About this Document

This document is intended for anyone with an interest in advanced networks. It serves as an introductory guide to the Synchronous Optical Network (SONET) standard and presents an overview of associated technology and applications.

The first sections define SONET and explain synchronization, the benefits of SONET, the frame format, and SONET enhancements to OAM&P. Next, the focus shifts to networking aspects of SONET with particular emphasis on network applications not covered by the standards literature. Topics such as traditional networks, their evolution, and how SONET can be deployed, are explored.

A section is also included describing the international Synchronous Digital Hierarchy (SDH) and its relationship to SONET. Some of the new concepts have been developed through in-depth studies undertaken by Northern Telecom and its research and development arm, Bell-Northern Research.

Note: The information contained in this document describes SONET as an industry standard. It should not be construed as Northern Telecom's implementation of SONET.

This document replaces *SONET 101: An Introduction to SONET (56118.11/06-92 Issue 2)*.

1 What is SONET?

NEW STANDARD FOR FIBER-OPTIC TRANSPORT

SONET (Synchronous Optical Network) is a standard for optical transport formulated by the Exchange Carriers Standards Association (ECSA) for the American National Standards Institute (ANSI), which sets industry standards in the U.S. for telecommunications and other industries.

The standard has also been incorporated into the Synchronous Digital Hierarchy recommendations of the Consultative Committee on International Telegraph and Telephone (CCITT) (now called the International Telecommunications Union [ITU]), which sets standards for international telecommunications.

The standard was initiated by Bellcore on behalf of the Regional Bell Operating Companies (RBOCs) and others for the following key purposes:

- Compatibility of equipment by all vendors who manufacture to the standard often referred to as "mid-span meet"
- Synchronous networking
- Enhanced OAM&P (operations, administration, maintenance, and provisioning)
- More efficient add/drop multiplexing (ADM)
- Standards-based survivable rings
- The recent positioning of the network for transport of new services, such as Asynchronous Transfer Mode (ATM)

In brief, SONET defines optical carrier (OC) levels and electrically equivalent synchronous transport signals (STSs) for the fiber-optic based transmission hierarchy. The standard SONET line rates and STS-equivalent formats are shown in Figure 1-1. The fiber-optic rates shown in bold seem to be the most widely supported by both network providers and vendors.

Figure 1-1 • SONET Optical Line Rates

Optical Carrier Level	Electrical Equivalent	Line Rate Mbps
OC-1	STS-1	51.84
OC-3	STS-3	155.52
OC-12	STS-12	622.08
OC-24	STS-24	1244.16
OC-48	STS-48	2488.32
OC-192	STS-192	9953.28

NOTE: The higher line rates are integer multiples of the base rate of 51.84 Mbps. For example, OC-12 = 12 x 51.84 Mbps = 622.08 Mbps. The highlighted fiber-optic rates are the most widely supported.

SONET MULTIPLEXING

Figure 1-2 illustrates the basic multiplexing structure of SONET. Any type of service, ranging from voice to high-speed data and video, can be accepted by various types of service adapters. A service adapter maps the signal into the payload envelope of the STS-1 or virtual tributary (VT). New services and signals can be transported by adding new service adapters at the edge of the SONET network.

All inputs are eventually converted to a base format of a synchronous STS-1 signal (51.84 Mbps or higher). Lower speed inputs such as DS-1s are first bit- or byte-multiplexed into virtual tributaries. Several synchronous STS-1s are then multiplexed together in either a single- or two-stage process to form an electrical STS-n signal (n = one or more).

STS multiplexing is performed at the Byte Interleave Synchronous Multiplexer. Basically, the bytes are interleaved together in a format such that the low-speed signals are visible. No additional signal processing occurs except a direct conversion from electrical to optical to form an OC-n signal.

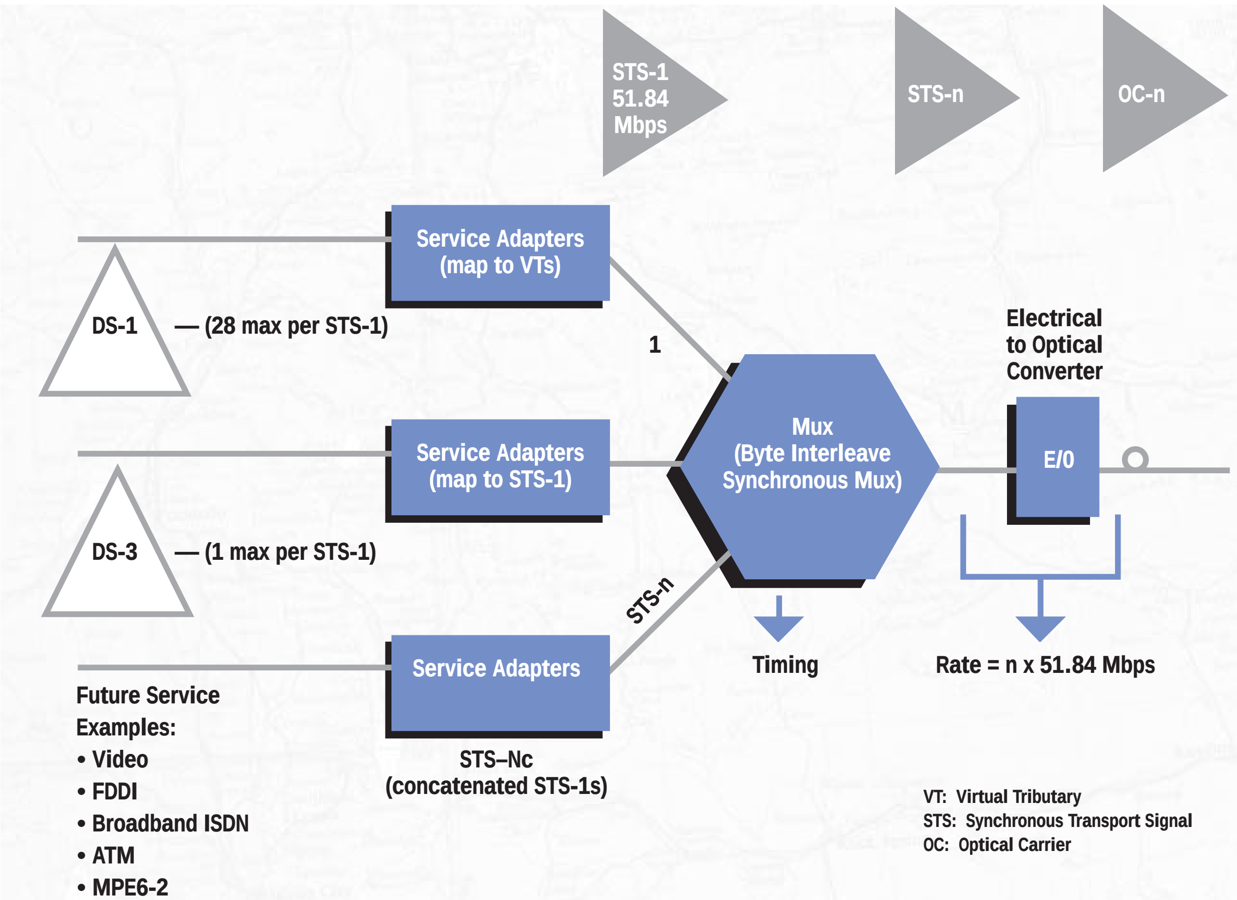


Figure 1-2 • SONET Multiplexing

TRANSPORT FOR BROADBAND ISDN

Currently many separate networks provide the communication services available to subscribers. Plain old telephone service (POTS) is provided over a voice channel connected to a circuit-switched network. A totally independent packet-switched network might be used for data communication, offering faster methods for data delivery.

An Integrated Services Digital Network (ISDN) provides a single network that can handle voice, data, and video. Whereas ISDN has traditionally applied to the narrowband telephony world, a broadband ISDN network consists of broadband ISDN switches and terminals (Figure 1-4) which can tie high-speed local area networks (LANs), digital TV and other video services, data communication devices, telemetry equipment (for example automatic electrical meter reading), and voice into one digital network.

SONET provides the necessary bandwidth to transport information from one BISDN switch (or terminal) to another. For example, an OC-3 (155 Mbps) rate may be used to transport an H4 digital broadband channel carrying a broadcast quality TV signal. Broadband ISDN will use asynchronous transfer mode (ATM) technology (see also the section: *New Services Using ATM*).

In the future, public and private networks will be based on ATM/cell-relay technology. ATM is the CCITT standard that supports cell-based voice, data, video, and multimedia communication in a public network under Broadband ISDN. SONET provides sufficient payload flexibility that it will be used as the underlying transport layer for BISDN ATM cells.

The ATM Forum is aligning with SONET as the transport layer for cell-based traffic.

Figure 1-3 • ISDN Channels (CCITT)

Channel Name	Type	Bit Rate	Applications
A	Voice Frequency	3.2 MHz analog	voice/voice band data (modems)/facsimile
B	Digital	64 kbps	PCM voice/wideband speech (7 KHz)/data
D	Digital	16 or 64 kbps	signaling channel/packet type data/telemetry
E	Digital	64 kbps	signaling for high-capacity users equipment (PABX)
H0	Digital Broadband	384 kbps	high-quality audio/high-speed digital info
H11	Digital Broadband	1.536 Mbps	video for teleconferencing/high-speed digital info
H12	Digital Broadband	1.92 Mbps	video for teleconferencing/high-speed digital info
H4	Digital Broadband	150 Mbps	high-definition TV (approximate rate)

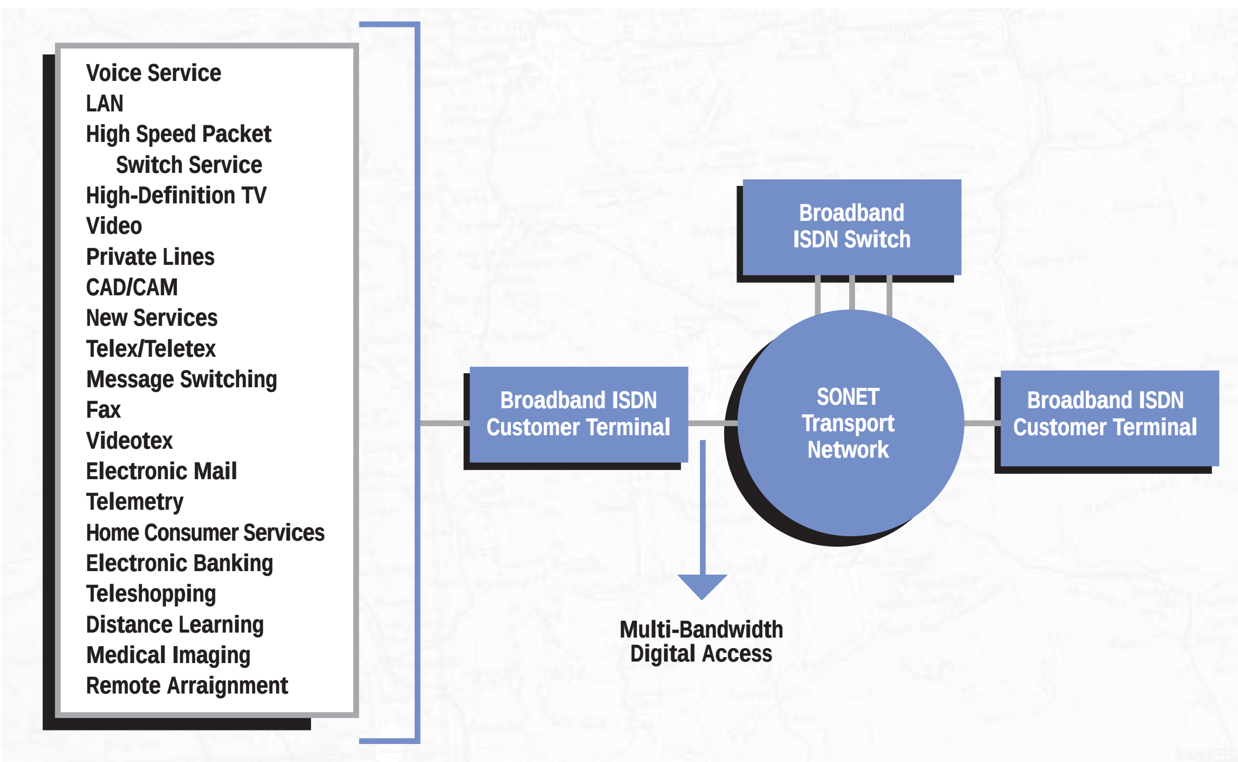


Figure 1-4 • Broadband ISDN Network Scenario

SONET FRAME FORMAT

SONET uses a basic transmission rate of STS-1—equivalent to 51.84 Mbps. Higher level signals are integer multiples of the base rate. For example, STS-3 is three times the rate of STS-1 (3 x 51.84 = 155.52 Mbps). An STS-12 rate would be 12 x 51.84 = 622.08 Mbps.

STS-1 Building Block

The frame format of the STS-1 signal appears in Figure 1-5. In general, the frame can be divided into two main areas: transport overhead and the synchronous payload envelope (SPE).

The synchronous payload envelope can also by divided into two parts: the STS path overhead and the payload. The payload is the revenue-producing traffic being transported and routed over the SONET network. Once the payload is multiplexed into the synchronous payload envelope, it can be transported and switched through SONET without having to be examined and possibly demultiplexed at intermediate nodes. Thus, SONET is said to be service-independent or transparent.

The STS-1 payload has the capacity to transport up to:
- 28 DS-1s
- 1 DS-3
- 21 CEPT-1s (2.048 Mbps CCITT type signal) or combinations of above.

Type	Digital Bit Rate	Voice	T1	DS-3
DS-1	1.544 Mbps	24	1	–
CEPT	2.048 Mbps	30	–	–
DS-3	44.736 Mbps	672	28	1

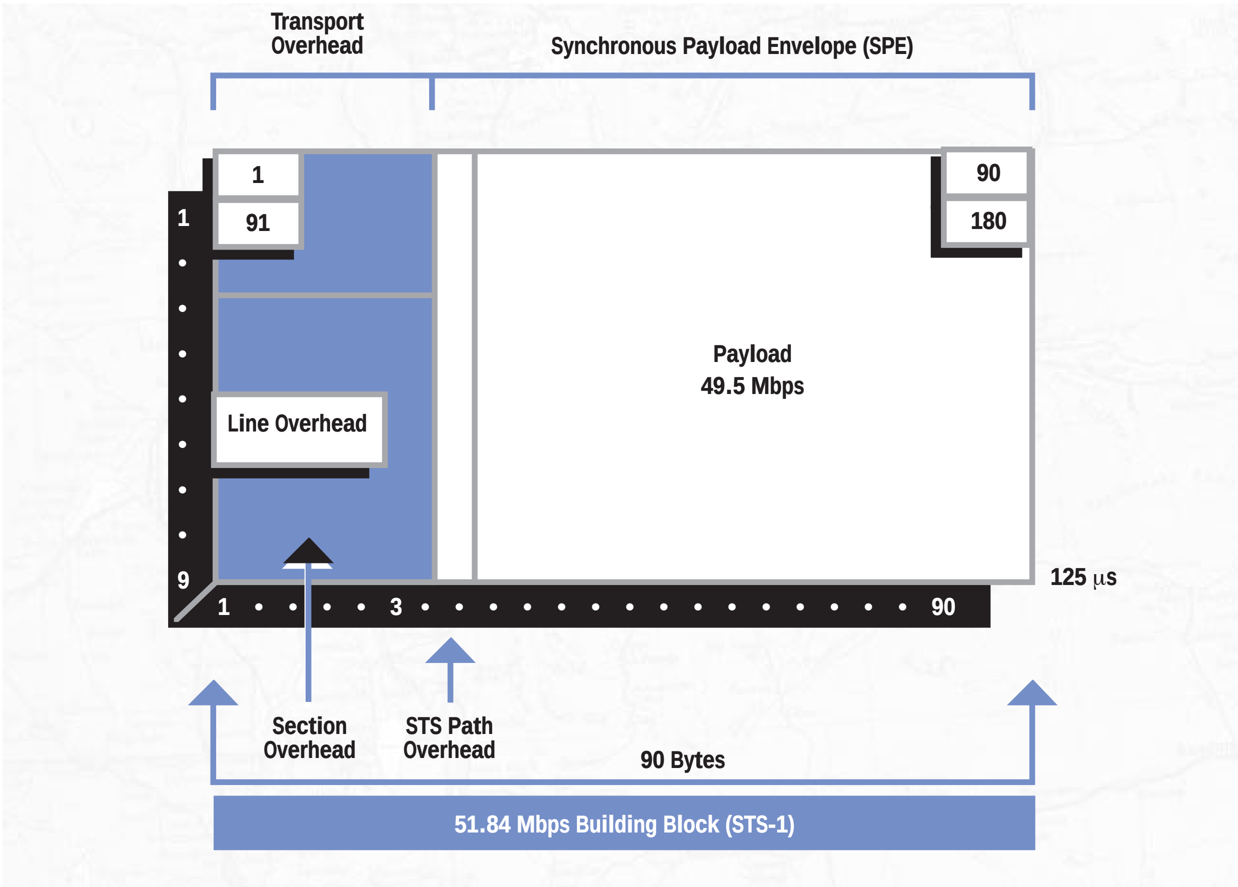


Figure 1-5 • SONET Frame Format

The STS-1 frame format is usually depicted as a matrix of nine rows of 90 bytes each as shown in Figure 1-5. The signal is transmitted byte-by-byte beginning with byte one, scanning left to right from row one to row nine. The entire frame is transmitted in 125 microseconds.

SONET provides substantial overhead information, allowing simpler multiplexing and greatly expanded OAM&P capabilities. The overhead information has several layers, which are shown in Figure 1-6. Path-level overhead is carried from end-to-end; it is added to DS-1 signals when they are mapped into virtual tributaries and for STS-1 payloads that travel end-to-end. Line overhead is for the STS-n signal between STS-n multiplexers. Section overhead is used for communications between adjacent network elements, such as regenerators.

From Figure 1-5, transport overhead is composed of section overhead and line overhead. The STS-1 path overhead is part of the synchronous payload envelope. Enough information is contained in the overhead to allow the network to operate and allow OAM&P communications between an intelligent network controller and the individual nodes.

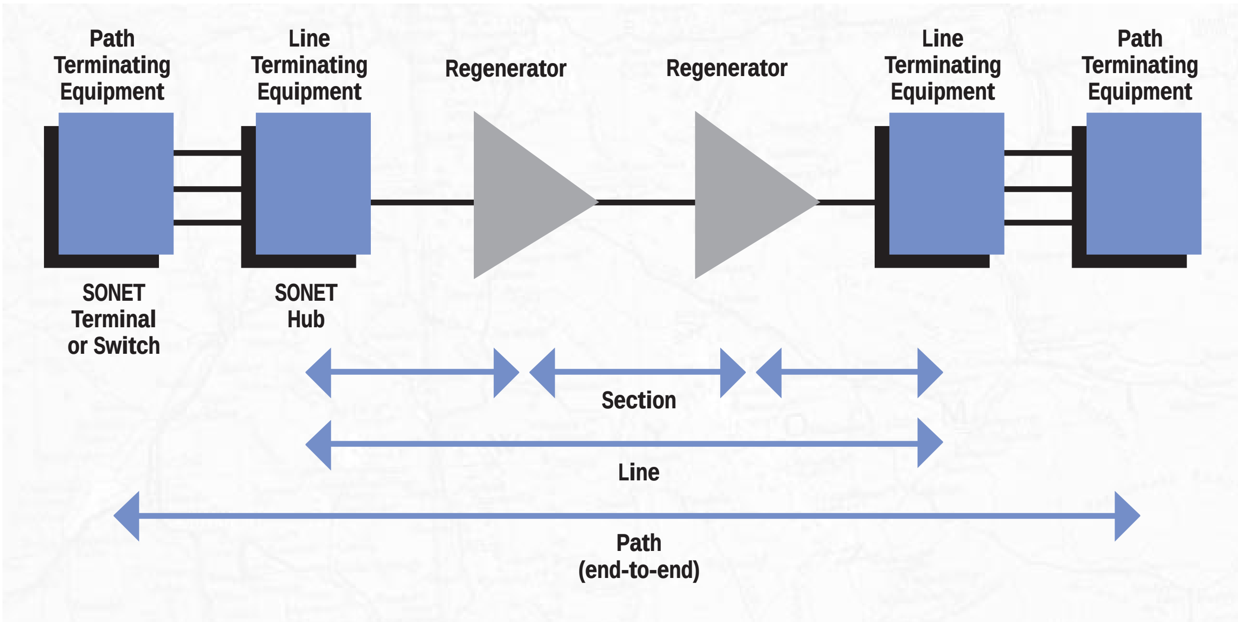


Figure 1-6 • SONET Multiplexing

Specifically, the overhead consists of:

Section Overhead:

- performance monitoring (STS-n signal)
- local orderwire
- data communication channels to carry information for OAM&P
- framing

Line Overhead:

- performance monitoring of the individual STS-1s
- express orderwire
- data channels for OAM&P
- pointer to the start of the synchronous payload envelope
- protection switching information
- line alarm indication signal (AIS)
- line far-end receive failure (FERF) indication

STS Path Overhead:

- performance monitoring of the STS SPE
- signal label (equipped or unequipped)
- path status
- path trace

VT Path Overhead:

- performance monitoring (virtual tributary level)
- signal label (equipped or unequipped)
- path status
- pointer (depending on VT type)

VIRTUAL TRIBUTARIES

In addition to the STS-1 base format, SONET also defines synchronous formats at sub-STS-1 levels. The STS-1 payload may be subdivided into virtual tributaries, which are synchronous signals used to transport lower-speed transmissions. There are three sizes of VTs:

Type	Transport for (typically)		VT Rate
VT-1.5	1 DS-1	1.544 Mbps	1.728 Mbps
VT-2	1 CETP 1	2.048 Mbps	2.304 Mbps
VT-6	1 DS-2	6.312 Mbps	6.912 Mbps

VT payloads and VT path overhead comprise the virtual tributary's synchronous payload envelope and are similar to the STS's payload. Within an STS-1 frame, each VT occupies a number of columns as shown in Figure 1-7. Within the STS-1, many VT groups can be mixed together to form an STS-1 payload.

VT Group

To accommodate different mixes of VTs in an efficient manner, the STS-1 SPE is divided into seven groups. A conceptual view of the VT groups appears in Figure 1-8. (The VT groups are actually interleaved.) A VT group may contain one VT-6, three VT-2s, or four VT-1.5s. A VT group must contain only one size of VTs, but different types of VT groups may be mixed into one STS-1 SPE.

DS-1 Visibility

Figure 1-7 shows the SONET STS-1 frame format. Individual DS-1s are visible (neatly stacked together for easy identification). Because the multiplexing is synchronous, the low-speed tributaries (input signals) can be multiplexed together but are still visible at higher rates. An individual VT containing a DS-1 can be extracted without demultiplexing the entire STS-1. This improved accessibility improves switching and grooming at VT or STS levels.

In an asynchronous DS-3 frame, the DS-1s have gone through two levels of multiplexing (DS-1 to DS-2; DS-2 to DS-3) which include the addition of stuffing and framing bits. The DS-1 signals are mixed somewhere in the information bit fields and cannot be easily identified without completely demultiplexing the entire frame.

Different synchronizing techniques are used for multiplexing. In existing asynchronous systems, the timing for each fiber optic transmission system (FOTS) terminal is not locked onto a common clock. Therefore, large frequency variations can occur. "Bit stuffing" is a technique used to synchronize the various low-speed signals to a common rate before multiplexing.

Note: A more detailed explanation of synchronization is provided in Section 2.

Pointers

SONET uses a concept called “pointers” to compensate for frequency and phase variations. Pointers allow the transparent transport of synchronous payload envelopes (either STS or VT) across plesiochronous boundaries, i.e., between nodes with separate network clocks having almost the same timing. The use of pointers avoids the delays and loss of data associated with the use of large (125-microsecond frame) slip buffers for synchronization.

Pointers provide a simple means of dynamically and flexibly phase-aligning STS and VT payloads, thereby permitting ease of dropping, inserting, and cross-connecting these payloads in the network. Transmission signal wander and jitter can also be readily minimized with pointers.

Figure 1-9 shows an STS-1 pointer which allows the SPE to be separated from the transport overhead. The pointer is simply an offset value that points to the byte where the SPE begins. The diagram depicts the typical case of the SPE overlapping onto two STS-1 frames. If there are any frequency or phase variations between the STS-1 frame and its SPE, the pointer value will be increased or decreased accordingly to maintain synchronization.

VT Mappings

There are several options for how payloads are actually mapped into the VT. Locked-mode VTs bypass the pointers with a fixed byte-oriented mapping of limited flexibility. Floating mode mappings use the pointers to allow the payload to float within the VT payload. There are three different floating mode mappings—asynchronous, bit-synchronous, and byte-synchronous.

Concatenated Payloads

For future services, the STS-1 may not have enough capacity to carry some services. SONET offers the flexibility of concatenating STS-1s to provide the necessary bandwidth. Figure 1-10 illustrates SONET flexibility by concatenating three STS-1s to 155.52 Mbps to provide the capacity to transport an H4 digital-video channel. STS-1s can be concatenated up to STS-3c. Beyond STS-3, concatenation is done in multiples of STS-3c. For ATM services, concatenation is done in multiples of STS-12c.

Virtual tributaries can be concatenated up to VT-6 in increments of VT-1.5, VT-2, or VT-6 (see Figure 1-7).

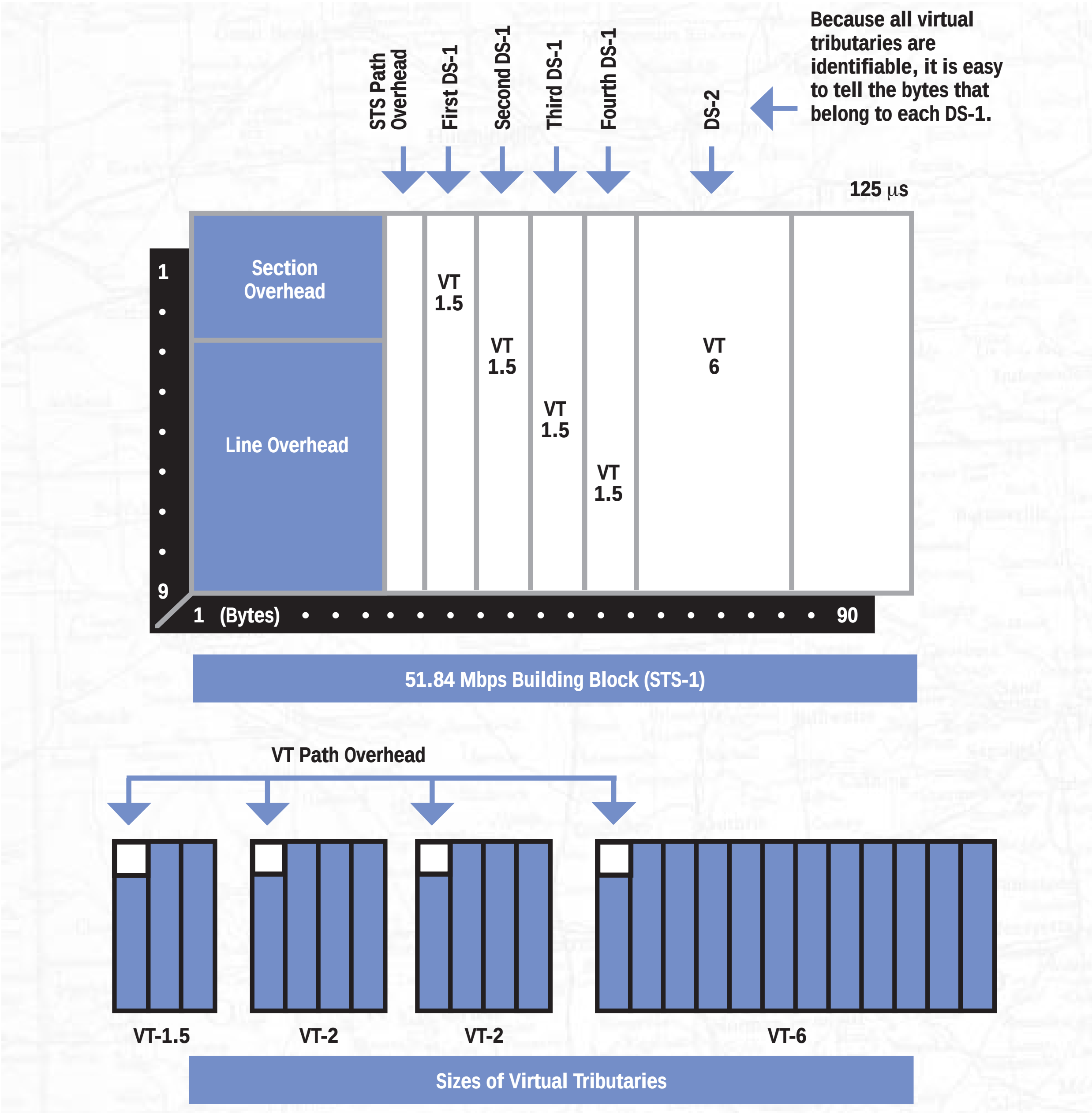


Figure 1-7 • DS-1 Visibility

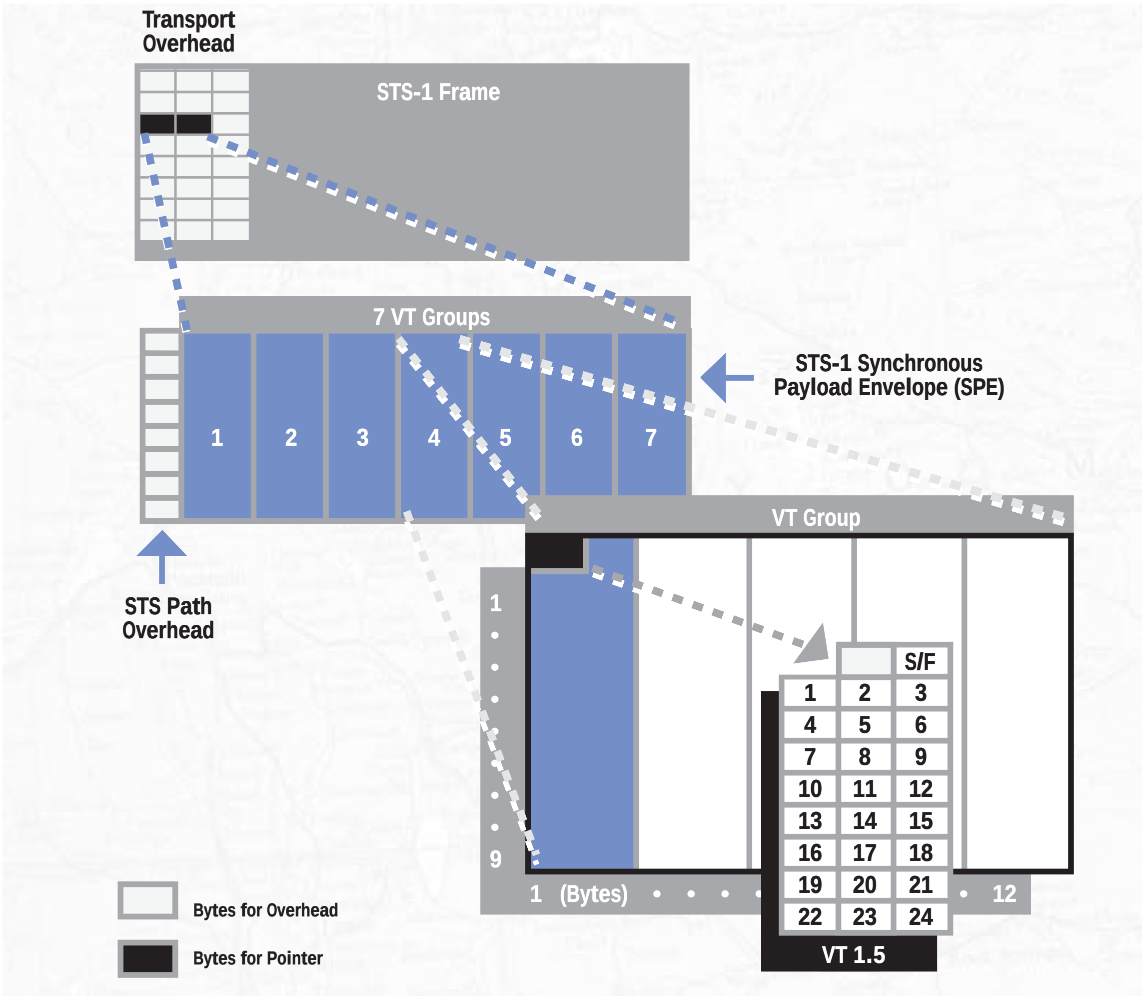


Figure 1-8 • VT Groups (Conceptual View)

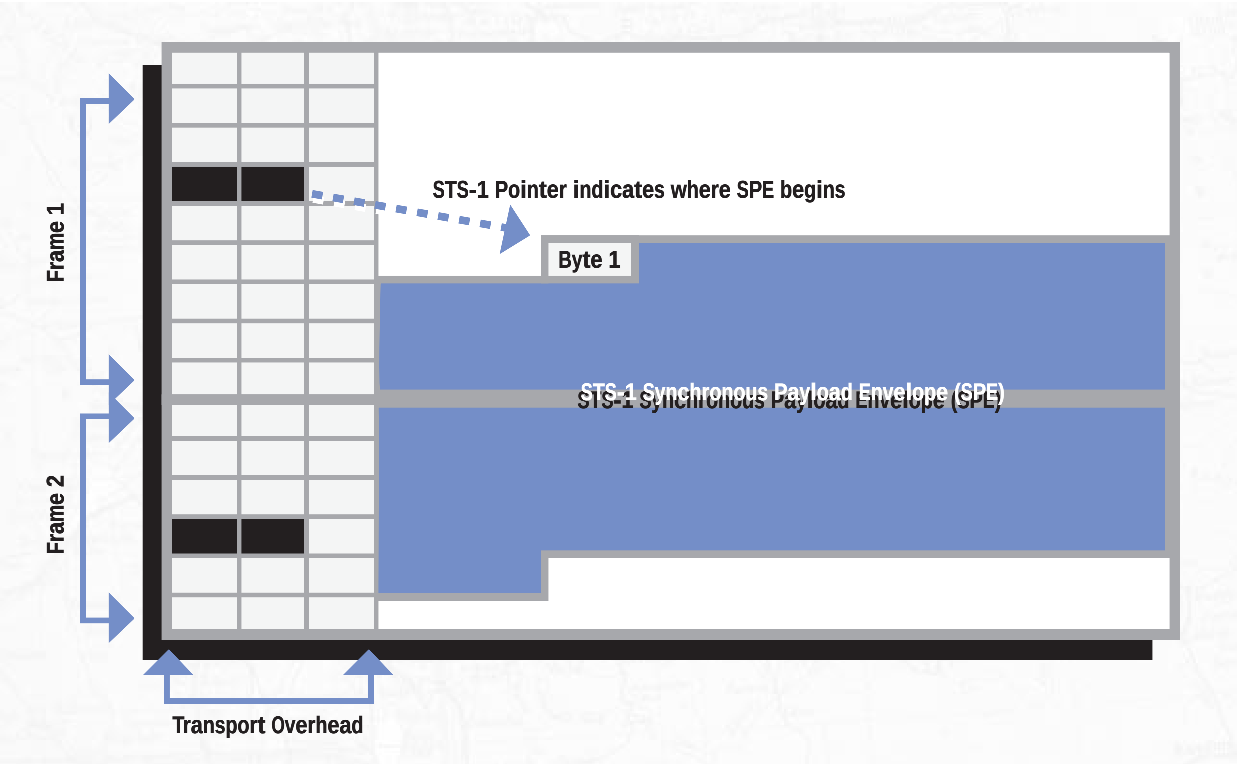
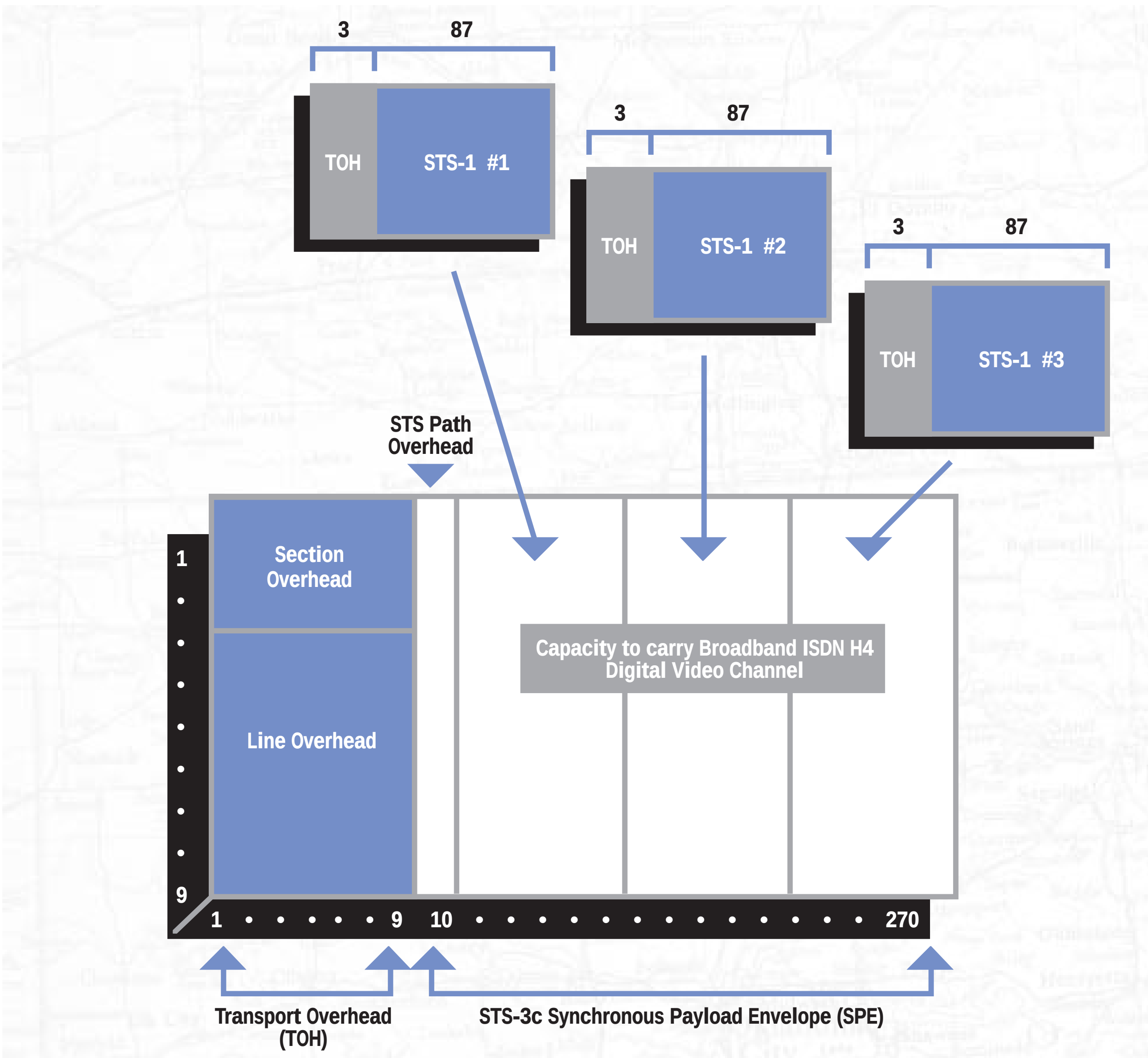


Figure 1-9 • Pointer



Example: STS-3c (155.52 Mbps) Formed by Three Concatenated STS-1s (51.84 Mbps)

Figure 1-10 • Concatenated STS-1s

SONET NETWORK ELEMENTS

Although network elements (NEs) are compatible at the OC-n level, they may differ in features from vendor to vendor. SONET does not restrict manufacturers from providing a single type of product, nor require them to provide all types. For example, one vendor might offer an add/drop multiplexer with access at DS-1 only, whereas another might offer simultaneous access at DS-1 and DS-3 rates. See Figure 1-11.

Add/Drop Multiplexer

A single-stage multiplexer/demultiplexer can multiplex various inputs into an OC-n signal. At an add/drop site, only those signals that need to be accessed are dropped or inserted. The remaining traffic continues through the network element without requiring special pass-through units or other signal processing.

In rural applications, an ADM can be deployed at a terminal site or any intermediate location for consolidating traffic from widely separated locations. An ADM can also be configured as a survivable ring.

Drop and Repeat

SONET enables drop and repeat (also known as drop and continue)—a key capability in both telephony and cable TV applications. With drop and repeat, a signal terminates at one node, is duplicated (repeated), and is then sent to the next node and to subsequent nodes (see Figure 1-11).

In ring-survivability applications, drop and repeat provides alternate routing for traffic passing through interconnecting rings in a “matched-nodes” configuration. If the connection cannot be made through one of the nodes, the signal is repeated and passed along an alternate route to the destination node.

In multi-node distribution applications, one transport channel can efficiently carry traffic between multiple distribution nodes. When transporting video, for example, each programming channel is delivered (dropped) at the node and repeated for delivery to the next and subsequent nodes. Not all bandwidth (program channels) need be terminated at all the nodes. Channels not terminating at a node can be passed through without physical intervention to other nodes.

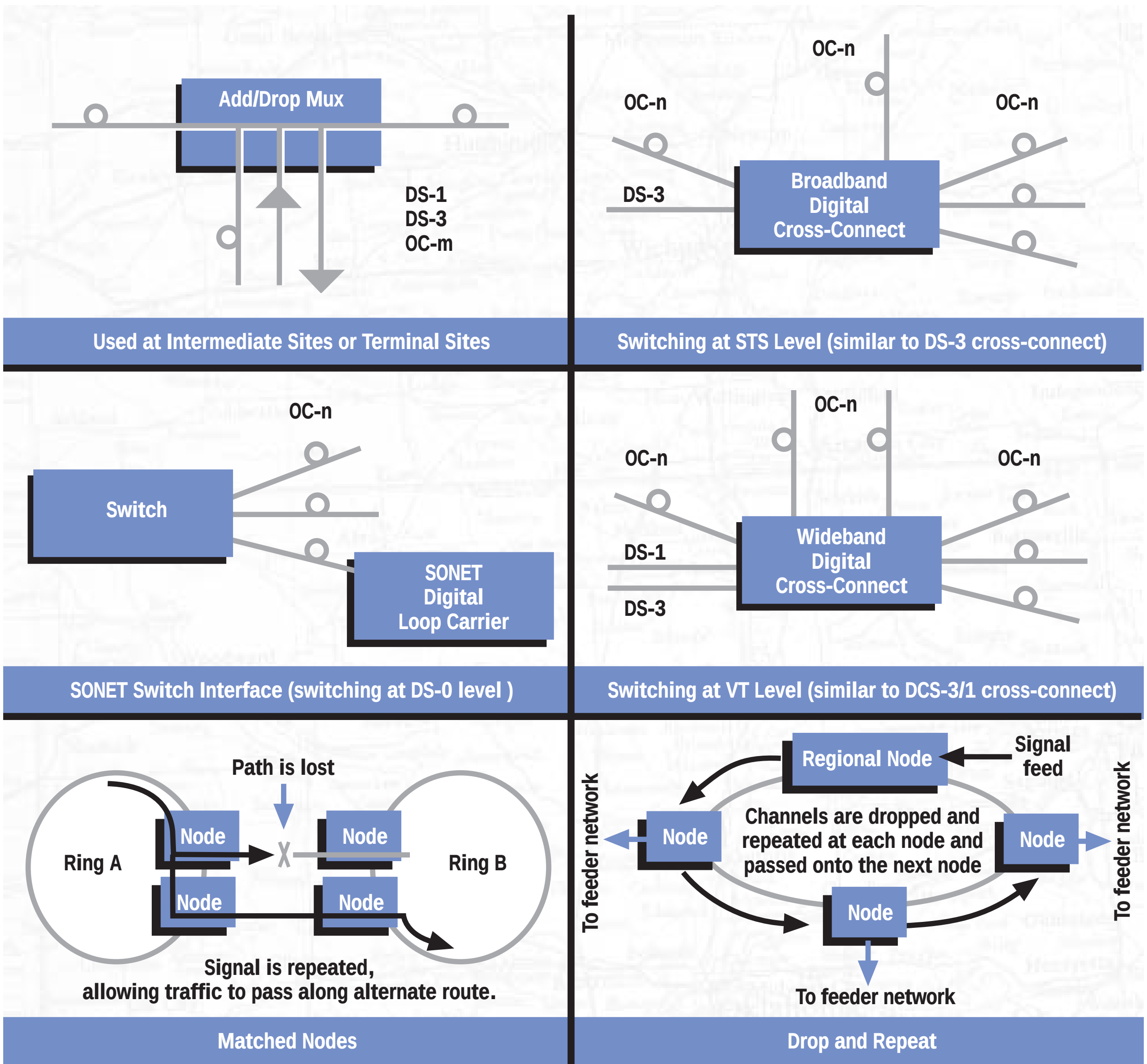


Figure 1-11 • SONET Network Elements

Broadband Digital Cross-Connect

A SONET cross-connect accepts various optical carrier rates, accesses the STS-1 signals, and switches at this level. It is ideally used at a SONET hub. One major difference between a cross-connect and an add-drop multiplexer is that a cross-connect may be used to interconnect a much larger number of STS-1s. The broadband cross-connect can be used for grooming (consolidating or segregating) of STS-1s or for broadband traffic management. For example, it may be used to segregate high-bandwidth from low-bandwidth traffic and send them separately to the high-bandwidth (for example video) switch and a low-bandwidth (voice) switch. It is the synchronous equivalent of a DS-3 digital cross-connect and supports hubbed network architectures.

Wideband Digital Cross-Connect

This type is similar to the broadband cross-connect except that the switching is done at VT levels (similar to DS-1/DS-2 levels). It is similar to a DS-3/1 cross-connect because it accepts DS-1s, DS-3s, and is equipped with optical interfaces to accept optical carrier signals. It is suitable for DS-1 level grooming applications at hub locations. One major advantage of wideband digital cross-connects is that less demultiplexing and multiplexing is required because only the required tributaries are accessed and switched.

2
Why Synchronize?

SYNCHRONOUS VERSUS ASYNCHRONOUS

Traditionally, transmission systems have been asynchronous, with each terminal in the network running on its own clock. In digital transmission, “clocking” is one of the most important considerations. Clocking means using a series of repetitive pulses to keep the bit rate of data constant and to indicate where the ones and zeroes are located in a data stream.

Since these clocks are totally free-running and not synchronized, large variations occur in the clock rate and thus the signal bit rate. For example, a DS-3 signal specified at 44.736 Mbps + 20 ppm (parts per million) can produce a variation of up to 1789 bps between one incoming DS-3 and another.

Asynchronous multiplexing uses multiple stages. Signals such as asynchronous DS-1s are multiplexed, extra bits are added (bit-stuffing) to account for the variations of each individual stream and are combined with other bits (framing bits) to form a DS-2 stream. Bit-stuffing is used again to multiplex up to DS-3. The DS-1s are neither visible nor accessible within a DS-3 frame. DS-3s are multiplexed up to higher rates in the same manner. At the higher asynchronous rate, they cannot be accessed without demultiplexing.

In a synchronous system, such as SONET, the average frequency of all clocks in the system will be the same (synchronous) or nearly the same (plesiochronous). Every clock can be traced back to a highly stable reference supply. Thus, the STS-1 rate remains at a nominal 51.84 Mbps, allowing many synchronous STS-1 signals to be stacked together when multiplexed without any bit-stuffing. Thus, the STS-1s are easily accessed at a higher STS-n rate.

Low-speed synchronous virtual tributary (VT) signals are also simple to interleave and transport at higher rates. At low speeds, DS-1s are transported by synchronous VT-1.5 signals at a constant rate of 1.728 Mbps. Single-step multiplexing up to STS-1 requires no bit stuffing and VTs are easily accessed.

Pointers accommodate differences in the reference source frequencies, phase wander, and prevent frequency differences during synchronization failures.

SYNCHRONIZATION HIERARCHY

Digital switches and digital cross-connect systems are commonly employed in the digital network synchronization hierarchy. The network is organized with a master-slave relationship with clocks of the higher level nodes feeding timing signals to clocks of the lower level nodes. All nodes can be traced up to a primary reference source, a Stratum 1 atomic clock with extremely high stability and accuracy. Less stable clocks are adequate to support the lower nodes.

The network of Figure 2-1 illustrates the digital network synchronization hierarchy, with all clocks normally operating at the same frequency as the reference source. A large network can comprise the interconnection of many such clusters of nodes, each operating plesiochronously.

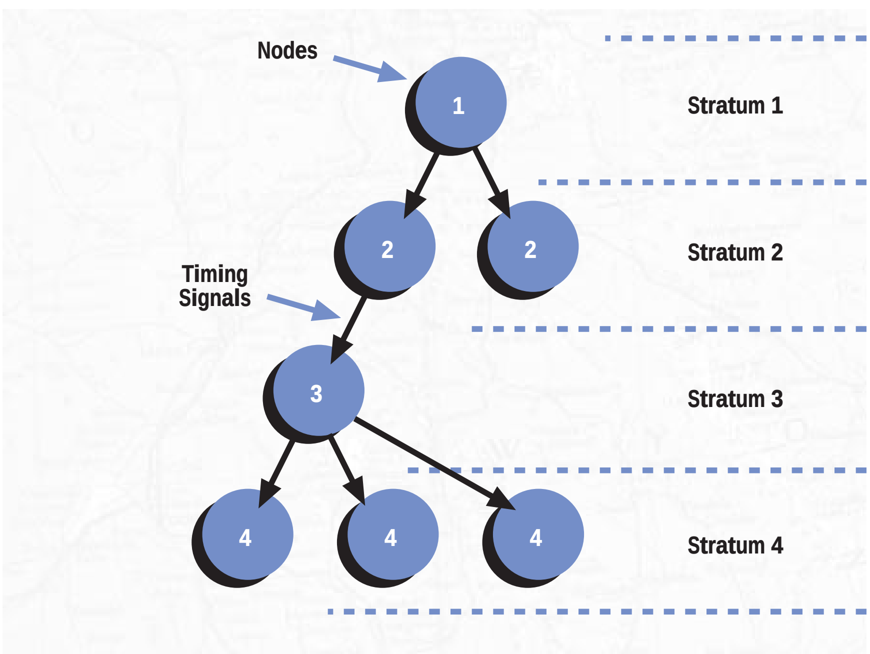


Figure 2-1 • Digital Network Synchronization Hierarchy

SYNCHRONIZING SONET

Figure 2-2 illustrates how a SONET network may be synchronized. The internal clock of a SONET terminal may derive its timing signal from a building integrated timing supply (BITS) used by switching systems and other equipment. Thus, this terminal will serve as a master for other SONET nodes, providing timing on its outgoing OC-n signal. Other SONET nodes will operate in a slave mode called “loop timing” with their internal clocks timed by the incoming OC-n signal. Present standards specify that a SONET network must be able to derive its timing from a Stratum 3 or higher clock.

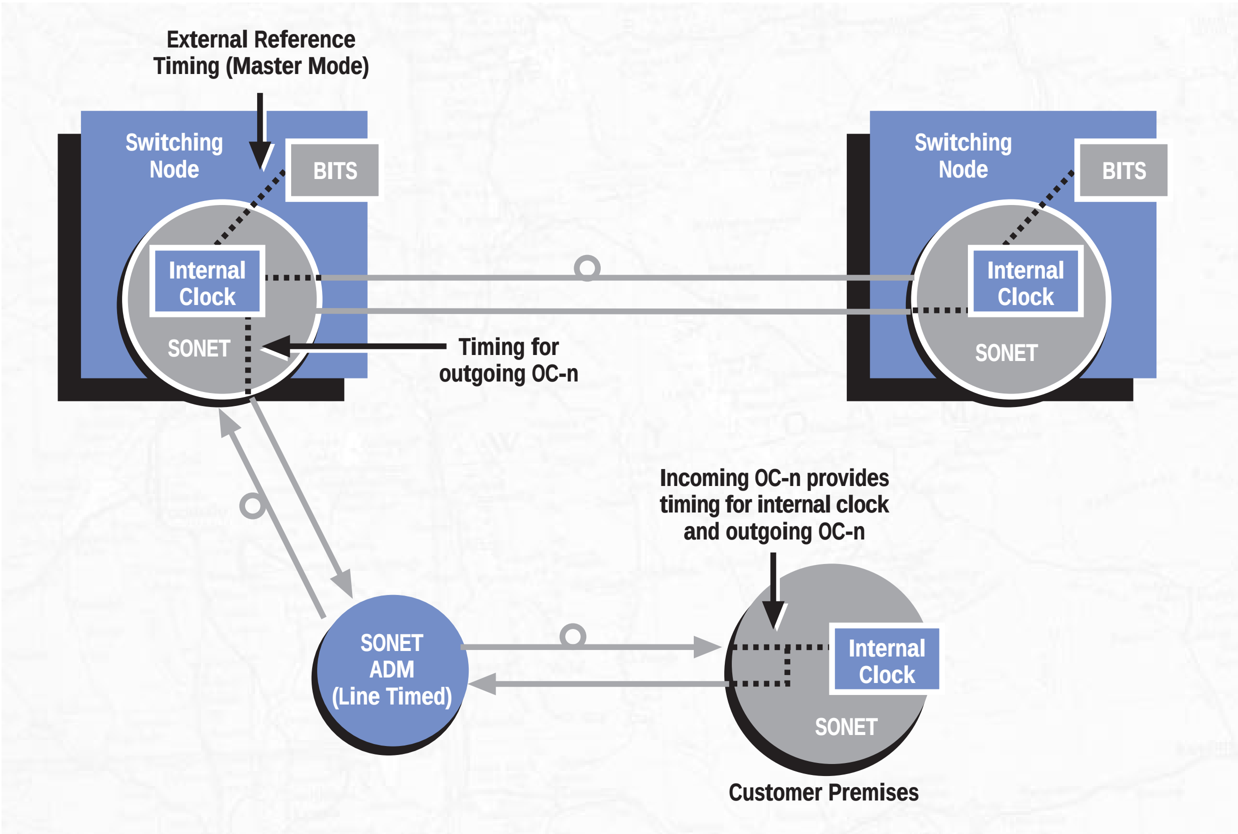


Figure 2-2 • Synchronizing a SONET Network

3

What are the Benefits of SONET?

The transport network using SONET provides much more powerful networking capabilities than existing asynchronous systems. The key benefits provided by SONET are summarized in the table of Figure 3-1.

Figure 3-1 • Key SONET Benefits

Feature	Reduced Capital	Lower Cost	Added Revenue
1. Multi-point configurations			
• Grooming	X		
• Reduced back-to-back terminals and Muxes	X		
• Reduced cabling and DSX panels	X		
2. Enhanced OAM&P			
• OAM&P integration		X	
• Enhanced performance monitoring		X	X
3. Concurrent NMA* and OPS/INE** operation		X	
4. New services			X
5. Optical interconnect	X	X	X

* NMA: Network Monitoring and Analysis
** OPS/INE: Operations System/Intelligent Network Element

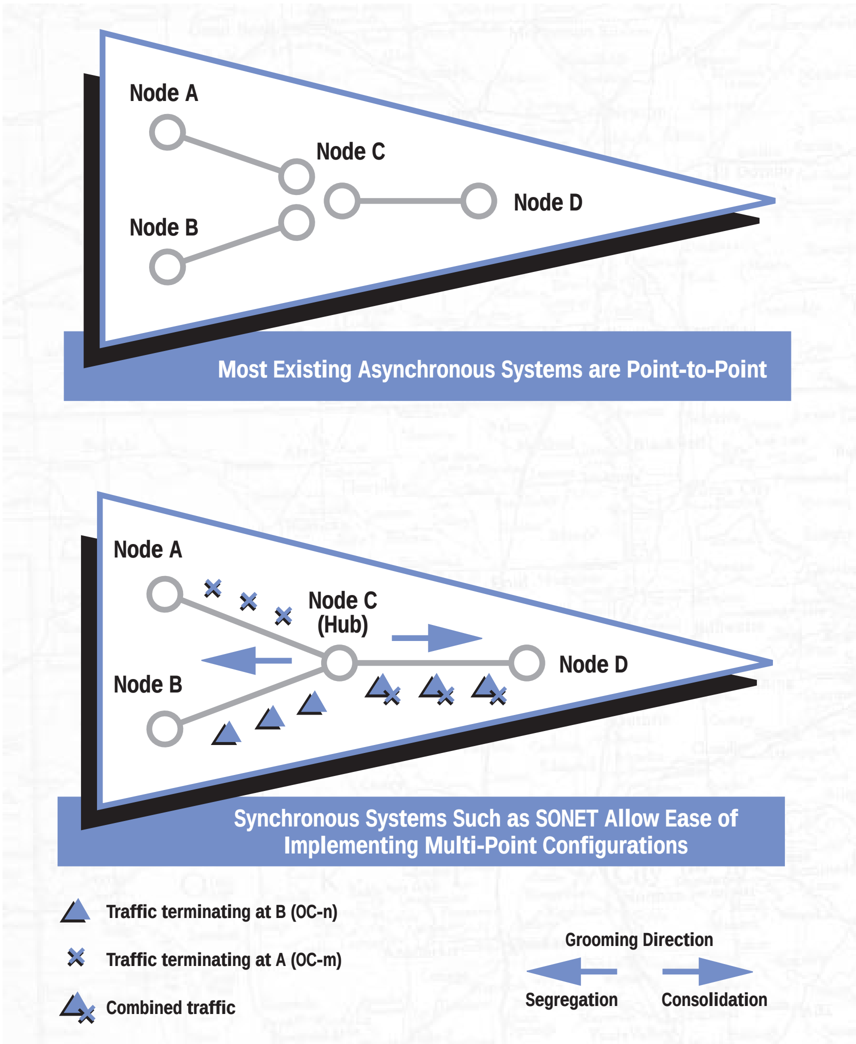


Figure 3-2 • Point-to-Point Versus Multi-Point and Grooming

MULTI-POINT CONFIGURATIONS

Figure 3-2 illustrates the difference between point-to-point and multi-point systems. Most existing asynchronous systems are only suitable for point-to-point, whereas SONET supports a multi-point or hub configuration.

A hub is an intermediate site from which traffic is distributed to three or more spurs. The hub allows the four nodes or sites to communicate as a single network instead of three separate systems. Hubbing reduces requirements for back-to-back multiplexing and demultiplexing, and helps realize the benefits of traffic grooming.

Network providers no longer need to own and maintain customer-located equipment. A multi-point implementation permits OC-n interconnects or mid-span meet, allowing network providers and their customers to optimize their shared use of the SONET infrastructure.

GROOMING

Grooming refers to either consolidating or segregating traffic to make more efficient use of the facilities. Consolidation means combining traffic from different locations onto one facility. In Figure 3-2, for example, fiber links from Node A to Node C and from Node B to Node C are both underutilized. Instead of connecting two fibers from A to D, traffic is consolidated along a single fiber toward Node D, maximizing utilization of facilities.

Segregation is the separation of traffic. For example, traffic from Node D must go to Nodes A and B. With existing systems, the cumbersome technique of back-hauling might be used to reduce the expense of repeated multiplexing and demultiplexing. Thus, traffic for Node B is carried past Node C toward Node A. The traffic for Node A is dropped and the traffic for Node B is routed back toward Node C using the excess capacity. It then reaches its final destination at Node B.

Grooming eliminates inefficient techniques like back-hauling. It is possible to groom traffic on asynchronous systems, however to do so requires expensive back-to-back configurations and manual DSX panels or electronic cross-connects. By contrast, a SONET system can segregate traffic at either an STS-1 or VT level to send it to the appropriate nodes.

Grooming can also provide segregation of services. For example, at an interconnect point, an incoming SONET line may contain different types of traffic, such as switched voice, data, or video. A SONET network can conveniently segregate the switched and non-switched traffic.

REDUCED BACK-TO-BACK MULTIPLEXING

The evolution of a fiber multiplex terminal is illustrated in Figure 3-3. Separate M13 multiplexers (DS-1 to DS-3) and FOTS terminals are used to multiplex a DS-1 signal to a DS-2, DS-2 to DS-3, and then DS-3 to an optical line rate. The next stage is a mechanically integrated fiber/multiplex terminal.

In the existing asynchronous format, care must be taken when routing circuits in order to avoid multiplexing and demultiplexing too many times since electronics (and their associated capital cost) are required every time a DS-1 signal is processed. With SONET, DS-1s can be multiplexed directly to the OC-n rate. Because of synchronization, an entire optical signal does not have to be demultiplexed, only the VT or STS signals that need to be accessed. (Refer to Figure 3-4.)

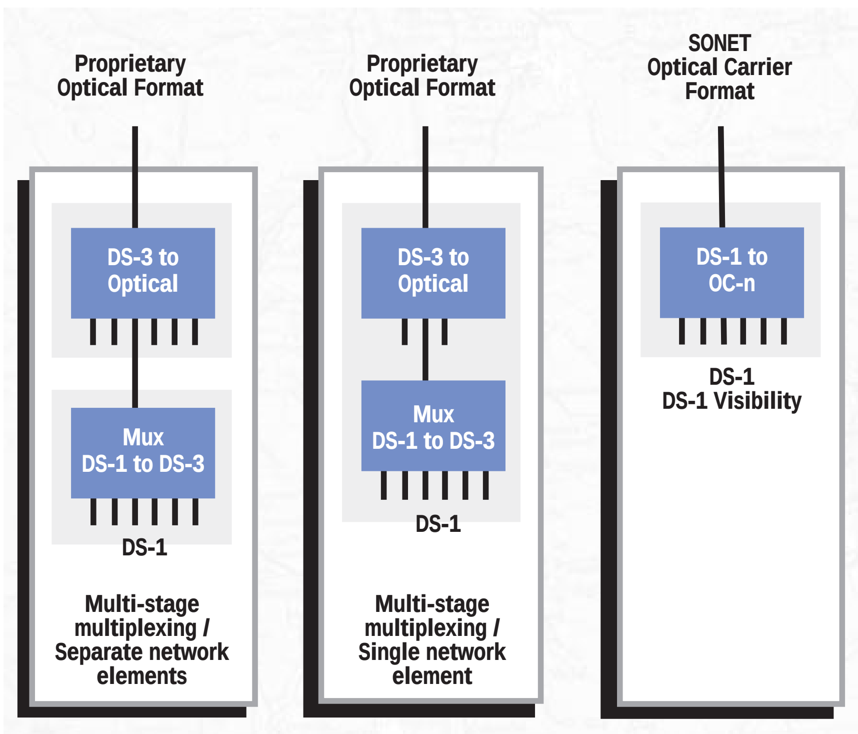


Figure 3-3 • Fiber Terminal Evolution

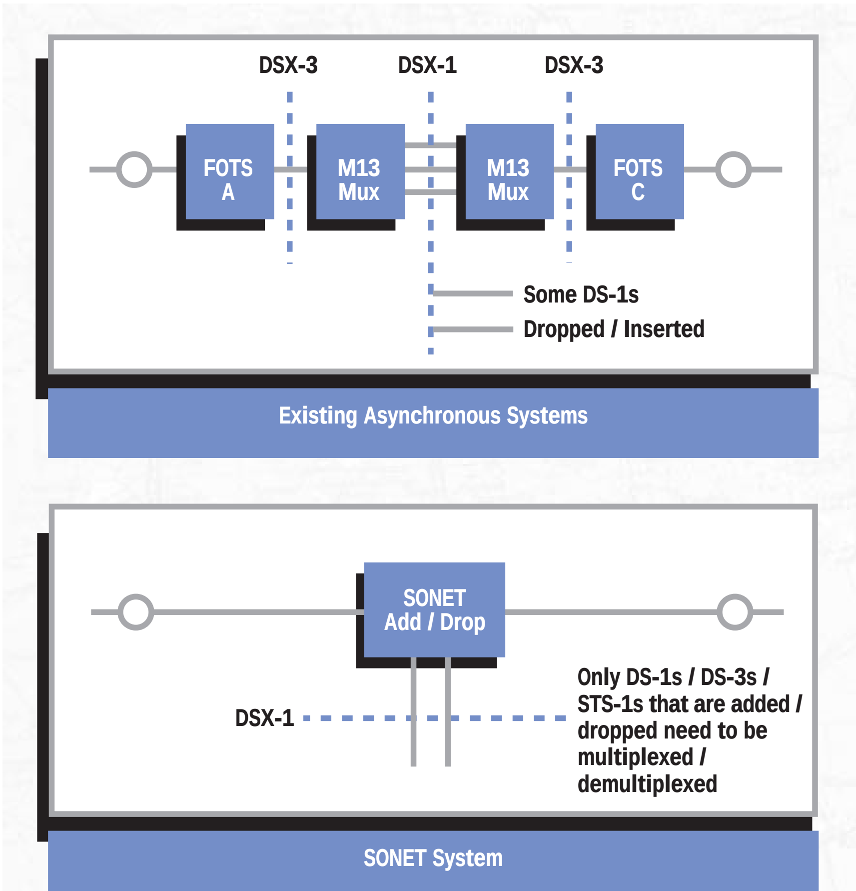


Figure 3-4 • Reduction of Back-to-Back Multiplexing

REDUCED CABLING AND ELIMINATION OF DSX PANELS

Asynchronous systems are dominated by back-to-back terminals because the asynchronous FOTS architecture is inefficient for other than point-to-point networks. (See Figure 3-5.) Excessive multiplexing and demultiplexing are used to transport a signal from one end to another, and many bays of DSX-1 cross-connect and DSX-3 panels are required to interconnect the systems. Associated expenses are the panel, bays, cabling, the labor installation, and the inconveniences of increased floor space and congested cable racks.

The corresponding SONET system allows a hub configuration, reducing the need for back-to-back terminals. Grooming is performed electronically so DSX panels are not used except when required to interface with existing asynchronous equipment.

ENHANCED OAM&P

SONET allows integrated network OAM&P, in accordance with the philosophy of single-ended maintenance. In other words, one connection can reach all network elements; separate links are not required for each network element. Remote provisioning provides centralized maintenance and reduced travel for maintenance personnel—which translates to expense savings.

Note: OAM&P is sometimes referred to as OA&M.

ENHANCED PERFORMANCE MONITORING

Substantial overhead information is provided in SONET to allow quicker troubleshooting and detection of failures before they degrade to serious levels.

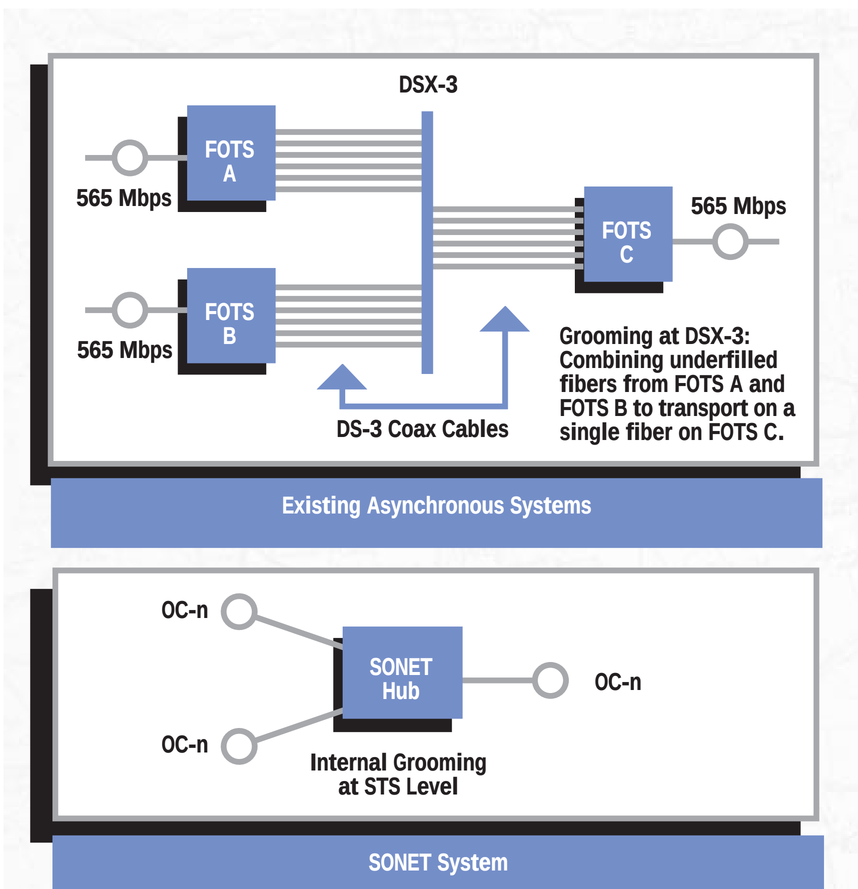


Figure 3-5 • Reduction of Cabling and DSX Panels

NEW SERVICES THAT USE ATM

One of the important benefits of SONET is its ability to position the network for carrying new revenue-generating services. With its modular, service-independent architecture, SONET provides vast capabilities in terms of services flexibility. High-speed packet-switched services, LAN transport, and high-definition television (HDTV) are examples of new SONET-supported services.

Many of these broadband services may use asynchronous transfer mode (ATM)— a fast-packet-switching technique using short, fixed-length packets called cells. Asynchronous transfer mode multiplexes the payload into cells that may be generated and routed as necessary. Because of the bandwidth capacity it offers, SONET is a logical carrier for ATM.

In principle, ATM is quite similar to other packet-switching techniques; however, the detail of ATM operation is somewhat different. Each ATM cell is made up of 53 octets, or bytes. Of these, 48 octets make up the user-information field and five octets make up the header. The cell header identifies the "virtual path" to be used in routing a cell through the network. The virtual path defines the connections through which the cell is routed to reach its destination.

An ATM-based network is bandwidth-transparent, which allows handling of a dynamically variable mixture of services at different bandwidths (see Figure 3-6). ATM also easily accommodates traffic of variable speeds. An example of a service that identifies the benefits of a variable-rate interface is that of a video codec-based service. The video signals can be coded into digital signals and packetized within ATM cells.

During periods of high activity within the video camera's field of view, the rate of packet transfer will increase. Hence, an average rate of transfer may take place below the maximum capacity of the physical layer. But during peaks in activity, the rate of packetization goes above the normal maximum.

The rate at which cells can be transmitted through the network is dependent upon the physical layer of the network used for transport of the cells. The interface rate presented to the user may vary between a minimum and a maximum rate. For periods of time, this maximum may be greater than the aggregate rate of the physical transport mechanism.

This is possible by buffering ATM cells at the user interface and transmitting them during periods of user inactivity. This method ensures much more efficient utilization of the bandwidth made available to the end user—hence, the adoption of ATM as the transfer mode for broadband ISDN and other broadband applications.

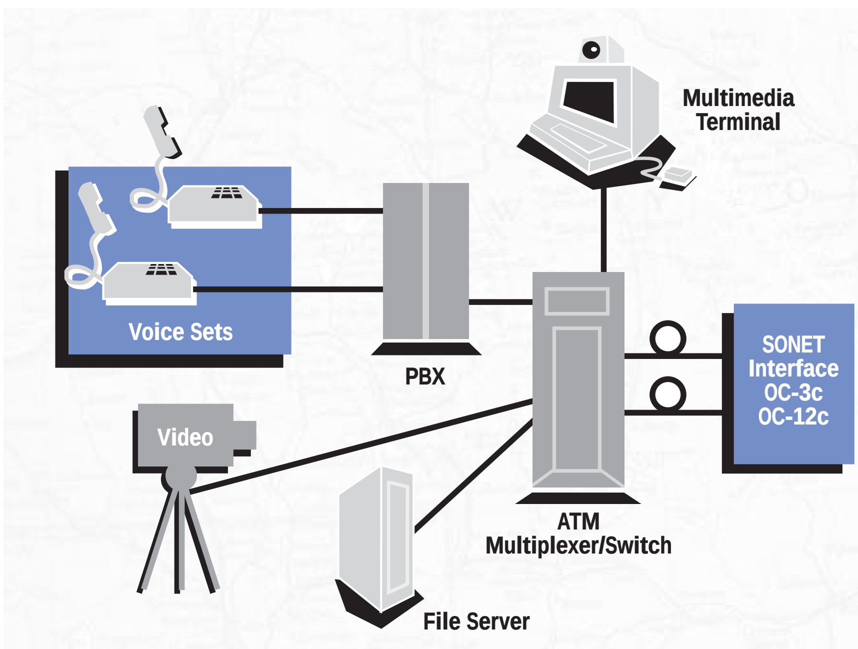


Figure 3-6 • ATM Network Handles Various Bandwidths/Services

OPTICAL INTERCONNECT

Because of different optical formats among vendors' asynchronous products, it is not possible to optically connect one vendor's fiber terminal to another. For example, one manufacturer may use 570 Mbps line rate; another 565 Mbps.

A major SONET value is that it allows mid-span meet with multi-vendor compatibility. See Figure 3-7. Today's SONET standards contain definitions for fiber-to-fiber interfaces at the physical (photonic) level. They determine the optical line rate, wavelength, power levels, pulse shapes, and coding. The current standards also fully define the frame structure, overhead, and payload mappings. Enhancements are being developed to define the messages in the overhead channels to provide increased OAM&P functionality.

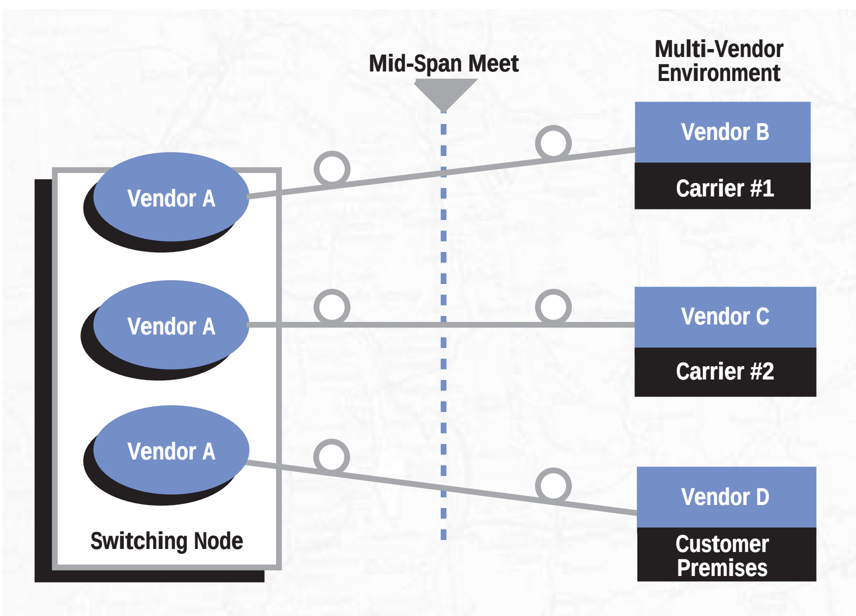


Figure 3-7 • Optical Interconnect

SONET allows optical interconnection between network providers regardless of who makes the equipment. The network provider can purchase one vendor's equipment and conveniently interface with other vendors' SONET equipment at either the different carrier locations or customer premises sites. Users may now obtain the OC-n equipment of their choice and meet with their network provider of choice at that OC-n level.

4
SONET OAM&P

OAM&P and network management are major concerns among network providers. Since the transmission network is continuously growing and there are many vendors and types of equipment, network providers must be able to administer, monitor, provision, and control the network from a central location. The Telecommunications Management Network (TMN) Standards Committee has agreed to an OAM&P architecture and is now formulating implementation standards for that architecture.

SONET improves network management by providing extra bandwidth and functionality in the overhead structure. It supports OAM&P data channels, enabling communications between intelligent controllers and individual network nodes as well as inter-node communications. These OAM&P channels are called data communications channels.

REMOTE PROVISIONING AND RECONFIGURATION

SONET allows circuits to be remotely enabled or disabled to carry or remove traffic. This flexibility allows the network to be dynamically reconfigured due to trouble situations (network restoration), traffic variations, or customer needs (like time-of-day service). Other benefits include: faster installation of circuits, which is important for special services needs; reduced need to dispatch personnel for circuit provisioning; and ease of reconfiguration, which makes the system more responsive to changes.

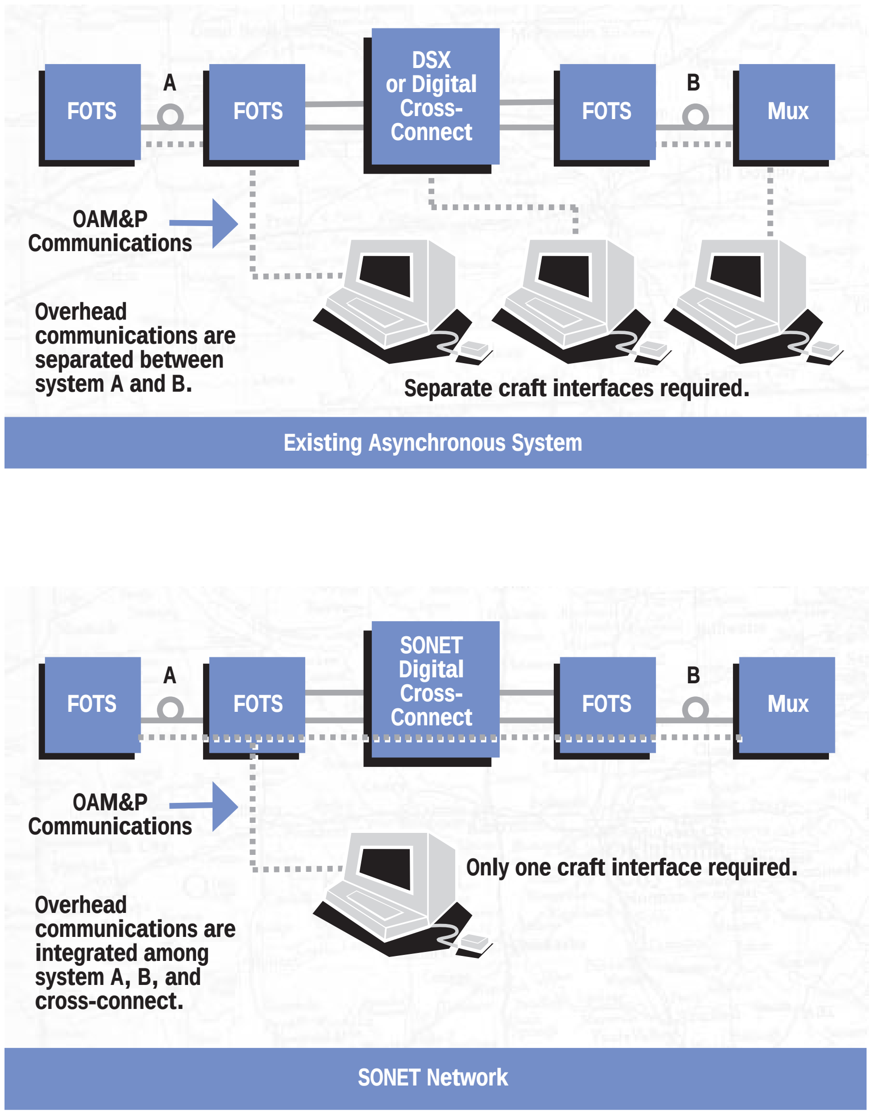


Figure 4-1 • SONET Integrated OAM&P

COMPATIBILITY WITH THE OS EVOLUTION

SONET supports the evolution of operations systems (OSs), such as those being developed by Bellcore. It supports the TMN's architecture for OAM&P data communications.

INTEGRATED OAM&P

In asynchronous networks:

- separate OSs are used to provide centralized single-ended maintenance
- a separate data link network is used to connect the OS to each NE
- OAM&P bandwidth and information are limited

To address these problems, SONET:

- makes OAM&P an integral part of the transmission standard by broadening bandwidth and information for OAM&P
- provides more operations-level information to simplify such activities as performance monitoring
- consists of an integral data communications/LAN network
- makes it easier to implement centralized OAM&P

Figure 4-1 illustrates one important element of integrated OAM&P. In asynchronous networks, there are many network elements provided by different vendors. The internal overhead channels for each system are not carried from one system to another. Typically, FOTS A and FOTS B behave as two separate systems. Thus, separate craft interfaces are needed to perform OAM&P functions, and overhead communications are not carried through the cross-connect.

In a SONET network, as long as the SONET signals are passed through, overhead communications are maintained from one system to the next. This philosophy, called "single-ended maintenance" permits an entire network to be controlled from a single network element.

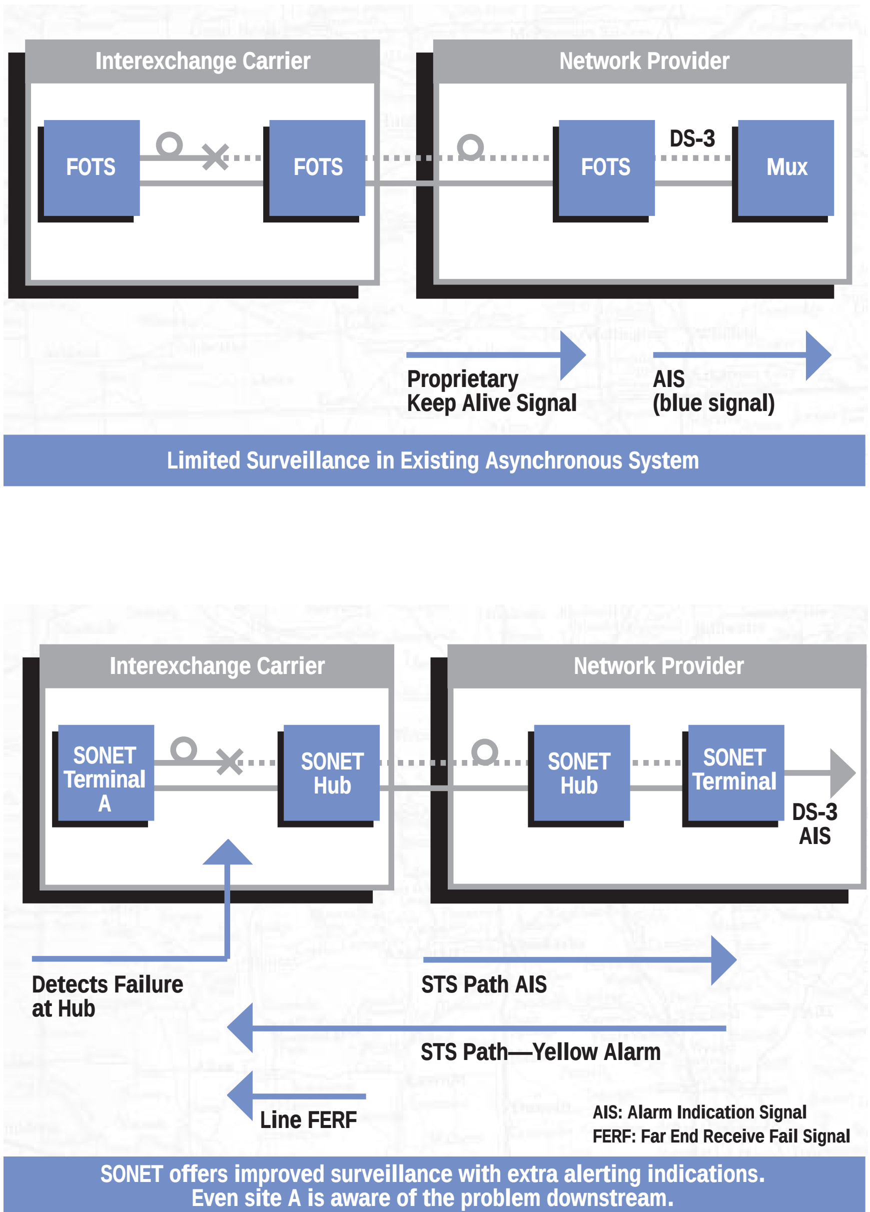


Figure 4-2 • Improved Surveillance

ENHANCED PERFORMANCE MONITORING

SONET overhead is organized into three layers defined as section, line, and path overhead. They provide abundant information for alarm surveillance and performance monitoring. Many bytes in the SONET overhead are allocated for Bit Interleave Parity-8 (BIP-8), a method of error monitoring. This BIP-8 is actually a byte (eight bits) which creates an even parity over a sequence of bits in the transmitting signal. A full set of performance monitoring statistics can be generated with the format, helping to locate degraded conditions before they become serious.

BIP-8 allows for sectionalization of alarms and single-ended maintenance. Performance information is available for all levels down to the VT path levels, which means parity error information is available for DS-1s on an end-to-end basis. At the VT level, performance monitoring is accomplished by a BIP-2. Present FOTS systems provide parity error information only for line rate and DS-3 rate.

An example of improved facility maintenance and surveillance appears at the bottom of Figure 4-2. In case of a failure indicated by an X in the diagram, an alarm indication signal (AIS) is sent to suppress downstream alarms. The terminal upstream at the left side (A) may be unaware that a failure has occurred. SONET provides extra information such as a yellow alarm indication signal at the path level from the far end terminal to site A. In addition, a far-end receive failure (FERF) signal at the line layer overhead is sent from the hub detecting the failure to tell site A that a failure has occurred downstream.

With SONET's enhanced performance monitoring and surveillance, the time it takes to restore service is reduced. Also, fewer maintenance actions are required since faults can be more easily sectionalized. Added to this are the advantages of SONET's built-in data communications networking.

TELECOMMUNICATIONS MANAGEMENT NETWORK (TMN) ARCHITECTURE

The architecture for OAM&P communications as defined by the International Telecommunications Union, an agency of the United Nations, is shown in Figure 4-3. It provides a framework for an OS to communicate with the network and vice versa. An OS is a sophisticated application software that manages the whole network.

An OS can gather information from the network, as well as from alarm, status, and performance statistics. It can also perform remote-circuit testing or network-administration tasks. An OS may also contain information on facilities available for provisioning and may be used to provision by sending remote-control commands to enable or disable circuits.

The OS communicates with the network elements either directly or through mediation devices. Mediation devices can support multiple functions such as consolidation of communication links to the various network elements at the same location, conversion of protocols back and forth, and management of performance monitoring data.

The advantage of SONET is that the data communication channel can be used as part of the Data Communications Network, as shown in the TMN's architecture.

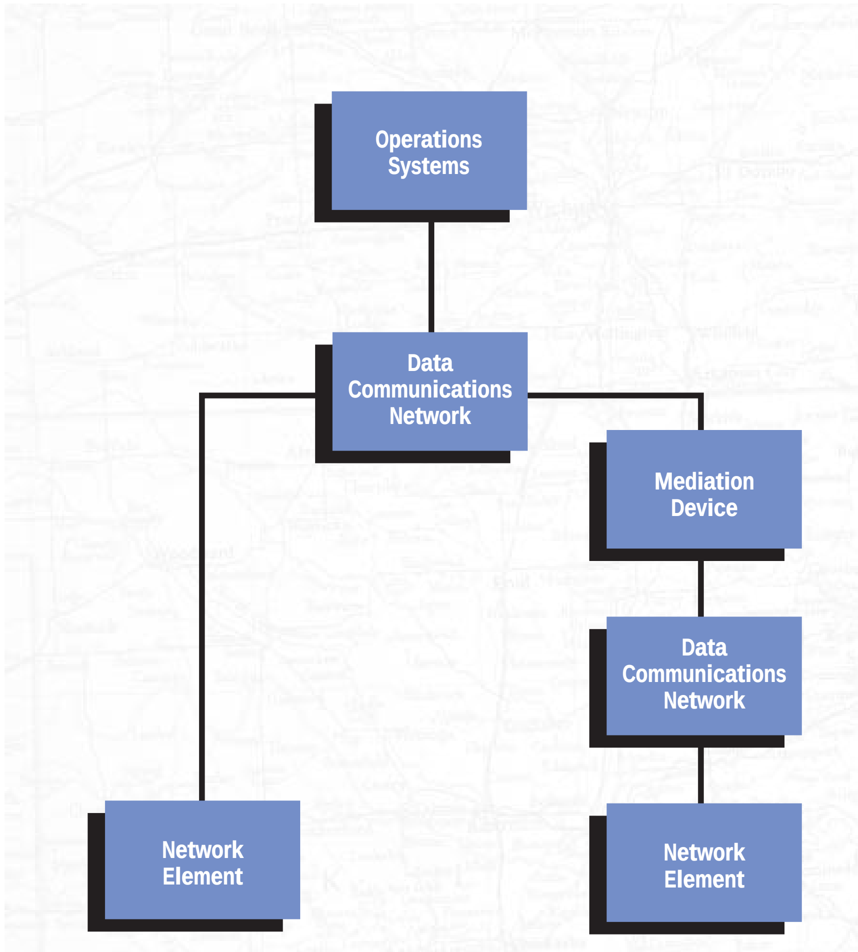


Figure 4-3 • Telecommunications Management Network OAM&P Communications

5

SONET Networking

SONET NETWORKING TRENDS

Increases in demand for services such as non-switched private lines mean more and more T1 multiplexers (intelligent channel banks) are being deployed by large end users. Some are now implementing T3 (DS-3) fiber services to meet these demands.

ISDN and Broadband ISDN will allow a multitude of new services to provide bandwidth on demand. Users of an integrated services network, which offers voice, data, and video onto a single network, have new requirements including variable bandwidth, high bandwidth, user control, measurement of traffic performance, and rapid service provisioning. To provide the necessary bandwidth, fiber has been deployed increasingly in the access area (connections between a service provider's node and the user).

THE TRADITIONAL NETWORK

Figures 5-1 and 5-2 illustrate the way a traditional network appears. Traditional networks can be divided into two main areas—access and inter-node.

The inter-node network consists of trunks used to interconnect service-provider nodes or to connect those nodes with inter-exchange carrier locations. Fiber routes consist of point-to-point systems with cross-connections at the DSX-3 panel. The fiber system is symmetrical with one terminal end of the system a mirror image of the other. DS-3s enter at one end, leave at the other, and occasionally may be accessed at intermediate drop/insert sites. Current deployments are SONET fiber terminals configured as point-to-point, ring, or 1:n systems.

The access network (local loop) is mostly composed of twisted copper pairs connecting a switch to a telephone or other terminating equipment. In some areas, T1 lines or fiber are used to connect a switch to a remote (digital loop carrier) terminal (such as the Northern Telecom DMS-1 URBAN). The digital loop carrier (DLC) terminal in turn connects copper pairs to the individual users in a carrier serving area (CSA).

SONET next-generation digital loop carriers (NGDLCs), such as Northern Telecom's S/DMS AccessNode, are being deployed today. NGDLCs combine the access functionality available from DS-0s with SONET transmission capabilities from DS-1 through OC-n.

The transport network is evolving towards a multi-point architecture and SONET enables new configurations to support this evolution. SONET add/drop multiplex and hub configurations can provide efficient traffic management capabilities, both in the inter-node and access environments.

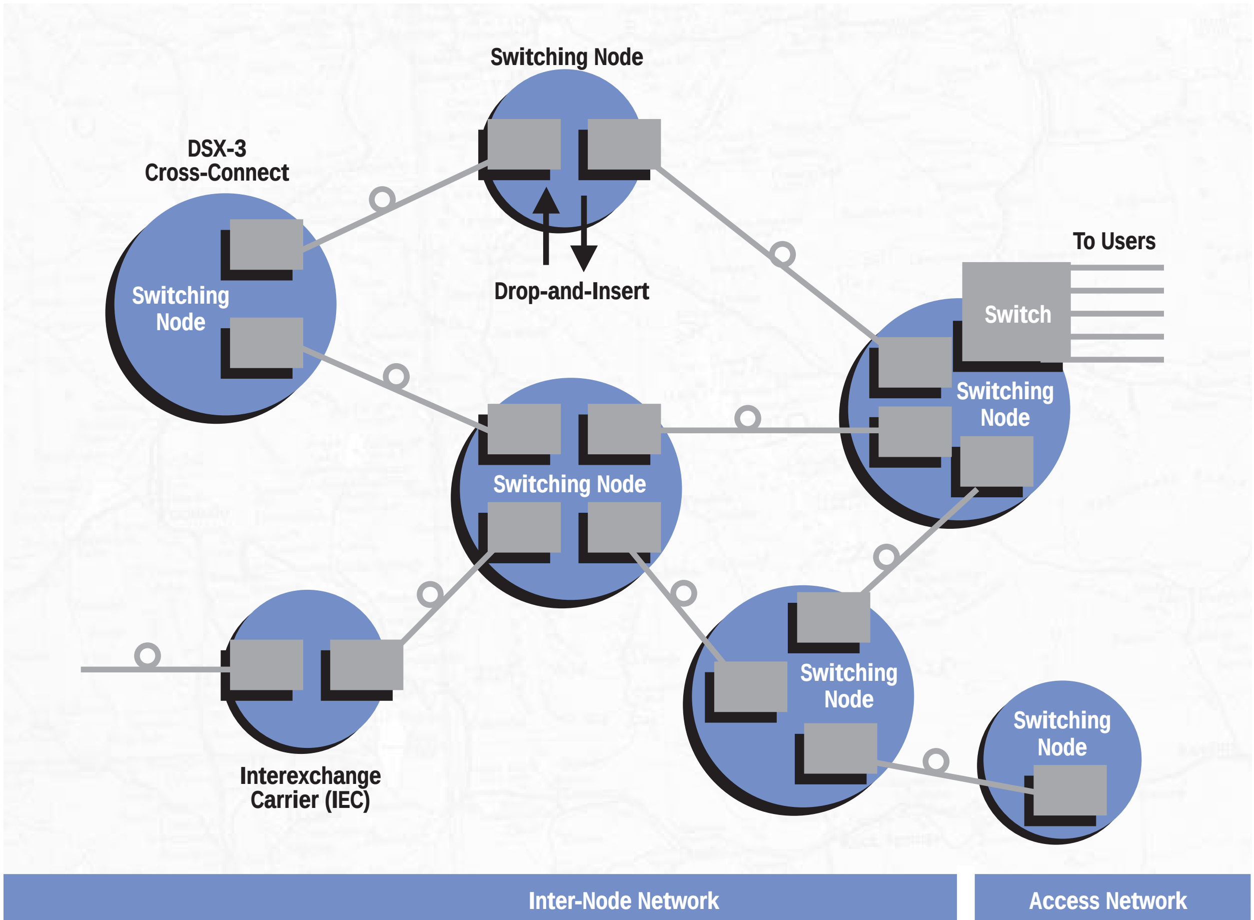


Figure 5-1 • Traditional Inter-Node Network

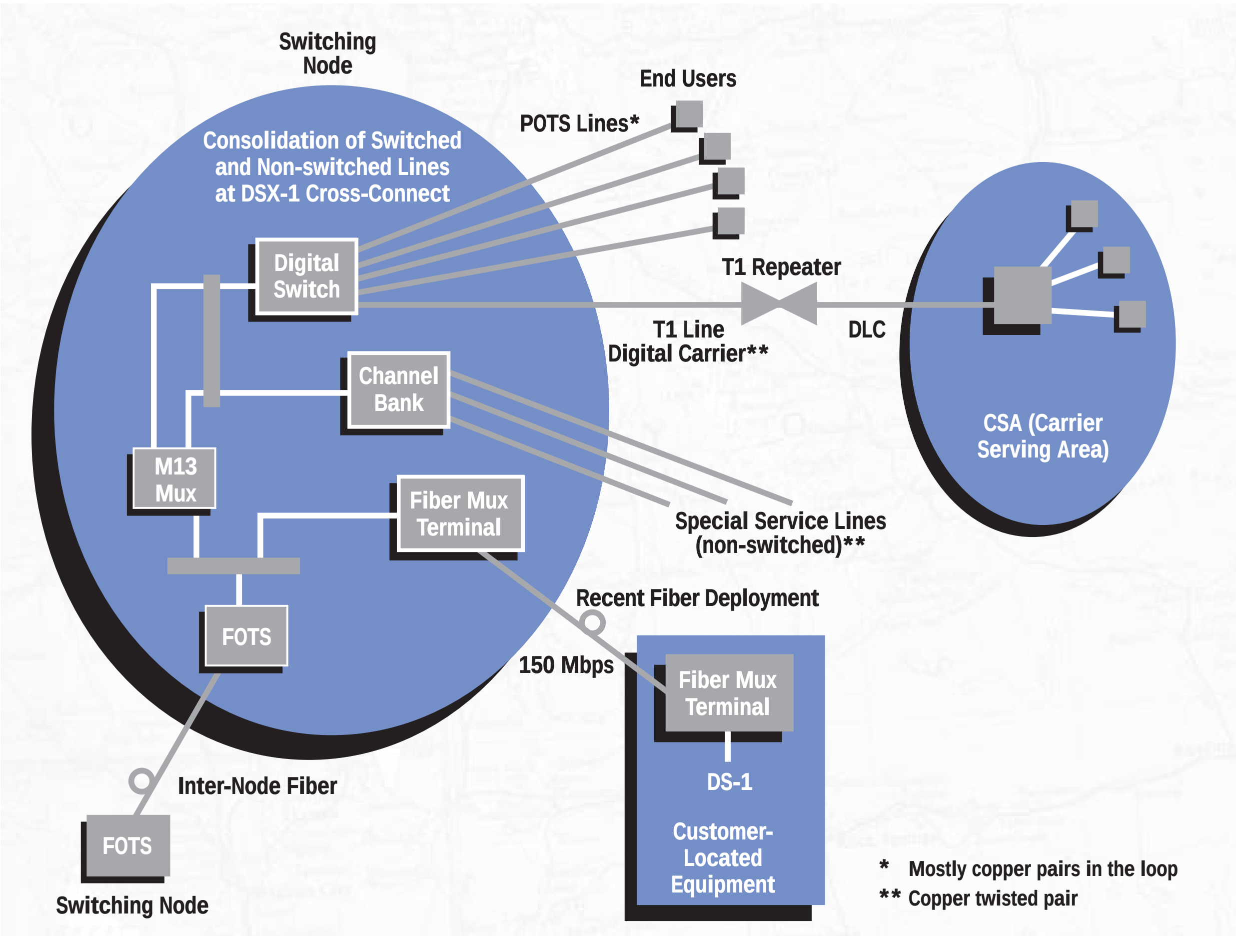


Figure 5-2 • Traditional Access Network

Enhanced Survivability/Bidirectional Line-Switched Rings

Network survivability is another important trend. Survivable rings and route diversity are cost-effective solutions for the metropolitan environment. SONET can implement with higher efficiency the restoration schemes already in place with asynchronous systems. These include 1 + 1 diverse routing, self-healing rings, and digital cross-connects.

SONET-based bidirectional line-switched rings (BLSRs) provide "re-useable bandwidth" for more efficient inter-node transport in "meshed" networks. A meshed network means the traffic is more or less evenly distributed among all the nodes rather than being funneled through a few hubbing locations.

When a traffic tributary is dropped off at one node in a BLSR, the leftover capacity becomes available for "re-use" to pick up traffic originating at that node. If there is no new traffic, the tributary continues to another node, where it can pick up traffic originating at that location.

Half the available bandwidth in a BLSR is allocated as a working route, and the other half is reserved for protection routing. Thus, in an OC-48 application, working traffic is placed in the first 24 STS-1 time-slots, with time-slots 25 through 48 serving as the protection facility.

SONET supports both BLSRs for inter-node networks and unidirectional path-switched rings (UPSRs) used in access networks.

SONET can be easily deployed in the inter-node network since it is compatible with DS-3, a signal on which existing asynchronous fiber transport systems are based. (See Figure 5-3.)

A network provider can begin deploying SONET whenever existing asynchronous systems exhaust their current optical channel capacity. The initial advantage is to provide synchronous transport of the existing DS-3 or even DS-1 traffic and to simplify grooming.

The simplest implementation strategy begins by deploying SONET point-to-point systems. As the network evolves, hubs are added to the network for grooming or restoration. These may be SONET add/drop multiplexers or SONET hubs. As more SONET network elements are added, the network becomes more and more integrated and homogenous in terms of control and OAM&P features.

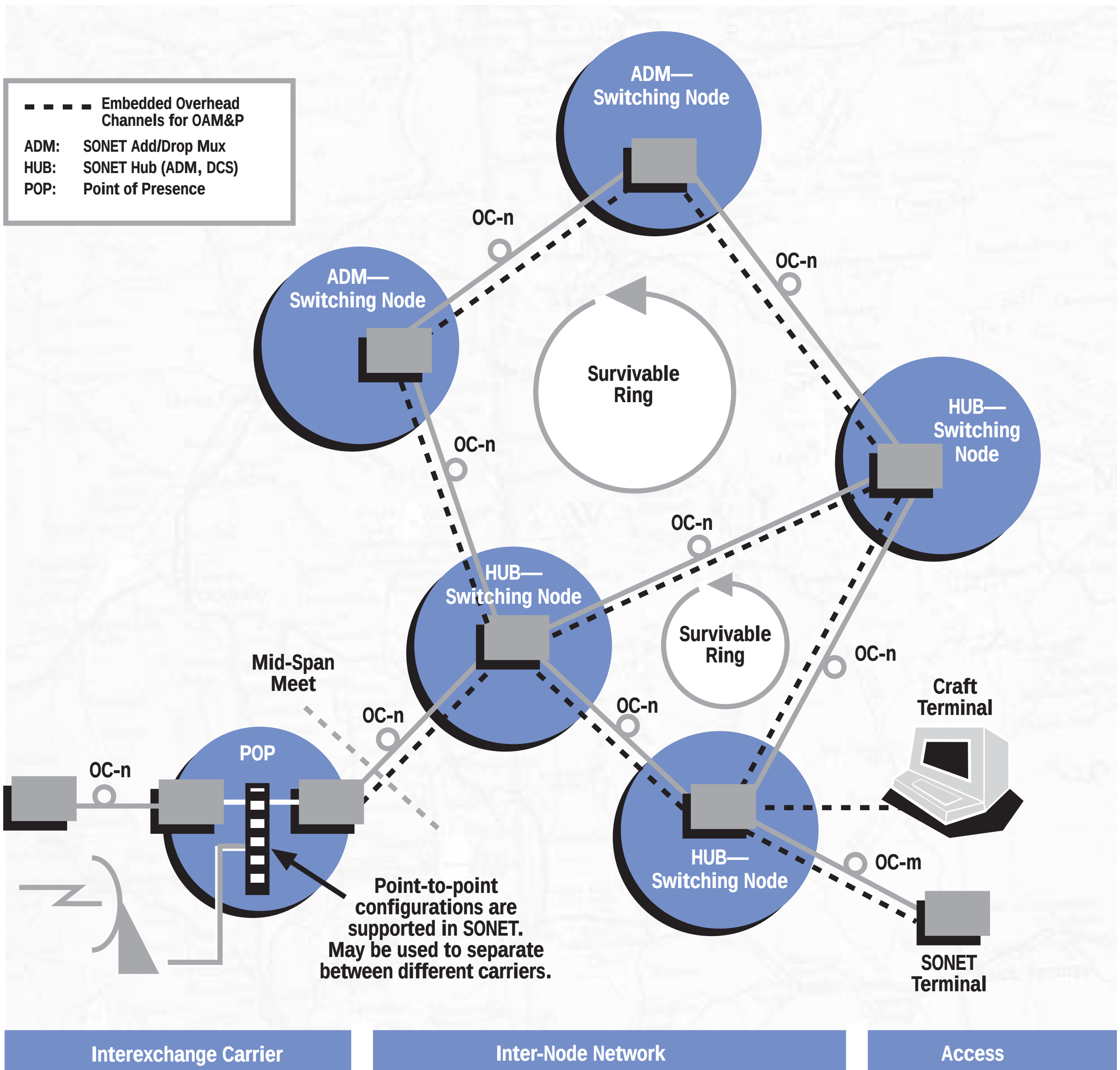


Figure 5-3 • SONET Inter-Node Network

Local Inter-Node Deployment Example

Figure 5-4 illustrates how SONET can penetrate the local inter-node network. The encircled area is the urban core—an area that could deploy SONET first because of growth in the core area, exhausted capacity in the current optical channels, and T1 modernization programs. Here, SONET allows inter-node trunking with room for further growth.

In the longer term, SONET deployment can expand to suburban and rural switching nodes. Hub topologies become common as circuits are consolidated to route towards the core area. SONET add/drop multiplexers are used along the way to pick up or drop off traffic.

Long-Haul Deployment Example

Figure 5-5 depicts a typical SONET network for inter-exchange carrier applications. A long-haul SONET network deploys an OC-n high-speed transport overlaying an existing asynchronous network, using a 565 Mbps FOTS. The main SONET network elements are the SONET add/drop multiplexer used in terminal and repeater configuration and the SONET broadband cross-connect used for traffic management.

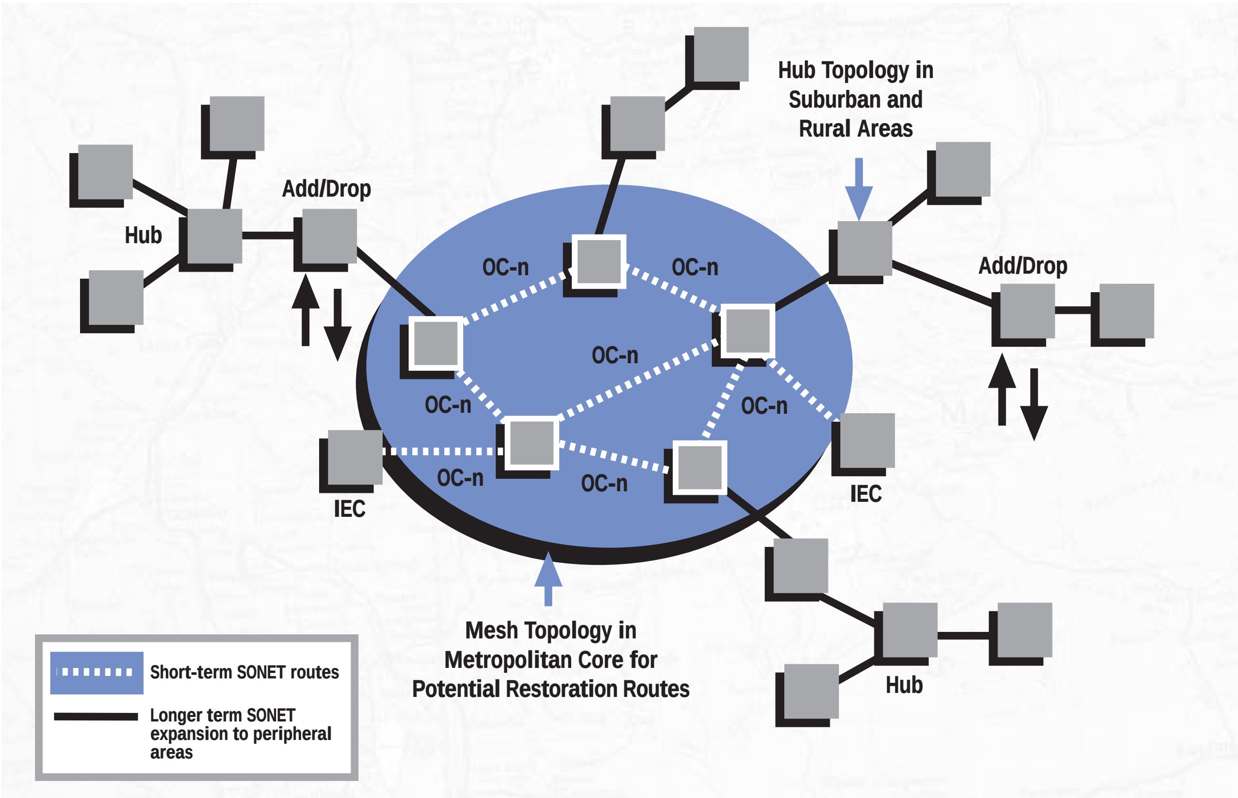


Figure 5-4 • Local Inter-Node SONET Deployment

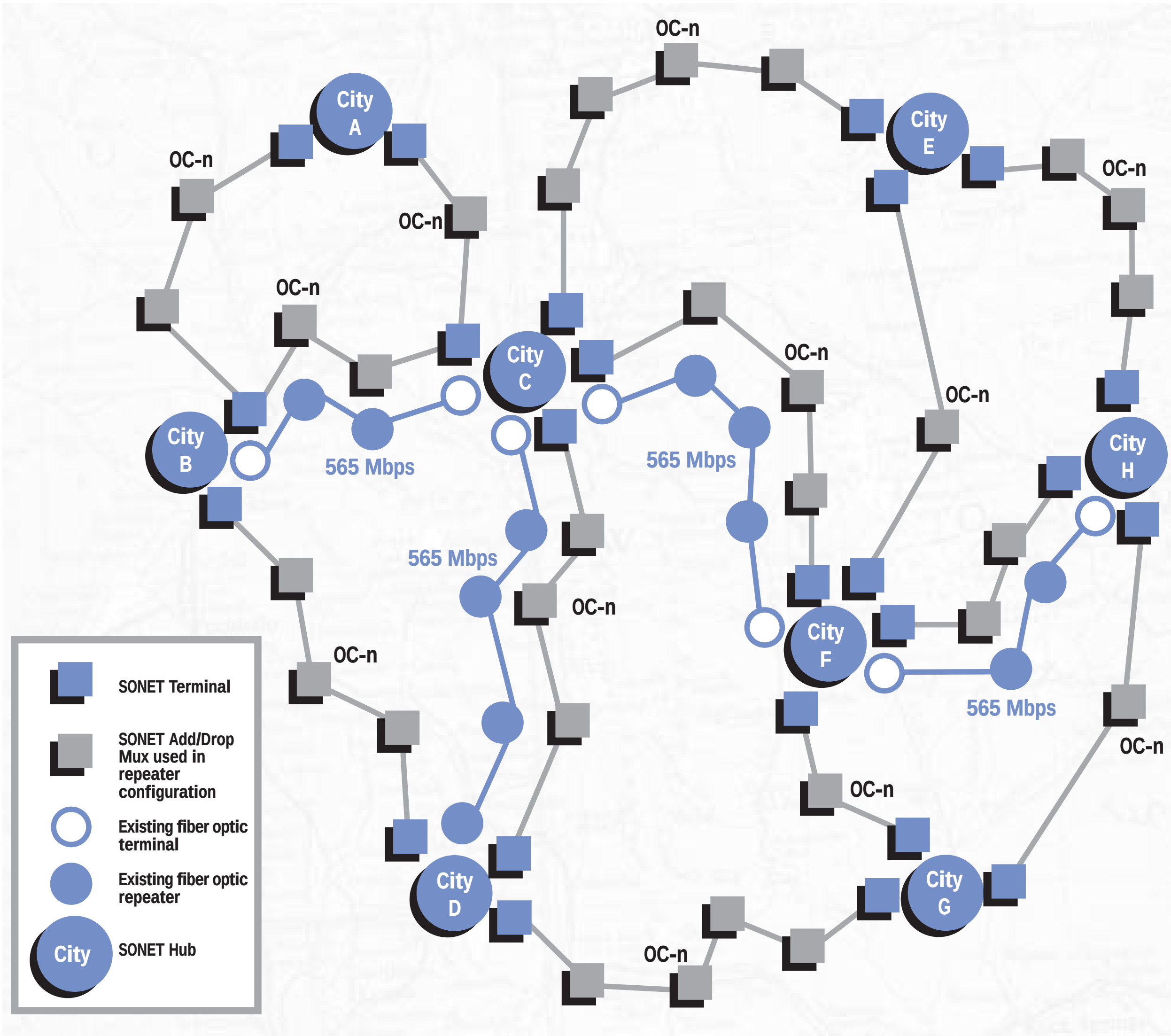


Figure 5-5 • Long-Haul SONET Deployment (Overlay on Existing 565-Mbps Network)

DEPLOYMENT OF SONET IN THE ACCESS NETWORK

As shown in Figures 5-6 and 5-7, SONET can be deployed in the access network, particularly where new fiber is being installed and/or existing routes are being exhausted, to provide new networking capabilities and transport of new services. Different application scenarios are described below:

Simple Point-to-Point

A point-to-point application is relatively simple to implement. Instead of a pair-gain link such as twisted pair copper, fiber is used to connect a control terminal from a switching node switch to a remote terminal. SONET will transport multiple DS-1s to the CSA with plenty of room for growth. The overhead channel links all systems together for integrated OAM&P.

Add/Drop Application

The SONET system transports traffic from the switching node to a terminal at a CSA or customer premises location. To pick up or drop off additional traffic, intermediate SONET add/drop multiplexers are used for CSAs located along the way. ADMs could also be connected in a closed OC-n loop to provide a survivable ring topology.

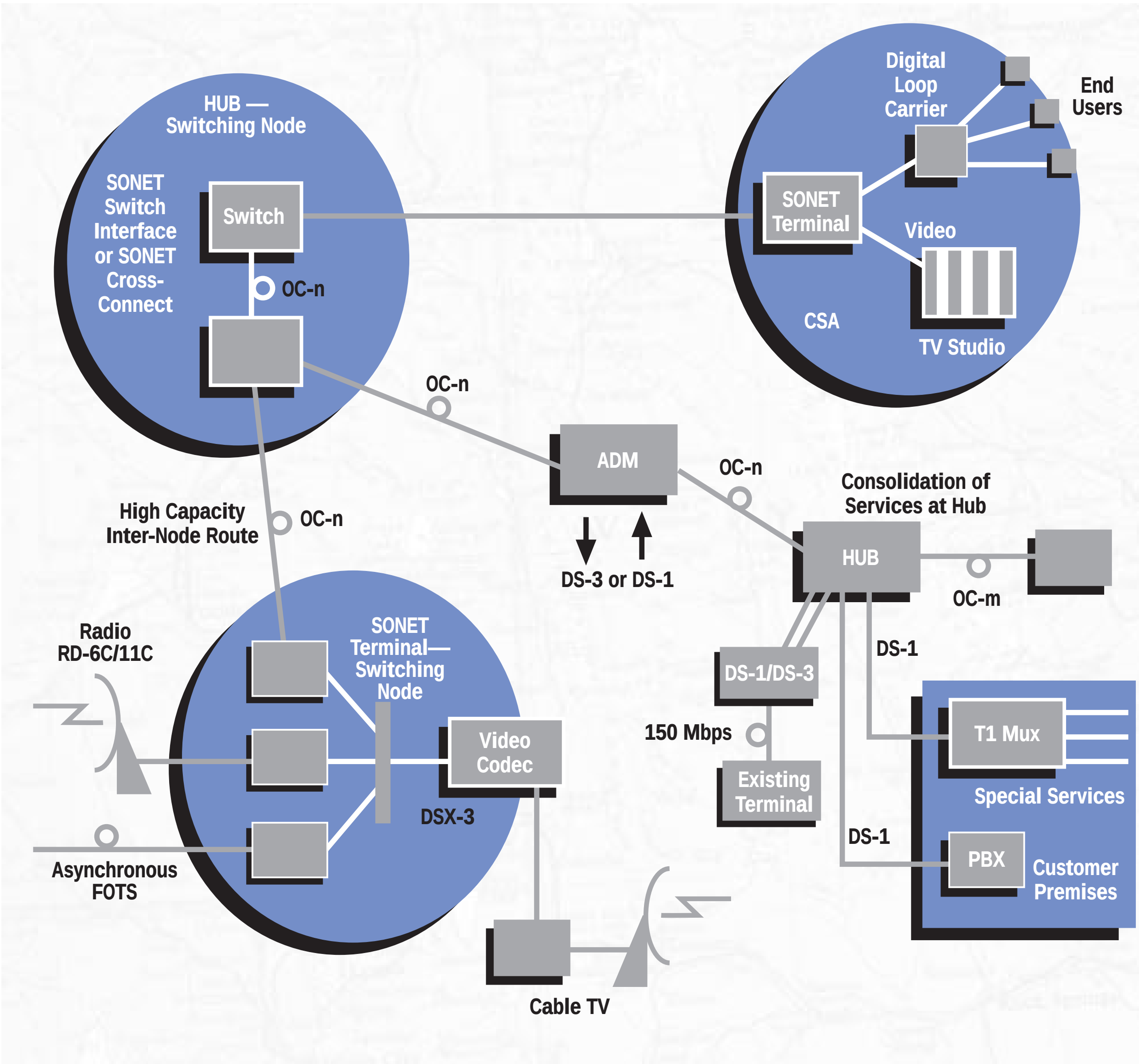


Figure 5-6 • SONET Access Network

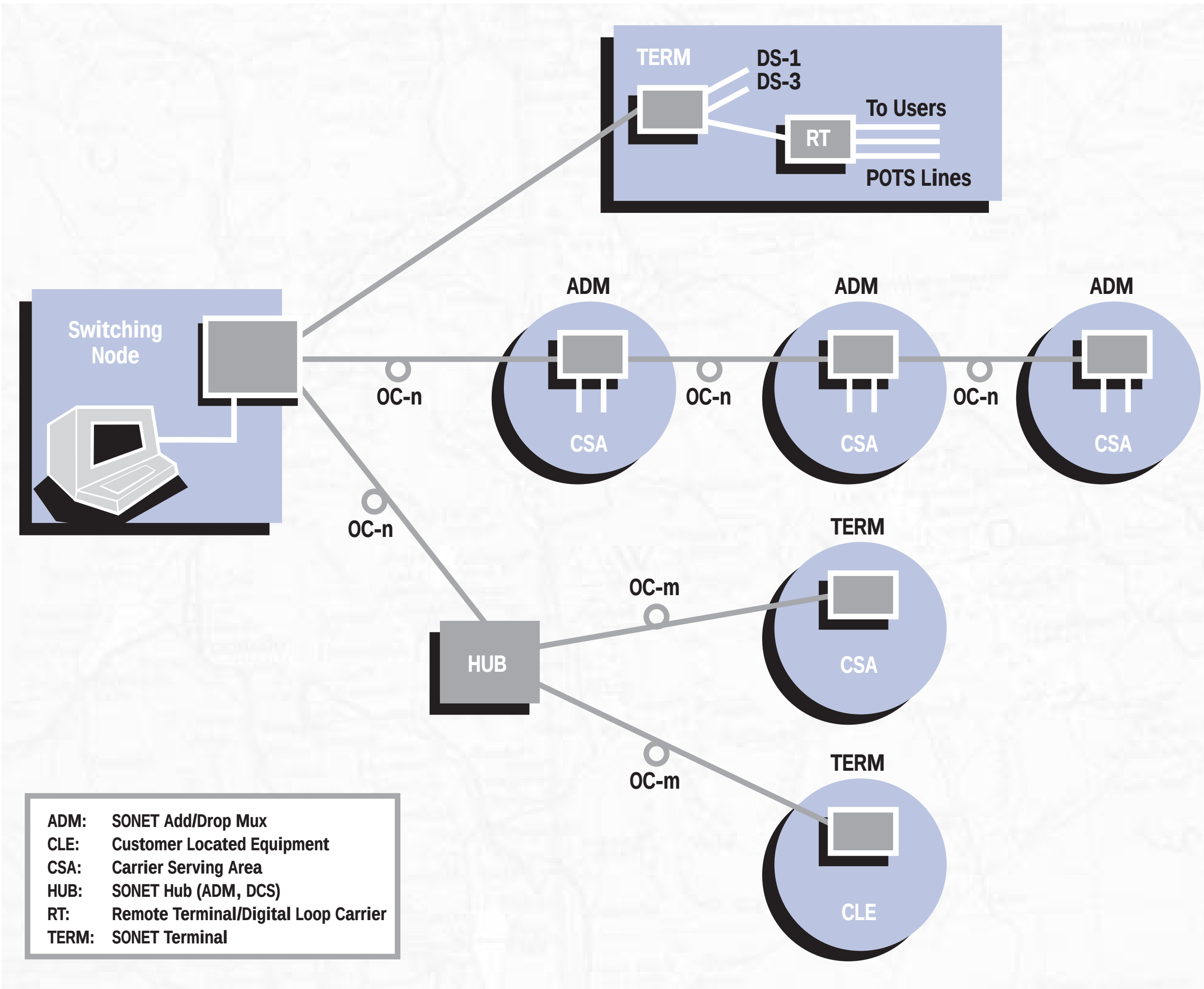


Figure 5-7 • SONET Access Applications

Hub Application

Underfilled fibers feed into a SONET hub which consolidates the traffic onto one fiber for transport to the switching node. At the switching node, the traffic is segregated into switched and non-switched (special service dedicated lines), DS-1 and DS-3, or any combination thereof.

ATM Interconnect

SONET enables network providers, including telephone companies or other service providers, to efficiently deliver wideband and broadband service to their business customers. With an ATM multiplexer or switch deployed at the provider location, DS-1, DS-3, and OC-3 bandwidths can be delivered directly to business customers' locations.

The ATM device can interface transport products offered by several vendors. Narrowband service, such as ISDN, can be delivered on various NGDLC access products using an OC-3 or OC-12 feed to the host switching node.

6
Synchronous Digital Hierarchy

A WORLD STANDARD OF SYNCHRONIZATION

Following ANSI's development of the SONET standard, the CCITT undertook to define a synchronization standard that would address interworking between the European and North American transmission hierarchies. That effort culminated in 1989 with CCITT's publication of the Synchronous Digital Hierarchy (SDH) standards. Synchronous Digital Hierarchy is a world standard, and as such, SONET can be considered a subset of SDH.

Transmission standards in North America and Europe evolved from different basic-rate signals in the non-synchronous hierarchy. Time Division Multiplexing (TDM) in North America combines twenty four 64-kbps channels (DS-0s) into one 1.54-Mbps DS-1 signal. European TDM multiplexes thirty-two 64-kbps channels (E-0s) into one 2.048 Mbps E-1 (CEPT format) signal. (The European standard has become common in many parts of the world.) Figure 6-1 compares the North American and European non-synchronous transmission hierarchies.

Figure 6-1 • Non-Synchronous Hierarchies

North American Rate			European Rate		
Signal	Speed	Channels	Signal	Speed	Channels
DS-0	64 kbps	1 DS-0	E-0	64 kbps	1 E-0
DS-1	1.54 Mbps	24 DS-0s	E-1	2.048 Mbps	32 E-0s
DS-2	6.3 Mbps	96 DS-0s	E-2	8.45 Mbps	128 E-0s
DS-3	44.8 Mbps	28 DS-1s	E-3	34 Mbps	16 E-1s
not defined			E-4	140 Mbps	64 E-1s

The issues between North American and CCITT standards-makers involved how to efficiently accommodate both the 1.5-Mbps and the 2-Mbps non-synchronous hierarchies in a single synchronization standard. The agreement reached specified a basic transmission rate of 51 Mbps for SONET and a basic rate of 155 Mbps for SDH.

Convergence of European and North American Hierarchies

SONET and SDH converge at SDH's 155-Mbps base level, defined as STM-1 or "Synchronous Transport Module-1." The base level for SONET is STS-1 (or OC-1) and is equivalent to 51.84 Mbps. Thus, SDH's STM-1 is equivalent to SONET's STS-3 (3 x 51.84 Mbps = 155.5 Mbps). Higher SDH rates of STM-4 (622 Mbps), STM-16 (2.4 Gbps), and STM-64 (9.9 Gbps) have also been defined. Figure 6-2 compares the transmission hierarchies of SONET and SDH.

Figure 6-2 • SONET/SDH Hierarchies

SONET	Bit Rate	SDH
STS-1 / OC-1	51.84 Mbps	—
STS-3 / OC-3	155.52 Mbps	STM-1
STS-12 / OC-12	622.08 Mbps	STM-4
STS-24 / OC-24	1244.16 Mbps	—
STS-48 / OC-48	2488.32 Mbps	STM-16
STS-192 / OC-192	9953.28 Mbps	STM-64

Multiplexing is accomplished by combining—or interleaving—multiple lower-order signals (1.5 Mbps, 2 Mbps, etc.) into higher-speed circuits (51 Mbps, 155 Mbps, etc.). By changing the SONET standard from bit-interleaving to byte-interleaving, it became possible for SDH to accommodate both the European and North American transmission hierarchies. This modification allows an STM-1 signal to carry multiple 1.5-Mbps or 2-Mbps signals—and multiple STM signals to be aggregated to carry higher orders of SONET or SDH tributaries.

Asynchronous and Synchronous Tributaries

SDH does away with a number of the lower multiplexing levels, allowing non-synchronous 2-Mbps tributaries to be multiplexed to the STM-1 level in a single step. SDH recommendations define methods of subdividing the payload area of an STM-1 frame in various ways so that it can carry combinations of synchronous and asynchronous tributaries. Using this method, synchronous transmission systems can accommodate signals generated by equipment operating from various levels of the non-synchronous hierarchy.

ANSI, CCITT, and the European Transmission Standards Institute (ETSI) continue to collaborate on SDH-SONET interworking. Areas of ongoing study for SDH-SONET products include market requirements, standards alignment and compatibility, and global standardization.

7
Contributions to SONET

SONET standardization efforts have been underway since 1985, mainly from the T1X1 subcommittee of the ECSA. Northern Telecom has helped define the fundamental concepts of payload, pointers, and STS-1 format, all of which form the backbone of the SONET standard. They are briefly explained below:

- Payload: an envelope used to transport signals of many types, giving SONET inherent flexibility to accommodate DS-1, DS-2, DS-3, video, broadband data, or any future services.
- Payload pointers: used for frequency justification in order to maintain synchronization without requiring huge buffers. They allow payloads to be concatenated, permitting SONET to also transport bandwidth signals greater than 50 Mbps.
- The STS-1 base format: provides flexible signal transport with sufficient overhead for OAM&P surveillance, performance monitoring, and communication channels.
- Network strategy and protocol proposals for efficient use of OAM&P data channels: recommendations helped define usage commands to communicate alarms, controls, and performance information at both system and network (inter-system) levels.
- Rationalization of section, line, and path performance monitoring to meet future network objectives: selecting and determining the right thresholds for achieving desired quality of service levels.
- Determination of alarm and control methods.
- Automatic protection switching: helped define usage and implementation of the protection bytes in the SONET overhead.
- Optical interfaces: proposals to the EIA (Electronics Industry Association) in the areas of central wavelength, reflection penalty, and spectral width measurements to account for mode partition noise.

Working in close consultation with Bellcore, network providers, carriers, and end users, Northern Telecom has also become the first supplier to offer a comprehensive SONET-based solution to networking.

The S/DMS Product Family implements the full power of SONET, not just the basic SONET interface standards. S/DMS products have built-in capabilities to ensure the full value of SONET can be realized in future networks. More information on the full family of products and Northern Telecom's vision can be obtained from the supplier.

8 List of Terms

AIS (Alarm Indicating Signal)—A code sent downstream indicating an upstream failure has occurred.

ANSI (American National Standards Institute)—A membership organization which develops U.S. industry standards and coordinates U.S. participation in the International Standards Organization (ISO).

Asynchronous—A network where transmission system payloads are not synchronized and each network terminal runs on its own clock.

ATM (Asynchronous Transfer Mode)—A type of multiplexing which Broadband ISDN will use, where payload is multiplexed into cells.

Backhauling—Cumbersome traffic management technique used to reduce expense of multiplexing/demultiplexing.

BIP-8 (Bit Interleaved Parity-8)—A method of error checking in SONET which allows a full set of performance statistics to be generated.

BISDN (Broadband Integrated Services Digital Network)—A single ISDN network which can handle voice, data, and eventually video services.

Bit Stuffing—In asynchronous systems, a technique used to synchronize asynchronous signals to a common rate before multiplexing.

Broadband—Services requiring 50-600 Mbps transport capacity.

CCITT—The technical organs of the United Nations specialized agency for telecommunications, now the International Telecommunications Union. They function through international committees of telephone administrations and private operating agencies.

CEPT—European Conference of Postal and Telecommunications Administrations. The CEPT format defines the 2.048-Mbps European T1/E-1 signal made up of 32 voice-frequency channels.

Concatenated—The linking together of various data structures, for example two bandwidths joined to form a single bandwidth.

Concatenated STS-1—A Synchronous Transport Signal (STS-NC), composed of n STS-1s combined. It is used to transport signals that do not fit into an STS-1 (51 Mbps) payload.

Concatenated VT—A virtual tributary (VT x Nc) which is composed of N x VTs combined. Its payload is transported as a single entity rather than separate signals.

Data Communications Channels—OAM&P channels in SONET that enable communications between intelligent controllers and individual network nodes as well as inter-node communications.

ECSA (Exchange Carrier Standards Association)—An organization that specifies telecommunications standards for ANSI.

EIA (Electronics Industry Association)

FERF (Far End Receive Failure)—A signal to indicate to the transmit site that a failure has occurred at the receive site.

FCOT (Fiber Central Office Terminal)—A generic term for fiber terminal which can be configured either fully digital, fully analog, or mixed.

FOTS (Fiber Optic Transmission System)

Grooming—Consolidating or segregating traffic for efficiency.

Interleave—The ability of SONET to mix together and transport different types of input signals in an efficient manner, thus allowing higher-transmission rates.

ISDN (Integrated Services Digital Network)—An international telecommunications network standard that provides end-to-end digital connections for both voice and non-voice service.

Jitter—Short waveform variations caused by vibration, voltage fluctuations, control system instability, etc.

Line—A transmission medium with equipment at both ends used to transport information between two network elements.

Mesochronous—A network whereby all nodes are timed to a single clock source, thus all timing is exactly the same (truly synchronous).

Narrowband—Services requiring up to 1.5 Mbps transport capacity.

NE (Network Elements)—In SONET, the five basic network elements are add/drop multiplexer, broadband digital cross-connect, wideband digital cross-connect, digital loop carrier, and switch interface.

OAM—Operations, Administration, and Maintenance. Also called OAM&P.

OAM&P (Operations, Administration, Maintenance, and Provisioning)—Provides the facilities and personnel required to manage a network.

OC-1 (Optical Carrier Level 1)—The optical equivalent of an STS-1 signal.

OC-n (Optical Carrier Level n)—The optical equivalent of an STS-n signal.

Orderwire—A channel used by installers to expedite the provisioning of lines.

OS (Operations System)—Sophisticated applications software that overlooks the entire network.

OSI Seven-Layer Model—A standard architecture for data communications. Layers define hardware and software required for multi-vendor information processing equipment to be mutually compatible. The seven layers from lowest to highest are: physical, link, network, transport, session, presentation, and application.

Overhead—Extra bits in a digital stream used to carry information besides traffic signals. Orderwire, for example, would be considered overhead information.

Packet Switching—An efficient method for breaking down and handling high-volume traffic in a network.

Path—A logical connection between a point where an STS or VT is multiplexed to the point where it is demultiplexed.

Payload—The portion of the SONET signal available to carry service signals such as DS-1, DS-2, and DS-3.

Payload Pointers—Indicates the beginning of the synchronous payload envelope.

Photonic—The basic unit of light transmission used to define the lowest (physical) layer in the OSI seven-layer model.

Plesiochronous—A network with nodes timed by separate clock sources with almost the same timing.

Poll—An individual control message from a central controller to an individual station on a multipoint network inviting that station to send.

POP (Point-of-Presence)—A point in the network where inter-exchange carrier facilities like DS-3 or OC-n meet with access facilities managed by telephone companies or other service providers.

SDH (Synchronous Digital Hierarchy)—The CCITT-defined world standard of synchronization whose base transmission level is 155 Mbps (STM-1) and is equivalent to SONET's STS-3 or OC-3 transmission rate. SDH standards were published in 1989 to address interworking between the European and North American transmission hierarchies.

Section—An optical span and its equipment.

Slip—An overflow (deletion) or underflow (repetition) of one frame of a signal in a receiving buffer.

SONET (Synchronous Optical Network)—A standard for optical transport that defines optical carrier levels and their electrically equivalent synchronous transport signals. SONET allows for a multi-vendor environment and positions the network for transport of new services, synchronous networking, and enhanced OAM&P.

Stratum—Level of clock source used to categorize accuracy.

Synchronous—A network where transmission system payloads are synchronized to a master (network) clock and traced to a reference clock.

Synchronous Transfer Module (STM)—A measure of the SDH transmission hierarchy. STM-1 is SDH's base-level transmission rate equal to 155 Mbps. Higher rates of STM-4, STM-16, and STM-64 are also defined.

SPE (Synchronous Payload Envelope)—The major portion of the SONET frame format used to transport payload and STS path overhead.

STS-1 (Synchronous Transport Signal Level 1)—The basic SONET building block signal transmitted at 51.84 Mbps data rate.

STS-n (Synchronous Transport Signal Level n)—The signal obtained by multiplexing integer multiples (n) of STS-1 signals together.

T1X1 Subcommittee—A committee within the ECSA that specifies SONET optical interface rates and formats.

VT (Virtual Tributary)—A signal designed for transport and switching of sub-STS-1 payloads.

VT Group—A 9 row x 12 column structure (108 bytes) that carries one or more VTs of the same size. Seven VT groups can be fitted into one STS-1 payload.

Wander—Long-term variations in a waveform.

Wideband—Services requiring 1.5-50 Mbps transport capacity.