

Introduction to SONET Networking

*A tutorial handbook
of advanced SONET
networking concepts*

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SONET, or Synchronous Optical Network, is now the preferred standard for optical transport of telecommunications traffic in North America. This standard has been developed and implemented over the last decade to give telecommunications carriers important benefits that are difficult to achieve using the previous asynchronous transport technology. Among the most important of these advantages are:

*Major advantages relative
to earlier asynchronous
transport technology*

- Greater compatibility among equipment from different manufacturers, especially when combined in the same network (known as multi-vendor interworking)
- Synchronous networking for improved reference timing of network elements
- Enhanced operations, administration, maintenance, and provisioning (OAM&P) capabilities
- Standards-based survivable ring architectures
- Compatibility with any service mix including both traditional and new services such as Asynchronous Transfer Mode (ATM) traffic

This document illustrates how SONET network elements can best be deployed to realize all of the above benefits. It is directed at network planners, engineers, managers, and marketing personnel—or anyone else who wants to maximize the value obtained from any SONET network. Readers unfamiliar with the SONET standard itself are encouraged to refer to our *SONET 101* handbook, publication 56118.11, available from our Broadband Networks home page on the Internet (<http://www.nortel.com/broadband>) or by calling 1-800-4 NORTEL.

For information on the industry-leading Northern Telecom (Nortel) S/DMS TransportNode family of SONET transport products, please refer to our *S/DMS TransportNode Overview* publication, document number 56015.16, also available from our Broadband Networks home page or by calling 1-800-4 NORTEL.

Your Nortel representative would be pleased to show you how S/DMS TransportNode's advanced SONET networking technology can be applied to meet the unique needs of your network today and for years to come.



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1

SONET Networking Topologies

Today's SONET transport networks typically employ a number of different topologies to satisfy important objectives for network simplicity, cost containment, bandwidth efficiency, and survivability. For example, an optical hubbing configuration may be used to eliminate the need for a costly and complicated arrangement consisting of several back-to-back network elements. Similarly, a self-healing ring can be deployed to assure service survivability through redundant, geographically diverse paths. This section defines each of the major SONET network element configurations and discusses their key attributes.

Point-to-Point Terminal

While not specifically designed to be completely survivable, the reliability of a point-to-point system may be enhanced through a geographically diverse protection path

The point-to-point terminal configuration is the traditional "classic" transmission topology that terminates the entire SONET payload at each end of a fiber span or route. Point-to-point systems are typically employed in a basic transport application calling for a single system/single route solution. While not specifically designed to be completely survivable, the reliability of a point-to-point system may be enhanced through a geographically diverse protection path as shown in Figure 1 below. Where diverse routing exceeds the normal reach of the transport system, one or more regenerators or optical amplifiers can be deployed to reconstitute (or boost) the optical signal.

S/DMS TransportNode point-to-point terminals support an extensive range of mixed electrical and optical tributary types; refer to our *S/DMS TransportNode Overview* document* for details.

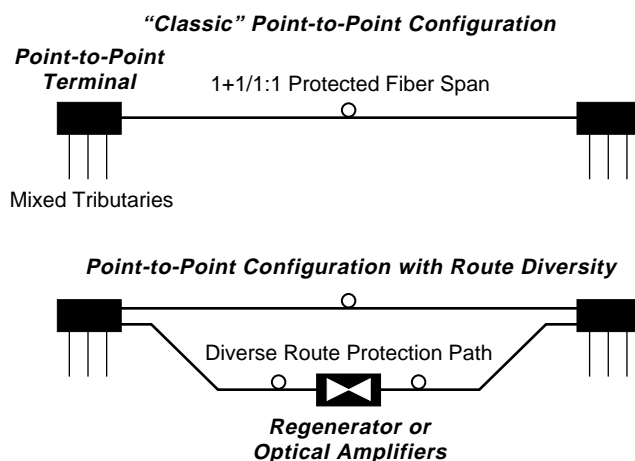


Figure 1. Point-to-Point Systems With and Without Route Diversity

* To obtain the *S/DMS TransportNode Overview* document, publication number 56015.16, visit our Broadband Networks home page (<http://www.nortel.com/broadband>) or call 1-800-4 NORTEL.

1:N Protection Channel Sharing

In applications with rapidly growing traffic demand, the 1:N protection arrangement can defer, or avoid altogether, the large capital outlays and long lead times associated with the deployment of new fiber cable

This is a multi-network element point-to-point configuration that conserves fiber pairs by allowing multiple systems to share a common protection channel. In applications with rapidly growing traffic demand, the 1:N protection arrangement can defer, or avoid altogether, the large capital outlays and long lead times associated with the deployment of new fiber cable.

If a failure or degradation occurs on any working optical channel, affected traffic is automatically rerouted over the protection channel via an inter-shelf protection loop and a dedicated protection shelf at each end of the span (see Figure 2 below). Each working shelf can be equipped with a full complement of mixed electrical and optical tributary types.

If desired, the 1:N protection configuration's protection shelves and the normally "empty" protection bandwidth may be exploited to transport unprotected extra traffic. For more information on extra traffic applications, refer to our *S/DMS TransportNode Overview* document.*

S/DMS TransportNode allows up to 11 point-to-point systems to share a common protection channel (i.e. 1:11 protection), the highest level of protection channel sharing available industry-wide.

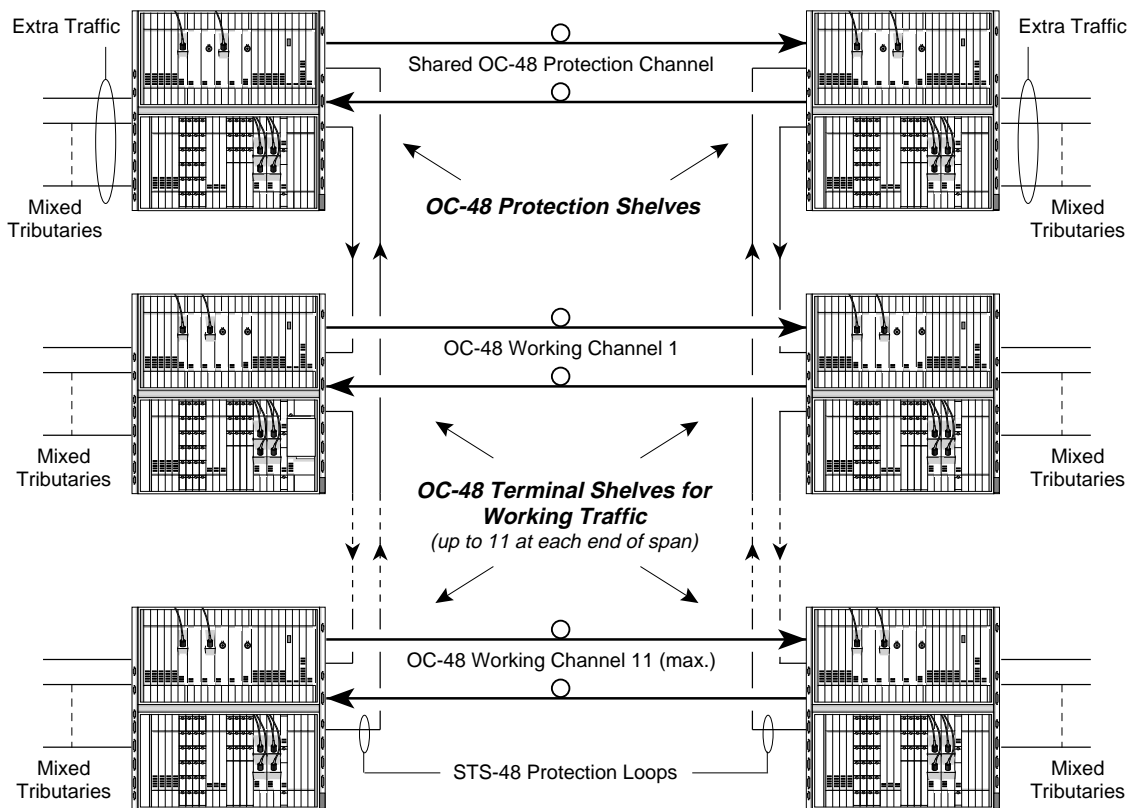


Figure 2. 1:N Protection Channel Sharing Configuration, S/DMS TransportNode OC-48 Application Shown

Linear Add/Drop Multiplexer

Cost savings and improved reliability in comparison to back-to-back terminals

The linear add/drop multiplexer (ADM) configuration provides direct access to individual eastbound or westbound VT/STS channels at intermediate sites along a fiber route—without unnecessary multiplexing/demultiplexing of pass-through traffic (Figure 3). It offers cost savings and improved reliability in comparison to intermediate sites equipped with complex back-to-back terminal arrangements.

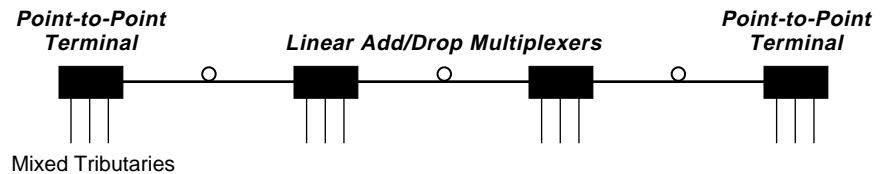


Figure 3. Example Linear Add/Drop Route

As with point-to-point terminal applications, the survivability of linear add/drop routes can be enhanced through geographically diverse protection paths. Alternatively, a high degree of survivability may be achieved using a hybrid linear ADM/subtending ring configuration known as a "path protected linear ADM route." Subtending rings are covered on the following page.

S/DMS TransportNode's linear ADMs support mixed electrical/optical tributary types and flexible VT/STS time slot assignment technology. The latter enables any desired routing of any tributary VT/STS channel to any eastbound or westbound VT/STS channel—or direct pass-through from east to west—as desired for optimum use of fiber span capacity and tributary hardware.

An Introduction to Self-Healing SONET Rings

Protection against cable cuts and node failures through duplicate, geographically diverse paths for each service

Self-healing ring architectures (Figure 4) are the preferred solution for applications where survivability is of the utmost importance. They protect against cable cuts and node failures by providing duplicate, geographically diverse paths for each service. To assure end-to-end survivability for services traversing multiple rings, adjacent rings may be interlocked using redundant matched node inter-ring gateways. (Refer to Section 5 for more information on matched nodes.)

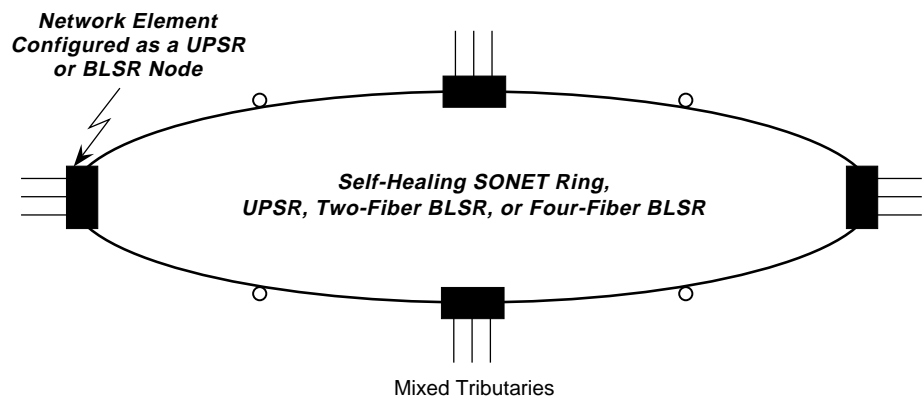


Figure 4. Ring Configuration Employed by All Types of SONET Self-Healing Rings

A SONET ring is generally of one of three types: a unidirectional path switched ring (UPSR), two-fiber bidirectional line switched ring (BLSR), or four-fiber BLSR. While each type of ring features fully self-healing operation, differing characteristics may make one architecture preferable in certain situations. For example, a two-fiber BLSR is a good choice for networks with a highly distributed “mesh” traffic pattern.

Table 1 below shows ideal applications for each SONET ring architecture, all of which are supported by S/DMS TransportNode. Refer to Sections 2, 3, and 4 for an explanation of the underlying technology associated with each ring.

Table 1. Ring Architecture Comparison

Ring Architecture	Best Used In	How It Works
UPSR	Access networks where most traffic terminates in a central office hub	See Section 2
Two-Fiber BLSR	Access and interoffice networks with a highly distributed traffic pattern	See Section 3
Four-Fiber BLSR	Applications requiring extra-high capacity and/or protection against multiple concurrent faults	See Section 4

Subtending Rings

Subtending rings offer substantial capital savings and network simplification at a central office hub by allowing a single network element to serve in place of multiple collocated shelves

A subtending ring is an advanced dual-ring configuration where a node’s tributary optics support a secondary ring (Figure 5). This arrangement offers substantial capital savings and network simplification at a central office hub by allowing a single network element to serve in place of multiple collocated shelves. A subtending ring can employ either UPSR or BLSR technology.

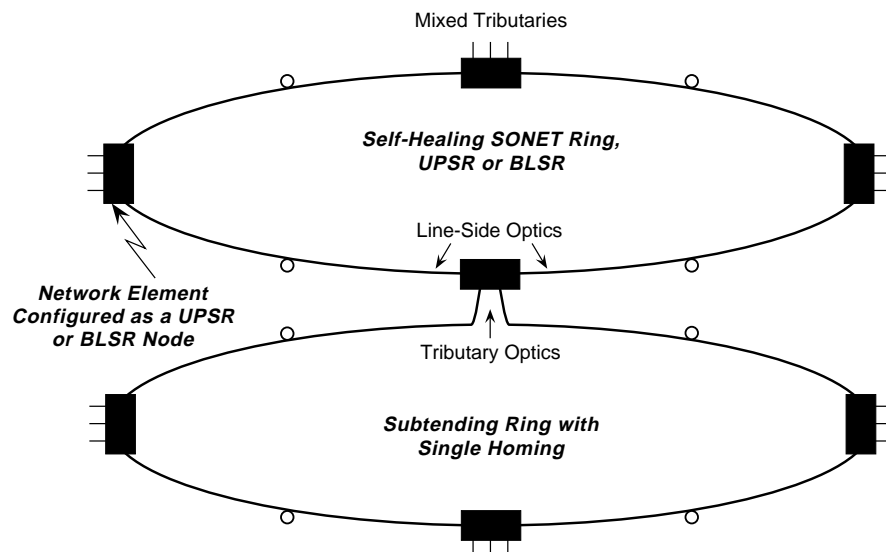


Figure 5. Subtending Ring with Single Homing

Subtending rings may be arranged for single homing (Figure 5), or for greater geographic diversity, in a dual homing architecture where the primary and subtending rings intersect at two points (Figure 6). Subtending rings may also be deployed in a hybrid linear ADM/subtending ring configuration to provide survivability for linear ADM routes. This is referred to as a path protected linear ADM route as illustrated in Figure 7.

S/DMS TransportNode OC-3 Express network elements support subtending UPSRs with either single or dual homing today. In addition, a subtending BLSR feature is planned for future introduction on S/DMS TransportNode OC-192 systems.

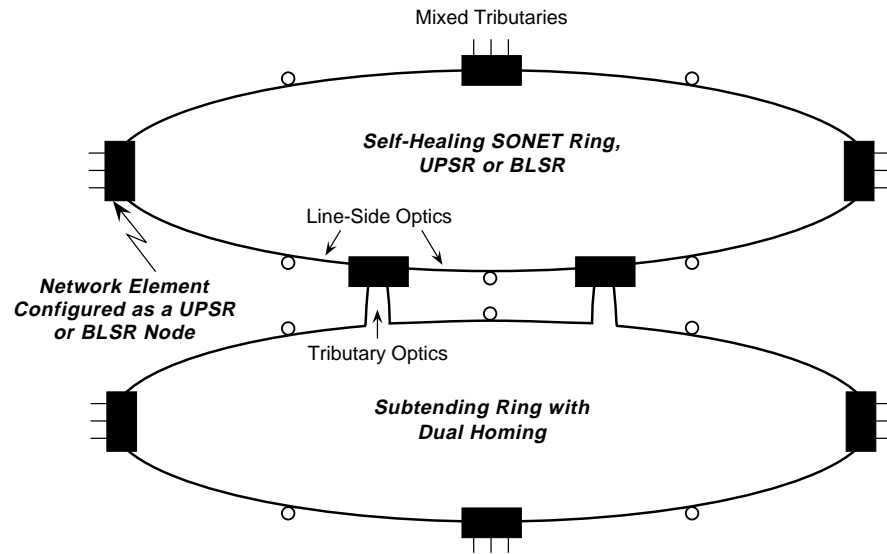


Figure 6. Subtending Ring with Dual Homing

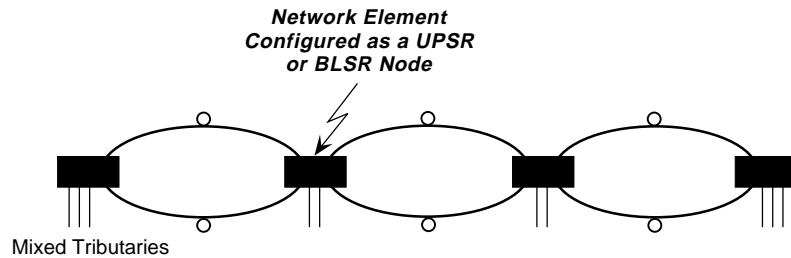


Figure 7. Path Protected Linear ADM Route Formed by Interlocked Subtending and Primary Rings

Folded Rings

In a configuration known as a folded ring, service providers can implement a UPSR or BLSR even where existing fiber infrastructure does not support a true route diversity ring system. The folded ring functions in exactly the same manner as a UPSR or BLSR, but the fibers on each side of the ring share a common conduit as shown in Figure 8. This solution enables a service provider to begin the conversion process from a linear to a ring system today, and then easily upgrade to a route diversity ring as additional fiber routes are constructed.

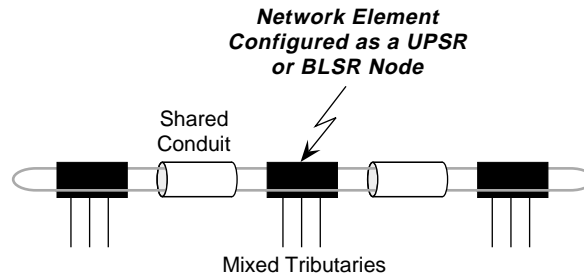


Figure 8. Non-Route Diverse Folded Ring

Optical Hubbing

Optical hubs eliminate the cost and complexity of multi-shelf arrangements that would otherwise be required to pass traffic from several (usually lower rate) fibers to a single (usually higher rate) system

Optical hubs consolidate traffic from multiple spur routes onto an optical channel extending to a remote site. The configuration eliminates the cost and complexity of multi-shelf arrangements that would otherwise be required to pass traffic from several (usually lower rate) fibers to a single (usually higher rate) system. The advantages of optical hubbing apply equally to point-to-point, linear add/drop, and ring systems (Figure 9).

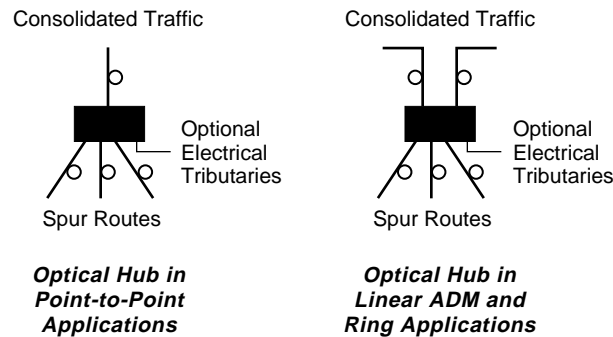


Figure 9. Network Elements Configured as Optical Hubs

S/DMS TransportNode OC-3, 12, 48, and 192 network elements all support optical tributaries for hubbing applications. And for added flexibility, mixed electrical/optical tributary interfaces may be combined on the same shelf as desired. OC-3 Express network elements offer the additional advantage of tributary-to-tributary hairpinning for convenient local termination of traffic entering from any spur route. (This feature is planned for future introduction on OC-192 systems as well.)

Regenerators

Multiple cascaded regenerators can be deployed to extend reach hundreds of miles

A regenerator extends system reach by reconstituting the optical signal at an intermediate point between two service terminating locations. If necessary, multiple cascaded regenerators can be deployed to extend reach hundreds of miles (Figure 10). Unlike some optical amplifier solutions, regenerators interwork with the SONET overhead section bytes for greater flexibility in operations access and improved isolation of troubles to a specific section along a fiber route.

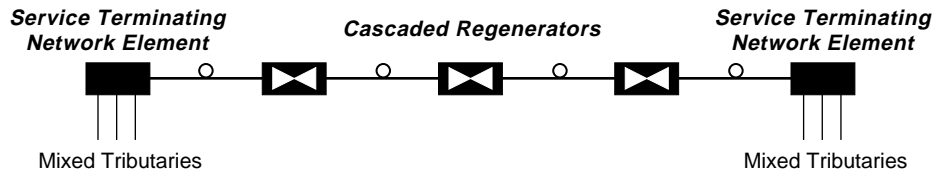


Figure 10. Extended Reach Application Supported by Cascaded Regenerators

Regenerators are generally of one of two types. A *non-route diverse* regenerator supports two bidirectional optical channels in each direction to reconstitute the optical signal on both the working and protection fibers of a 1+1/1:1 protected point-to-point or linear system without route diversity. A *diverse route regenerator* supports the single bidirectional optical channel associated with two-fiber BLSRs and other route diversity arrangements (such as the example depicted in Figure 1.)

S/DMS TransportNode offers regenerator solutions for all of its intermediate and long-haul product lines (i.e. OC-12/48/192/radio systems). See also optical amplifier solutions discussed in our *S/DMS TransportNode Overview* document.*



2

Understanding OC-3 UPSRs

A unidirectional path-switched ring is a survivable, closed-loop transport architecture that protects against cable cuts and node failures by providing duplicate, geographically diverse paths for each service. Adjacent nodes on the ring are interconnected using a single pair of optical fibers. UPSRs feature a unique unidirectional traffic flow as illustrated in Figure 11. Working traffic travels in only one direction (e.g. clockwise) on the ring, while a second unidirectional protection path is provided in the opposite direction (e.g. counterclockwise).

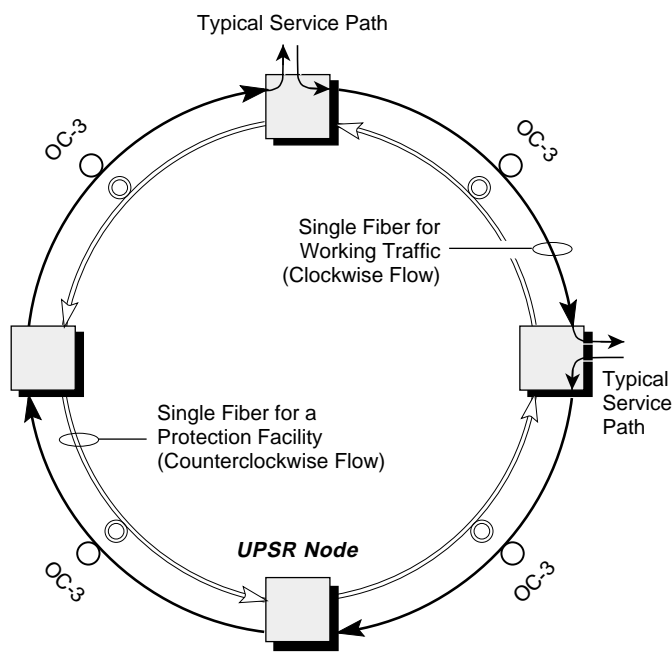


Figure 11. Simplified View of OC-3 UPSR Architecture

OC-3 UPSRs are typically deployed in access networks where traffic from multiple carrier serving areas (CSAs) terminates at a central office hub site. (BLSRs are often the preferred choice for other types of traffic as indicated in Table 1 of Section 1.) Because the UPSR supports virtual ring configurations, isolated CSAs/nodes can easily be placed on the same ring with several other physically interconnected nodes.

This advantage is exclusive to the UPSR architecture.

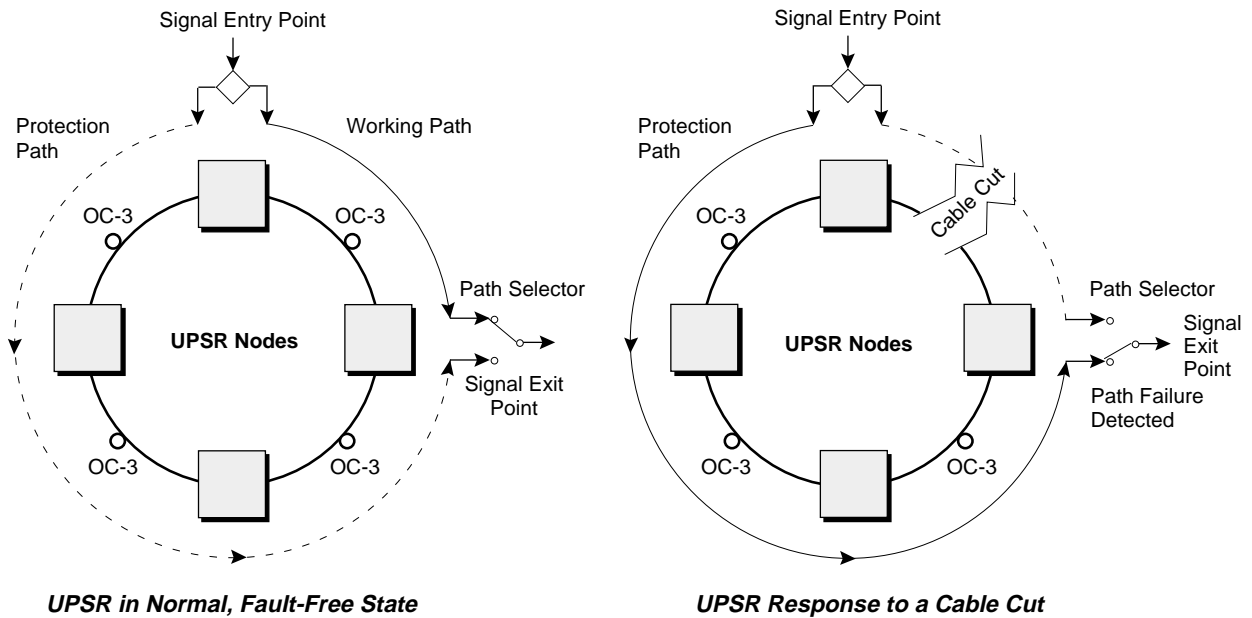
Services may originate and terminate on the same UPSR or may be passed to an adjacent access or interoffice ring for survivable transport to the service terminating location. OC-3 UPSRs support matched node inter-ring gateways that assure survivable interconnection between rings irrespective of type (UPSR or BLSR), line rate, or equipment supplier. (Refer to Section 5 for more information on matched nodes.)

UPSR Operation

All traffic is managed at the path (i.e. service) layer on an OC-3 UPSR. As each individual DS-1, DS-3, or STS-1 service travels in one direction around the ring, a duplicate signal passes in the opposite direction for protection (see Figure 12). A path selector continuously monitors both the working and protection signals at each end of the path and automatically switches to the protection signal in the event of optical span or node failure (or degradation).

The path selector detects path failure and signal degradation based on industry-standard parameters such as:

- Path alarm indication signal (AIS)



**Figure 12. OC-3 UPSR Protection Switching,
One Direction of Transmission Shown**

- Path loss of pointer (LOP)
- Signal degrade (SD)
- Excessive path layer bit interleaved parity (BIP) errors

Once protection switching has been activated, traffic flows in a traditional bidirectional pattern similar to a linear add/drop topology. The S/DMS TransportNode OC-3 Express product line supports UPSR protection switching in accord with the GR-1400 industry standard.

Support for Virtual Rings

A virtual ring is an excellent choice for interconnecting an isolated business campus or CSA with several remote sites that share a common access network

Because intermediate nodes are essentially transparent in the UPSR protection switching scheme, other survivability architectures such as a two-fiber or four-fiber BLSR may be incorporated within a UPSR in a hybrid arrangement known as a virtual ring or “path-in-line” ring. This alternative is an excellent choice for interconnecting an isolated business campus or CSA with several remote sites that share a common access network as shown in Figure 13. Virtual rings can also provide a survivable, geographically diverse path to an interexchange carrier (IEC) point of presence (POP).

Path protection switching in a virtual ring operates in exactly the same manner as a conventional UPSR since any intermediate BLSR nodes (or other “foreign” nodes) are completely transparent to the virtual ring. Similarly, an intermediate BLSR protects its portion of the path using standard line layer BLSR ring protection switching (see Sections 2 and 3). ***Note that survivability is completely assured without use of protected optics on the OC-3 links between the virtual ring and an intermediate BLSR.*** This advantage can yield substantial circuit pack inventory savings and frees up shelf space for other revenue-generating services.

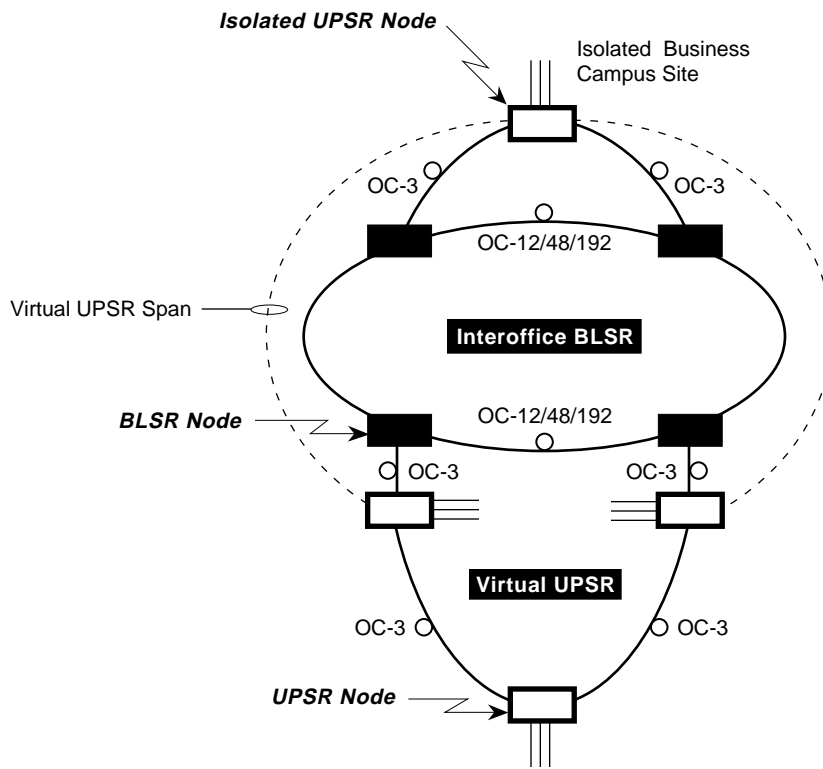


Figure 13. Virtual OC-3 UPSR Architecture



3

Understanding Two-Fiber BLSRs

With the ability to reuse bandwidth as traffic is added/dropped at various locations around the ring, two-fiber BLSRs are ideal for distributed “mesh” and node-to-adjacent-node traffic patterns typical of interoffice networks—and sometimes found in access networks as well

As with the OC-3 UPSR discussed in Section 2, the two-fiber bidirectional line switched ring is a survivable SONET transport architecture that protects against cable cuts and node failures by providing duplicate, geographically diverse paths for each service. With the ability to reuse bandwidth as traffic is added/dropped at various locations around the ring, two-fiber BLSRs are ideal for distributed “mesh” and node-to-adjacent-node traffic patterns typical of interoffice networks—and sometimes found in access networks as well.

To meet a wide range of capacity demands, S/DMS TransportNode offers two-fiber BLSRs operating at a choice of line rates: OC-12, OC-48, or OC-192, the most comprehensive portfolio available industry-wide. All S/DMS TransportNode two-fiber BLSRs comply with the latest GR-1230 industry standards and support matched node inter-ring gateways to assure survivability for services traversing multiple interconnected rings. These gateways are fully interoperable with two-fiber BLSRs, four-fiber BLSRs, and UPSRs irrespective of line rate or equipment vendor. (Refer to Section 5 for more information on matched nodes.)

S/DMS TransportNode also offers BLSR configurations supporting extra traffic, a feature that enhances the revenue potential of existing fiber plant.

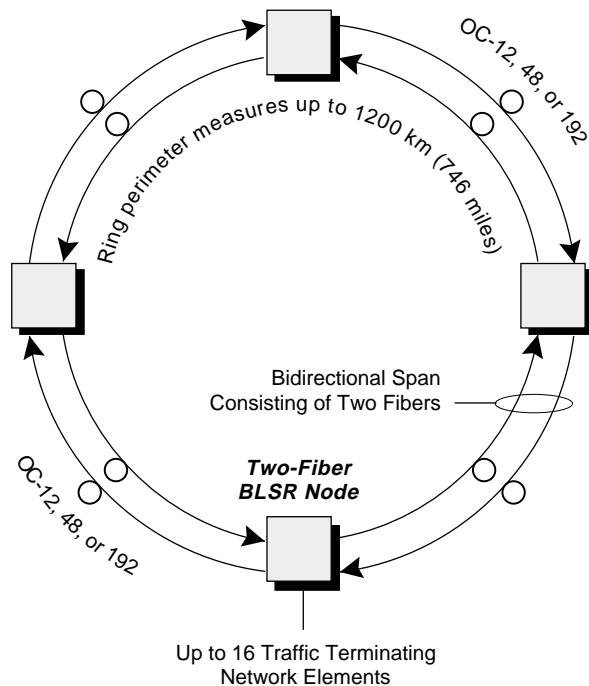


Figure 14. Simplified View of Two-Fiber BLSR Architecture

The Two-Fiber BLSR Architecture

In the two-fiber BLSR architecture, SONET OC-12/48/192 network elements are interconnected in a closed loop using bidirectional spans consisting of two fibers (Figure 14). Each fiber handles one direction of transmission similar to traditional point-to-point and linear add/drop topologies. The perimeter of the ring can measure up to 1200 km (746 miles) and up to 16 traffic terminating nodes can be placed on the ring. Regenerators or optical amplifiers may be deployed between nodes as needed to maintain the level of the optical signal.

Allocation of Bandwidth

Exactly one half of the bandwidth available between adjacent nodes can be used for working traffic, with the remaining bandwidth reserved for protection. As shown in Figure 15, this bandwidth partitioning is accomplished by mapping traffic into STS-1 channels (time

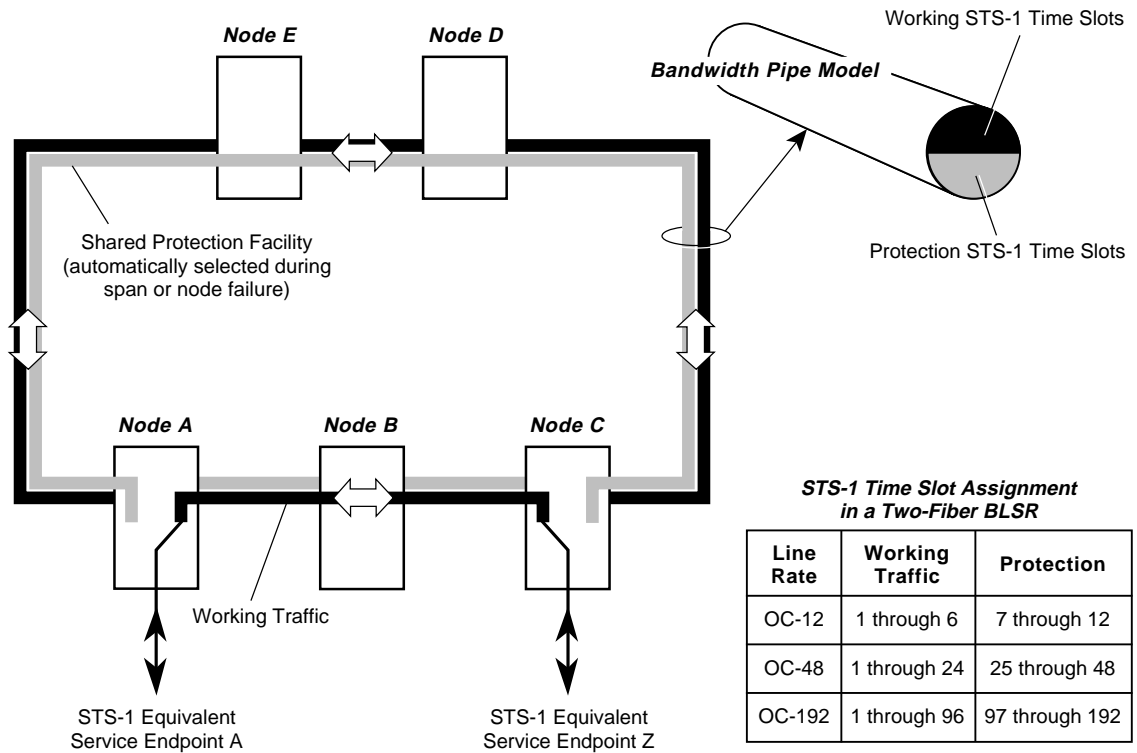


Figure 15. Span Bandwidth Allocation in a Two-Fiber BLSR

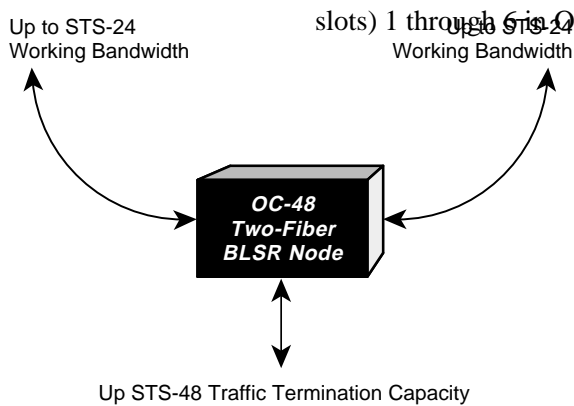


Figure 16. Two-Fiber BLSR Dual Traffic Routing, OC-48 Application Shown

slots) 1 through 6 in OC-12 applications, into channels 1 through 24 in OC-48 applications, or into channels 1 through 96 in OC-192 applications.

Note that STS-1 time slot usage within a two-fiber BLSR **does not** impose a bandwidth penalty since any service can be routed from either side of the ring (Figure 16). Thus, a two-fiber BLSR node has a maximum fully protected traffic termination capacity of STS-12 (OC-12 applications), STS-48 (OC-48 applications), or STS-192 (OC-192 applications) equivalent bandwidth.

Service Delivery via a Two-Fiber BLSR

A service path is provisioned on a two-fiber BLSR by selecting endpoint network elements, tributary ports, and an STS-1 time slot linking the service entry and exit points. A service may reach its destination by traveling in either direction around the ring, as needed for optimum utilization of the available STS-1 channels. Intermediate nodes on the service path, if any, simply pass the service from east to west without modifying the STS-1 channel assignment.

transport service A-D-C. Node D passes service A-D-C through to Node A without modifying its time slot assignment. *Thus, the sample two-fiber bidirectional line switched ring of Figure 17 is able to transport traffic having STS-3 total bandwidth while using only a single STS-1 channel.*

Automatic Healing of Failed or Degraded Optical Spans

In the event of failure or degradation in an optical span, automatic ring protection switching (RPS) reroutes affected traffic away from the fault within 50 milliseconds—preventing a service outage. Traffic is redirected by looping back STS-1 time slots as shown in Figure 18. Logically, the normally unused protection bandwidth bridges the defective span thereby maintaining service for all terminating and pass-through traffic. When setting up the bidirectional loopback path, OC-12 systems

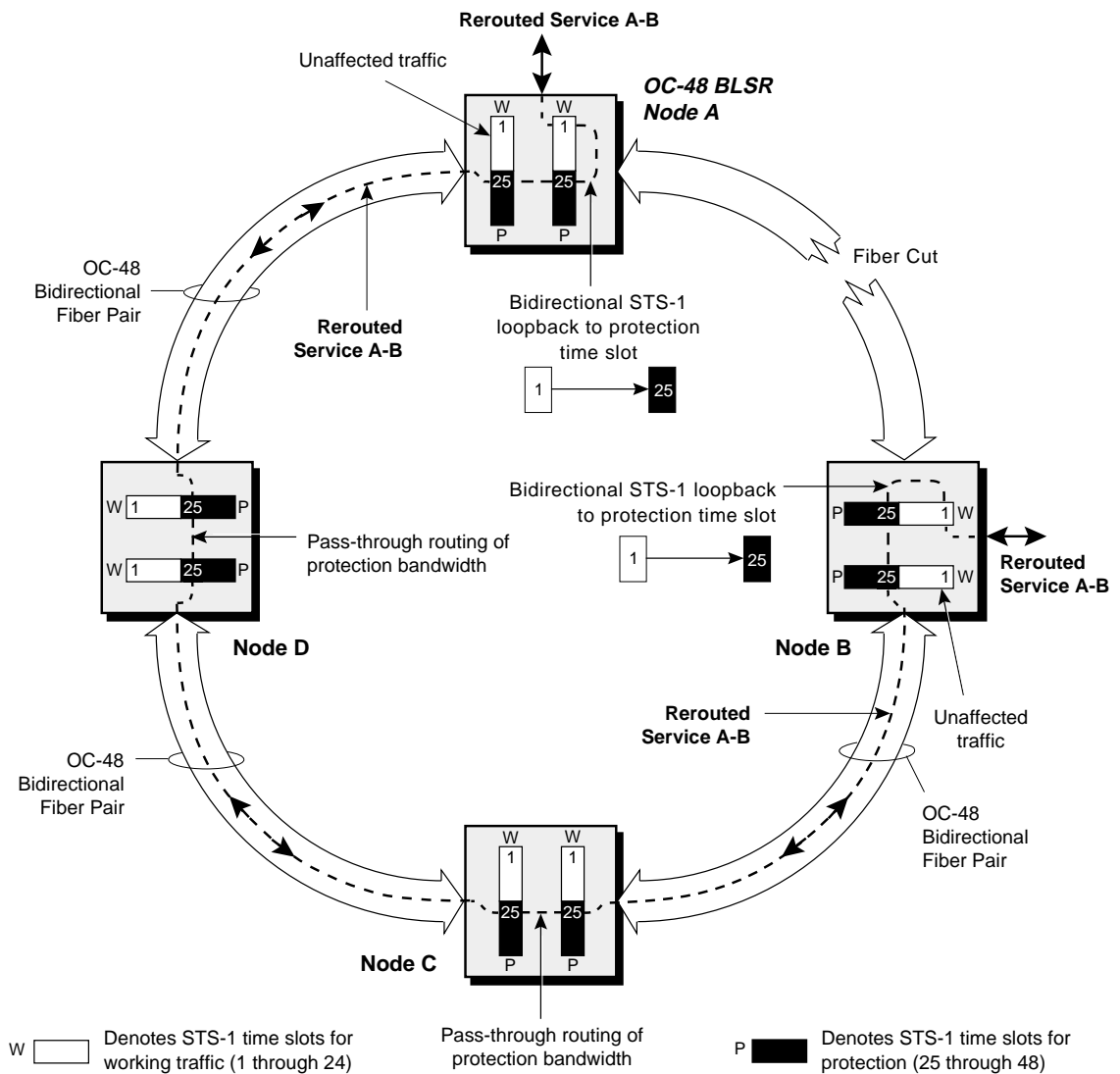


Figure 18. Two-Fiber BLSR Response to an Optical Span Failure, OC-48 Application Shown

map working STS-1 time slots 1 through 6 to protection time slots 7 through 12 (respectively), OC-48 network elements map working STS-1 time slots 1 through 24 to protection time slots 25 through 48, and OC-192 systems map working STS-1 time slots 1 through 96 to protection time slots 97 through 192.

STS-1 time slot bridging occurs only at the nodes adjacent to the fault, with intermediate nodes (e.g. Nodes C and D in Figure 18) simply passing through the redirected traffic mapped to the protection time slots. STS-1 time slot assignments for working traffic at intermediate nodes are unaffected by the fault.

Conditions which trigger RPS include total failure modes such as loss of signal (LOS), and also degradation in terms of excessive line layer BIP errors. Because protection switching is revertive in a two-fiber BLSR, traffic automatically returns to its normal routing—without human intervention—after a fault-free state exists for a user-defined wait-to-restore interval.

Rerouting of Pass-Through Traffic During Node Failures

The two-fiber BLSR architecture also fully protects all restorable traffic in the event of a node failure anywhere along the ring. While tributaries terminating at the failed node cannot be protected, traffic passing through that node is automatically redirected away from the fault via time slot loopback similar to the previous span failure example of Figure 18. In an action referred to as “squelching,” nodes adjacent to the failure replace non-restorable traffic with a path layer alarm indication signal (AIS) to notify the far end of the interruption in service. The squelching feature employs automatically generated squelch maps that require no manual record keeping to maintain.

The two-fiber BLSR architecture also fully protects all restorable traffic in the event of a node failure anywhere along the ring

Capacity Advantages of Two-Fiber BLSRs

A BLSR may offer significant capacity advantages over UPSRs—depending on the traffic pattern

Due to the BLSR’s ability to reuse STS-1 channels, a BLSR may offer significant capacity advantages over UPSRs—depending on the traffic pattern (Figure 19). Where traffic is entirely hubbed (as in most access networks), capacity *equals* that of a UPSR operating at the same line rate. As traffic becomes more distributed (or

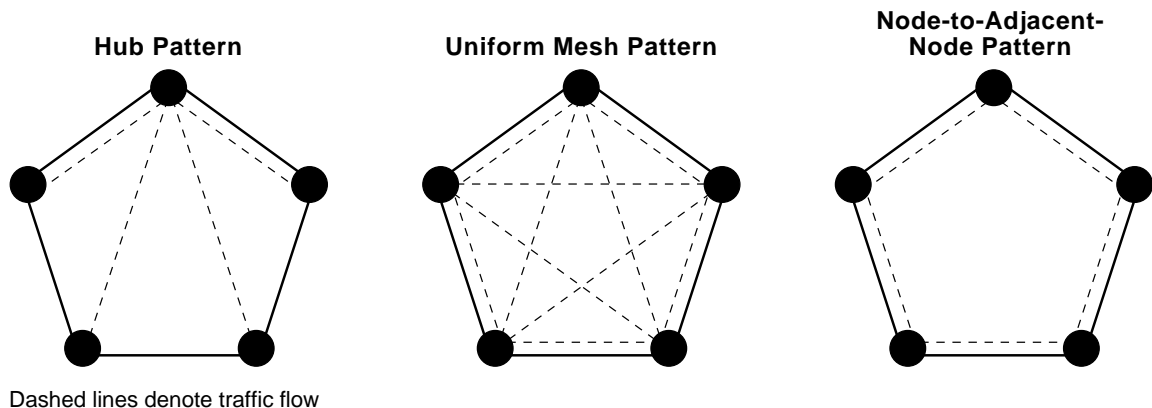


Figure 19. Ring Traffic Patterns

mesh-like) however, a BLSR provides a *substantial capacity benefit that can typically range up to 300 percent of the capacity of a UPSR with an identical optical rate. The greatest capacity advantage occurs with the node-to-adjacent-node pattern because this traffic model allows a very high level of channel reuse.* See Figure 20 for a capacity comparison of all three traffic patterns relative to a UPSR.

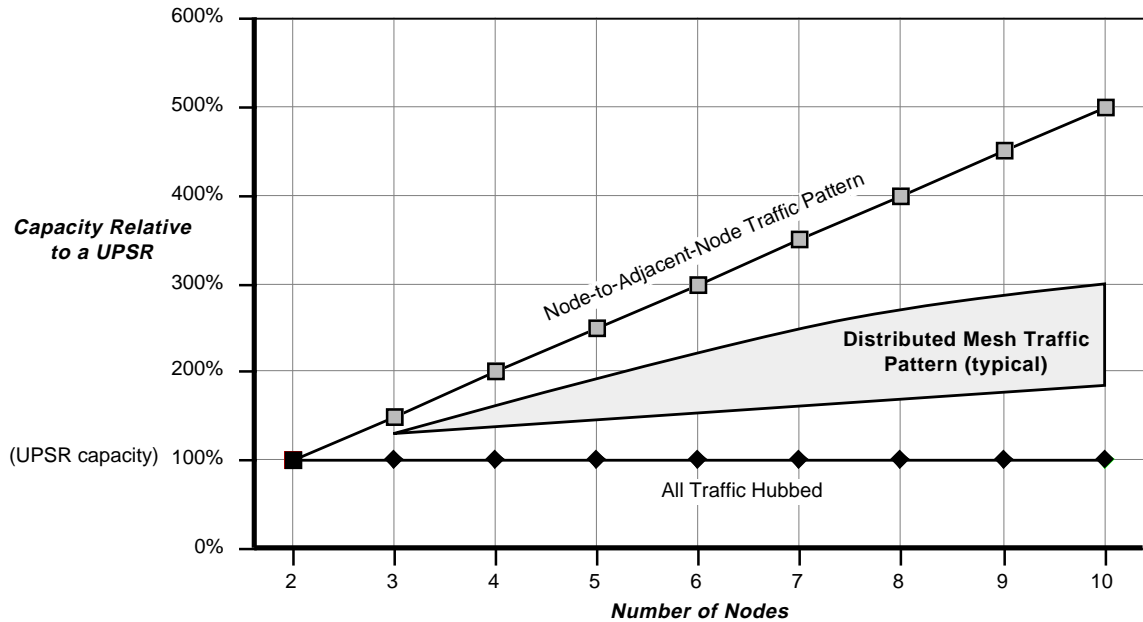


Figure 20. BLSR Capacity Analysis

In a given ring application, the capacity required on a BLSR depends only on the aggregate eastbound or westbound traffic *at the busiest node*. When implementing the same ring as a UPSR, the aggregate of all services transported by the *entire ring* must be taken into account.

Synergies with ATM

BLSRs offer additional advantages for ATM networks

Asynchronous Transfer Mode has recently emerged as a preferred transport technology for a broad mix of multimedia and data services. ATM offers enhanced bandwidth efficiency, scalability, and service transparency for all types of data, voice, video, and multimedia applications. To date, ATM has been extensively deployed in enterprise data networks, especially WANs with large amounts of bursty traffic. In these environments, the statistical multiplexing capabilities of ATM network elements allow efficient transport of bursty data without unacceptable under-utilization of facilities during off peak periods.

When distributing data embedded in ATM payloads among various WAN sites, two-fiber BLSRs offer two major advantages:

- A level of survivability that meets the most demanding reliability objects for “mission critical” applications
- Efficient sharing of a common STS-3c ATM payload among multiple locations

The latter benefit is illustrated in the example ATM network of Figure 21. As shown, a two-fiber BLSR links each site in the network. The ring's ability to reuse bandwidth is employed to deliver the same STS-3c concatenated SONET payload ("STS-3c Payload A") to each location. This traffic routing enables the ATM network element at each site to efficiently pack traffic into a common payload through statistical multiplexing. Thus, one economical STS-3c channel can replace a more expensive arrangement of dedicated channels linking each site with every other site.

To facilitate ATM interworking, S/DMS TransportNode two-fiber BLSRs fully support concatenated payloads and OC-3c/OC-12c optical tributaries.

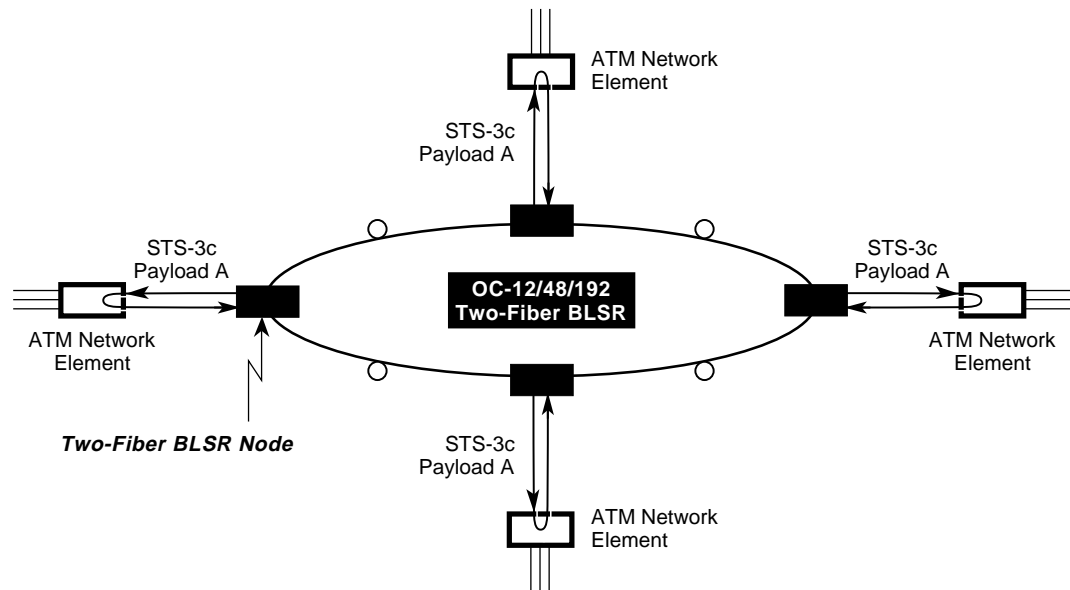


Figure 21. ATM Network Interconnected by a Two-Fiber BLSR

Transporting Extra Traffic on BLSRs

The additional capacity permits the introduction of new revenue-enhancing services without further investment in fiber plant

If desired, the protection bandwidth on a two-fiber (or four-fiber) BLSR may be used to transport unprotected "extra traffic." The additional capacity permits the introduction of new revenue-enhancing services without further investment in fiber plant. For more information on extra traffic applications, refer to our *S/DMS TransportNode Overview* document.*

S/DMS TransportNode OC-48 BLSRs offer flexible extra traffic features today with an equivalent OC-192 offering planned for a future software release. Extra traffic can be terminated along with regular protected traffic using any available tributary ports on the network element. If all tributary capacity is exhausted, an additional collocated BLSR node may be deployed to provide additional tributary interfaces as required.

Extra traffic is automatically removed from the protection channels when protection switching occurs on the BLSR.



4

Understanding Four-Fiber BLSRs

Double the capacity of a two-fiber BLSR plus protection against multiple concurrent faults

The four fiber-fiber bidirectional line switched ring architecture assures service survivability through duplicate, geographically diverse paths similar to a two-fiber BLSR. It differs from the two-fiber configuration in that four fibers (or two bidirectional fiber pairs) link adjacent nodes on the ring as shown in Figure 22. The additional fiber enhances the architecture in two important ways:

- A doubling in the traffic handling capacity of the ring since twice the number of fibers are available
- Two protection switching modes—automatic ring protection switching and traditional 1+1/1:1 span switching for self-healing operation during multiple fault conditions

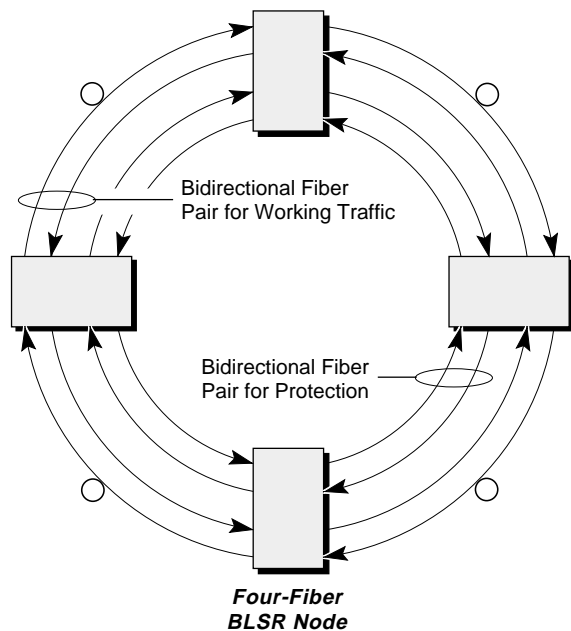


Figure 22. Simplified View of Four-Fiber BLSR Architecture

The allocation of bandwidth in a four-fiber BLSR is identical to point-to-point and linear add/drop topologies. One fiber pair between nodes carries working traffic exclusively while the other pair serves as a protection facility.

The four-fiber BLSR architecture is a planned future feature enhancement for S/DMS TransportNode OC-192 systems. This survivability option incorporates advanced ring capabilities such as matched node inter-ring gateways (Section 5) and extra traffic.

Capacity Advantages of Four-Fiber BLSRs

As in a two-fiber BLSR, a node on a four-fiber BLSR may terminate traffic fed from either side of the ring. With a fiber pair in each direction entirely dedicated to working traffic, an individual node on a four-fiber BLSR has twice the traffic terminating capacity of a two-fiber BLSR node operating at the same line rate. For example, at the OC-192 rate, a four-fiber BLSR node terminates the equivalent of up to STS-384 *fully protected* tributary traffic. In a two-fiber configuration, fully protected tributary traffic is limited to a maximum equivalent bandwidth of STS-192. (This comparison assumes a sufficient number of tributary ports as in S/DMS TransportNode OC-192 systems.)

Similarly, the maximum levels of pass-through traffic and unprotected extra traffic terminations are doubled in a four-fiber BLSR. Refer to Table 2 for a concise listing of the maximum capacities offered by OC-192 two-fiber and four-fiber BLSRs.

Similarly, the maximum levels of pass-through traffic and unprotected extra traffic terminations are doubled in a four-fiber BLSR. Refer to Table 2 for a concise listing of the maximum capacities offered by OC-192 two-fiber and four-fiber BLSRs.

Table 2. OC-192 Two-Fiber/Four-Fiber BLSR Node Capacity Comparison

BLSR Type	Max. Tributary Capacity for Fully Protected Traffic	Max. Pass-Through Traffic on Working Time Slots	Max. Extra Traffic Terminations
Two Fiber	STS-192	STS-96	STS-192
Four Fiber	STS-384	STS-192	STS-384

Span Protection Switching

Because span protection switching operates independently on each link, service is maintained in the presence of several concurrent working path faults

Four-fiber BLSR 1+1/1:1 span protection switching bypasses unidirectional or bidirectional faults that affect only the working fiber pair. Examples include a defective splice, faulty connector, and optical transmitter/receiver problems. A cable cut also affects only the working fiber pair in applications where geographically diverse routes link adjacent nodes. Because span protection switching operates independently on each link, service is maintained in the presence of several concurrent working path faults. Thus, in a representative dual fault scenario (Figure 23),

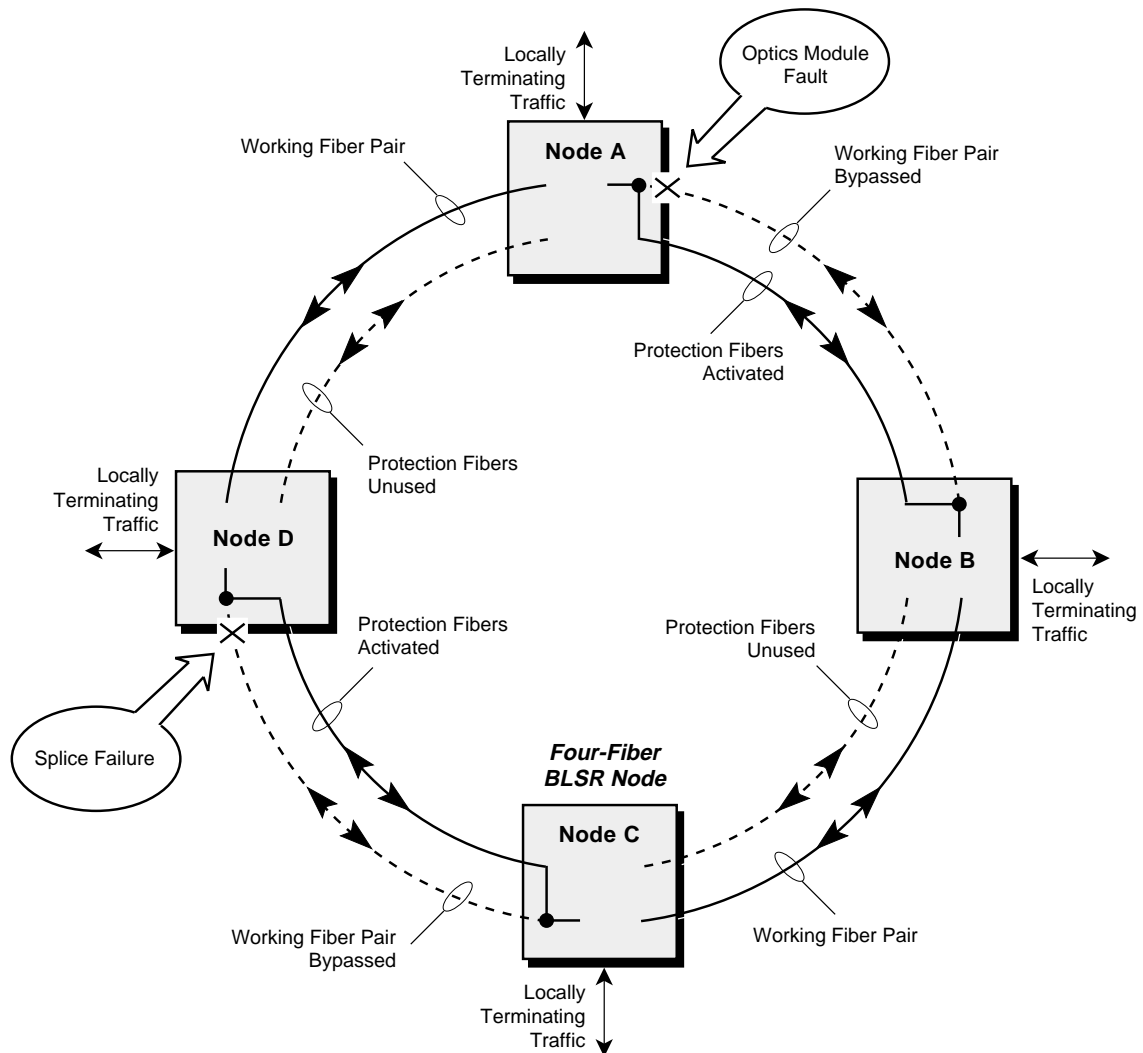


Figure 23. Four-Fiber BLSR Span Switching Example

span protection switching can be activated between Nodes A and B to address an optics module failure—while at the same time—the protection fibers between Nodes C and D are in use to bypass a defective splice.

Four-Fiber BLSR Ring Protection Switching

If a fault affects both the working and protection fibers, automatic ring protection switching redirects traffic in a manner similar to a two-fiber BLSR

If a fault affects both the working and protection fibers (e.g. a node failure or a cable cut in a span without route diversity) automatic ring protection switching redirects traffic in a manner similar to a two-fiber BLSR. However, instead of looping back time slots within the same fiber pair as in a two-fiber BLSR, the four-fiber architecture loops back traffic from the working fiber pair to the protection fiber pair (Figure 24). Other aspects of four-fiber BLSR ring protection switching are similar to the operation of a two-fiber BLSR (see Section 3 for details).

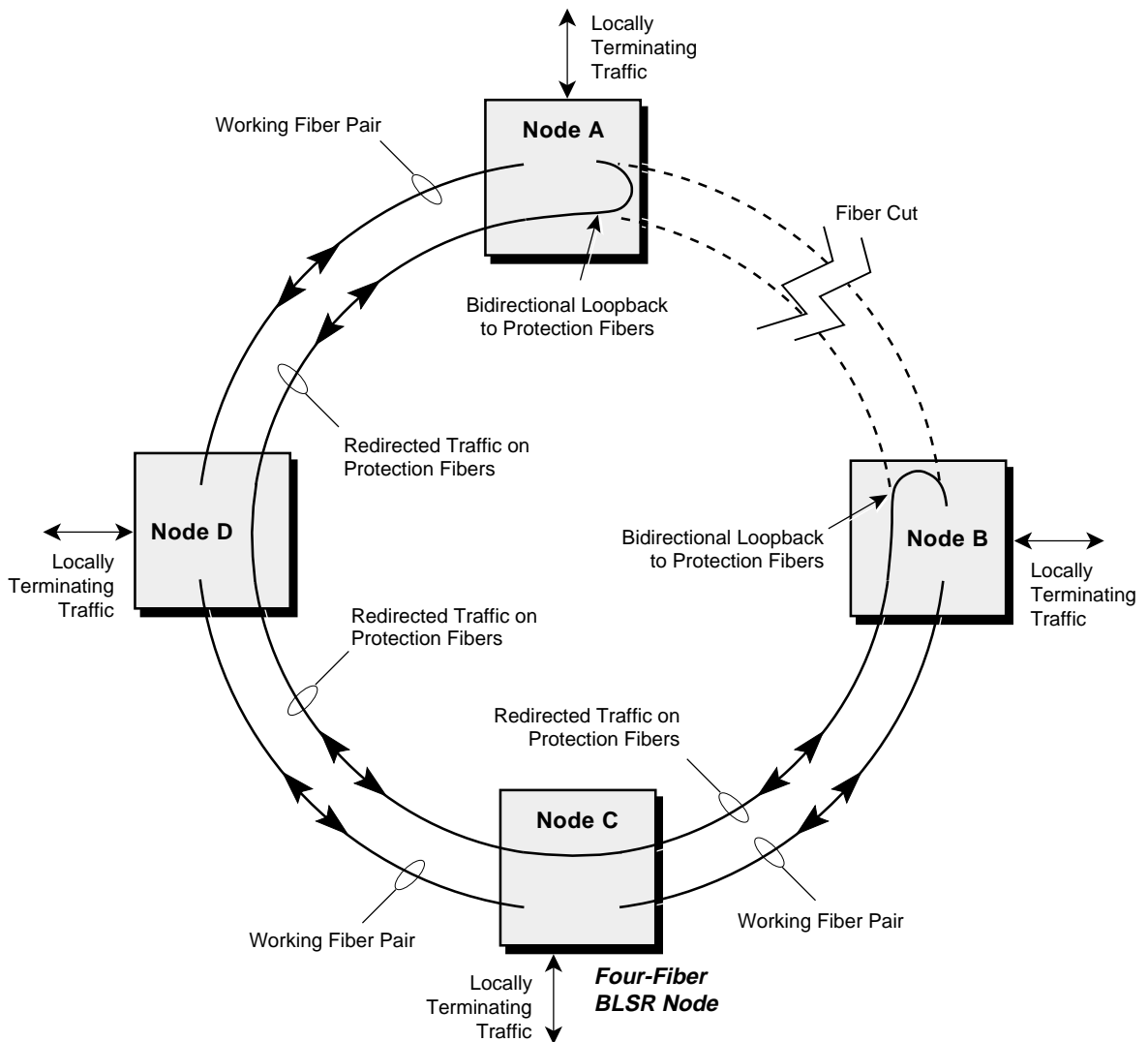


Figure 24. Four-Fiber BLSR Ring Protection Switching Example



5

Understanding Matched Nodes

The SONET matched node configuration has been expressly designed to provide survivable connections between adjacent rings

While the route diversity provided by ring topologies fully protects all working traffic passing from node to node along a ring, service paths must be protected on an end-to-end basis. This means survivable ring interconnections are required as traffic passes from an access ring through one or more interoffice rings, and then to another access ring serving the service termination point. The SONET matched node configuration (Figure 25) has been expressly designed to provide these survivable connections between adjacent rings.

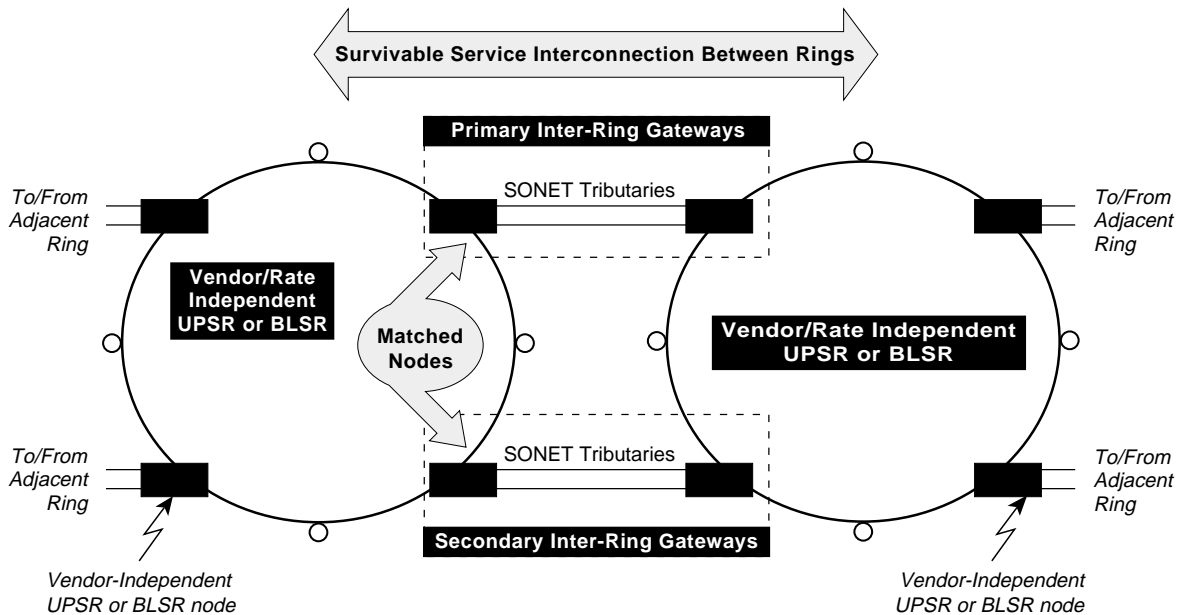


Figure 25. Inter-Ring Service Transport Using Survivable Matched Node Gateways

Matched node gateways are completely vendor/technology independent, allowing seamless interworking between rings of different types without regard to line rate or equipment supplier. Thus, matched node inter-ring gateways can provide survivable interconnections between (for example) an OC-3 UPSR from one equipment supplier and an OC-192 four-fiber BLSR from a different supplier.

S/DMS TransportNode offers matched node solutions meeting the GR-1230 industry standard.

Survivable Service Interconnections Between Rings

Redundant service paths

To assure survivability for services traversing multiple interconnected rings, the matched node configuration provides redundant (i.e. duplicate) routing across inter-ring boundaries as illustrated in the BLSR example of Figure 26. In the outbound direction, drop-and-continue routing is employed within a primary gateway network element to simultaneously pass an exiting signal to both the neighboring ring and a remote node configured as a secondary inter-ring gateway. For the opposite direction of transmission, the primary inter-ring gateway incorporates a service selector that chooses either the primary or secondary input from the adjacent ring.

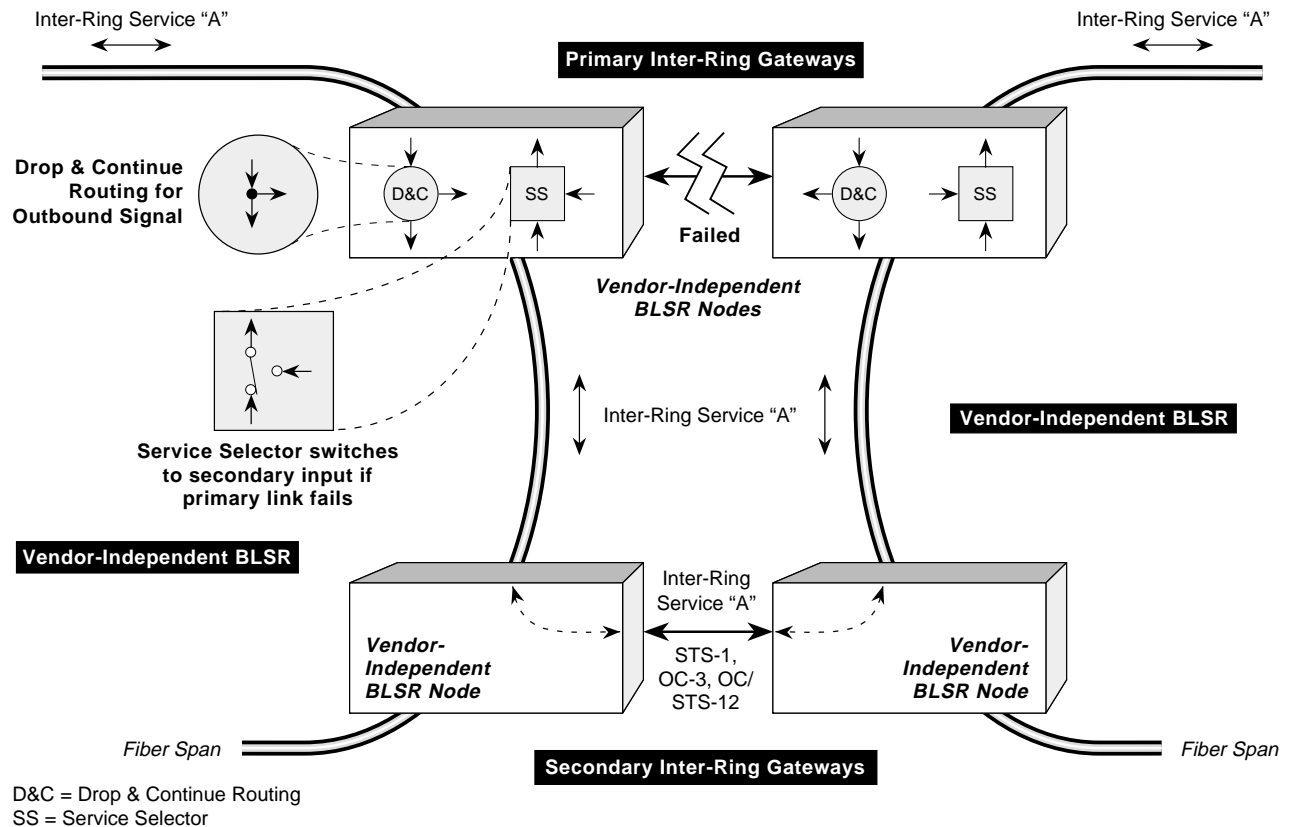


Figure 26. Duplicate Inter-Ring Service Paths Provided by Matched Node Gateways, BLSR Example Shown

UPSR matched node configurations employ standard UPSR path selection techniques plus drop-and-continue routing as shown in Figure 27. From the point of view of an adjacent ring, this arrangement functions in exactly the same manner as BLSR matched node inter-ring gateways.

A network element provisioned as a primary gateway for one inter-ring service may be provisioned as a secondary gateway (or neither) for another inter-ring service—as needed for most efficient use of the ring's available bandwidth. Also, a primary gateway on one ring may feed either a primary *or* secondary gateway on an adjacent ring as desired.

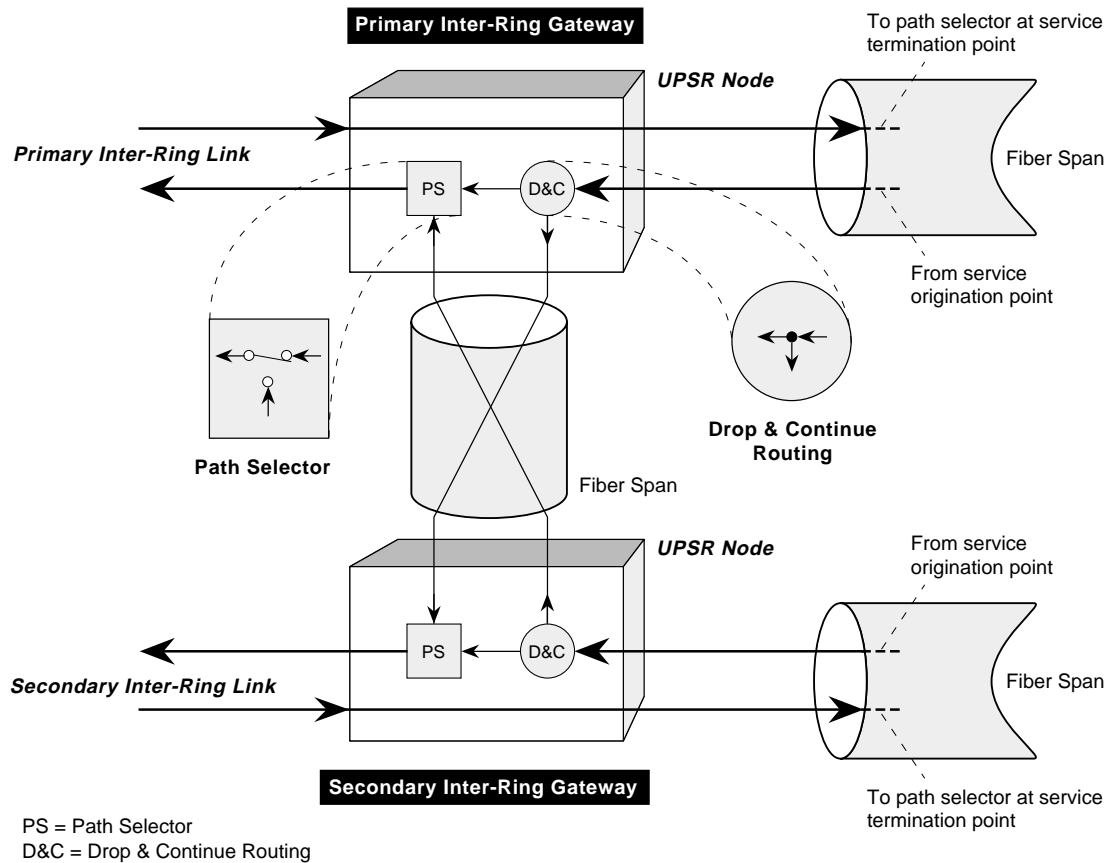


Figure 27. UPSR Matched Node Configuration

Adjacent rings are physically interconnected via SONET links (e.g. STS-1, OC-3, or OC/STS-12 facilities) that serve as “conduits” for various inter-ring services (e.g. VT-1.5/DS-1 or STS-1/DS-3 traffic). Routing and selection of inter-ring traffic is always performed at the service layer on both BLSRs and UPSRs.

Path analysis on matched node connections enhances fault detection and application flexibility

The service selector or path selector in a BLSR/UPSR matched node configuration switches from the primary input signal to the secondary input based on standard performance parameters such as line and/or path alarm indication signal (AIS). In the case of S/DMS TransportNode BLSR systems, both line layer and path layer analysis are provided to protect inter-ring services against an extended range of fault conditions compared to other BLSRs that support line analysis only. Path analysis also allows use of SONET systems on the inter-ring link, permitting (for example) wide separation between interconnecting gateways as illustrated in Figure 28.

For many types of failure situations, end-to-end service is maintained through a combination of ring protection switching and duplicate inter-ring gateways. In the event of a primary gateway failure for instance, ring protection switching bypasses the faulty node and inter-ring services pass through the secondary gateway to the adjacent ring.

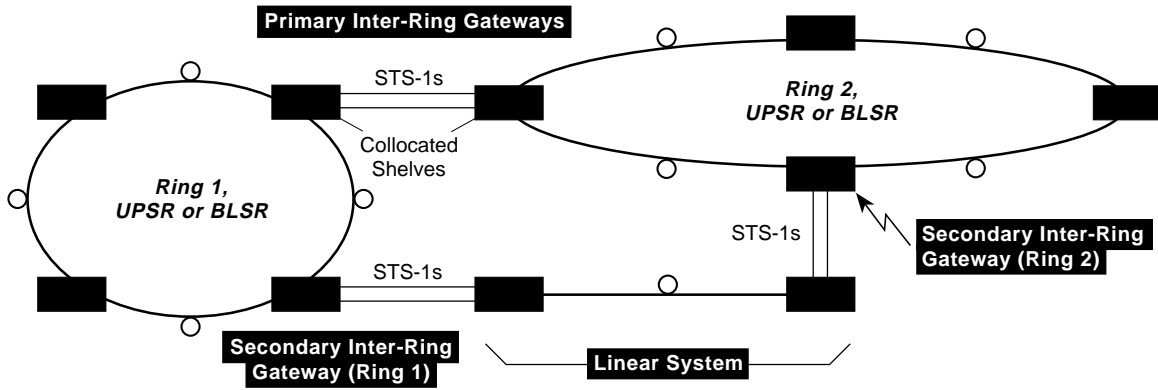


Figure 28. Interconnecting Remote Secondary Gateways Using a Linear SONET System

6

Wave Division Multiplexing

Because it defers—or avoids altogether—the large capital outlays and long lead times associated with deploying new fiber cable, WDM is an ideal solution for critical high-growth routes having an immediate need for more bandwidth

WDM multiplies (up to eight times) the capacity of existing fiber spans by combining two or more optical signals of different wavelengths on a single fiber. Because it defers—or avoids altogether—the large capital outlays and long lead times associated with deploying new fiber cable, wave division multiplexing is an ideal solution for critical high-growth routes having an immediate need for more bandwidth.

An external coupling device performs the actual mixing of the different optical signals. In *unidirectional WDM*, multiple wavelengths travel in the same direction on an optical fiber while they pass in opposite directions in *bidirectional WDM* arrangements. Bidirectional WDM is often the preferred approach, especially in applications employing two wavelengths due to the one-to-one association of an individual transport system to an individual optical fiber.

WDM can be further classified as either *wideband* (also called crossband), *narrowband*, or *dense* depending on the wavelengths involved. The S/DMS TransportNode family supports all three types on bidirectional optical fiber.

Wideband WDM

This WDM technique doubles the capacity of a fiber span by combining the 1310 nm wavelength with a second wavelength in the low-loss window of optical fiber between 1528 and 1560 nm. Both the S/DMS TransportNode OC-12 TBM and OC-48 product lines permit wideband WDM implementations using currently available wavelength options. An example bidirectional wideband WDM configuration based on the TBM's 1310 and 1550-nm wavelengths appears below in Figure 29.

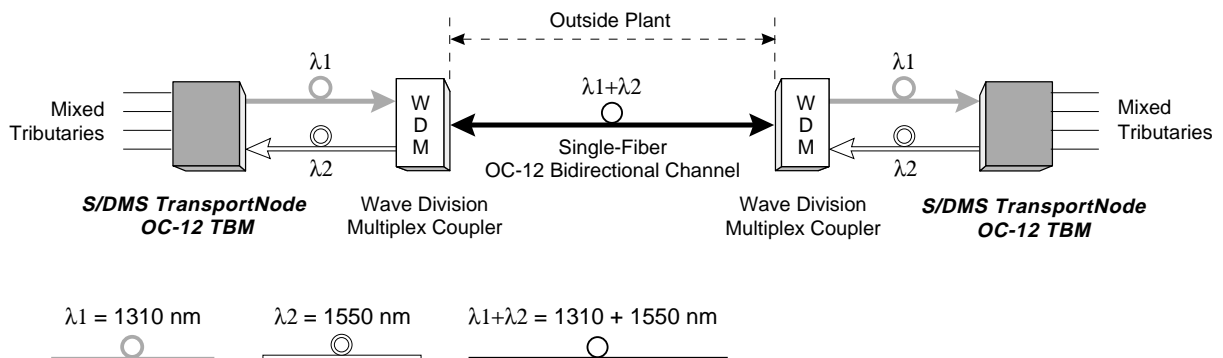


Figure 29. OC-12 TBM Shelves Deployed in a Typical Bidirectional Wideband WDM Application

Narrowband WDM

As with wideband WDM, the narrowband method provides a twofold increase in fiber span capacity. It employs two low-loss wavelengths, typically 1533 and 1557 nm. S/DMS TransportNode's OC-48 and OC-192 product lines both offer wavelength options that fully support bidirectional narrowband WDM as depicted in Figure 30.

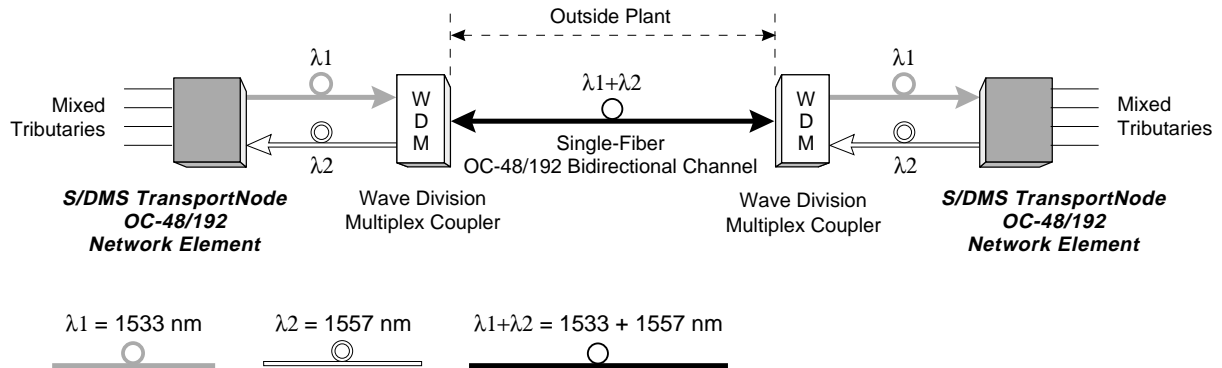


Figure 30. S/DMS TransportNode OC-48/192 Network Elements Deployed in a Typical Bidirectional Narrowband WDM Application

On long-haul routes where system reach is an important consideration, narrowband WDM is usually a better choice relative to wideband WDM

On long-haul routes where system reach is an important consideration, narrowband WDM is usually a better choice relative to wideband WDM. In addition, narrowband WDM offers total compatibility with S/DMS TransportNode's optical amplifier product line on both single-hop and multi-hop OC-48/192 routes. This means the economic advantages of expanded fiber capacity and extended reach can be achieved ***in the same application.***

Refer to our *S/DMS TransportNode Overview* document* for more information on S/DMS TransportNode's optical amplifier products.

Dense WDM

Advanced dense WDM technology employs as many as eight wavelengths to increase fiber span capacity up to eightfold. These wavelengths fall within two bands: a blue band between 1529 and 1541 nm and a red band between 1549 and 1557 nm. Each band is dedicated to a particular direction of transmission.

S/DMS TransportNode offers bidirectional dense WDM solutions for OC-48, OC-192, and hybrid OC-48/192 applications. Refer to our *S/DMS TransportNode Overview* document* for a complete wavelength plan. Figure 31 on the following page illustrates a short-reach bidirectional eight-wavelength OC-192 configuration.

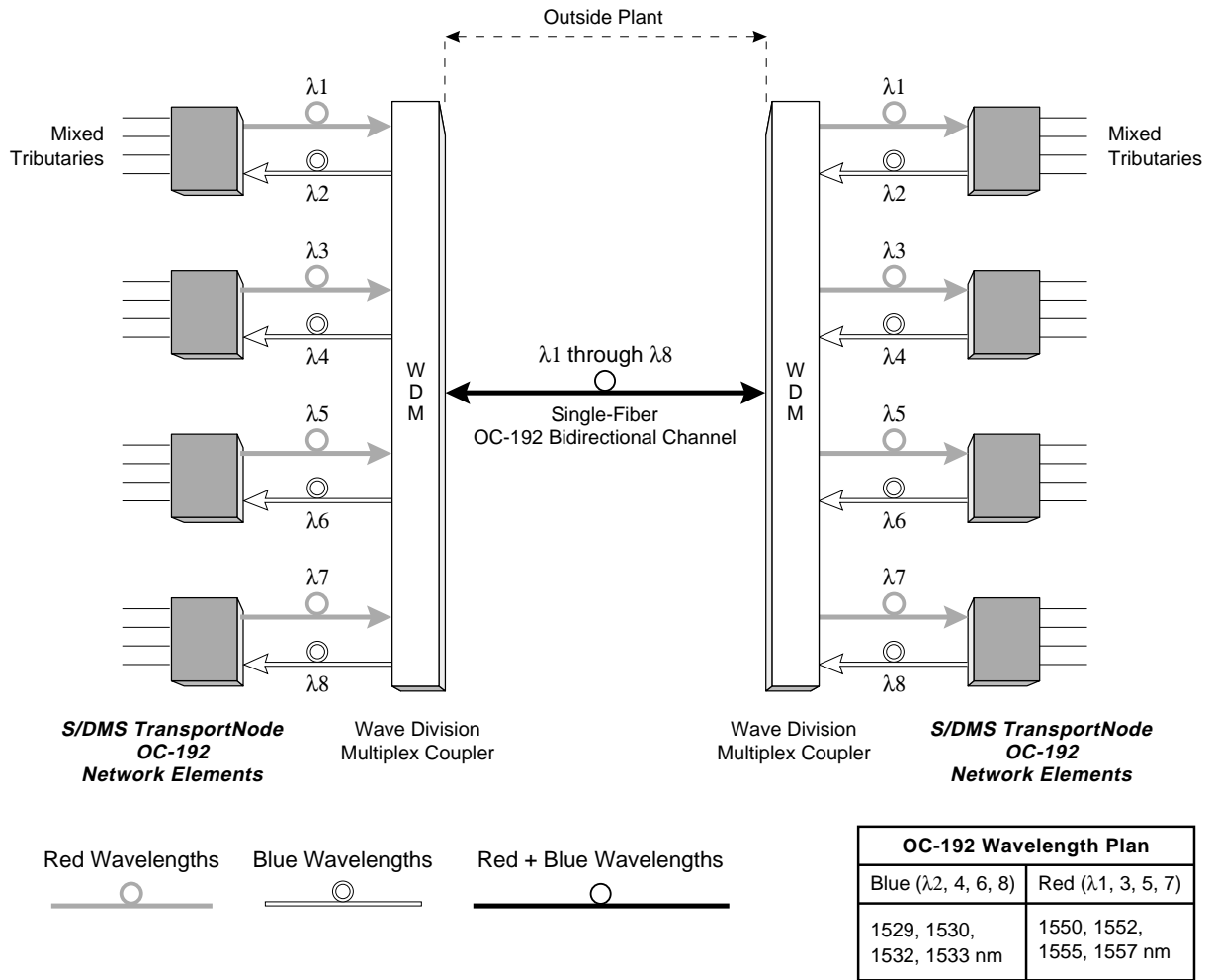


Figure 31. S/DMS TransportNode OC-192 Bidirectional Dense WDM Configuration (Short Reach)

Extended reach dense WDM supported via MOR plug-ins

To permit extended reach in dense WDM applications, S/DMS TransportNode’s optical amplifier portfolio includes a leading-edge bidirectional Multi-Wavelength Optical Repeater (MOR) that handles the associated wavelengths in both the blue and red bands. See our *S/DMS TransportNode Overview* document* for more information.



7

Using SONET Rings to Manage Bandwidth in Small-City Networks

Efficient management of DS-1 traffic is a critically important function in just about every interoffice network since most services are transported in the VT/DS-1 layer

DCS cost-effectiveness begins to diminish as office size decreases

Efficient management of DS-1 traffic is a critically important function in just about every interoffice network since most services are transported in the VT/DS-1 layer. Effective solutions for traffic routing, grooming, consolidation, and the like must be put in place to avoid escalating operational costs, congestion, and a premature need for network expansion.

Bandwidth management strategies range from manual rearrangement of cross-connect panels in smaller offices to sophisticated digital cross-connect systems (DCSs) in offices with heavy traffic demand. While DCSs offer a high degree of flexibility and substantial labor savings, their cost-effectiveness begins to diminish as traffic demand falls below 36 STS-1s/DS-3s that require VT/DS-1 layer grooming. As can be seen in Figure 32, traffic in the vast majority of central offices is well below this level.

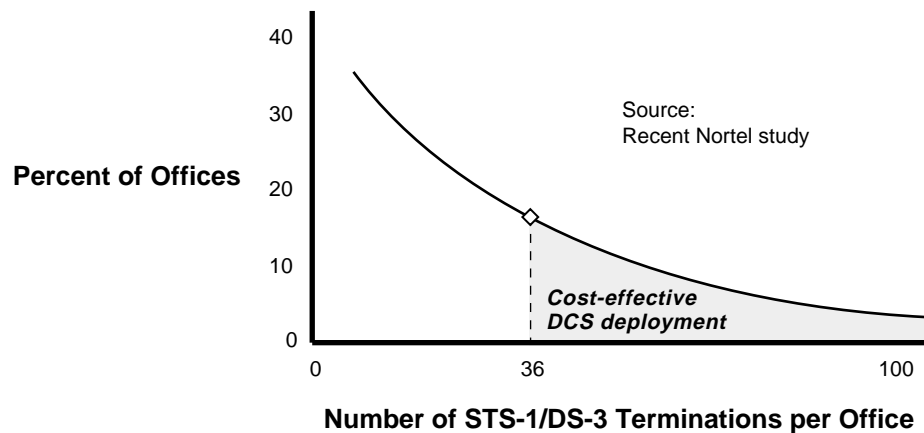


Figure 32. Traffic Distribution Among Central Offices in Typical Small to Medium-Capacity Interoffice Networks

To effectively manage bandwidth at reasonable cost in small to medium-capacity metropolitan networks, many service providers have adopted a cross-connect hub architecture similar to Figure 33. This approach allows a single DCS at a hub site to handle all bandwidth management needs for an entire network that contains numerous small offices. Traffic requiring grooming and consolidation is first back-hauled to the DCS site before being routed to its final destination. Drawbacks include increased operational complexity and the requirement for additional bandwidth to support back-haul channels.

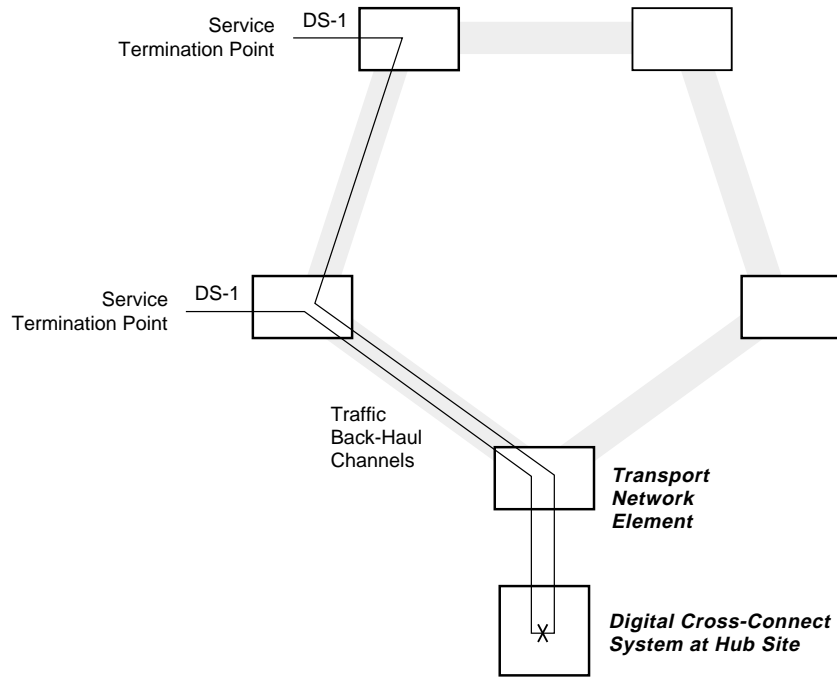


Figure 33. Back-Hauling Traffic to a Cross-Connect Hub

Bandwidth Management Solutions Based on OC-12 BLSRs

Solutions based on VT-managed OC-12 BLSRs (such as S/DMS TransportNode TBM rings) offer an attractive bandwidth management alternative for small to medium-capacity metropolitan networks. A VT-managed TBM ring provides a

distributed cross-connect capability that can either enhance an existing cross-connect hub architecture or eliminate the need for an external DCS entirely (Figure 34). The TBM's VT-1.5 time slot assignment features groom, consolidate, and route traffic without cumbersome back-hauling to a shared DCS. This conserves fiber span capacity as well as valuable DCS ports and core resources. In addition, end-to-end survivability is improved because services do not need to exit the ring for grooming.

Fiber capacity and DCS resource savings stem from two important advantages of the VT-managed BLSR:

- Efficient packing of DS-1 traffic into STS-1 channels

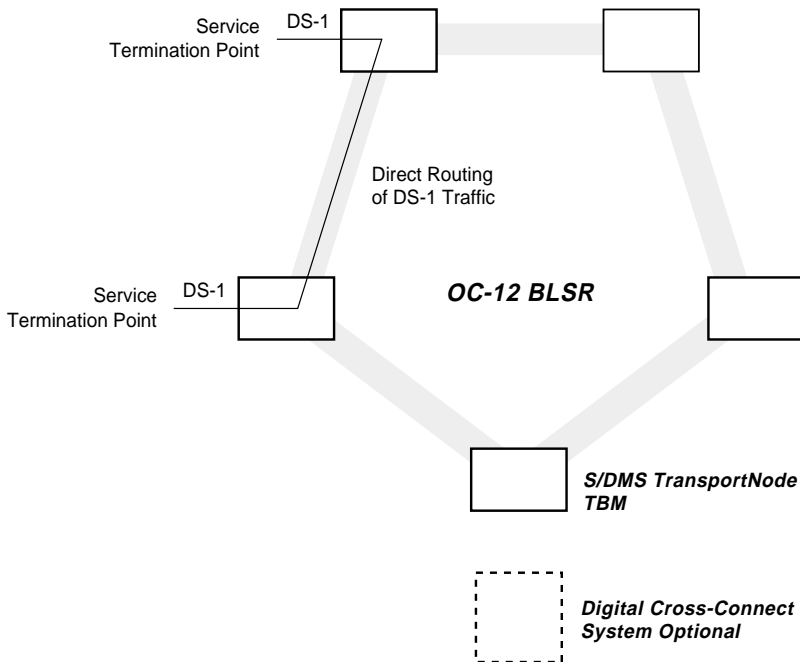


Figure 34. Traffic Routing in a VT-Managed BLSR

- Fewer services back-hauled to a hub site for grooming

These savings can be substantial, depending on the desired network management strategy of the individual service provider. In the example small-city traffic demand of Figure 35, a VT-managed TBM ring reduces the number of DCS ports required from 14 to 10 for a savings of nearly 30 percent. *Note also that this application cannot be handled with a single STS-managed OC-12 BLSR* since a total of STS-14 working bandwidth would be required at the hub site.

Equipment and bandwidth savings lead to lower capital costs; operational savings are also realized

Besides cross-connect port and core resource savings, a VT-managed OC-12 BLSR reduces transport shelf tributary hardware requirements due to efficient concentration of traffic to a minimum number of DS-1 mapper plug-ins. Fiber bandwidth savings increase the effective capacity of the network and thus defer or avoid the need for additional fiber pairs and more network elements. The net result is a

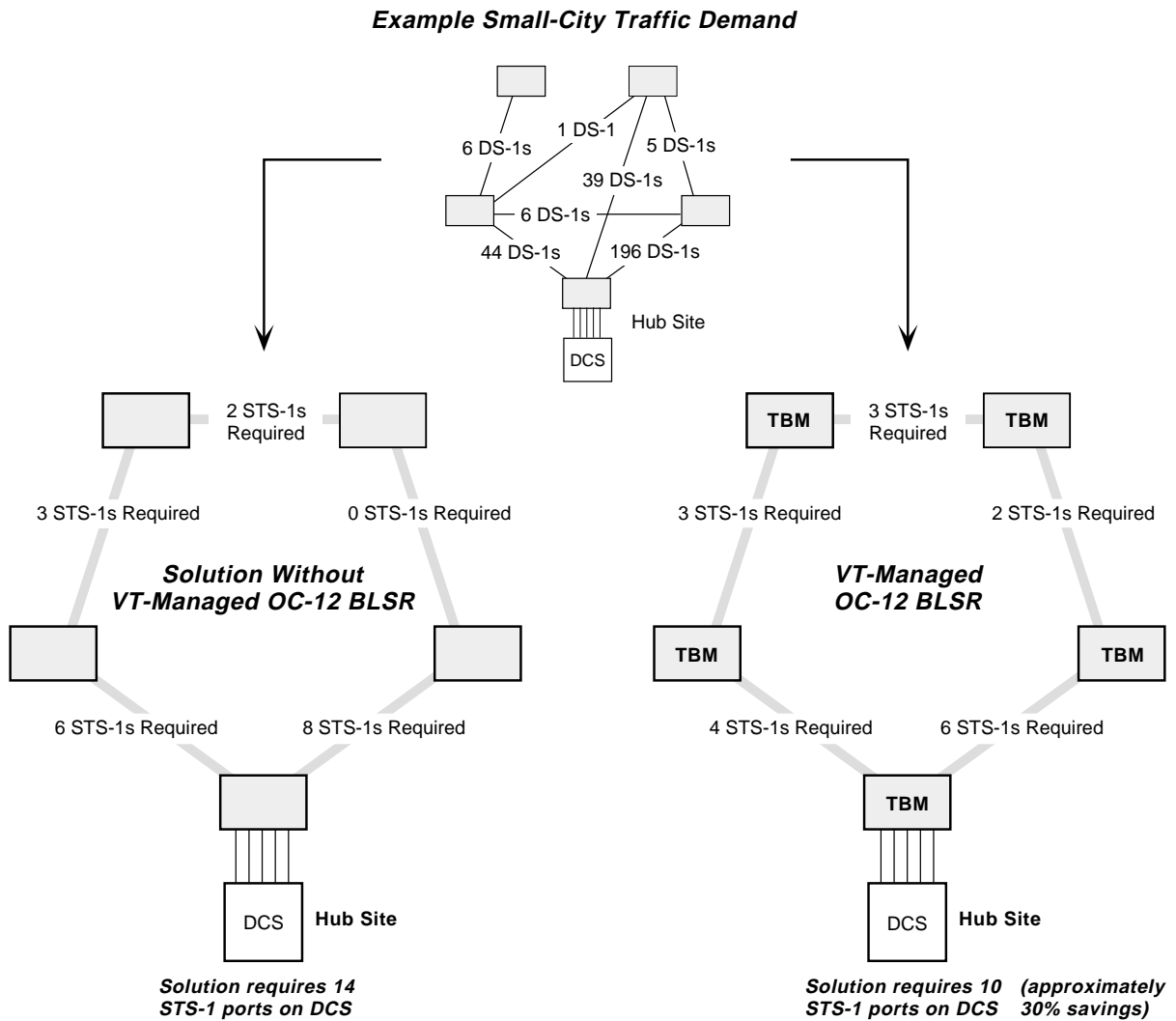


Figure 35. Cross-Connect Savings in a Typical Small-City Network

substantial reduction in capital costs in the typical small-city network. Also, operational costs (and labor) are reduced as well because fewer back-hauled services mean less management complexity.

Our *VTBM 101* handbook, document number 56135.11, provides an in-depth analysis of the many applications, implementation strategies, economic advantages, and other benefits associated with VT-managed bidirectional line switched rings. If you would like to further explore this important SONET networking technology, just visit our Broadband Networks home page (<http://www.nortel.com/broadband>) and download the *VTBM 101* document—or call 1-800-4 NORTEL (1-800-466-7835) and ask a Nortel representative to send you a paper copy.

8

Acronyms and Abbreviations

ADM	Add/Drop Multiplexer
AIS	Alarm Indication Signal
ATM	Asynchronous Transfer Mode
BIP	Bit Interleaved Parity
BLSR	Bidirectional Line-Switched Ring
CSA	Carrier Serving Area
DCS	Digital Cross-Connect System
DS	Digital Signal
DS-“N”	Digital Signal at level “N” in the asynchronous digital hierarchy
GR	Generic Requirement
IEC	Interexchange Carrier
km	Kilometer
LOP	Loss of Pointer
LOS	Loss of Signal
MOR	Multi-Wavelength Optical Repeater
nm	Nanometer
OAM&P	Operations, Administration, Maintenance, and Provisioning
OC	Optical Carrier
OC-“N”	Optical Carrier “N” where N denotes a multiple of 51.84 Mb/s
POP	Point of Presence
RPS	Ring Protection Switching
SD	Signal Degrade
SONET	Synchronous Optical Network
STS	Synchronous Transport Signal
STS-“N”	Synchronous Transport Signal “N” where N denotes a multiple of 51.84 Mb/s
TBM	Transport Bandwidth Manager

TSA	Time Slot Assignment
UPSR	Unidirectional Path-Switched Ring
VT	Virtual Tributary
VT-1.5	Virtual Tributary containing DS-1 rate signal (1.544 Mb/s)
VTBM	VT Bandwidth Management
WAN	Wide Area Network
WDM	Wave Division Multiplexing



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Published by Northern Telecom
October 1996

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