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ABSTRACT: This contribution describes multi-technology network architectural terms and concepts and gives a set of reference architectures representing the collective architectural input from NSIF service providers. Each reference architecture captures a broad grouping of potential technologies and configurations. The set of architectures exhibit a progression from current networks to future networks that will be based on technologies that in some cases are just now beginning to emerge. The reference architectures are intended to provide a basis for the development of use cases and requirements in NSIF. Due to the optionality allowed in the reference architectures, additional refinements will generally be needed to define use cases.

This document has received the approval of the Network Services and Integration Forum (NSIF).

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1 Introduction

This contribution describes multi-technology network architectural terms and concepts and gives a set of reference architectures for use in NSIF. The information in this document represents the collective architectural input from NSIF service providers and is intended to provide the basis for multi-technology network architectures subject to study in NSIF.

1.1 Purpose

This contribution provides an architectural framework for the development of use cases and requirements in NSIF. It defines generic and technology-specific architectural terms and concepts and proposes a set of multi-technology reference architectures.

1.2 Scope

The architectural terms and concepts used in this document are based on existing standards and other consortia specifications as much as possible to avoid creating new definitions.

The reference architectures are based on analyses of multi-technology architectural input from NSIF service providers. Service provider inputs are documented in contributions to the December 1999 and February 2000 NSIF meetings(see References below). Reference architectures are presented using the framework described in NSIF-GN-0003-013.

Each reference architecture captures a grouping of potential technologies and configurations. The set of architectures exhibit a progression from current technology networks to future networks that will be based on technologies that in some cases are just now beginning to emerge. Due to the ample optionality allowed in the reference architectures, additional refinements will generally be needed to define use cases.

Each reference architecture is constructed by overlaying a physical architecture with a layer domain architecture. The physical architecture identifies relationships among network elements and transport media; the layer domain architecture identifies specific adaptation relationships among transport layer domains. Four reference architectures are defined building on three distinct physical architectures.

A glossary of architectural terms is given in Section 2. Section 3 provides an overview of generic network topology and technology-specific topologies. Section 4 presents the reference architectures including an explanatory overview, a description of three physical architectures, and descriptions of the four reference architectures.

1.3 References

ITU-T Recommendations:

ITU-T Recommendation **G.805** (11/95) - *Generic Functional Architecture of Transport Networks.*

ITU-T Recommendation **G.872** (2/99), *Architecture of Optical Transport Networks.*

ITU-T Recommendation **X.731**, *Information Technology – Open Systems Interconnection – Systems*

Management: State Management Function.

ITU-T Recommendation **G.841**, *Types and Characteristics of SDH Network Protection Architectures*, Version 10/1998.

ITU-T Recommendation **G.842**, *Interworking of SDH Network Protection Architectures.*

<u>*ANSI Industry Standards:*</u>

"T1.105.01-1998, *Synchronous Optical Network (SONET) – Automatic Protection Switching*, ANSI, 1998.

<u>*NSIF Contributions*</u>*:*

NSIF-GN-9911-120, *Metropolitan Area Optical Networks*, Ameritech, December 1999.

NSIF-GN-0001-007, *Clarifications to Ameritech's OTN Architecture*, Ameritech, January 2000.

NSIF-GN-0001-008, *Bell Atlantic Optical Architectures*, Bell Atlantic, January 2000.

NSIF-GN-0001-009, *Defining a Focus across Multiple Network Architectural Layers- A Challenge for All*, Sprint, January 2000.

NSIF-GN-0003-013, *Templates for Multi-Technology Reference Architectures*, Telcordia, March 2000.

<u>*Telcordia Documents:*</u>

Telcordia **GR-1230-CORE**, *SONET Bidirectional Line-Switched Ring Generic Criteria*, Issue 4, December 1998.

Telcordia **GR-1248-CORE**, *Generic Requirements for Operations of ATM Network Elements (NEs)*, Issue 4, November 1998.

Telcordia **GR-1400-CORE**, *SONET Dual-Fed Unidirectional Path Switched Ring (UPSR) Equipment Generic Criteria*, Issue 2, January 1999.

Telcordia **GR-2918-CORE**, *DWDM Network Transport Systems with Digital Tributaries for Use in Metropolitan Area Applications: Common Generic Criteria*, Issue 4, December 1999.

Telcordia **GR-2980-CORE**, *Generic Criteria for ATM Layer Protection Switching Mechanism*, February 1998.

Telcordia **GR-2999-COR**E, *Generic Requirements for Wave Division Multiplexing (WDM) Network Management Systems (NMSs*), January 1999.

Telcordia **GR-3009-CORE**, *Optical Cross-Connect Generic Requirements*, December 1999.

2 Glossary of Architectural Terms

This section defines terms used to describe multi-technology network architectures including protection/restoration architectures and considerations for network management. Definitions from existing standards documents are used where applicable. “Double quotes” indicates the term is defined elsewhere in this glossary.

2.1.1 1+1 protection

Protection switching is considered to be 1+1 if, per direction of transmission, the protection switch occurs without coordination between the endpoints. In 1+1 architectures, per direction of transmission, the receive end can perform a protection switch without coordinating with the transmit end since the signal is permanently bridged at the transmit end, and an APS channel is not necessarily required. [T1.105.01]

2.1.2 access group

A group of co-located “trail termination” functions that are connected to the same “sub-network” or “link.”[G.805]

2.1.3 adaptation management

The set of processes for managing client layer network adaptation to/from the server layer network. [G.872]

2.1.4 administrative state

An attribute of a network resource that indicates ‘permission to use or prohibit against using the resource, imposed through the management services.’ The values of the administrative state are: locked, unlocked, and shutting down.[X.731]

2.1.5 assignment state

An attribute of a network resource that reflects its state relative to providing service. The values of the assignment state are: unassigned, reserved, partially assigned, and assigned. (proposed extension to X.731)

2.1.6 bicast

A configuration of a uni-directional transport entity originating at a single source termination point and terminating at two sink termination points. A bicast connection can be used as a component of an end-to-end protected connection.

2.1.7 bridge

The act of transmitting identical traffic on both the working and protection channels. [T1.105.01]

2.1.8 connection type

The connection type indicates the basic configuration of a connection including cardinality relationships among endpoints of a subnetwork connection or trail. Possible types include:

- point-to-point
- point-to-multipoint
- bicast
- exclusive merge
- exclusive composite

2.1.9 Dense Wavelength Division Multiplexing (DWDM)

See Wavelength Division Multiplexing.

2.1.10 drop and continue

A function within a ring node where traffic is both extracted from the working channels on the ring (drop), and transmitted onwards on the ring (continue). [G.842]

2.1.11 drop traffic

Normal or extra traffic extracted from working, protection, or non-preemptible unprotected channels on the ring at a ring node. [G.841]

2.1.12 dual hubbed

A configuration in which customer traffic can be routed to either or both of two hubs to enable diverse route protection. (see G.842)

2.1.13 dual node interconnect

An architecture between two rings where two nodes in each ring are interconnected to enable diverse route protected ring interconnection. (see G.842)

2.1.14 exclusive composite

A configuration of a bi-directional transport entity connecting three bi-directional termination points with an "exclusive merge" configuration in one direction and a "bicast" configuration in the opposite direction. An exclusive composite connection can be used as a component of an end-to-end protected connection configuration; it is not intended for supporting multicast services to customers.

2.1.15 exclusive merge

A configuration of a uni-directional transport entity originating at two source termination points and terminating at a single sink termination point in which only one of the two source signals is passed to the sink at any given time. An exclusive merge connection provides a component of an end-to-end protected connection configuration.

2.1.16 extra traffic

Traffic that is carried over the protection channels when that capacity is not used for the protection of working traffic. Extra Traffic is not protected. Whenever the protection channels are required to protect the working traffic, the Extra Traffic is preempted. Ring interworking on protection is considered Extra

Traffic. [T1.105.01]

2.1.17 hardwired multiplex

An add-drop multiplex configuration in which specific VT/STS-1 time-slots are dedicated to specific low-speed ports [SR-2672].

2.1.18 hold off time

The time that a protection switch controller waits after detecting a failure before initiating the switch. [G.842]

2.1.19 highly protected

The “protection level” of a transport entity that is protected against single failures of either a facility or a node (except for bicast, exclusive merge, or composite configurations in which the node that contains the bridge/selector function is not protected). Service traffic on a highly protected transport entity is not preemptible.

2.1.20 Inter-Domain Interface (IrDI)

A physical interface that represents the boundary between two administrative domains. [G.872]

2.1.21 Intra-Domain Interface (IaDI)

A physical interface within an administrative domain. [G.872]

2.1.22 layer network

A "topological component" that includes both transport entities and transport processing functions that describes the generation, transport and termination of a particular characteristic information.[G.805]

2.1.23 lifecycle state

An attribute of a network resource that tracks the progress through stages relative to placing the resource into a service providing state. The lifecycle state has three values: planned, committed, and decommitted. (proposed extension to X.731)

2.1.24 link

A “topological component” which describes a fixed relationship between a “sub-network” or “access group” and another “sub-network” or “access group.”[G.805]

2.1.25 logical ring

(See subnetwork connection protection.)

2.1.26 M:N protection switching

Protection switching is considered to be M:N if, per direction of transmission, the protection switch requires coordination between endpoints. In 1:1 architectures, for example, per direction of transmission, the receive end must request a bridge from the transmit end in order to perform a protection switch, and an APS channel is required. [T1.105.01]

2.1.27 non-preemptible unprotected channel

A channel in a BLSR (MS shared protection ring) provisioned bidirectionally to provide transport without MS shared protection ring automatic protection switching. Non-preemptible unprotected channels are provisioned from (corresponding) working and protection channel pairs.

2.1.28 non-preemptible unprotected traffic

Unprotected traffic carried on protection locked-out channel which may not be preempted (e.g., by protection switches).

2.1.29 OCh shared protection ring

This architecture virtually provides each OCh with a pre-assigned 1:1 protection route and capacity. The protection OCh itself does not carry a copy of the working OCh under non-failure conditions; therefore, the capacity is not occupied and can be used for the extra traffic. This protection capacity can be shared by other protection OChs on a link-by-link basis. To restore a network failure, the affected working OChs are switched to counter-directional routes on an end-to-end basis with pre-assigned wavelengths. Necessary APS protocols will be given in other recommendation.[G.872]

2.1.30 OMS shared protection ring

OMS shared protection rings are characterized by dividing the total payload per OMS equally into working and protection capacity. For example, for a two fiber OTM-N ring, there are N/2 OTUs available for working and N/2 OTUs available for protection, while in a four fiber OTM-N ring, there are N OTUs available for working and N OTUs available for protection. The ring protection capacity can be accessed by any OMS of a multinode ring under a section or node failure condition. Thus, the protection capacity may allow an OMS shared protection ring to carry extra traffic with a lower priority. This extra traffic is not itself protected. Necessary APS protocols will be given in other recommendations.[G.872]

2.1.31 operational state

An attribute of a network resource that expresses its operability. The operational state has two values: disabled and enabled. (see X.731)

2.1.32 optical channel layer network

This layer network provides end-to-end networking of optical channels for transparently conveying client information of varying format (e.g. SDH STM-N, PDH 565 Mbit/s, cell based ATM, etc.).[G.872]

2.1.33 optical cross-connect

An optical cross-connect is a network element that allows remotely reconfigurable interconnection of optical signals or their constituent wavelengths between its ports. [GR-3009]

2.1.34 optical multiplex section layer network

This layer network provides functionality for networking of a multi-wavelength optical signal. Note that a "multi-wavelength" signal includes the case of just one optical channel.[G.872]

2.1.35 (optical) network restoration

Optical network restoration techniques are based on optical channel cross-connection. In general, the algorithms used for restoration involve rerouting. To restore an impaired connection, alternative facilities may be chosen among the available capacity of the optical layer network.[G.872]

2.1.36 optical transmission section layer network

This layer network provides functionality for transmission of optical signals on optical media of various types (e.g. G.652, G.653 and G.655 fibre).[G.872]

2.1.37 optical transport network

A transport network bounded by optical channel access points. [G.872]

2.1.38 Optical Supervisory Channel (OSC)

The optical supervisory channel is an optical carrier that transfers overhead information between optical transmission section transport entities. The optical supervisory channel supports more than one type of overhead information and some of this overhead information may be used by one or more transport network layers. [G.872]

2.1.39 path layer network

A "layer network" which is independent of the transmission media and which is concerned with the transfer of information between path layer network "access points."[G.805]

2.1.40 preemptible

The “protection level” associated with a transport entity provisioned to carry “extra traffic.” The “extra traffic” may be preempted to provide transport capacity for “protected” or “highly protected” transport entities in the event of failure.

2.1.41 protection channels

The channels allocated to transport the working traffic during a switch event. When there is a switch event, traffic on the affected working channels is bridged onto on the protection channels. [T1.105.01]

2.1.42 protection control

The information and set of processes for providing control of protection switching for a trail or subnetwork connection. [G.872]

2.1.43 protection level

The protection level indicates the class of network level protection provided in response to basic types of failure. Two types of protection level are addressed: The provisioned protection level indicates the level of protection established via provisioning. The operational protection level indicates the level of protection actually being supported at a given time.

2.1.44 protection

In the network view, protection refers to the ability to switch service from a primary "transport entity" to a preconfigured backup "transport entity" in response to a detected failure on the primary "transport entity." Protection mechanisms may be entirely within a "layer network" or may involve a server layer mechanism supporting client transport services, and may be activated on the basis of a variety of monitoring. Trail protection is a protection method applied in a "layer network" when a defect condition is detected in the same "layer network." Subnetwork connection protection is applied in the client layer network when a defect condition is detected in a server layer network, sub-layer or other transport layer network.

2.1.45 protection control

The information and set of processes for providing control of protection switching for a trail or subnetwork connection [G.872]

2.1.46 requested effort level

The degree of commitment to obtain a requested "protection level" agreed to as part of connection set-up. Three effort levels are identified:

- required minimum - connection cannot be set up if requested protection level or higher is not available
- required exact - connection cannot be set up if requested protection level is not available
- best effort - connection may be set up even if requested protection level is not available

2.1.47 restoration

In the network view, restoration refers to an application in which the NMS responds to a confirmed failure by requesting a new connection. This action may be viewed by the EMS as a release of the failed connection and the set-up of a new connection.

2.1.48 ring interconnection

An architecture between two rings where one or more nodes in each ring are interconnected. [G.842]

2.1.49 ring interworking

A network topology whereby two rings are interconnected at two nodes on each ring, and the topology operates such that a failure at either of these two nodes will not cause loss of any working traffic. [G.842]

2.1.50 ring switch

Protection mechanism that applies to both two-fibre and four-fibre rings. During a ring switch, the traffic from the affected span is carried over the protection channels on the long path. [G.841]

2.1.51 route separation

A qualitative measure of the relationship between "routes" assigned to primary and protection connections.

2.1.52 span switch

Protection mechanism similar to 1:1 linear APS that applies only to four-fibre rings where working and protection channels are contained in separate fibres and the failure only affects the working channels. During a span switch, the normal traffic is carried over the protection channels on the same span as the failure. [G.841]

2.1.53 selector

The NE function that selects and allows to pass one signal out of two inputs based on predefined criteria.

2.1.54 sub-network

A "topological component" used to effect routing of a specific characteristic information.[G.805]

2.1.55 subnetwork connection protection

A type of protection architecture (using "1+1 protection switching") applied to a subnetwork connection in which a transmitted signal is bridged onto two paths at the source and selected between the two paths near the receiver based on pre-defined criteria. Also referred to as "logical ring."

2.1.56 topological component

an architectural component, used to describe the transport network in terms of the topological relationships between sets of points within the same "layer network." [G.805]

2.1.57 trail protection

Normal traffic is carried over/selected from a protection trail instead of a working trail if the working trail fails, or if its performance falls below a required level. [G.841]

2.1.58 unprotected

The protection level associated with a transport entity that has no guarantee of protection against facility failures. Service traffic on an unprotected transport entity is not preemptible.

2.1.59 usage state

An attribute of a network resource that indicates "whether or not the resource is actively in use at a specific instant, and if so, whether or not it has spare capacity for additional users at that instant."[X.731]

2.1.60 Wavelength Division Multiplexing (WDM)

The combination of various wavelengths of light carrying information over a single optical fiber, resulting in the multiplexing of numerous high speed information channels onto a single physical optical fiber path. The term WDM includes the concept of dense wavelength division multiplexing (DWDM), where the density of wavelengths is such that a large number of wavelengths (commonly considered to be above the range of four to eight) is placed on a single fiber, or where the spacing between the adjacent light channels is closer in frequency than initially deployed WDM systems. The term is also included in various commercial descriptions of systems related to certain deployment scenarios, such as Metro WDM or Metro DWDM.

2.1.61 wavelength pass-through

An optical architecture that allows certain optical signals associated with selected wavelengths to be passed through a node without termination and conversion to electrical signals.

3 Network Topology Overview

In order to compare network topologies and examine the interactions of topologies across different technologies it is necessary to agree upon some generic terminology. ITU-T Recommendation G.805 (11/95) - *Generic Functional Architecture of Transport Networks*, provides a good model for examining topology, allowing networks to be decomposed into layer networks that handle the different characteristic information. However, common usage architectural terms, such as SONET UPSR, while containing topological terms, such as ring, are not solely topological terms, but describe a combination of connectivity (topology) and equipment functionality (UPSR protection) across multiple layers (physical, STS-n Section/Line, STS-n Path layers). In order to relate common usage terms from different technologies to one another, a set of common terms needs to be agreed upon.

3.1 Topology Definitions

First, *topology* itself should be defined, as it is not itself defined in G.805. As a reference, the Concise Oxford Dictionary definition of topology is "the study of geometrical properties and spatial relations unaffected by the continuous change of shape or size of figures." G.805 does define *topological component* as an architectural component, used to describe the transport network in terms of the topological relationships between sets of points within the same layer network.

3.1.1 Topology Components

G.805 describes four topology component types: layer network, sub-network, link, and access group. These terms can be used and in some cases simplified for our purposes.

A layer network refers to resources that support a specific characteristic information (e.g., STS-12c). A layer network's transport entities are identified by links, and its transport processing functions are identified by sub-networks (which we shall simplify as *fabrics*) and access groups. A lower, server layer network provides connectivity for higher, client layer networks at its access groups. Each layer network has the potential to have its own unique topology.

G.805 allows portions of a layer network to be aggregated into larger sub-networks. However, when considering a layer network's complete topology, we generally need to decompose all sub-networks to their lowest level, which correspond to ***fabrics***.

Links represent fixed connectivity for a particular layer network. They are established by setting up trails between termination functions in a lower server layer network.

Access groups indicate where paths may be terminated in a layer network.

3.1.2 Layer Network Types

G.805 divides layer networks into two types:

> **Transmission media layer network -** a "layer network" which may be media dependent and which is concerned with the transfer of information between transmission media layer network "access points" in support of one or more "path layer networks".
>
> **Path layer network -** a "layer network" which is independent of the transmission media and which

is concerned with the transfer of information between path layer network "access points".

For use in NSIF, it is useful to define two types of views of network architecture that are in the spirit of G.805 but with hooks into some of the more tangible elements of a network:

Physical architecture – the configuration of 1) transport media and 2) NEs or other devices that provide the ability to terminate physical transport layer signals.

Layer network topology – the configuration of links connecting cross-connection fabrics (or sub-networks) or termination points (access groups) within a given transport layer.

The physical architecture is analogous to the configuration of transmission media layer network combined with specification of network elements. It is noted that in the transmission media layer for an optical transport network (in terms of fibers, not WDM optical paths, which are associated with a separate layer network) all paths are point-to-point between devices, or network equipment. The layer network topology is basically the topological configuration of a path layer network.

3.2 Generic Topology Types

Having defined different topological components, we need to agree on some generic terms for topology types. While these terms are familiar, they are often not well defined in common usage. The following definitions for generic topology types are proposed. Where possible, they are based on discrete mathematics terminology.

The simplest topology is **point-to-point** which is comprised of a link connecting two nodes.

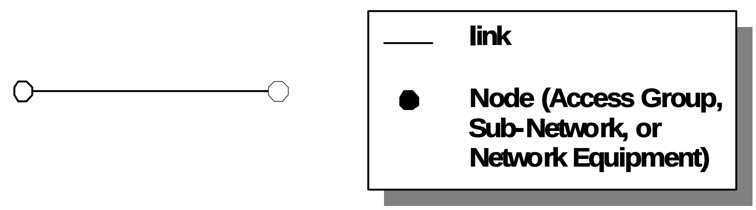

Figure 1 Point-to-Point Topology

Stringing several nodes together serially with point-to-point links forms a **linear chain** topology. The intermediate nodes provide cross-connect as well as termination functionality.

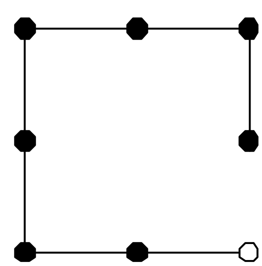

Figure 2 Linear Chain Topology

In a **star** topology all other nodes in the topology are only connected to one hub node. Only the hub node needs to provide crossconnection functionality; however, all connectivity is lost if the hub node is removed.

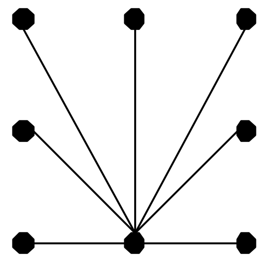

Figure 3 Star Topology

Sometimes in common usage the term “tree” is used to imply hierarchical routing. But in terms of connectivity it just indicates that there is only one route between any two nodes in the topology. Linear chain and star topologies are sub-classes of **tree** topology, but any node in a generic tree topology may have links to more than two other nodes.

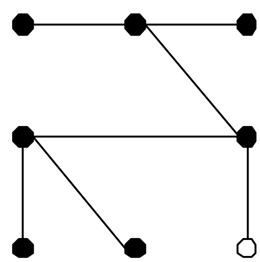

Figure 4 Tree Topology

A **ring** topology differs from the previous topologies in that it provides route diversity. Specifically, in a ring topology each node has exactly two links connected to it, so that the links form a ring. Thus, there are exactly two paths between any two nodes. (Logical rings may not have *physical* route diversity because of the underlying layer network topologies.)

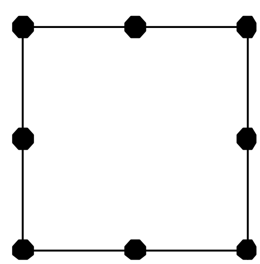

Figure 5 Ring Topology

The term “mesh” is particularly ill defined in common usage, being neither a discrete mathematics term, nor a clear pictorial description. It is often used to mean a fully connected mesh (described below), but sometimes it is just used to describe a more complex topology that cannot be described using one of the more restrictive terms defined above. We will define a **mesh** topology simply as one in which there two or more paths between at least two of its nodes. Using this definition, a mesh topology is one that contains a loop, so that it is not a type of tree topology, but may contain other links than those that form a single loop, which would be a ring. A simple mesh topology can be thought of as a conglomeration of several of the topologies above.

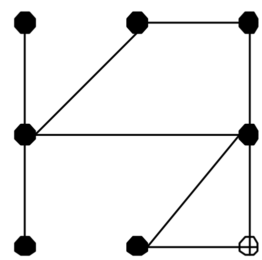

Figure 6 Mesh Topology

A **fully connected mesh** topology is sometimes referred to simply as a mesh topology; however, it is much more specific. There is a direct link between each node and every other node in this topology. No crossconnection functionality is required to connect any of the nodes, and should a point-to-point link fail, there is a high degree of route diversity to ensure continued connectivity. Fully connected mesh topologies do not scale well because N*(N-1)/2 links are required for N nodes.

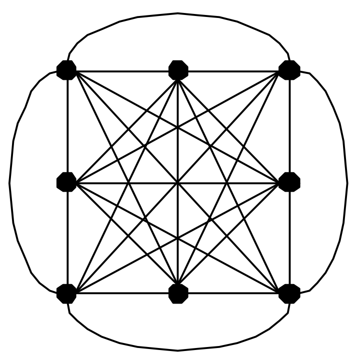

Figure 7 Fully Connected Mesh Topology

There is another type of mesh that is of interest in terms of survivability. We will define a *highly connected mesh topology* as one that has at least two paths between each node and every other node. In such a topology, loss of any single link would not cause loss of potential connectivity between any of the nodes, and loss of single node would not cause loss of potential connectivity between any of the other nodes. The simplest form of such a topology would of course be a ring.

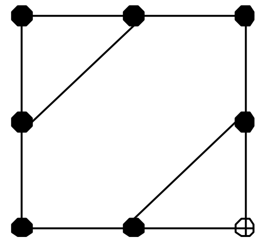

Figure 8 Highly Connected Mesh Topology

3.3 Topology vs. Architecture

What many people may consider as topologies, such as SONET OC-48 BLSR or STS-3c logical ring, may be more accurately be described by the more generic terms, *architectures* or *transport architectures*, because they have implications on both topological (connectivity) and transport network functionality. G.805 defines an architectural component as any item used to generically describe transport network functionality.

For example, a SONET OC-48 BLSR ring can be described as being composed of a ring physical architecture (point-to-point fiber terminating on successive pairs of ADMs arranged to form a ring) that supports a ring logical topology (comprised of e.g. point-to-point STS links connecting successive pairs of STS cross-connection fabrics).

Note that in SONET, the term *link* refers to a bundle of pre-provisioned point-to-point link connections between two endpoints; in ATM (in a topology context) it more accurately represents a quantity of bandwidth between two endpoints.

A SONET STS-3c logical ring provides an example of how topologies at different layers are somewhat independent. A SONET STS-3c logical ring architecture does not define a particular physical topology, which could be a mesh (as in Figure 9) or even a linear chain. In the linear case, diverse routing is not achieved since the ring is collapsed. In the case of a DCS physical mesh, a ring could be configured through the mesh in conjunction with DCS ring functionality; diverse routing would need to be guaranteed by selection of non-overlapping ring segments.

A SONET STS-3c logical ring does describe the topology of at the STS-3c Path Layer. The topology would be formed by creating point-to-point STS-3c trails at the STS Section/Line layers to form a ring. One may assume that a SONET STS-3c logical ring also defines Sub-Network Connection Protection (SNCP) protection switching functionality.

Continuing with the example in Figure 9, let us assume that all of the equipment have ATM VP termination capability and the equipment on the OC-12 ring also have ATM VP crossconnect capability. If STS-3c trails were created from each node to the one on the far left then the ATM VP layer network would have a star topology. If instead, VP connections were created among all of the nodes on the OC-12 ring then the ATM VP layer would have a fully connected mesh network. The other equipment would not appear at the ATM VP layer because there was no connectivity provided to them by STS-3c trails.

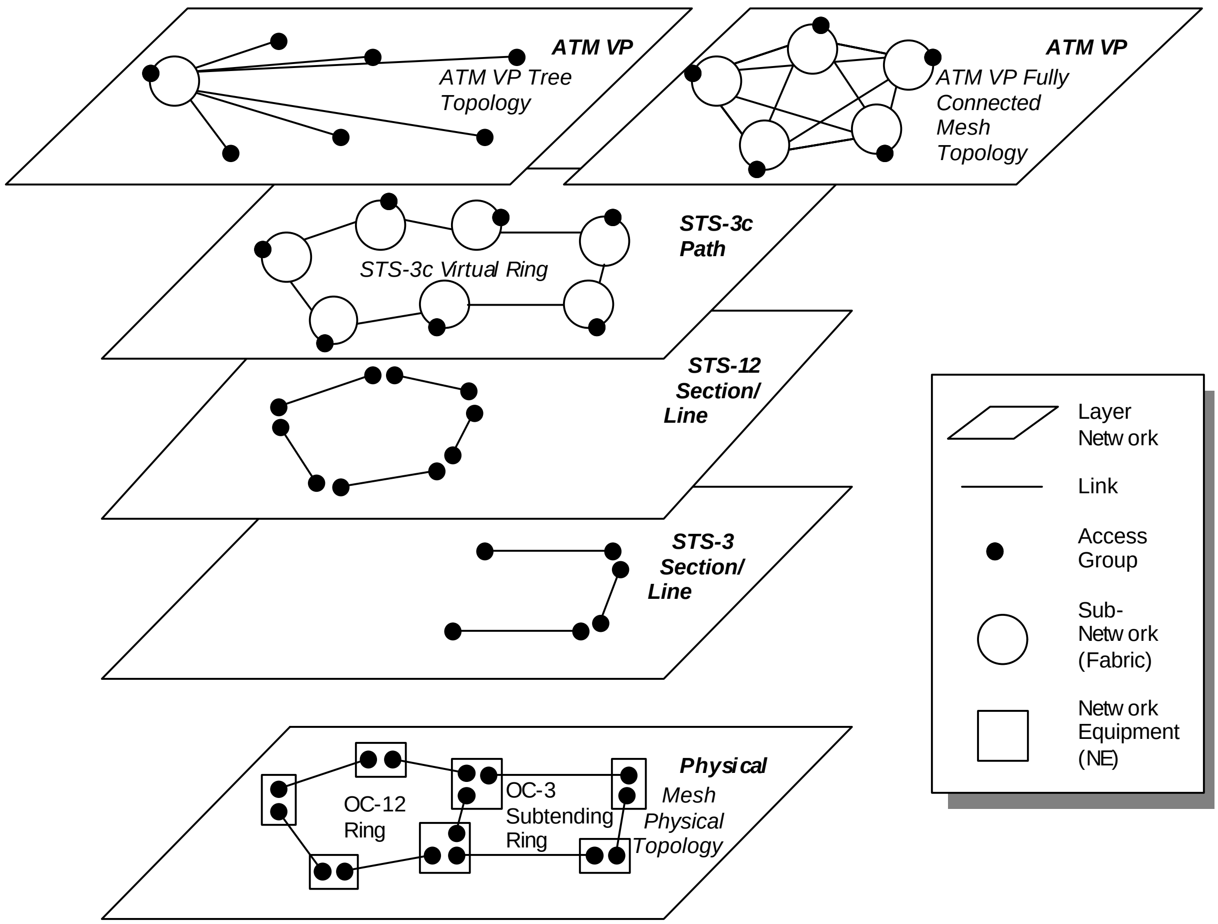

Figure 9 Topologies at Physical and Logical Layers

3.4 Technology-specific Topological Terms

This section provides some examples of generic topology terms being used in connection with specific technologies. Sometimes their usage aligns with the terms as we have defined them, but often they have additional implications when related to a particular technology. The topology terms are usually used in connection with architectures and often have bearing on the type of equipment used to construct the topology.

3.4.1 SONET

3.4.1.1 Point-to-Point

The term "point-to-point" is fairly intuitive, but has occasionally been used to mean other physical topologies. In a point-to-point architecture, as shown in Figure 10, SONET Terminal Multiplexers (TMs) provide transport between two distinct locations. At the two locations in the network, each TM multiplexes/demultiplexes DSm or STS-M electrical signals into an OC-N optical signal (where M<N).

The classic definition of a point-to-point architecture is that traffic originates at one point and its final destination is the second point. However, with SONET, the term point-to-point has been used to describe the general usage of Terminal Multiplexing equipment. Sometimes hubbing architectures have been referred to as point-to-point architectures because TMs are involved.

In this document, point-to-point is used to refer to the situation where the traffic originates in one location and its final desination is the second location.

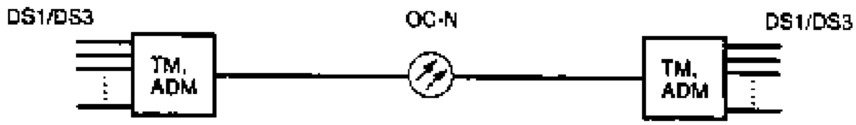

Figure 10 Point-to-Point Architecture

3.4.1.2 Linear and Tree

A linear configuration, as shown in Figure 11, consists of a string of identical ADMs in the add/drop mode transversing multiple locations. Each ADM transports an OC-N signal and add/drops DS1, DS3s, or optical OC-M signals (where M<N). A tree configuration, as shown in Figure 12, uses ADMs in the add/drop and terminal mode. For example, a tree architecture uses ADMs in the terminal mode to multiplex lower rate signals, e.g., DS1s and/or DS3s, into a higher rate signals at an OC-M rate. ADMs in the add/drop mode carry the OC-M between locations. These ADMs also add/drop lower rate signals, e.g., DS1s and/or DS3s, in the near term. ADMs in the terminal mode might be used in a later stage to multiplex the OC-M signals into an OC-N signal. This structure forms a tree.

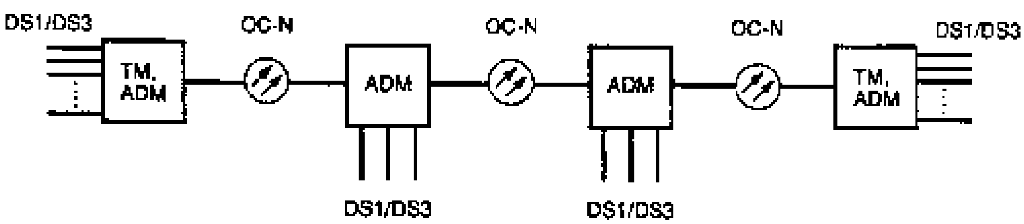

Figure 11 Linear Architecture

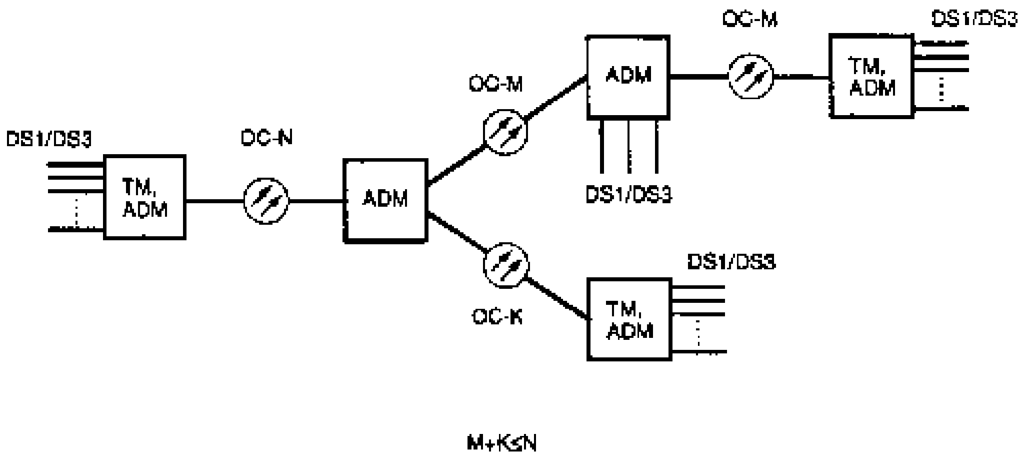

Figure 12 Tree Architecture

3.4.1.3 Ring

For SONET, the term “ring” is almost always used in relation to an automatic protection architecture. A Unidirectional Path-Switched Ring (UPSR) is a 2-fiber ring in which the same add traffic is carried on two diverse paths around the ring simultaneously and dropped at the exit node by determining which is the better of the two received signals. Figure 13 shows a UPSR protection configuration. (See GR-1400-CORE for more information.)

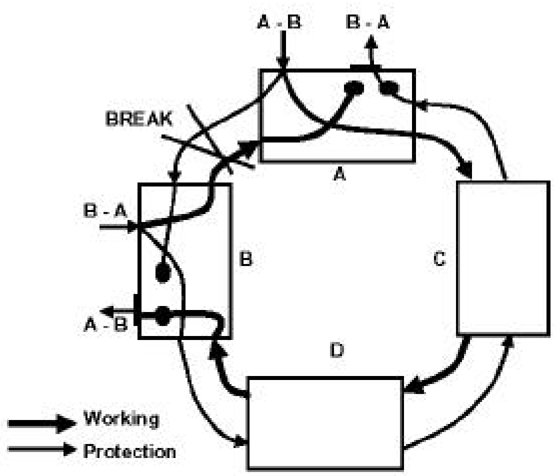

Figure 13 UPSR Implementation

A ***logical ring*** is formed by bridging the incoming signal at a source node, diversely routing the two paths through a SONET network, and selecting the “better” of the two diversely routed paths at the destination node. The paths may traverse over any type of physical linear, mesh or ring. This protection method is also referred to as *Subnetwork Connection Protection.*

Note that for UPSR, the term *ring* refers both to the physical topology and the logical topology, unlike for the logical ring. Both describe the protection-switching functionality required of the NEs.

For Bidirectional Line-Switched Rings (BLSRs), *ring* always relates to the physical topology, defining the number of fibers in each link as well as the protection-switching functionality required of the NEs.

A *2-fiber BLSR* includes a set of nodes interconnected by a pair of fibers, possibly including regenerators and optical amplifiers between nodes. If it is necessary to provide the maximum restoration (i.e., 100% restoration of restorable traffic) for single failures, one half of the ring's capacity is reserved for protection. Figure 14 illustrates a 4-node, 2-fiber BLSR."

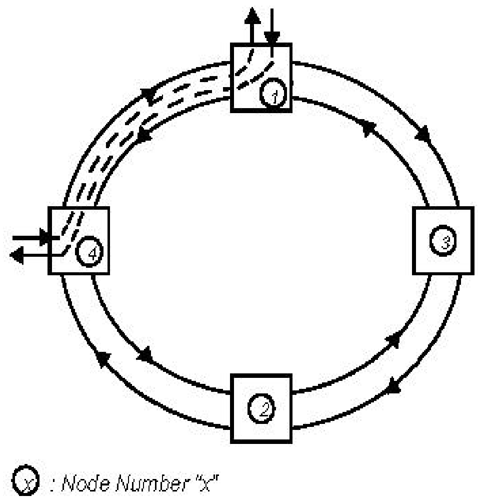

Figure 14 4-Node, 2-Fiber BLSR

A *4-fiber BLSR* consists of a set of nodes interconnected with two pairs of fibers (four fibers), possibly including regenerators and optical amplifiers, to form a closed loop. Two fibers are used to carry working channels, and the other two are used to carry protection channels. A 4-fiber BLSR operating at an OC-N rate has a span capacity of OC-N, as opposed to OC-(N/2) for the 2-fiber BLSR. Figure 15 illustrates a 4-fiber BLSR. (See GR-1230-CORE for more information on BLSRs.)

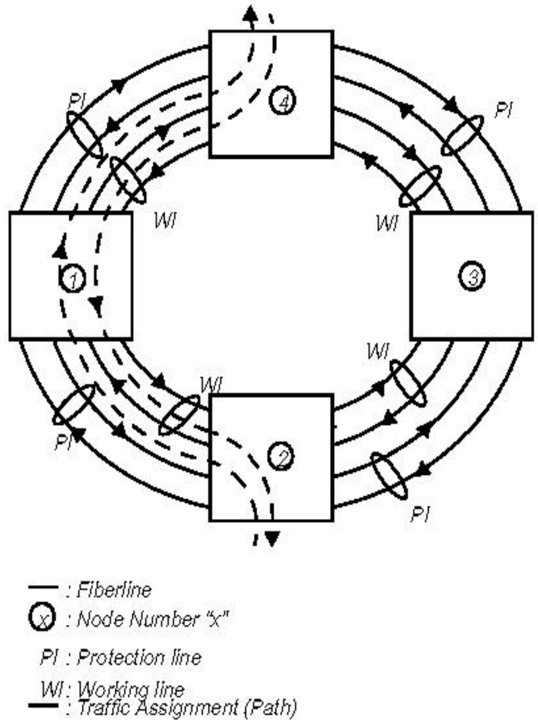

Figure 15 4-Node, 4-Fiber BLSR

3.4.2 ATM

Topological terms are less frequently used in relation to ATM; perhaps because it is carried over other technologies. ATM protection generally consists of switching mechanisms on dedicated point-to-point Virtual Path (VP) and Virtual Path Group (VPG) entities. This type of protection mechanism can be applied to linear, ring or mesh physical topologies. Figure 16 shows an example of the application of multiple, dedicated point-to-point protection switching mechanisms in a physical ring. (See GR-2980-CORE for information on ATM layer protection.)

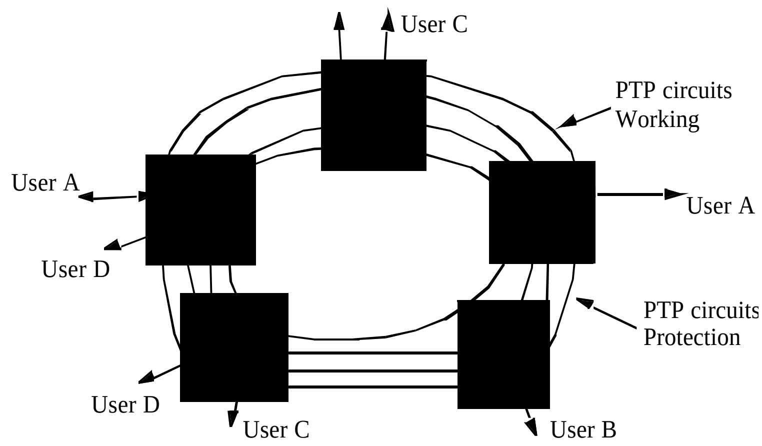

Figure 16 Ring Configuration of Dedicated Point-to-Point ATM Circuits

3.4.3 WDM/OTN

Wavelength Division Multiplexing (WDM) / Optical Transportation Networking (OTN) provides interesting scenarios for discussing topology because of the possibility of crossconnecting at the optical layer. Several optical layers have been defined (see below) allowing distinct behaviors for physical transport and logical layers, in a manner similar to the multiple layers of STS line and path in SONET.

The architecture terms used to describe WDM networks and and OTNs can be found in ITU-T Recommendation G.872, *Architecture Of Optical Transport Network*s. The terms are based on the network layer concepts in G.805. Three layers have been defined for optical networks in G.872:

- the optical channel (OCh) layer
- the optical multiplex section (OMS) layer
- the optical transmission section (OTS) layer.

Within each of these layer networks, end-to-end connections can be defined as shown in Figure 17 for a point-to-point system.

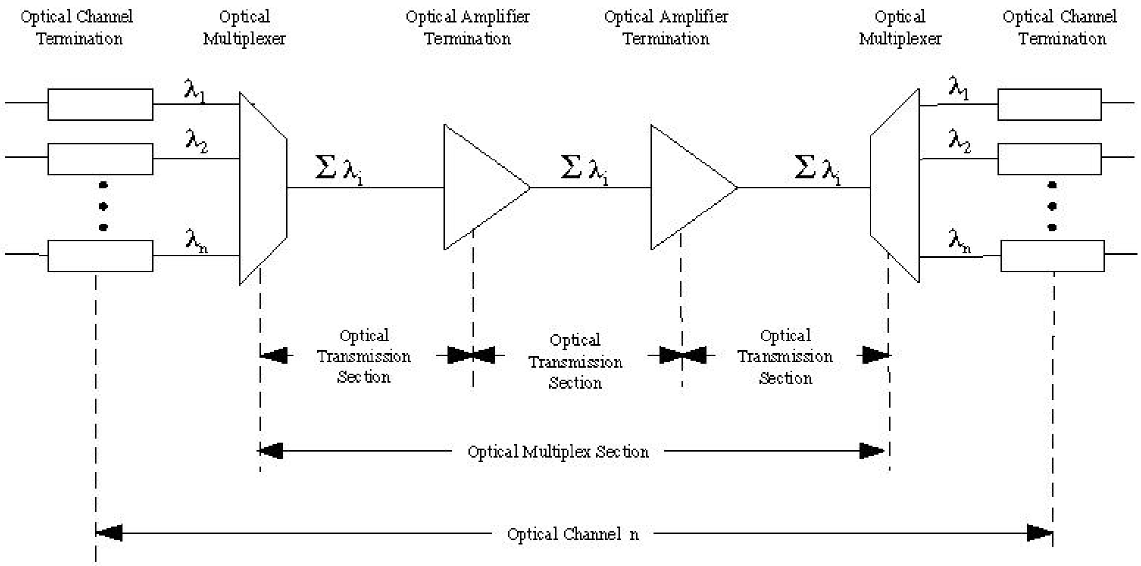

Figure 17 Example Connections in Optical Layers for Point-to-Point System

3.4.3.1 Point-to-Point

A *point-to-point* WDM configuration uses Optical Terminal Multiplexers (OTMs) as illustrated in Figure 18. Only one direction of transmission is shown. Each of the optical inputs (λ_i) to the OTM has undergone electrical to optical (E/O) conversion before entering the OTM at Location A. A mix of client signal types may be supported.

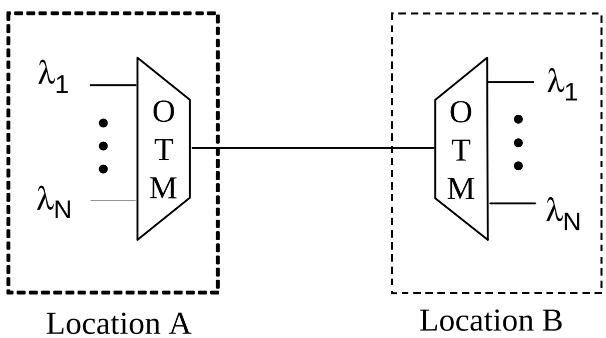

Figure 18 Point-to-Point Configuration

3.4.3.2 Wavelength Pass-Through

Figure 19 illustrates a WDM network architecture with *wavelength pass-through*. This architecture allows for wavelength pass-through at a node, i.e., not all wavelengths are required to undergo O/E conversion at Location B. Signals not being dropped at Location B can be passed-through optically rather than having to undergo O/E and E/O conversion if the optical source (λ_1 in this example) can be launched with sufficient power to reach the receiver at Location C. The demultiplexed wavelength signal at Location B is manually connected to the input of the second WDM system at Location B. As indicated in the figure, the rest of the optical channels in the system between Locations A and B are terminated at Location B. Thus, other signals entering at B can be added into the system between B and C. See GR-2999-CORE for additional information on WDM systems.

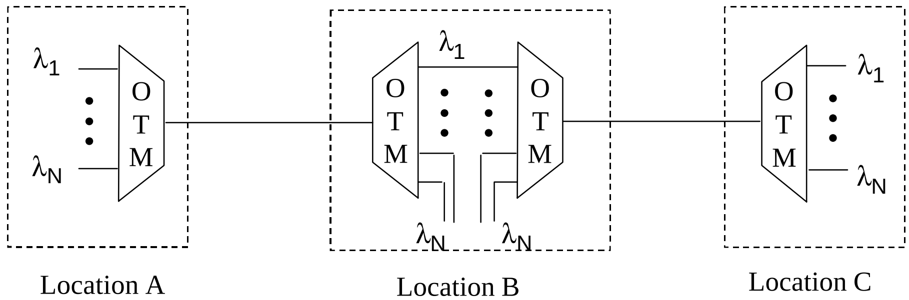

Figure 19 Point-to-point WDM Systems with Wavelength Pass-through

The wavelength pass-through architecture can be represented by the layer network topologies in Figure 20. The optical channel (path) layer has an extra link as compared to the physical layer network topology. The wavelength passthrough is static, reflecting the fact that there is no remotely configurable fabric at the optical path layer; it has to be manually configured.

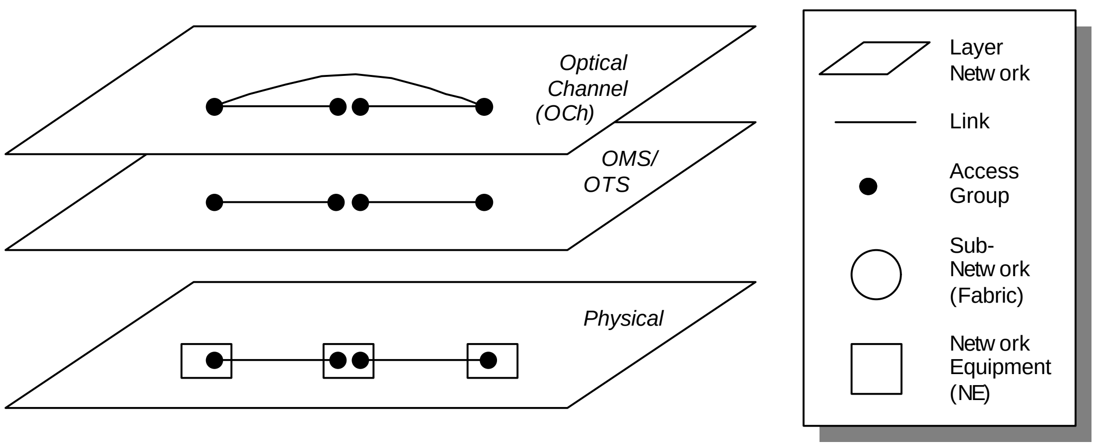

Figure 20 Wavelength Pass-Through Topologies

3.4.3.3 Linear Chain

In optical networking, the term *linear chain* is used to refer to cases where specific wavelengths are terminated at different points in a chain of optical NEs. This architecture is realized through a combination of OTMs and Optical Add-Drop Multiplexers (OADMs) as shown in Figure 21. The OADM is capable of terminating certain optical channels and passing through other optical channels to the next node on the chain without requiring any E/O or O/E conversion.

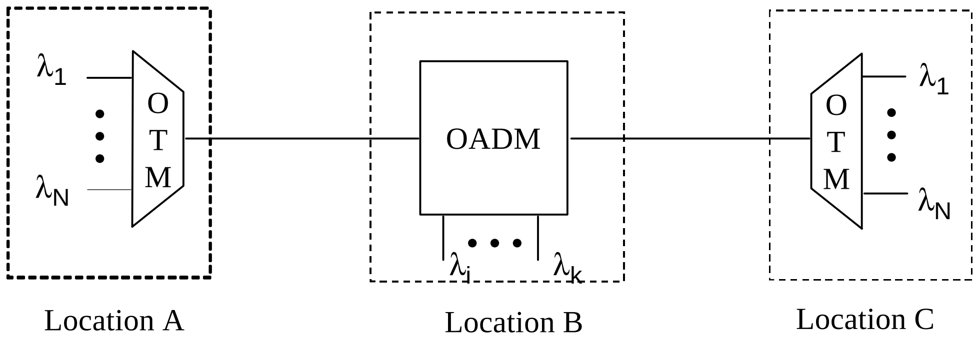

Figure 21 Linear Chain with OTMs and OADM

Unlike wavelength pass-through NEs, OADMs in a linear chain allow flexible connectivity at the optical channel layer, as indicated by the fabric in Figure 22.

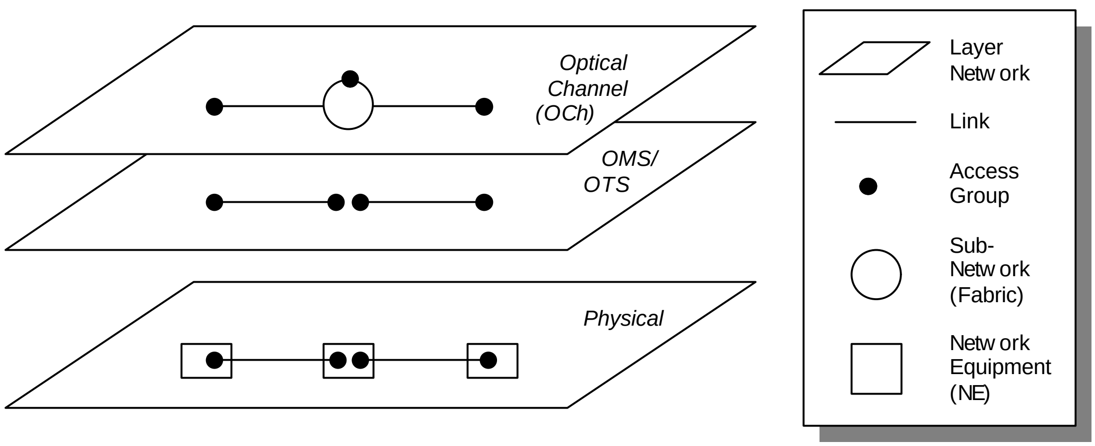

Figure 22 Layer Topologies for Optical Linear Chain

3.4.3.4 Ring

Several ring architectures have been suggested using OADMs with various protection configurations. The Optical Channel Dedicated Protection Ring (OChDPRING) uses a ring topology at the optical path layer in conjunction with Subnetwork Connection Protection (SNCP) functionality (see GR-2979-CORE for details). Several optional methods for configuring working and protecting paths on fibers are possible.

In the Optical Channel Shared Protection Ring (OChSPRING) configuration, a 1:1 protection route and capacity is pre-assigned for each OCh (see G.872). However, the protection path does not carry a copy of the working path signal under non-failure conditions. The protection capacity is shared by multiple OChs on a link by link basis.

An OMS shared protection ring divides the total payload equally into working and protection capacity and makes the protection capacity available for use by any OMS on the ring under a section or node failure condition. The OMS shared protection ring has 2- and 4-fiber versions. The protection capacity is available for use by extra traffic under non-failure conditions.

3.4.3.5 Hub

The term *hub* is sometimes used to refer to a star topology, or to a tree topology in which most traffic will flow to or from one of the nodes. In a *hub* network architecture, one network element is connected to a number of other network elements through point-to-point links. A WSXC (Wavelength-Selective Crossconnect) can be used at the hub location to cross-connect traffic to and from the other locations and create a hub optical transport network. Figure 23 depicts a WSXC hub network application centered in Location C. (See GR-3009-CORE for additional information.)

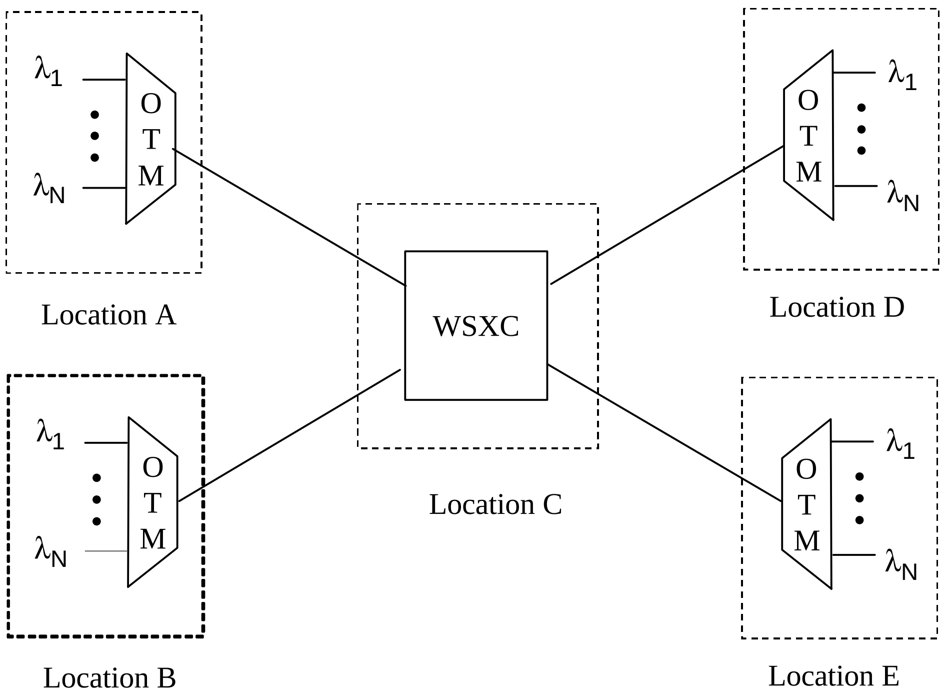

Figure 23 WSXC Used in a Hub Network

3.4.3.6 Mesh

An optical mesh network can be established using WSXCs because they support multiple optical interfaces. Mesh architectures are suited to support distributed traffic with heavy point-to-point demands. Figure 24 depicts the mesh network application using WSXCs and OADMs.

Mesh networks can provide survivability through protection and network reconfiguration due to the availability of multiple routes between WSXCs. Allocation of restoration routes can become quite involved for sizable mesh networks with multiple wavelengths. Mesh restoration can be achieved with centralized or distributed control. See GR-3009-CORE for additional information.

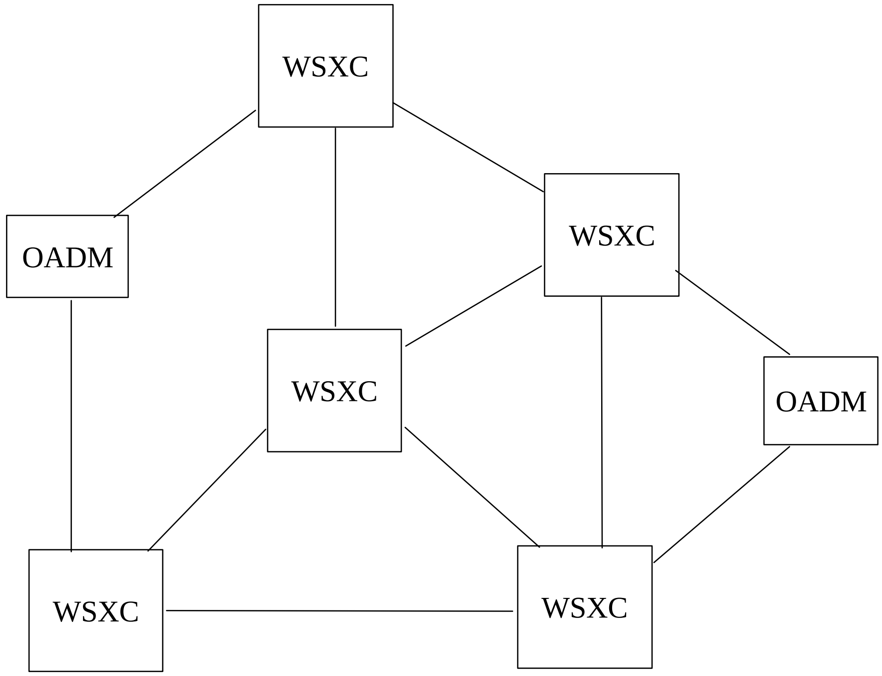

Figure 24 Mesh Network of WSXCs and OADMs

4 Reference Architectures

In this section, four reference architectures are presented. Each reference architecture consists of two views of a network:

- Physical Architecture – the configuration of physical transport media and Network Elements (NEs). The possible types of NEs that may be included are identified. NE types are defined in terms of the types of cross-connect or switching fabric(s) supported and may include supported adaptations of transport layers at trail terminations.
- Layer Domain Architecture – the configuration of transport layers related through adaptation of server layer bandwidth to client layer connections. This view indicates support of flexible connections or inflexible connections within each transport layer. In addition, it shows mappings of services to layer domains.

Each reference architecture is formed by combining a specific layer domain architecture with one of three physical architectures.

Other network views may be overlaid on a reference architecture comprised of these components. It is expected that the reference architectures described in this document will be refined via additional specifications when applied to specific use cases in NSIF work groups. These refinements may include:

- Specific combinations of NEs and NE connectivity
- Protection architecture of the physical transport layer
- Subnetwork topologies and protection architectures of logical transport layers
- Subnetwork topologies specific to component transport layers within a technology layer
- Specific connections between termination points
- Specific segment of the network (e.g. long haul, metropolitan area, secondary/access)

Subnetwork topology gives the configuration of transport bandwidth and cross-connect/switching resources representing the potential connections within a single transport layer. An example of component transport layers within a technology layer is regenerator section, multiplex section, STS-1, STS-3c, VT1.5 component layers within the aggregate SONET layer.

4.1 Physical Architectures

Three *physical architectures* are described. They are presented in the time order in which they will likely appear in implementations. For each physical architecture, the potential NE types are listed and the configuration of physical transport media is identified. An example configuration is constructed for each architecture and is shown in a figure. It is noted that the figures are intended to depict example configurations to help visualize the architectures; they should not be viewed as excluding other example configurations. In particular it is noted that hybrid NEs may include cross-connect or switching fabrics for any combination of technologies supported by a given architecture.

4.1.1 SONET Ring-Based Physical Architecture

This physical architecture has the following properties:

- Physical topology is based on SONET ring – either UPSR or BLSR

- NE types connected by ring include: SONET ADMs and DCS; hybrid SONET/ATM/IP NEs are possible
- Ring interconnection via DCSs or ADMs via dual node interconnection
- SONET ring protection plus ATM protection mechanisms possible.

An example configuration is shown in Figure 25.

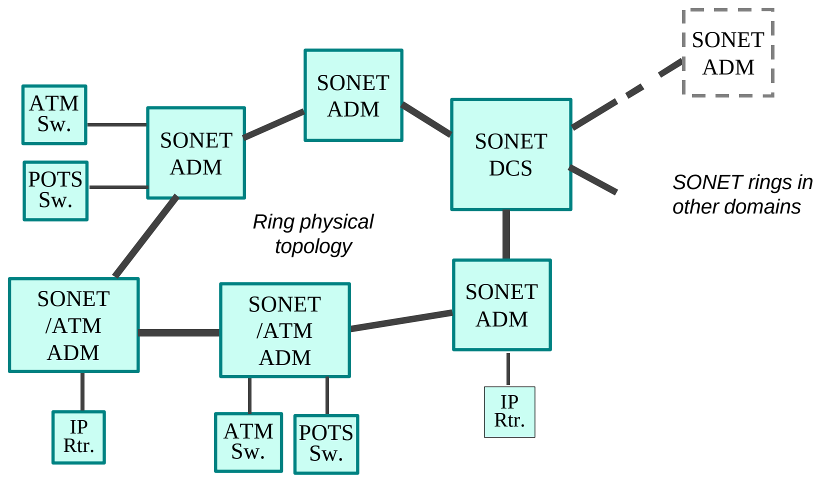

Figure 25 SONET Ring-based Physical Architecture Example

Although the SONET DCS is included in this ring scenario, it does not have widespread acceptance as a viable SONET ring element. It is noted that a variety of protection architectures are possible for protecting services in the ATM layer.

4.1.2 Optical ADM Ring-Based Physical Architecture

This physical architecture has the following properties

- OTN (Optical Transport Network) - architecture based on ITU-T G.872
- Physical topology is a fiber optic ring transporting multiple wavelengths
- NEs on the optical ring include OTN ADMs and hybrid ADMs comprised of any combination of OTN/SONET/ATM/IP
- Dual interconnection to other subnetworks
- Variety of protection methods possible

An example configuration is shown in Figure 26.

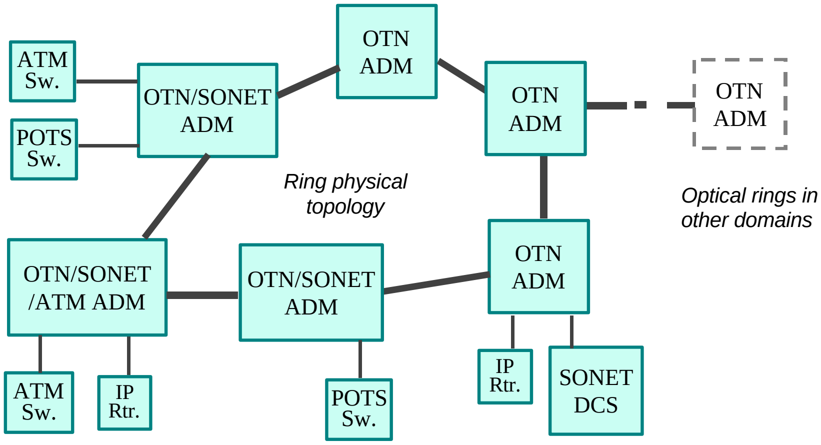

Figure 26 Optical ADM Ring-based Physical Architecture Example

The standards basis in G.872 is referenced as a goal, with the understanding that pre-standard implementation agreements are not precluded in the scope of NSIF. An OTN ADM can add/drop Optical Channel signals each of which is transported as a distinct wavelength.

4.1.3 Optical Mesh-Based Physical Architecture

This physical architecture has the following properties

- OTN (Optical Transport Network) - architecture based on ITU-T G.872
- Physical topology is a fiber optic mesh; fiber carries multiple multiplexed wavelengths
- NEs on the optical mesh include OTN Cross Connect (XC) and hybrid NEs based on OTN and any combination of SONET, ATM, and/or IP.
- A variety of protection and restoration methods are possible.

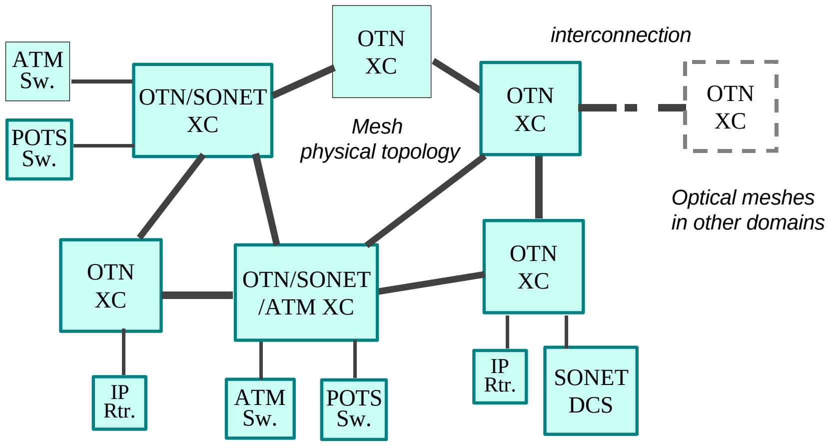

Figure 27 Optical Mesh-based Physical Architecture Example

An OTN XC can cross-connect Optical Channel signals each of which is transported as a distinct wavelength.

4.2 Key for Reference Architecture Figures

The legend used in the reference architecture diagrams is described in the following text and in Figure 28. A layer domain is indicated by an oval shape. The downward thick arrow indicates an adaptation relationship between a client transport layer on top and a server layer below. A client layer may be supported by several server layers. Mappings of services (rectangular boxes) to layer domains are identified. Different symbols are used to indicate flexible transport layers and fixed transport layers. A flexible layer allows flexible routing of connections via cross-connect or switching functionality.

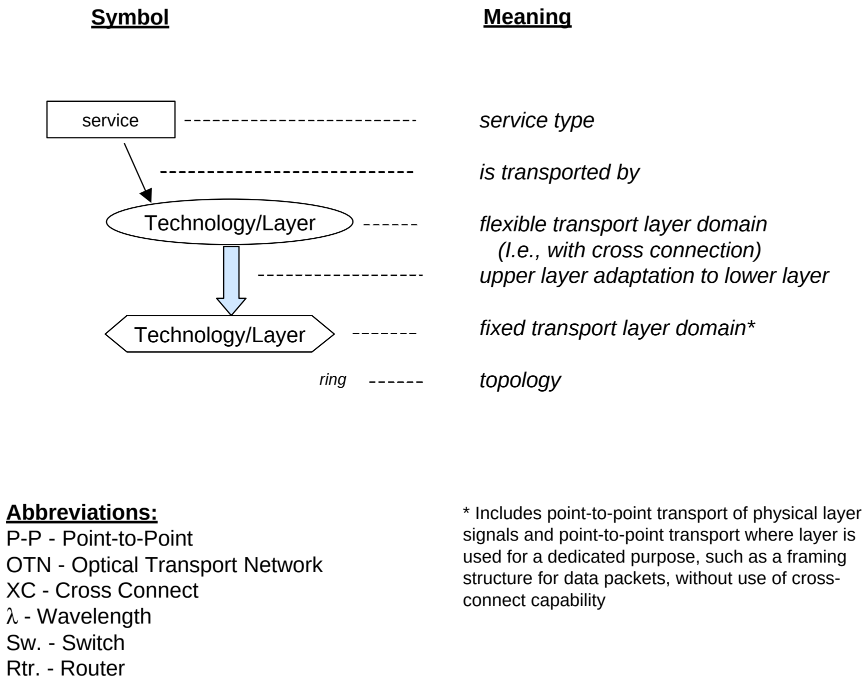

Figure 28 Legend for Reference Architecture Figures

The composition of a domain may be based upon a single transport layer (e.g., Virtual Path) or a grouping of layers such as that included within a technology (e.g., ATM, including both VP and VC). The term *layer* is used in the G.805 sense, referring to transport of signals of a given characteristic information (e.g. STS-12 path). It is useful to select a domain based on collective behavior, for example, common capabilities for connection set up. For the purposes of developing reference architectures, aggregate layers associated with a given technology are used without splitting out component transport layers.

In the reference architecture figures below, color coding is used to match NEs in the physical architecture with the supported transport layers in the layer domain architecture (not visible in black and white/grayscale editions).

4.3 Reference Architecture 1A

This reference architecture combines Physical Architecture 1 with a layer domain architecture that transports ATM and IP over SONET and carries circuit-switched services over ATM and SONET.

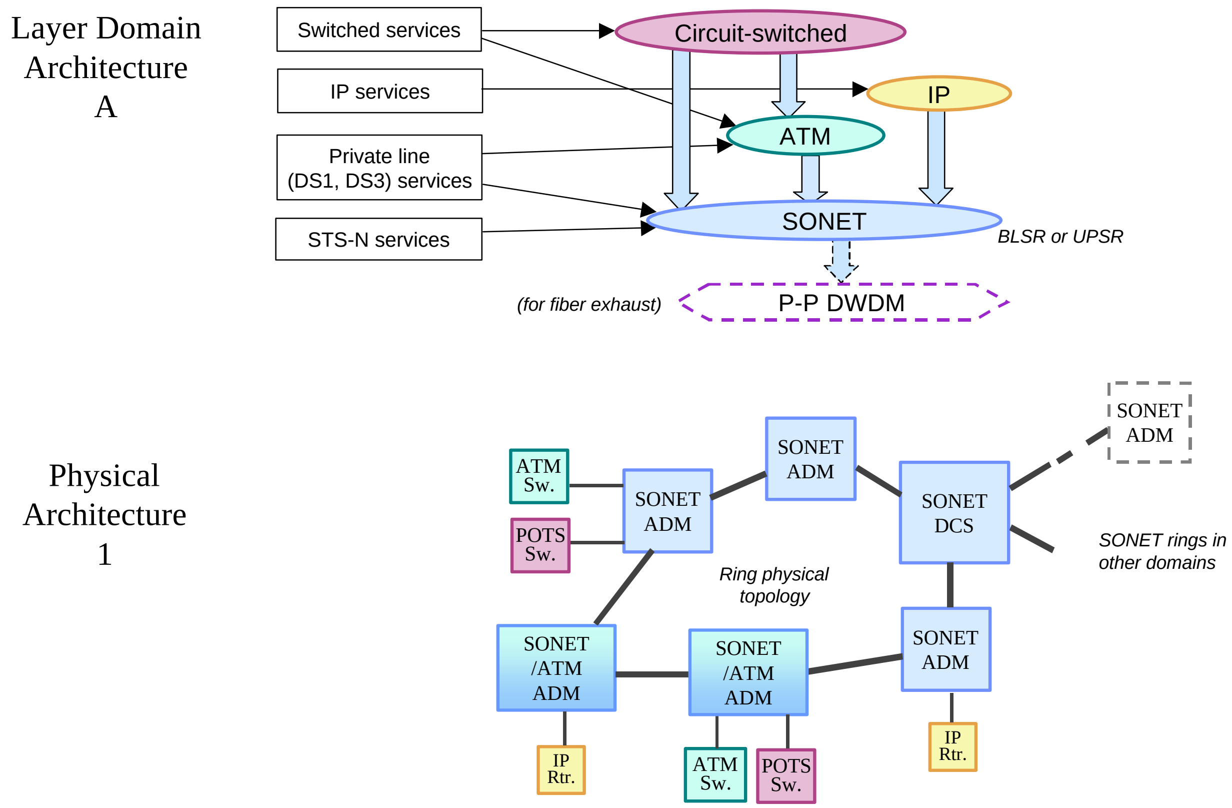

Figure 29 Reference Architecture 1A

4.4 Reference Architecture 1B

This reference architecture combines Physical Architecture 1 with a layer domain architecture that transports ATM and IP over a flexible SONET infrastructure and over an (inflexible) SONET framing mechanism. In addition, this architecture enables IP to be transported over ATM. Circuit-switched services are carried over ATM and SONET as in the previous architecture.

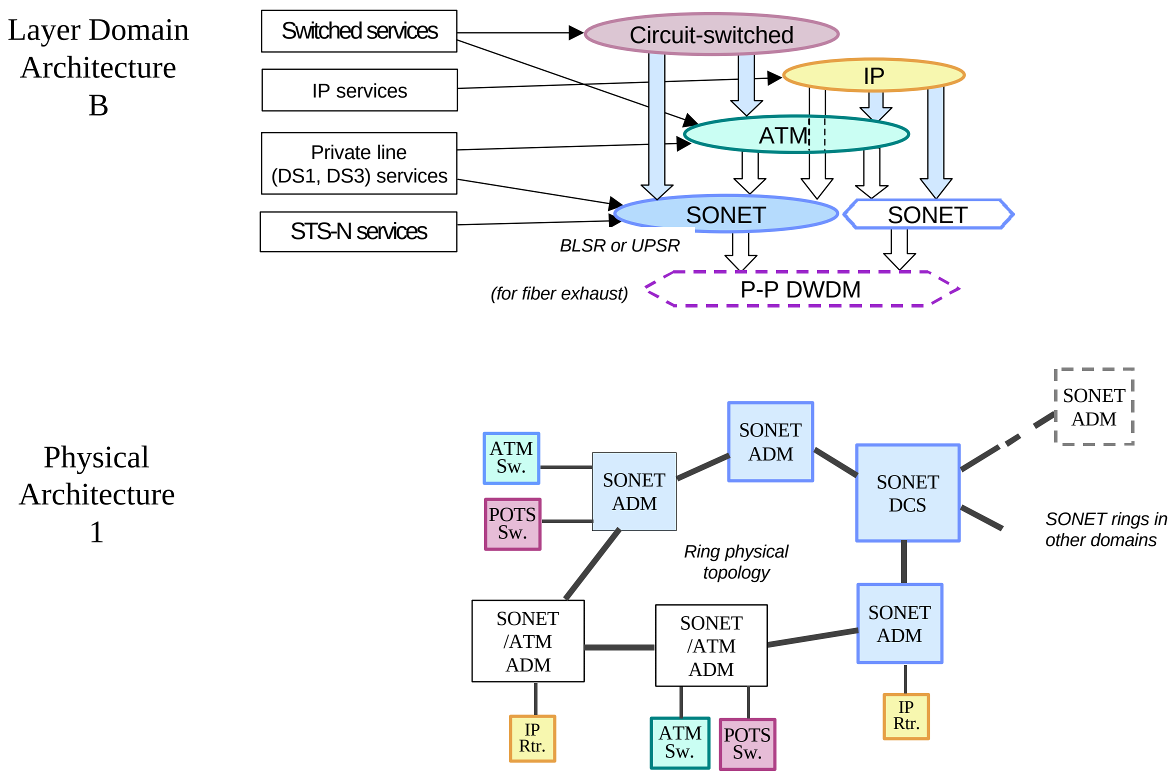

Figure 30 Reference Architecture 1B

4.5 Reference Architecture 2C

This reference architecture combines Physical Architecture 2 with a layer domain architecture that builds on the capabilities of layer domain architecture B. Wavelength (λ) services are supported via the flexible OTN layer. Circuit-switched services may be carried over SONET, ATM, and/or IP. IP may be transported via ATM, SONET framing, and/or directly over the OTN, assuming suitable digital framing/wrapper is provided. ATM traffic may be carried over a flexible SONET network, SONET framing, or directly over the OTN. Both flexible and inflexible (point-to-point) SONET signals may be transported over OTN.

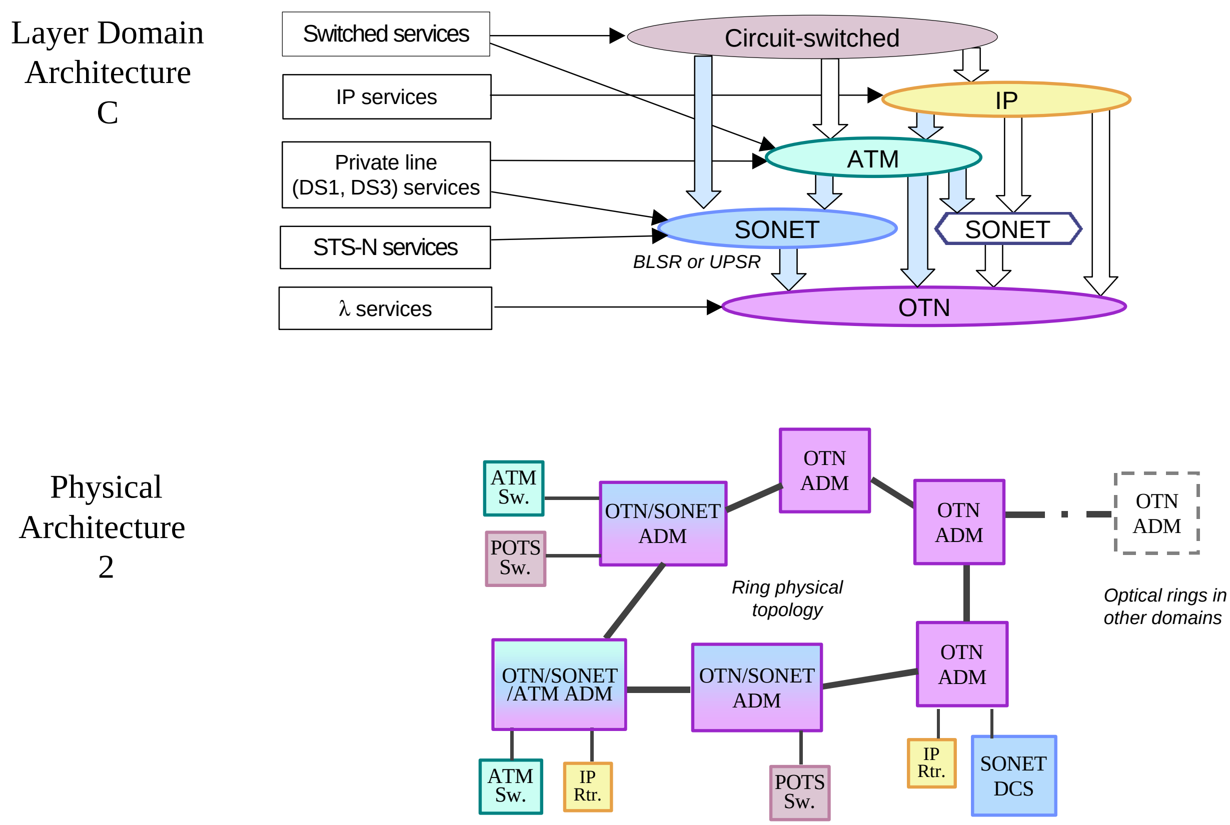

Figure 31 Reference Architecture 2C

4.6 Reference Architecture 3C

This reference architecture combines Physical Architecture 3 with the layer domain architecture C described in the previous reference architecture. It is noted that protection may be provided via OTN mesh techniques, SONET rings, and/or ATM and IP layer methods depending upon the protection strategy implemented.

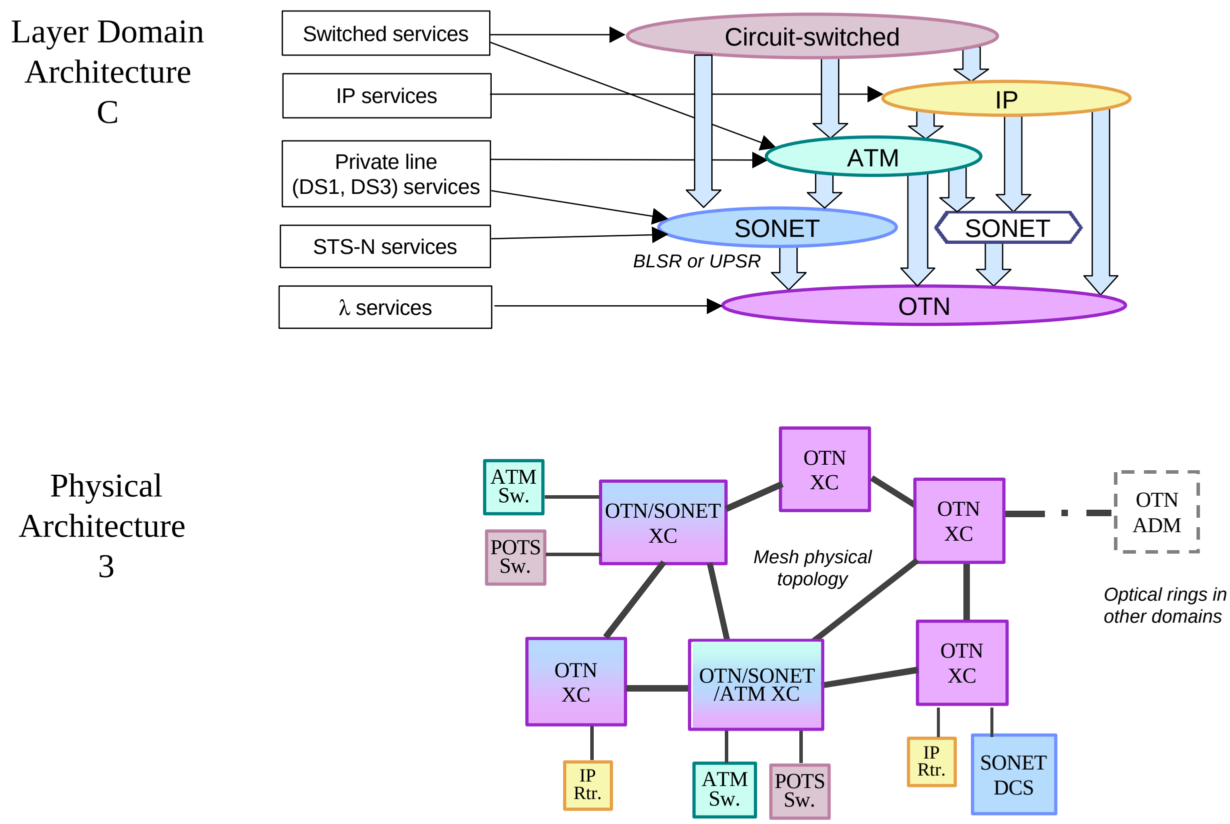

Figure 32 Reference Architecture 3C

5 Conclusions

This document provides an architectural framework for the development of use cases and requirements in NSIF. Generic and technology-specific architectural terms and concepts are defined. A set of multi-technology reference architectures is proposed based on NSIF service provider inputs. The reference architectures capture groupings of potential technologies and configurations that address current networks and anticipated future networks based on emerging technologies.

It is expected that the reference architectures will be applicable to the definition of scenarios and use cases in several NSIF work areas, particularly for work on protection, bandwidth management, and fault and performance management. Because the reference architectures allow considerable optionality, additional refinements will generally be needed in the process of defining use cases. An example use of reference architectures for analysis of protection methods in given in NSIF-PR-0004-016.

6 Acronyms

This section defines acronyms used in this document or that may be useful in other NSIF work related to network architecture.

Acronym	**Definition**
ADM	Add Drop Multiplexer
AIS	Alarm Indication Signal
APS	Automatic Protection Switching
ANSI	American National Standards Institute
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode
BISs	Boundary Intermediate Systems
BLSR	Bi-directional Line Switched Ring
CLNP	ConnectionLess mode Network Protocol
CMIP	Common Management Information Protocol
CMISE	Common Management Information Service Element
CNM	Customer Network Management
CPE	Customer Premises Equipment
DCC	Data Communications Channel
DCN	Data Communications Network
DCS	Digital Cross Connect System
DWDM	Dense Wavelength Division Multiplexing
EB	Electronic Bonding
EBG	Electronic Bonding Gateway
EML	Element Manager Layer
EMS	Element Management System
E/O	Electrical-to-Optical Conversion
FDDI	Fiber Distributed Data Interface
FTAM	File Transfer, Access and Management
FXC	Fiber Cross-Connect

GNE	Gateway Network Element
IaDI	Intra-Domain Interface
IEC	InterExchange Carrier
ICI	InterCarrier Interface
IDRP	Inter-Domain Routing Protocol
IDT	Integrated Digital Terminal
INE	Intermediate Network Element
IP	Internet Protocol
IrDI	Inter-Domain Interface
IS-IS	IS to IS intra-domain routing information exchange protocol
IS	Intermediate System
ISO	International Organization for Standardization
ITU	International Telecommunications Union
IWF	InterWorking Function
LC	Link Connection
LEC	Local Exchange Carrier
LTE	Line Terminating Equipment
MD	Mediation Device
MF	Mediation Function
MIB	Management Information Base
NE	Network Element
NEF	Network Element Function
NET	Network Entity Title
NMA	Network Monitoring and Analysis
NML	Network Management Layer
NMS	Network Management System
NNI	Network-Network Interface
NSAP	Network Service Access Point
NSIF	Network & Services Integration Forum
OADM	Optical Add Drop Multiplexer
OAM&P	Operations, Administration, Maintenance & Provisioning

OCh	Optical Channel
OChDPRING	Optical Channel Dedicated Protection Ring
OC-x	Optical Carrier (level)
O/E	Optical-to-Electrical Conversion
OMS	Optical Multiplex Section
OSI	Open Systems Interconnection
OSS	Operations Support System
OTM	Optical Terminal Multiplexer
OTN	Optical Transport Network
OTS	Optical Transmission Section
OXC	Optical Cross-Connect
P-P	Point-to-Point
PDH	Plesiochronous Digital Hierarchy
PDU	Protocol Data Unit
PM	Performance Monitoring
POTS	Plain Old Telephone Service
PRS	Primary Reference Source
RDT	Remote Digital Terminal
SONET	Synchronous Optical NETwork
SPE	Synchronous Payload Envelope
SNC	Sub-Network Connection
SNCP	Sub-Network Connection Protection
STE	Section Terminating Equipment
STS	Synchronous Transport Signal
TM	Terminal Multiplexer
TMN	Telecommunications Management Network
UNI	User-Network Interface
UPSR	Unidirectional Path Switched Ring
VC	Virtual Channel
VCI	Virtual Circuit (channel) Identifier
VP	Virtual Path

VPI	Virtual Path Identifier
VT	Virtual Tributary
WDM	Wavelength Division Multiplexing
WIXC	Wavelength Interchanging Cross-Connect
WSXC	Wavelength Selective Cross-Connect
XC	Cross Connect