2 Concepts and Models

The purpose of SP Guru Transport Planner is to model, design, and evaluate optical transport networks. This chapter gives an overview of the main concepts of these networks and how they are modelled in SP Guru Transport Planner.

SONET/SDH and Optical Technology

SP Guru Transport Planner models two main technologies:

- SONET/SDH Systems—SONET (Synchronous Optical Network) or its European counterpart, SDH (Synchronous Digital Hierarchy)
- WDM Systems—Wavelength Division Multiplexing

Both technologies are multiplexing technologies, in which several lower-rate *tributary signals* can be grouped into a higher-rate *aggregate signal*. This enables the network to transport multiple signals at once with reduced cost and complexity. SONET and SDH are *time division multiplexing* (TDM) technologies, which group lower-bit-rate signals into a higher-bit-rate signal so they can transmit time slots at a higher rate. By contrast, *wavelength division multiplexing* (WDM) uses different wavelengths—rather than different bit rates—to group multiple optical signals on the same fiber.

Both technologies are complementary: multiplexed SONET/SDH signals can be multiplexed again using the wavelengths of WDM. This is also known as *SONET/SDH-over-Optical* or *SONET/SDH-over-WDM*.

SONET/SDH Systems

SONET is a standardized TDM protocol that allows individual low-bit-rate tributary signals to be multiplexed directly into higher-bit-rate SONET signals. In addition, SONET has built-in overhead, which is restricted to about five percent of the total signal capacity; this overhead provides capabilities for advanced network management, maintenance, and fault recovery.

The information structure used to transmit SONET signals is called the *Synchronous Transport Signal* (STS). An STS consists of payload and overhead information fields, and is organized in a block frame structure that repeats every 125 microseconds. The basic STS frame is STS-1, with a bit rate of 51.84 Mbps. STS-1 signals can be multiplexed into higher-level STS-*N* signals, where *N* is an integer (typically a multiple of 3 or 4). The optical interface for transporting STS-*N* signals over optical fiber is called the *Optical Carrier Level N* (OC-*N*).

SDH uses a similar signal called the *Synchronous Transport Module* (STM). The basic STM frame is STM-1, with a bit rate of 155.52 Mbps. STM-1 signals can be multiplexed into STM-*N* signals, where *N* is typically a multiple of four. The SDH STM-1 signal has the same bit rate as the SONET STS-3 signal.

The STS-1 payload (called *SPE*, for *Synchronous Payload Envelope*) can vary, depending on the type of data in the frame. If one DS-3 is being mapped to the frame, it is placed directly into the SPE. But if sub-DS-3 services are being transmitted, a new container must be defined. This new container is called the *VT* (*virtual tributary*). VT-rate circuits are part of the lower order path (LOP) layer of SONET.

VTs are defined for four types of service, corresponding with the PDH signals they support: DS-1 (VT-1.5), E1 (VT-2), DS-1c (VT-3) and DS-2 (VT-6). Each type carries a different bandwidth and therefore occupies a different amount of space within the payload. VT-1.5 occupies 9 bytes x 3 bytes (three columns), VT-2 is four columns, VT-3 is six columns, and VT-6 is 12 columns. To solve the problem of mixing and matching VTs within a payload, SONET defines a VTG (VT group): one STS-1 frame has seven VTGs, and each VTG occupies 12 columns of the payload. VTs are matched and placed into a VTG that contains identical services. A single VTG can contain four VT-1.5s, three VT-2s, two VT-3s or one VT-6.

SDH uses a similar type of lower-order container called the VC (virtual container). VCs are defined for five types of service: DS-1 (VC-11), E1 (VC-12), DS-2 (VC-2) and E-3 (VC-3) and E-4 (VC-4). The VC-11, VC-12 and VC-2 containers are mapped into a *TUG* (*tributary unit group*), similar to the VTG in SONET. Seven TUGs fit into a VC-3. An STM-1 frame can host 3 VC-3s or a VC-4.

Table 2-1 lists the VT signals and matching VC signals modeled in SP Guru Transport Planner.

Table 2-1 VT Levels and Matching VC Signals

SONET		**SDH**	
Name	**Payload Bit Rate**	**Name**	**Payload Bit Rate**
VT-1.5	1.728Mb/s	VC-11	1.728Mb/s
VT-2	2.304Mb/s	VC-12	2.304Mb/s
VT-3	3.456Mb/s	—	—
VT-6	6.912Mb/s	VC-2	6.912Mb/s
STS-1	50.112Mb/s	VC-3	48.960Mb/s
		VC-4	150.336Mb/s
End of Table 2-1			

Table 2-2 lists the STS rates and the corresponding STM rates modeled in SP Guru Transport Planner.

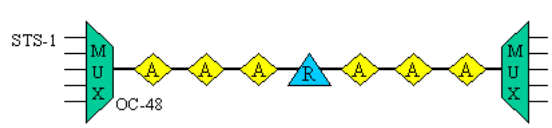
Table 2-2 OC Levels and Matching SONET/SDH Signals

OC Level	Bit Rate	STS Level (SONET)	STM Level (SDH)
OC–1	51.5 Mb/s	STS–1	–
OC–3	155 Mb/s	STS–3	STM–1
OC–12	622 Mb/s	STS–12	STM–4
OC–48	2.5 Gb/s	STS–48	STM–16
OC–192	10.0 Gb/s	STS–192	STM–64
OC–768	40.0 Gb/s	STS–768	STM–256
OC–1536	80.0 Gb/s	STS–1536	STM–512
OC–3072	160 Gb/s	STS–3072	STM–1024
End of Table 2-2			

The standardized set of STS/STM and VT/VC signals were devised to fit the traditional voice-based PDH signals. However, as today's networks are increasingly relying on data services, SONET/SDH has been extended with the principle of *virtual concatenation* of signals. Virtual concatenation defines an inverse multiplexing procedure that groups multiple signals and transports them as one entity across the network. The concatenated signals are obtained by grouping the payloads of the constituent signals. Both STS/STM and VT/VC support virtual concatenation: for example, an STS-1-21vc signal can be defined that groups the payload of 21 STS-1 containers (combined payload of 21 x 50.112 Mb/s = 1.052 Gb/s) to efficiently transport 1 Gigabit Ethernet services over SONET.

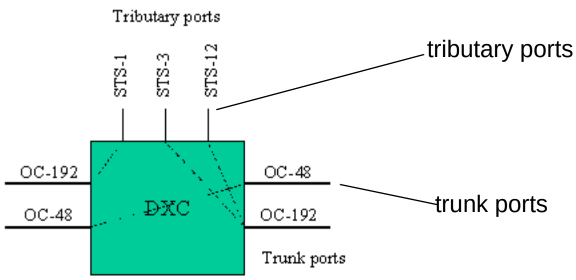
In its basic form, a SONET link consists of an optical fiber with terminal multiplexers at the endpoints, and amplifiers and regenerators between the endpoints. The terminal multiplexers combine STM-N signals in a higher-rate STM-M signal (M > N). At regular intervals along the fiber, optical amplifiers boost signals that have propagation losses in the fiber. To ensure correct transmission, regenerators must clean up the signal at intermediate points due to non-linear degradations in the fiber (a process called *3R regeneration*). This process reamplifies, reshapes, and retimes the signal at the electrical level, not the optical level.

Figure 2-1 SONET Link



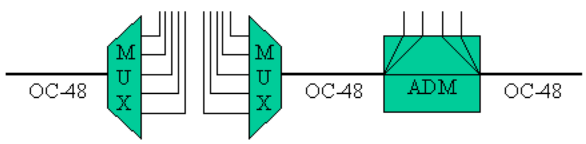
Nodes in the network use *digital cross-connects* (DXCs) to transport SONET signals efficiently throughout the network. A DXC typically terminates several SONET links on its *trunk* ports; it can also add or drop local traffic through its *tributary* ports. Thus a DXC can transfer cross-connect traffic between two SONET links (*transit traffic)*; a DXC can also add/drop tributary traffic from a SONET link (*local traffic)*.

Figure 2-2 DXC



If cross-connection is not required, you can substitute a DXC with an add/drop multiplexer (ADM) or a SONET/SDH terminal multiplexer (TM) at locations with a lower nodal degree. An ADM can add/drop traffic in the location; it can also pass express traffic. ADMs are also used in the nodes of SONET/SDH rings. A terminal multiplexer aggregates the tributary traffic to the bit rate of its trunk, and has no transit capabilities.

Figure 2-3 Terminal Multiplexer and ADM



TM Site (no cross-connectin g)

ADM Site (pass-through and add/drop)

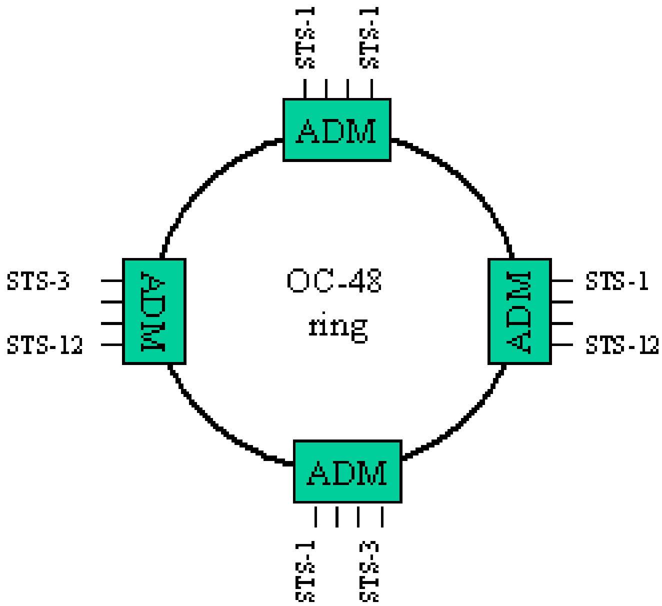
You can construct three types of networks in SP Guru Transport Planner:

- Mesh SONET/SDH networks that use DXCs and Terminal Multiplexers
- SONET/SDH ring networks that use ADMs. SP Guru Transport Planner supports the three main ring types:
  - — **UPSR:** Unidirectional Path Switched Ring
  - — **2F-BLSR:** 2-Fiber Bidirectional Line Switched Ring
  - — **4F-BLSR:** 4-Fiber Bidirectional Line Switched Ring

- Combined—You can also create networks that combine these two types of topologies.

Note—*UPSR* and *BLSR* are North American terminology for SONET networks. In European terminology for SDH networks, the UPSR is known as a Sub-Network Connection Protection (*SNCP*) ring and the BLSR is known as a Multiplex Section Shared Protection Ring (*MS-SPRing*).

Figure 2-4 Ring Network: Example



The UPSR and 2F-BLSR are supported by one underlying fiber pair or one wavelength pair if the ring is supported by a (D)WDM system. The 4F-BLSR is supported by two underlying fiber pairs or two wavelength pairs. On a UPSR ring, a connection is always routed using a working path along one side of the ring and a protection path along the opposite side of the ring. On a BLSR, in contrast, half of the ring capacity is reserved up front for protection purposes while traffic is routed in the remaining capacity (with no explicit protection path).

For more information, see Protection Methods in Ring Networks on page TrP-2-17.

WDM Systems

Applying higher TDM rates can help a network transmit more data at a higher bit rate over an optical fiber. However, this approach is not very scalable because there are practical limitations to the bit rate of a single optical channel. This limitation can be overcome using *wavelength division multiplexing* (WDM). A WDM system uses multiple channels (each channel modulated with a different TDM signal) transmitted at different wavelengths over a single optical fiber. This technique multiplies the total fiber capacity by the number of multiplexed wavelengths.

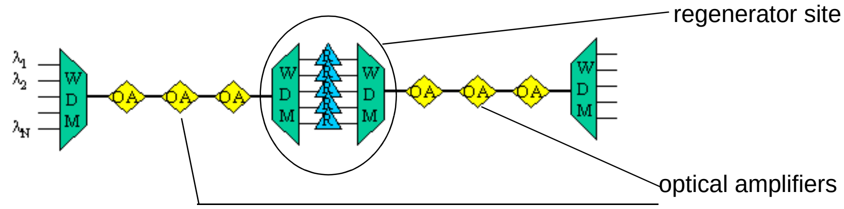
A WDM network uses wavelengths to convey traffic. The links consist of fibers equipped with WDM line systems. A line system consists of the following:

- A WDM terminal multiplexer that combines different wavelengths on one multi-wavelength optical channel
- An optical amplifier that boosts the signal of the entire multi-wavelength optical channel at once
- Regenerators that refresh each optical channel (this requires demultiplexing the multi-wavelength optical channel)

The amplifiers and regenerators in this system work as described in SONET/SDH Systems on page TrP-2-1.

The WDM system might be designed so that wavelengths are grouped into spectral transmission bands. This might be due to the architecture of the multiplexers/demultiplexers or the amplifiers. The ability to upgrade the system band-per-band (instead of the entire system at once) allows for a more modular and cost-efficient upgrade scenario. Most of today's WDM systems work in two, three, or even more bands.

Figure 2-5   Terminal Multiplexer, Optical Amplifier, and Regenerator Site



WDM operates in the 1500 nm region of the optical fiber. This wavelength has good transmission characteristics and is preferred due to the availability of an amplifier that can boost all channels with a flat gain.

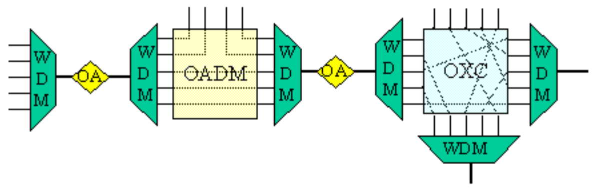
Traditional SONET/SDH equipment operates at around 1310 nm. A device called a *transponder* is used to convert the 1310 nm interfaces of SONET/SDH equipment to the WDM wavelengths.

Two types of equipment can add/drop or cross-connect traffic in a node: *optical add/drop multiplexers* (OADMs) and *optical cross-connects* (OXCs). An OADM terminates two fiber pairs. It can insert or extract one or more “tributary” wavelength channels into or out of the multi-wavelength “trunk” channel while transparently passing through the remaining wavelengths. OADMs are typically deployed in nodes with limited amounts of add-drop traffic. In banded WDM systems, certain bands of the OADM might be entirely passed through, while other bands drop the traffic destined for that node. For more information, see Optical Nodes: OADM on page TrP-2-29.

An OXC consists of a large switching matrix that enables connectivity between the different ports of the OXC. The demultiplexed channels of the terminated fibers are interconnected to the trunk ports of the OXC; the add/drop channels are fed into the OXC through the tributary ports.

You can distinguish between different types of OXC switching matrices. Non-blocking OXCs can switch between any two ports, while wavelength plane or WP-OXCs can switch ports only on the same wavelength. For more information, see Optical Nodes: WP-OXC on page TrP-2-26.

Figure 2-6 OADM and OXC



SONET and WDM Representation in SP Guru Transport Planner

You can think of a transport network that uses multiple technologies as a number of independent *layer networks* with a *client/server relationship* between adjacent layers: the server layer provides transport facilities, which are used to transport client-layer traffic. This means that when a connection is set up in the server (lower) layer, a logical link is created in the client (upper) layer. This logical link provides trunk capacity for client-layer traffic.

Layers in SP Guru Transport Planner

SP Guru Transport Planner has five network layers. From bottom to top, these layers are:

- The Optical Transmission (OTS) layer represents the physical topology, which consists of buildings interconnected by cables.
- The Optical Multiplex Section (OMS) layer represents how fiber pairs are used on different cables of the OTS layer, and which WDM line system type is used on each fiber.
- The Optical Channel (OCH) layer represents optical line systems and cross-connects.

- The Digital Client (DCL) layer represents the STS/STM granularity of the SONET/SDH layer. This layer contains logical links created by wavelengths (which are routed in the OCH layer) between nodes that have OCH counterparts, and physical links between nodes that do not have OCH counterparts.
- The Lower Order Path (LOP) layer represents the VT/VC granularity of the SONET/SDH layer.

When you equip fiber pairs in the OMS layer, this creates available capacity in the form of wavelengths or optical channels (represented by links in the OCH layer). The available capacity of the OCH links depends on the WDM line system types deployed on the fibers.

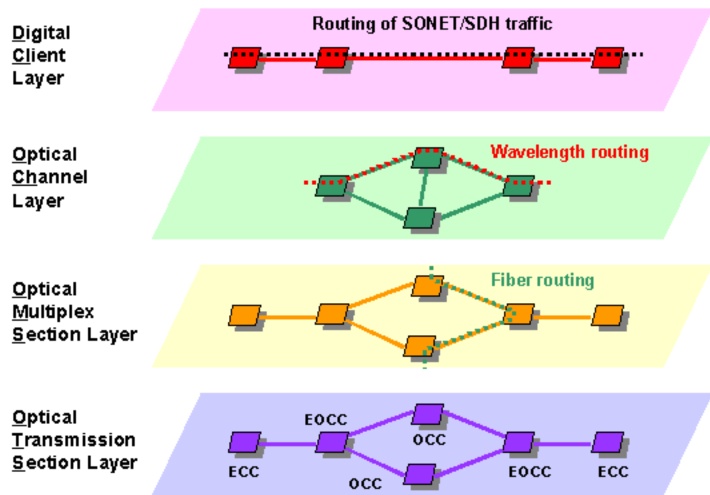
In contrast with the OTS and OMS layer, the OCH layer is used for routing traffic (such a layer is also referred to as a *path layer*). OCH traffic is expressed as wavelength demands between node pairs. To fulfill these demands, SP Guru Transport Planner sets up OCH connections between nodes. These connections require spare wavelengths on the OCH links and switching capacity (provided by OXCs) in the nodes.

When SP Guru Transport Planner sets up an OCH connection between two nodes, this creates a logical link in the DCL layer. The capacity that becomes available on the DCL link depends on the bit rate of this optical channel. For example, an OC–48 optical channel results in a DCL link with a capacity of 48 STS–1 time slots. The network can use this DCL capacity to transport DCL connections.

However, not all set-up OCH connections are trailed to DCL links. Some OCH connections can be labeled as *native connections*. These connections are pure wavelength demands and the wavelengths are not used to convey SONET traffic. Thus, when this type of OCH connection is set up, no logical DCL link is created.

Just as non-native OCH connections result in DCL links, non-native DCL connections result in LOP links. Currently, SP Guru Transport Planner does not model the LOP layer as a full network layer: you cannot route traffic and define equipment for this layer. However, you can define an LOP traffic matrix and then run LOP grooming operations to translate this into a DCL traffic matrix. Then you can use the resulting DCL traffic matrix as you would use any other DCL traffic matrix.

Figure 2-7   Layers in SP Guru Transport Planner



Optical Nodes vs. SONET/SDH Nodes

The two layers that support traffic are the DCL (SONET/SDH) and OCH (optical) layers. Not all node types support both layers. SP Guru Transport Planner considers the following types of nodes:

- ECC (electrical cross-connect) nodes can switch SONET traffic only and have no optical counterpart. ECC nodes cannot switch optical wavelengths, so these nodes are not represented in the OCH layer. ECC nodes are typically at the edge of the network, where traffic volumes are relatively small and there is no need for optical switching.

- OCC (optical cross-connect) nodes can switch optical traffic only and have no electrical counterpart. OCC nodes cannot handle SONET traffic, so these nodes are not represented at the DCL layer. OCC nodes can be used as flexibility points at the core of the network, where there is no need to add/drop SONET traffic.
- EOCC (electrical/optical cross-connect) nodes can switch both SONET/SDH traffic and wavelengths. Therefore, EOCC nodes are represented in both the DCL and OCH layer. EOCC nodes are used where adding and dropping both SONET and optical traffic are required; they are also used to groom SONET traffic.

Note—SP Guru Transport Planner also supports a fourth node type: the cable splitter. A cable splitter is a bifurcation point for optical fiber pairs. These nodes cannot switch optical or SONET traffic and are represented in the OTS layer only.

OCH vs. DCL Links

When you create a network with different node types, this creates different topologies at the DCL and OCH layers. This type of network is called a *two-tier network*. Depending on the node types, a link between two nodes is part of either the optical tier (an OCH link) or the electrical tier (a DCL link).

- OCH links connect node pairs with optical representations (OCC–OCC, OCC–EOCC, and EOCC-EOCC node pairs). When you deploy a DWDM system on a pair of fibers, this creates an OCH link and the resulting capacity becomes available in the OCH layer.

  For example, suppose you deploy a 40-wavelength WDM system on a fiber pair. This creates a link with 40 optical channels of available capacity in the OCH layer. Because the DCL layer does not show OCH links, you can establish optical channels in the OCH layer only.

- DCL links are terminated by at least one electrical (ECC) node. There are two kinds of DCL links:
  - On *no-WDM links* a SONET/SDH line system is deployed directly on the fiber pair.
  - On *point-to-point WDM links* a WDM line system is deployed on the fiber pair and on each of its wavelengths a SONET/SDH line system is deployed. Because these DCL links are not used to route OCH traffic, they appear as white links in the OCH layer in SP Guru Transport Planner (as opposed to OCH links, which are blue).

Note—You cannot create links between OCC and ECC nodes.

Optical Transparency

The term *transparency* applies to transporting information in the OCH layer: a connection travels transparently if it is not converted electrically (for regeneration purposes) in any node along the way.

SP Guru Transport Planner can work both in Opaque Mode and Transparent Mode.

Opaque Mode

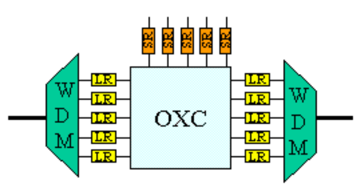
SP Guru Transport Planner uses the opaque mode for the OCH layer by default, which means that an optical signal gets regenerated at every intermediate node. Regeneration is done by the long-reach transponders, which are used at the WDM multiplexers.

Long-reach transponders convert a standard optical signal at 1310 nm (a *gray interface*) to a specific WDM wavelength in the 1500 nm region (a *colored interface*). The 1310 nm transponder input then interconnects with the trunk ports of the OXC. All signals in the OXC operate at 1310 nm; therefore, these signals can interconnect any “internal” wavelength (that is, from any WDM line system that terminates in that node) with any “external” wavelength (from any other WDM line system). For this purpose, SP Guru Transport Planner assumes that the OXC deployed in the node provides full internal connectivity. The OXC can have either an electrical or an optical core.

An important advantage of an opaque network is that it is fully compatible with WDM line systems of different types. The major disadvantage of opaque systems is the high cost of the transponders.

SP Guru Transport Planner considers long-reach transponders used at the line systems to be part of the line cost. In addition, short-reach transponders are used at the tributary ports of the OXC. These transponders provide an interface to signals from the client equipment (SONET signals, for example).

Figure 2-8 Opaque Node



Transparent Mode

In transparent mode, the long-reach transponders are at the tributary ports of the OXC/OADM, where they guide the signal, at the correct wavelength, into the network. (In opaque mode, by contrast, the transponders are in the WDM line systems.) Wavelengths pass transparently through the OXC, which imposes two constraints:

- The OXC cannot cross-connect different wavelengths between line systems that terminate in a node.
- The OXC cannot cross-connect wavelengths between different types of line systems.

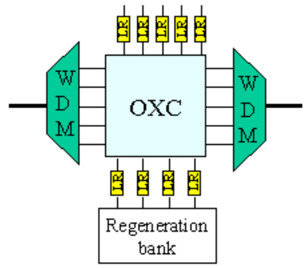
These constraints mean that, in transparent network mode, all links in the network should use the same line system type. This constraint enables the network to be divided into a number of wavelength planes. The number of available planes is equal to the number of wavelengths on the default WDM line system. Each plane represents a separate network that routes optical connections transparently.

Transparent routing also requires an optical switch matrix, since an electrical switch matrix does not allow optical signals to pass through transparently. Performing regeneration or wavelength conversion breaks the connection out of the wavelength plane. Wavelength conversion provides a mechanism for changing between different wavelength planes. Both regeneration and wavelength conversion require adding/dropping the signal through the OXC and using transponders at the appropriate wavelength.

Transparent networks use ultra-long-haul WDM systems that can transmit signals for thousands of kilometers without regeneration. However, in US or pan-European transmission networks, some paths exceed the maximum transparency length and require regeneration along the way.

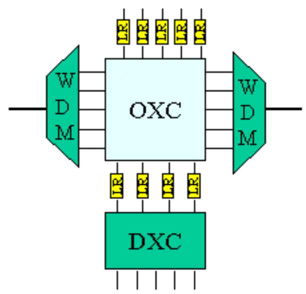
A transparent network can use two methods to regenerate connections that exceed the maximum transparency length. One method is to connect a regeneration bank to the OXC. Connections that pass through the node can be selectively regenerated using two additional OXC tributary ports (to drop to the regeneration bank) and two long-reach transponders (one for each line system). The regeneration bank can also be used to convert wavelengths and thereby overcome blocking.

Figure 2-9 Transparent Node with Regeneration Bank



The other method is to support regeneration or wavelength conversion through the DXC. Two long-reach transponders are used between the tributary ports of the OXC and the trunk ports of the DXC. This configuration has the advantage that the transponders can be flexibly allocated for regeneration or for setting up additional connections.

Figure 2-10 Transparent Node with Regeneration Using DXC



Note—SP Guru Transport Planner also supports opaque nodes in a transparent network. For more information about opaque nodes, see Opaque Mode on page TrP-2-11.

Protection Methods in Meshed Networks

In addition to unprotected routing, SP Guru Transport Planner supports four protection strategies at the OCH layer:

- 1 + 1 Path Protection
- Shared Path Protection
- Link Restoration
- Path Restoration

The following sections describe the different recovery schemes and the impact on link capacity and node models.

Note—At the DCL layer, SP Guru Transport Planner currently supports 1+1 protection only.

1 + 1 Path Protection

You can apply 1+1 path protection at the DCL and OCH layer. With 1 + 1 protection enabled, the network transmits traffic from the source to the destination simultaneously using a working path and a protection path. The destination node monitors information on both paths and selects between “working-path” and “protection-path” traffic. If the working path gets interrupted, the system switches to the protection path.

A protection path can be *link disjoint*, which means it has no common links with the working path. A protection path can also be *node disjoint*, which means it has no common nodes (except for source and destination) and links with the working path. Link disjointness protects against single-link failures, while node disjointness protects against single-link and single-node failures. Note that even node disjointness does not protect against failures in the source or destination node, because the working and the protection path have these nodes in common.

Protection switching can be done at three possible locations. The switching location determines the number of cross-connect ports (at the tributary side) that the network must reserve for a 1+1 protected path:

- By the cross-connect—If the protection switching can be done internally in the cross-connect, only one tributary port is needed at the cross-connect.

- By a separate protection switch—When protection switching is done by a separate protection switch—for example, a protection transponder before the cross-connect (see Optical Nodes: Non-Blocking OXC on page TrP-2-24)—two tributary interfaces are also required at the cross-connect for working and protection paths.
- At the client side—For client-layer protected traffic, the client has already done the protection switching and hands off two interfaces (one for the working path and one for the protection path) and requests for diverse routing of both interfaces through the network. Both interfaces are counted at the tributaries.

There is no difference between these different 1+1 protection schemes with respect to the link capacity requirements and the routes taken by working and protection paths. The only difference is in the required ports in the cross-connect. For more information, see section Node Modeling Capabilities in SP Guru Transport Planner on page TrP-2-21.

Shared Path Protection

Like 1+1 path protection, shared-path protection uses a predefined working and protection path. With shared-path protection under fault-free conditions, traffic is routed on the working path only (in contrast with 1 + 1 protection, where traffic is routed on both working and protection paths). Traffic is switched to the protection path only if a failure occurs in the working path. This means that, although the protection path is already defined, it is not set up before the failure. Therefore, the protection path does not consume network capacity under normal operating conditions and the capacity required for the protection path can be reused to protect other connections.

To preserve robustness for single-link failure, SP Guru Transport Planner supports sharing protection capacity among connections with disjoint working paths only.

Link Restoration

Unlike 1 + 1 or shared protection, link restoration does not use a pre-established backup path. The network establishes the restoration path and reroutes the affected traffic only when a failure occurs. This allows restoration capacity to be shared on the network links. When a link fails, SP Guru Transport Planner uses the switching capabilities of the OXC to reroute all affected traffic between the end nodes of the failed link. This strategy typically consumes a lot of spare capacity near the point of failure; however, spare capacity can be reused to recover connections affected by different link failures. If traffic rerouting is successful, all connections routed over the failed link are restored at the same time. SP Guru Transport Planner ensures that enough spare capacity is available in the network to overcome all single-link failures. However, link restoration cannot protect against node failures.

For port requirements, link restoration behaves as unprotected traffic for the working path. The restoration capacity uses extra link capacity as well as OXC trunk ports.

Path Restoration

Path restoration, like link restoration, does not use a pre-established backup path. When a node or link fails, the network reroutes each connection individually around the failing entity between the end-points of the connection (and not, as in link restoration, between the endpoints of the failed link). The restoration path depends on the failure location. For different failures, different restoration paths can be used for the same connection. This is the main difference between path restoration and shared path protection.

Path restoration is more flexible with respect to unexpected failures. The network can share restoration capacity between different restoration paths, corresponding to different link failures. When it designs a network with path restoration, SP Guru Transport Planner ensures that enough restoration capacity is available to overcome all single-link failures.

For port requirements, path restoration behaves as unprotected traffic for the working path. The restoration capacity uses extra link capacity as well as OXC trunk ports.

Protection Methods in Ring Networks

SP Guru Transport Planner supports two protection methods in ring architectures:

- UPSRs (Unidirectional Path Switched Ring (UPSR)
- BLSRs (Bidirectional Line Switched Ring (BLSR))

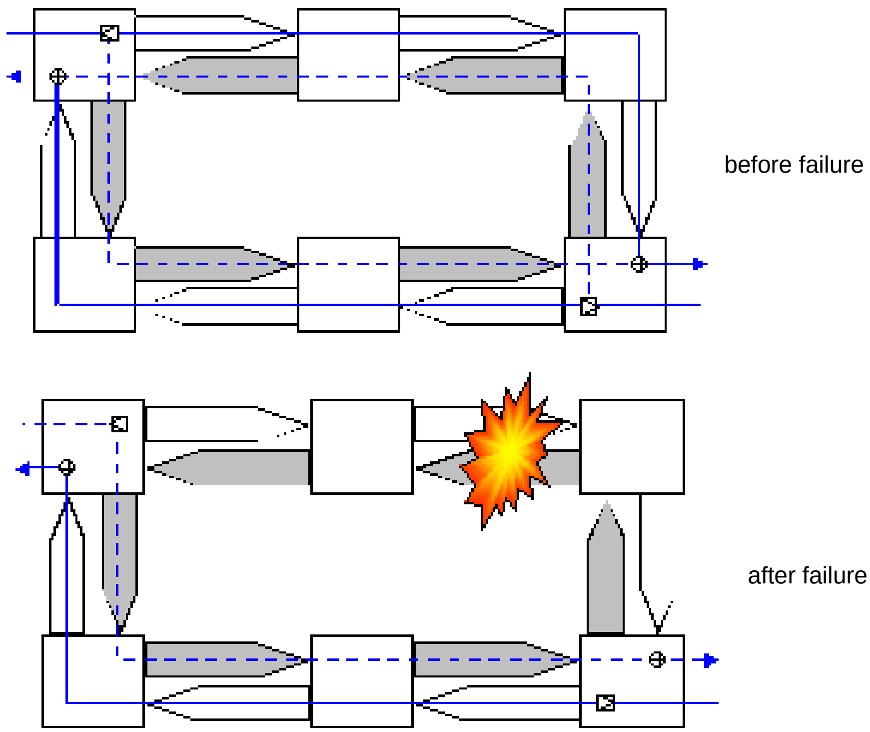
Unidirectional Path Switched Ring (UPSR)

The UPSR consists of two corresponding rings (a working and a protection ring) that transfer data in opposite directions. This configuration ensures that each connection on the working ring can be protected along the reverse side on the protection ring. Because a protected bi-directional connection is thus routed on both sides of the ring, it uses up an entire capacity slot along the ring. This capacity cannot be shared by any other connection. The capacity requirements of the ring equal the total amount of traffic to be protected on the UPSR.

The ADMs within the ring nodes perform protection switching: the transmitting ADM duplicates the traffic, and single-ended switching occurs at the receiving ADM.

Figure 2-11 shows the concept of a UPSR before and after a link failure. The working fiber is drawn in white, the protection fiber appears in gray. Both working paths (solid lines) of the bidirectional demand are routed along different sides of the ring. The protection paths (dashed lines) are transmitted on the reverse side. One fiber has working traffic only; the reverse fiber has protection traffic only. Thus the link failure affects the working path in a single direction and causes a switchover to the protection path.

Figure 2-11 UPSR Before and After Link Failure



Bidirectional Line Switched Ring (BLSR)

A BLSR ensures that multiple connections can share the ring capacity. Both directions of a bidirectional connection can be routed on one side of the ring; as a result, multiple non-overlapping connections can reuse capacity on the other side. If multiple connections share the same ring capacity, a single failure affects one connection only (in both directions); this means that protection bandwidth can be shared among multiple connections.

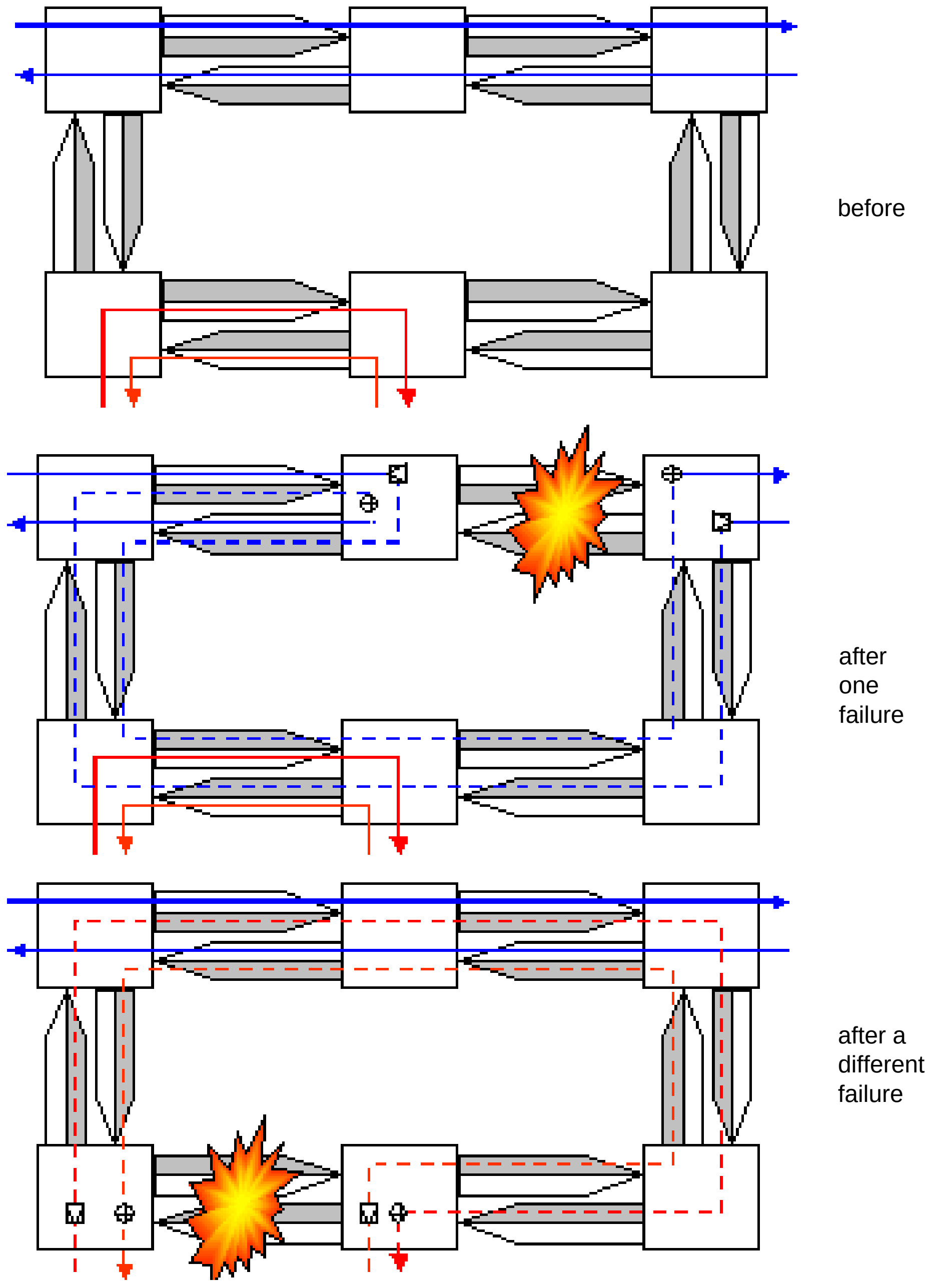
A particular node failure might affect two connections that share the same ring capacity; these connections cannot recover from the node failure anyway, since both connections terminate in that node.

The shared protection ring can be implemented using either two or four fibers. The two-fiber implementation (2F-BLSR) uses two fiber rings that transfer data in opposite directions. Half of the capacity on each fiber is reserved for protection capacity. Thus working connections in one fiber can be protected using the protection capacity in the other fiber. Both directions of a bi-directional connection are routed in different fibers on the same side of the ring (see

Figure 2-12 2F-BLSR Before and After Failures on page TrP-2-20). The same ring protection capacity can be reused for another connection between different nodes. There is no dedicated protection connection; instead, different connections can access a pool of spare capacity. If a failure occurs at the multiplex section level, ADMs near the failure will use the ring's protection capacity to simultaneously loop back all the affected connections (see Figure 2-12). An Automatic Protection Switching (APS) protocol is required to coordinate the switching and the shared use of protection capacity (to prevent the loopback from getting initiated after a second failure).

In the four-fiber implementation (4F-BLSR), two fibers are used (one in each direction) for working traffic and two fibers are reserved for protection capacity. Therefore the 4F-BLSR has twice the capacity of a 2F-BLSR. The four-fiber arrangement combines both ring protection and span protection on the same architecture. Span protection implies that if a failure affects the multiplex section in the ring's working fiber only, the parallel protection fiber can be addressed by a simple span switch and no loopback occurs. This way, some types of multiple failures can be fully protected.

Figure 2-12   2F-BLSR Before and After Failures



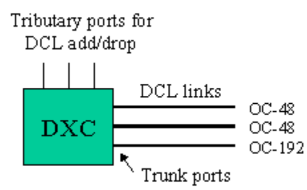
Node Modeling Capabilities in SP Guru Transport Planner

The type of equipment deployed in a node depends on the node type and some additional properties. This section describes the different node models

SONET Nodes: DXC

An ECC node can cross-connect SONET traffic only and not optical traffic; therefore, the ECC node is equipped with a DXC by default. The trunk ports of the DXC connect to the physical DCL links that terminate in the node. For example, if an OC-48 DCL link terminates in the node, an OC-48 trunk port is used on the DXC. The DXC is a digital switching matrix that can switch traffic down to the STS-1 level (STM-1 level for SDH traffic) between different DCL links (*transit traffic*) or between a DCL link and the tributary ports for a local add/drop port (*local traffic*).

Figure 2-13   DXC in ECC Node



Minimum and Maximum Bit Rates for Tributary and Trunk Ports

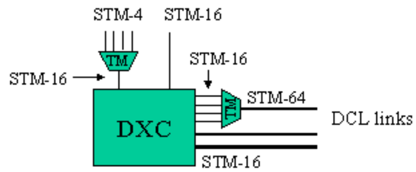
A DXC node type is specified by the number of equivalent STS-3/STM-1 ports. By default, the bit rates on available ports are determined by either the traffic terminated at the add/drop ports, or the bit rate of the links terminated at the trunk ports.

Despite this default, you can limit the bit rates for the DXC ports. At the tributary side, you can specify a *minimum tributary port bit rate*. Any add/drop traffic with a lower bit rate than this specified minimum bit rate is not directly fed to the DXC but is attached to a SONET/SDH terminal multiplexer, which aggregates traffic up to the minimum bit rate.

You can also specify a *maximum trunk port bit rate*, which specifies the maximum bit rate allowed at the trunk ports. For example, the maximum bit rate could be STM-16 while DCL links in the network work at STM-64 rate. This configuration requires a mid-stage multiplexer to aggregate the traffic through the DXC STM-16 ports up to STM-64 signals, carried on a DCL link.

Figure 2-14 on page TrP-2-22 shows a DXC with minimum and maximum bit rates equal to STM-16. At the tributary ports, all traffic with a bit rate lower than STM-16 is multiplexed to a STM-16 rate. At the trunk ports, all channels that operate above the STM-16 rate are de-multiplexed into STM-16 constituents. The aggregation rates affect the port count on the DXC only; they do not affect the routing, the grooming, or the internal switching granularity of the DXC.

Figure 2-14 DXC with Minimum Tributary and Maximum Trunk Bit Rate of STM-16



Protection Options

DCL traffic can be client-protected. If it is client-protected, two tributary ports are required on the DXC for each protected connection. If the traffic is not client-protected, one tributary port is sufficient and the protection switching is done internally in the DXC.

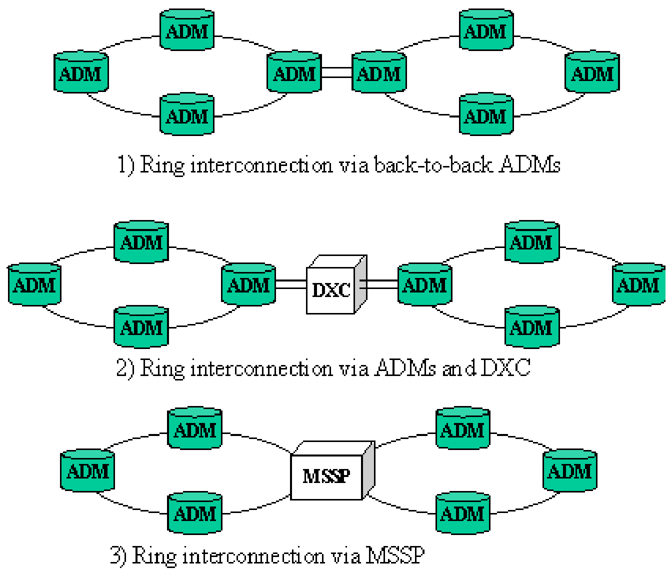
SONET Nodes: TM

SP Guru Transport Planner supports the use of SDH terminal multiplexers instead of a more expensive DXC to handle SONET traffic. SDH terminal multiplexers aggregate the SONET traffic that terminates in one or more wavelengths within the node. However, it is not possible to switch transit SONET traffic in a TM node. Therefore, the flexibility in a TM node is much lower than in a DXC node (for more information, see Chapter 8 Grooming DCL to OCH Traffic on page TrP-8-1).

SONET Nodes: ADM

A SONET ring contains Add/Drop Multiplexers (ADMs) at each node of the ring. An ADM terminates the two links of a ring in a node and allows the add/drop of local traffic and the pass-through of express traffic (*transit traffic*). As such, an ADM is a simple implementation of a DXC with only two trunk ports and a number of tributary ports sufficient to add or drop local traffic. When multiple rings are passing through the same physical node, the node contains an ADM for each ring.

Figure 2-15 Ring Interconnection



Rings can be interconnected in several ways (Figure 2-15):

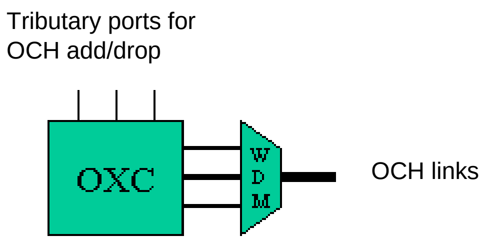
- First, the rings can be interconnected in a back-to-back ADM configuration in which the tributary ports of the one ADM are hard-wired to the tributary ports of the other ADM. Such a hard-wired configuration does not offer any flexibility and is suitable for static traffic only.
- A second, more flexible, design interconnects the collocated ADMs in a node through the tributary ports of the DXC in that node.
- A third configuration integrates the functionality of the ADMs and DXC in a single device called a MSSP (Multi Service Switching Platform). The MSSP is a DXC that can terminate the ring at its trunk ports and support ring-switching capabilities.

SP Guru Transport Planner allows you to choose among these three possibilities on a per-node basis using the Node Browser in the DCL layer by right-clicking on a node and setting the Ring Interconnection option.

Optical Nodes: Non-Blocking OXC

An OCC node can cross-connect optical traffic only and no SONET traffic; therefore the OXC node is equipped with an OXC by default. The OXC can be an optical or an electrical switching matrix (see Optical Transparency on page TrP-2-11 for more information). The trunk ports of the OXC connect to the wavelengths of the WDM line systems of OCH links that terminate in the node. The OXC switches wavelengths between different WDM line systems (*transit traffic*) or between the OXC tributary ports and the WDM line systems (*local traffic*).

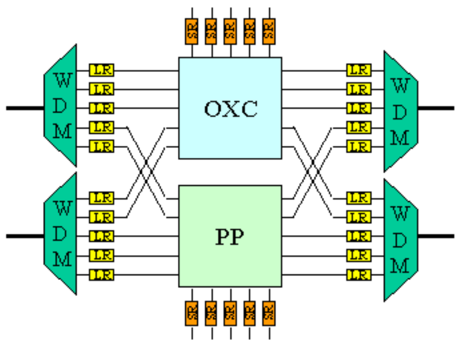
Figure 2-16   OXC in OCC Node



Patch Panel

OCH-layer traffic consists of wavelengths that are transported on WDM line systems and are cross-connected by OXCs within nodes. Some traffic can be static, which does not need the flexible (and expensive) switching capabilities of the OXC. This traffic can be labeled *hardwired* in SP Guru Transport Planner and is not switched using the OXC, but through a static patch panel (PP). If both hardwired and non-hardwired traffic coexist in a node, the node includes both an OXC and a PP (see Figure 2-17). You can also define an entire node as static; in this case, a patch panel cross-connects all traffic (whether hardwired or not) and no OXC is present in the node.

Figure 2-17   OXC and Patch Panel (Opaque Scenario)

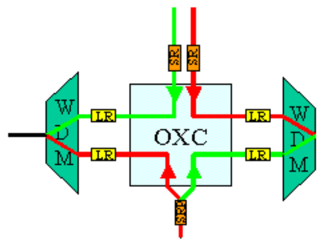


Protection Options

If OCH traffic is client-protected, two OXC tributary ports interconnect two short-reach transponders (in opaque mode) or two long-reach transponders (in transparent mode) to guide the working and protection constituents of traffic in the OXC. This traffic is switched toward the OXC trunk ports. The OXC is connected to the WDM line system, either through long-reach transponders (opaque mode) or directly (transparent mode).

Figure 2-18 Impact of Client Protection on Required Transponders and OXC Ports (Opaque Scenario)

Client-Protected Native OCH Traffic



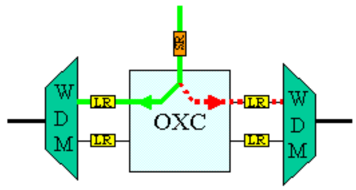
Protected Native OCH Traffic

If the OCH traffic is not client-protected, the OCH layer handles the protection switching. Most OXCs today cannot do protection switching (in contrast with DXCs and IXCs, which are electrical switches that support protection switching). Therefore, a protection transponder outside the OXC does the actual switching. The protection transponder takes one signal as input and splits the signal into a working and protection path; these paths feed into two tributary OXC ports. The OXC switches the working and protection paths to the appropriate trunk ports, which are connected to the WDM line system. The protection transponder comes in short-reach (opaque mode) and long-reach (transparent mode) versions.

Shared path protection differs from 1+1 protection in this regard: 1 + 1 protection uses single-ended switching, while shared protection uses dual-ended switching.

- 1+1 protection uses single-ended switching. Therefore only the destination node does switching, while the source node duplicates the traffic (since the OXC cannot broadcast traffic this way, the network uses a protection transponder instead).
- Shared protection uses dual-ended switching, which is done by the OXC. The OXC needs only one tributary port to terminate shared path-protected traffic. One OXC trunk port is dedicated for the working path, while another OXC trunk port is used for the protection path (this trunk port can be shared with other protection paths).

Figure 2-19 Shared Path Protection in OXC (Opaque Scenario)



Optical Nodes: WP-OXC

In addition to the non-blocking OXC, SP Guru Transport Planner supports another OXC type for switching traffic: the wavelength plane OXC (WP-OXC). A WP-OXC can switch within one wavelength plane only. It is used exclusively in transparent networks, which use the same type of WDM line system on all links. The number of wavelengths on the WDM line system defines the number of wavelength planes.

The main difference between the two OXC types is the way they deal with add/drop traffic. The non-blocking OXC, with an NxN switch matrix, is more flexible when combined with tunable transponders at the tributary side. In this case, the transponders can be tuned to the appropriate wavelength and switched towards any wavelength at the trunk side. In case of a WP-OXC, the tributary ports are bound to a specific wavelength plane (and thus can use fixed-wavelength transponders), which results in additional blocking.

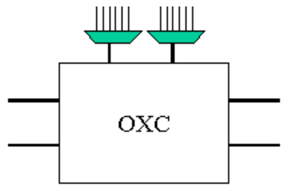
For transparent transit traffic, the non-blocking OXC offers no additional flexibility over the WP-OXC. Because of the wavelength continuity constraint, the wavelength cannot be changed within the node without breaking out of the wavelength plane. Thus both OXC types must switch between the same wavelengths.

Because the cross-connect functionality is assumed to be the same for each wavelength plane, the discrete WP-OXCs are specified in terms of fiber ports. Therefore if an OXC has eight fiber ports, it has eight wavelength ports per wavelength plane.

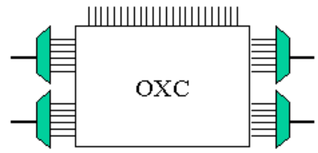
The concept of “fiber ports” can also be physically realized by integrating the WDM terminal multiplexers in the OXC. In this configuration, the fibers are connected directly to the OXC instead of demultiplexing the wavelengths. When the terminal multiplexers are integrated, the OXC uses fiber ports and the trunk fibers can be directly interconnected to the OXC. In this case, external terminal multiplexers are required at the tributary side to multiplex the add/drop wavelengths towards the tributary fibers.

When the OXC terminal multiplexers are not integrated, the OXC uses wavelength ports and relies on external terminal multiplexers to (de)multiplex the wavelengths from the trunk fibers to the OXC ports.

Figure 2-20   Integrated and Non-Integrated WP-OXCs



Integrated WP-OXC with fiber ports and terminal multiplexers at tributary side



Non-integrated WP-OXC with wavelength ports and terminal multiplexers at fibers

WP-OXC Architectures

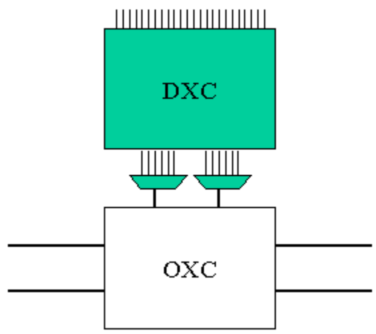
When you are working with a WP-OXC that has fiber ports and integrated terminal multiplexers, you can use an OXC fiber port in one of three ways:

- Trunk—The trunk fibers are directly interconnected with the OXC fiber ports.
- Tap—This is similar to a trunk fiber, but an additional tap is placed on the fiber (before the OXC), splitting the fiber in two directions: one towards the OXC and the other towards a terminal multiplexer. The multiplexer enables wavelengths to add/drop from this fiber without using the OXC.
- Trib—Each tributary fiber port allows add/drop of one wavelength per wavelength plane. Each port uses a terminal multiplexer to provide access to individual wavelengths.

The use of trunk, trib, and tap fiber ports on a WP-OXC allows for different node architectures, each with different degrees of flexibility (and thus blocking). These configurations are valid only in a WP-OXC with fiber ports and integrated terminal multiplexers.

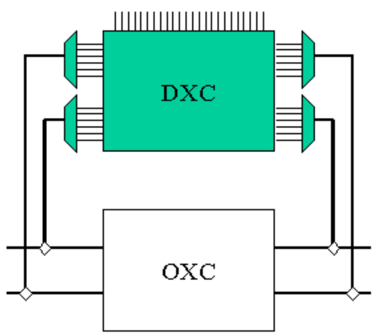
Architecture 1: All Add/Drop Occurs through WP-OXC Tributary Fiber Ports In this case, the OXC handles both transit and add/drop traffic. The flexibility of this solution is determined by the number of tributary fiber ports (and thus the number of tributary wavelengths per wavelength plane). A possible under-utilization of tributary fiber ports (and thus OXC) can occur if one wavelength is added/dropped substantially more than others. Hence, this aspect should be optimized by the wavelength assignment algorithm.

Figure 2-21 WP-OXC with All Add/Drop Occurring via Tributary Fiber Ports



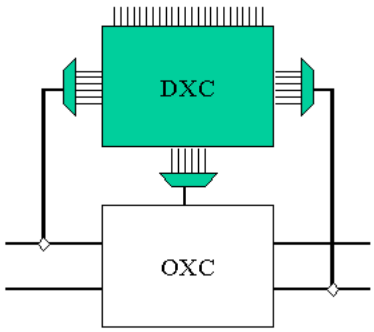
Architecture 2: Use Taps on All Trunk Fibers A second node architecture uses taps on all trunk fibers, so that all add/drop traffic (including regenerated and wavelength-converted pass-through traffic) can occur through the tap and no separate tributary fiber ports are required. In this case, the OXC is used for transparent pass-through of traffic only. This architecture typically requires fewer OXC fiber ports than the previous architecture (where the OXC tributary fiber ports handle the add/drop). Each trunk fiber that is tapped requires a WDM multiplexer; this means that the OXC requires more multiplexers than the previous architecture. Since the add/drop is hard-wired in this case (using taps), the DXC is used to offer flexibility to the add/drop traffic.

Figure 2-22 WP-OXC with All Add/Drop Occurring via Taps on Trunk Fibers



Architecture 3: Mixed Design (Combine Trunk/Tap/Tributary Fiber Ports) A mixed design, which combines trunk, tap and tributary fiber ports, offers a trade-off cost and flexibility. Some trunk fiber ports (those with a lot of add/drop traffic) can use taps, while on other trunk fibers, add/drop can occur via OXC tributary fiber ports.

Figure 2-23 WP-OXC with Mixed Add/Drop via Tributary Fiber Ports and via Taps on Trunk Fibers



Optical Nodes: OADM

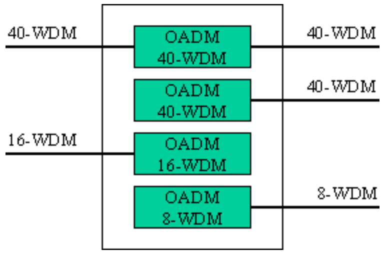
An Optical Add/Drop Multiplexer (OADM) is a type of node equipment that connects two fiber pairs (using the same WDM line system) and allows traffic to pass-through or add/drop between both fiber pairs. You can define OADMs for each line system in the WDM Link Equipment dialog box (Network > Equipment Properties > WDM Link Equipment).

SP Guru Transport Planner can model OADMs two ways: it can define nodes as complete OADM nodes and it can specify selective OADMs between two fiber pairs.

Complete OADM Node

SP Guru Transport Planner supports OADM nodes in both opaque and transparent mode, but only in nodes of degree 2 or lower. In this case, the node contains OADM equipment only. The number and type of OADMs in the node depends on the line systems used on the fibers that terminate at the node. Each fiber terminates at an OADM of the same line system. If two terminating fibers use the same line system, the same OADM is reused as shown in Figure 2-24.

Figure 2-24 OADM Node

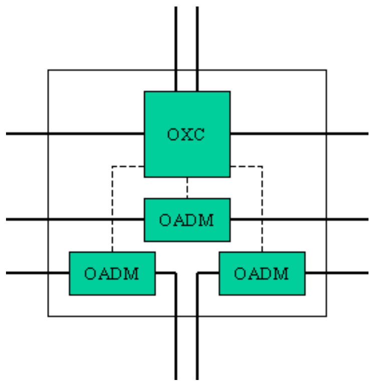


Selective OADMs Between Two Fiber Pairs

SP Guru Transport Planner supports selective OADMs in nodes of any degree, but in transparent mode only (that is, when the same type of line system is used on all fiber pairs). In this case, the node contains both of the following:

1) OADM equipment for selected fiber pairs
2) Conventional node equipment (such as OXC, IXC or Patch Panel) to deal with the traffic on fiber pairs that are not directly interconnected by an OADM, as shown in Figure 2-25

Figure 2-25 Selective OADMs Between Fiber Pairs

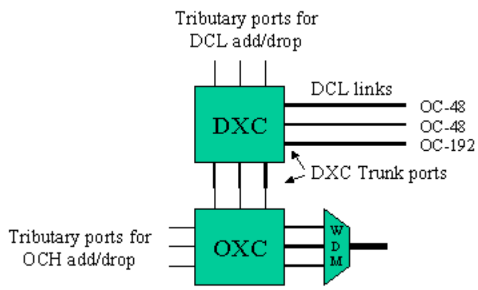


SONET/ Optical Nodes: DXC + OXC

An EOCC node can cross-connect both SONET and optical traffic. Therefore the EOCC node is equipped with a DXC and an OXC by default. This node type has the following characteristics:

- DXC—Within the DXC, traffic can be switched to the STS-1 level—or STM-1 level for SDH traffic—to the tributary ports (for local add/drop) and the physical and logical DCL links (for grooming). At the DXC tributary ports, local SONET traffic is add/dropped. The DXC trunk ports terminate both physical DCL trunks (to an ECC node) and logical DCL trunks (between two EOCC nodes)—that is, as non-native OCH connections that terminate in the node. These trunk ports (for logical DCL links) interconnect with the OXC tributary ports.
- OXC—The OXC switches wavelengths between different WDM line systems, or between the OXC tributary ports and the WDM line systems. For non-native OCH connections, the OXC tributary ports are connected to the DXC trunk ports. Separate OXC tributary ports (which do not interconnect with the DXC trunk ports) are used for native OCH connections. OXC trunk ports interconnect with the WDM line system wavelengths of the OCH links. These links connect to EOCC or OCC nodes and terminate in the connected node.

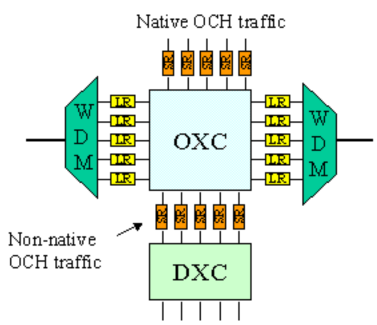
Figure 2-26 DXC + OXC in EOCC Node



Native Traffic

Native OCH traffic contains wavelengths that are not available for routing SONET/SDH traffic; in the layered view, native OCH connections are not trailed to DCL links. These connections do not terminate at the DXC of its end nodes—as is the case for non-native connections—but occupy a tributary OXC port only.

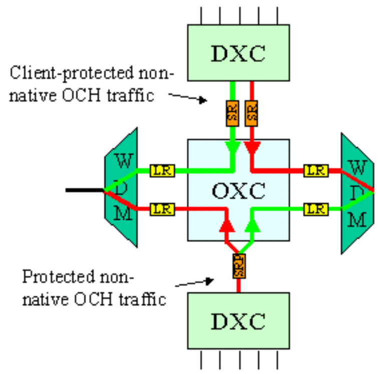
Figure 2-27 Native and Non-Native Traffic on OXC + DXC (Opaque Scenario)



Protection Options

OCH traffic can be client-protected or non-client-protected (much like an OCC node with an OXC). For native traffic, the situation is the same as for an OCC. For *client-protected, non-native* OCH traffic, the client is the SDH layer, and the protection switching is done by the DXC; this requires two DXC trunk ports. For *non-client-protected, non-native* traffic, only one trunk port is required at the DXC and the protection transponder is used for the protection switching. In both cases (client-protected or non-client-protected), two OXC tributary ports are required.

Figure 2-28 Impact of Client Protection on Non-Native OCH Traffic

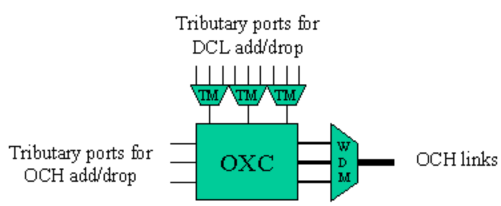


Grooming

Grooming is important for transporting SONET traffic over the wavelengths of the WDM network. Grooming is the process of mapping SONET traffic to wavelengths efficiently, by switching traffic either at the SONET (DCL) or wavelength (OCH) layer. Grooming requires a switch that can switch traffic down to the lowest traffic granularity.

Only nodes that contain an electrical cross-connect can perform grooming. Therefore, it is not possible to groom in an OCC node. In an EOCC or ECC node, grooming requires a DXC or an IXC. It is not possible to groom in TM node, because the SDH terminal multiplexers do not allow switching transit SONET traffic.

Figure 2-29 TM + OXC Node (Without Grooming)



SONET/SDH Rings

When a SONET/SDH ring is terminated in an EOCC node, behavior within the node differs depending on whether the DCL link that terminates within the node is a physical or a logical link:

- In the case of a physical DCL link (towards an ECC), the behavior in the node is similar to the ECC.

- In the case of a logical DCL link (towards an EOCC or OCC), the DLC link is supported by an optical channel. The optical channel is terminated in the node using either an OXC or a patch panel port (you can define this in the Network Properties dialog box, as described in Network Properties on page TrP-3-23).

Note—This section considers the DXC + OXC case, but SP Guru Transport Planner also supports the following combinations: DXC + WP-OXC, DXC + OADM and DXC + Patch Panel.

Integrated SONET/Optical Nodes: IXC

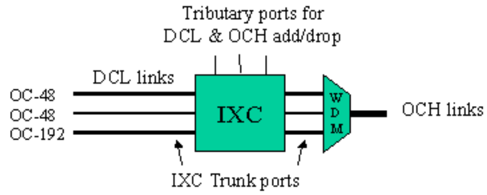
A different node type can be considered for EOCC nodes. The Integrated optical-digital Cross-Connect (IXC) consolidates the functions of the DXC and the OXC in one device; this eliminates the need for intermediate ports.

The IXC consists of an electrical switching matrix that can

- switch SONET traffic down to the STS-1 level (STM-1 level for SDH traffic) for grooming purposes (between DCL links)
- add/drop local SONET traffic via the IXC tributary ports
- switch an entire wavelength between different WDM line systems
- add/drop local native OCH traffic from a WDM line system via an IXC tributary port

The IXC tributary ports add or drop SONET local traffic and native OCH local traffic. The trunk ports of the IXC terminate the physical DCL trunks (to an ECC node) and wavelengths of the WDM line systems of the OCH links (to EOCC or OCC nodes).

Figure 2-30 IXC in EOCC Node

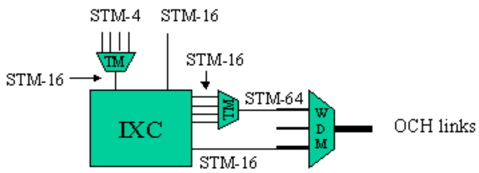


Minimum and Maximum Bit Rates for Tributary and Trunk Ports

You specify an IXC by the number of equivalent STS-3/STM-1 ports. You can also limit the bit rates allowed for the IXC ports, and specify a minimum tributary port bit rate and a maximum trunk port bit rate. In these respects, IXCs resemble DXCs; for more information about minimum and maximum bit rates for DXCs, see SONET Nodes: DXC on page TrP-2-21.

The following figure shows an IXC with minimum and maximum bit rates equal to STM-16.

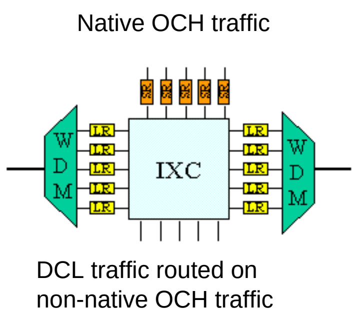
Figure 2-31 IXC with Minimum Tributary and Maximum Trunk Bit Rate of STM-16



Native Traffic

In an IXC scenario, native connections that terminate in that node consume a tributary and a trunk port. Non-native OCH connections that are trailed to the DCL layer use a trunk port only (the SONET traffic routed over these trunks uses tributary ports at the IXC when added or dropped at this node).

Figure 2-32 Native OCH Traffic on an IXC

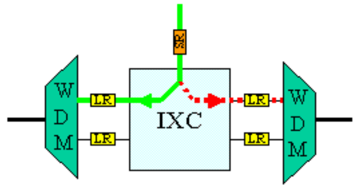


Protection Options

For non-client protected native OCH traffic through an IXC, the situation is slightly different from an OXC. In this case, the IXC is an electrical switch that can do protection switching for OCH and DCL traffic. Only one tributary port is required at the IXC and protection switching happens in the IXC. For client-protected native OCH traffic, the situation is similar to an OXC (that is, two tributary ports are needed on the IXC).

For DCL traffic, the situation is similar to a DXC: two tributary ports are required on the IXC for client-protected traffic; if the traffic is not client-protected, one tributary port is adequate and the protection switching is done internally in the DXC.

Figure 2-33 Non-Client Protected OCH Traffic in IXC



ADMs and IXC

ADMs in combination with an IXC are not explicitly counted. In this case, the ADM functionality is realized by the IXC, which acts as an MSSP (multi-service switching platform).