, no. 1, Jan./Feb. 2003, pp. 11–25.

[4] OIF-UNI-01.0, "User Network Interface (UNI) 1.0 Signaling Specification," Oct. 2001.

[5] H. Ould-Brahim and Y. Rekhter, Eds., "GVPN Services: Generalized VPN Services using BGP and GMPLS Toolkit," Internet draft, May 2004, work in progress.

[6] ITU-T Rec. G.7714/Y.1705, "Generalized Automatic Discovery Techniques," Nov. 2001.

[7] ITU-T Rec. G.7715/Y.1706, "Architecture and Requirements for Routing in the Automatically Switched Optical Networks," June 2002.

[8] W. Alanqar *et al.*, "Requirements for Generalized MPLS (GMPLS) Routing for Automatically Switched Optical Network (ASON)," Internet draft, May 2004, work in progress.

[9] ITU-T Rec. G.7713/Y.1704, "Distributed Call and Connection Management (DCM)," Dec. 2001.

[10] ITU-T Rec. G.7713.1/Y.1704.1, "Distributed Call and Connection Management (DCM) Based on PNNI," Mar. 2003.

[11] ITU-T Rec. G.7713.2/Y.1704.2, "DCM Signaling Mechanism Using GMPLS RSVP-TE," Mar. 2003.

[12] ITU-T Rec. G.7713.3/Y.1704.3, "Distributed Call and Connection Management Using GMPLS CR-LDP," Mar. 2003.

[13] ITU-T Rec. G.7712/Y.1703, "Architecture and Specification of Data Communication Network," Nov. 2001.

[14] D. Papadimitriou *et al.*, "Requirements for Generalized MPLS (GMPLS) Signaling Usage and Extensions for Automatically Switched Optical Network (ASON)," Internet draft, Apr. 2004, work in progress.

[15] J. Drake *et al.*, "Generalized MPLS (GMPLS) RSVP-TE Signaling in Support of Automatically Switched Optical Network (ASON)," Internet draft, Jan. 2004, work in progress.

Biography

Andrzej Jajszczyk [F'99] (jajszczyk@kt.agh.edu.pl) is a professor at AGH University of Science and Technology, Kraków, Poland.

He received his M.S., Ph.D., and Dr Hab. degrees from Poznan University of Technology in 1974, 1979, and 1986, respectively. He is the author or co-author of six books and over 190 scientific papers, as well as 19 patents in the areas of telecommunications switching, high-speed networking, and network management. He has been a consultant to industry, telecommunications operators, and government agencies in Poland, Australia, Canada, France, Germany, India, and the United States. He was founding editor of *IEEE Global Communications Newsletter*, an editor for *IEEE Transactions on Communications*, and Editor-in-Chief of *IEEE Communications Magazine*. Since January 2004 he is Director of Magazines of IEEE Communications Society. He has also served on technical program and steering committees of numerous conferences. He is an IEEE Communications Society Distinguished Lecturer.