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This unique network of connecting rings has the ability to reroute service around disruptions in as little as 60 milliseconds. Less than the blink of an eye.

Even in the event of an electronics failure or cable cut, any voice, data, image or video service will continue uninterrupted — going virtually unnoticed.

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“T he significant problems we face cannot be solved by the same level of thinking that created them.”

Albert Einstein
**Introduction**

High capacity fiber optic facilities and total service consistency are becoming critical aspects of the corporate enterprise network as businesses become more reliant on high bandwidth data applications. SONET optical interface standards, combined with end-to-end architectures based on four fiber, bi-directional line switched rings, provide the highest possible level of service assurances, while guaranteeing bandwidth ranges to support the most demanding business applications. This Technology Guide examines the SONET architecture, within the context of a national fail-safe ring structure. It explores the manner in which the four fiber, bi-directional ring approach is uniquely suited to trouble free service, while enabling efficient network management and equipment interoperability.

**The Networking Needs of the Corporate Community**

It is clear that businesses, governmental agencies, and academia are all confronted by a revolutionary growth in their dependence on information systems. To operate efficiently in today’s complex information milieu, they need a complex set of interrelated, high powered capabilities. These capabilities fall into five major categories.

**High Speed and Increased Bandwidth**

The new applications that excite contemporary network users are based on placing complex business functions onto the network as well as sharing large files and graphically based information systems. Medical imaging, industrial CAD/CAM applications, document archival, and retrieval are all becoming as commonplace as networking resources become more readily available at cost efficient ratios. However, transmitting database files and graphics requires significantly more bandwidth than earlier applications. There is a great demand for increased bandwidth to accommodate the sheer volume of new traffic from new applications on the network. Increased bandwidth is needed as well to support the performance requirements of database and graphical applications. The timely delivery of megabyte sized files has caused the bandwidth capacity requirements of networks to increase geometrically.

This increased bandwidth requirement, which has occurred simultaneously around the globe, but mostly in North America, the Asian Rim, and Western Europe, has caused the telecommunications carriers to accelerate their deployment of a fiber optic based infrastructure. With fiber optic throughout the network, carriers are positioned to support the most demanding bandwidth requirements of its customer base well into the next century.

**Broad Connectivity**

Accompanying the demand for higher bandwidth is the need to establish information connectivity within a much larger group of end users. Previously, data connectivity was restricted to end users within the corporate environment and, oftentimes, only within the same building complex. This was supported by traditional leased lines for WAN connectivity and relatively low speed token ring or Ethernet LANs. As new applications come on line, the need to acquire connectivity beyond this limited group of users has grown dramatically. Within the corporate body, there is a need for connectivity at virtually every level for E-mail, collaborative processing, and new, function specific applications. This is compounded by the parallel need to
communicate outside the domain of the corporate real estate, with suppliers, subcontractors, trading partners, and even, as time goes on, the end user consumer. This broad connectivity is geographically dispersed across the country as well as globally. In many ways, data networking requirements have assumed many of the characteristics of the voice, or PBX, environment. This has evolved into a networking architecture that uses relatively brief connectivity, infrequent communications and widely dispersed end points.

New service types such as Frame Relay, ISDN, and ATM all attempt to solve parts of this puzzle. Carrier infrastructures built on fiber optic resources are positioned well to support this high degree of diverse connectivity.

Flexible Bandwidth Allocation Capabilities

As the many diverse traffic and connectivity options work themselves out into the corporate structure, new patterns of traffic ebb and flow are emerging. Bursty traffic, when overlaid on more constant, application traffic, results in a need to manage traffic bandwidth on a more dynamic basis. This need is felt not only in the corporate environment, but in the realm of the carrier as well. Carriers need to be able to supply bandwidth on demand to customers using such services as Frame Relay and ATM. With a fiber optic based infrastructure, carriers have the fundamental depth of resource needed to supply flexible bandwidth to the most demanding customers in the network.

Fail Safe and Secure Operations

Amid all of these changes, it is increasingly clear that networked applications are becoming increasingly ‘mission-critical.’ As a result, corporations can not tolerate catastrophic or even chronic service problems within the network structure. There is a need, not just for systems that can be quickly restored, but for systems and infrastructure that provide a better level of service consistency. Service consistency means that traffic will not be subjected to unplanned, disruptive outage, regardless of the possibility of fast service restoral. Service consistency implies, and even demands, non-stop networking and fail safe systems. This is most often needed within the carrier infrastructure itself, because failures at the core of the network represent a potential catastrophe for hundreds and perhaps thousands of customers. Fail safe networking is a critical component of the strategic enterprise wide network. This service consistency is made possible through the aggressive use of various fiber optic loop technologies; particularly the four fiber optic, bi-directional ring approach, which is uniquely suited to trouble free service.

Management and Control of Network Resources

Another essential element of the new network infrastructure is the need for flexible and adaptable service management and control capabilities. The ability to dynamically configure and assign network resources depending on network circumstances is critical to the service consistency which users demand in their networks as they increasingly invest in the network as the vehicle to deliver critical business operations. Network Management is facilitated in SONET based networks through the use of a standardized frame format overhead which allows networks to be virtually self healing.

These requirements for high bandwidth, widespread deployment, and flexible bandwidth on demand, within the context of fail safe operation, are best met within fiber optic systems using the SONET standard and appropriate ring architectures.
What is SONET?

SONET

SONET (Synchronous Optical Network) is an American National Standards Institute (ANSI) standard for high capacity optical telecommunications. SONET was first introduced into the network in 1994 and has been deployed at rapid rates since then. Today, it is the premier backbone transmission technology for leading carriers. It is deployed at all levels of the telephone infrastructure, including the local loop, the local telephone network, and the long distance carrier network. It is based on overlaying a synchronous multiplexed signal onto a light stream transmitted over fiber optical cable.

Although SONET is a North American standard promulgated by ANSI, there is an equivalent standard approved by the International Telecommunication Union (ITU) called Synchronous Digital Hierarchy (SDH). The world wide acceptance of this SONET/SDH multiplexing scheme for optical signalling has made it the implementation of choice where high bandwidth and failure resistant technologies are needed. SONET gives network managers more preventive monitoring capabilities and speeds up the restoration of fiber loops when breaks do occur.

Higher SONET signal rates are obtained by multiplexing byte interleaved increments of STS-1. These signal rates are denoted by OC-n and STS-n, where ‘n’ is equal to an integer representing a multiple of OC-1 rates. OC-3, for example is 3 x 51.84, or 155.52 M bps. A theoretical maximum value of ‘n’ is 255. Figure 1 illustrates the relative speeds and equivalent capacities of SONET vs. the older DS3, D1, and DS0 designations. For example, an OC-1 is the equivalent of a DS3, which is equivalent to 672 DS0’s.

SONET Line Interfaces

Both optical and electrical physical interfaces are defined for SONET. There are three basic line interface types for short, intermediate, and long reach, as defined in the appendices. Fundamentally, a SONET signal can be transmitted up to approximately 40 K m, without requiring a signal regeneration or amplification.

The Optical Signal on SONET

The actual optical signal used in fiber optics transmission is a serial digital stream consisting of a light source being turned on and off very quickly to match.
the incoming electrical signal from the input source. The electronic binary ‘on-off’ becomes an optical binary ‘on-off’. The fiber material consists of an inner cylindrical glass core surrounded by an outer glass sheath called a cladding. The cladding is reflective, while the inner core is highly transparent. The light transmitted into the end of the fiber goes through the transparent core and stays within the core by bouncing off the reflective cladding (figure 2). The cladding is like a cylindrical mirror surrounding the core, so that light stays in the fiber core as if it were a ‘light pipe’ in the same way water stays in a metal clad pipe.

Figure 2

“It is interesting to note just how transparent the glass is in the core of an optical fiber. It is composed of pure silicon dioxide (SiO2). Consider the picture window you have at home in your living room; it is \( \frac{3}{8} \) plate glass. You could replace it with a window made of fiber optic core glass that was three miles thick, and you could get the same bright image coming through the three mile thick window that you currently do with the \( \frac{3}{8} \) plate glass window.”

Single Mode vs. Multi-Mode

The use of single mode vs. multi-mode is a function of the core diameter of the fiber. In multi-mode, the core is from 50 to 100 microns (1/500th to 1/250th of an inch). In single mode, the diameter is 7 to 9 microns (about 1/3000th of an inch). With a wider core, different rays of light bounce off the fiber cladding at different angles and they actually travel different total distances as they go through a long cable from one end to the other. Since some light rays travel longer distances and some shorter, while the speed of light is constant (186,000 mps), some of the rays will arrive at the distant end later than others. Therefore, a square pulse of light power may exhibit pulse spreading or dispersion over long distances. In single mode, the transmission is with a single ray of light, usually with a laser. However, an LED can be used. In single mode systems, a square wave pulse maintains its integrity throughout the pipe. For very high rates and long distances, single mode provides the best method of transmission.

STS-1 Frame Structure

As the serial digital signal is transmitted over the fiber cable, information is overlaid according to a predefined organizational structure called the STS-1 Frame. This STS-1 Frame overlays data on the optical signal at 51.84 M bps. The signal layout is usually depicted as a two dimensional array (figure 3) consisting of nine rows by 90 columns, representing 810 8-bit bytes, or 6,480 bits per frame. The frame repetition rate is 8,000 frames per second. The duration of each frame is 125 microseconds. At 6,480 bits per frame x 8,000 frames a second equals 51,840,000 bps.

2. Quotation from the Fiber Optic Handbook -copyright 1990 Codenoll Technology Corporation
At 8,000 samples per second, each byte within the SONET signal structure represents a channel capacity of 64,000 bps, the same size as a DS0 channel.

Higher Level STS Frames

Groups of synchronous transport frames can be packaged for transport as a higher order signal. This is achieved by byte interleaved multiplexing in which parallel streams of transport signals are mixed together on a fixed byte by byte basis. These parallel streams of transport signals must have the same frame structure, bit rate, and be synchronized with each other. Simply stated, the higher order multiplexer takes one byte in turn from each of the STS-1 signals presented to it and interleaves them on the higher speed circuit. Figure 4 illustrates 3 STS-1 frames combined onto a single STS-3 signal.

Virtual Tributaries

The term Virtual Tributary is used to designate the frame structures used to map DS1 and DS2 channels onto the STS frame. The STS-1 signal is specifically intended to provide transport for a DS3 tributary channel. Hence, lower increments, such as the 1.544 M bps of a DS1, or the 2.048 M bps of a CEPT signal are supported by designating a portion of the STS-1 frame as a virtual tributary. These VTs are sequentially assigned segments of the STS frame. A fixed number of VTs fits neatly into the STS frame to simplify multiplexing tasks.

There are four Virtual Tributary sizes used to accommodate four different inputs:

- **VT 1.5**—Three columns of nine bytes each. At 8,000 frames, this provides capacity of 1.728 M bps, sufficient for the 1.544 M bps of a DS1 (T1). Twenty-eight VT 1.5’s can be multiplexed onto the STS-1 signal.

- **VT 2**—Four columns of nine bytes each. At 8,000 frames, this provides capacity of 2.304 M bps, sufficient for the 2.048 M bps of a CEPT (European E-1 equivalent of the T1). Twenty-one VT 2’s can be multiplexed onto the STS-1 signal.

- **VT 3**—Six columns of nine bytes each. At 8,000 frames, this provides capacity of 3.456 M bps, sufficient for the 3.088 M bps of a DS1C signal. Fourteen VT 3’s can be multiplexed onto the STS-1 signal.

Concatenation

Concatenation is used when a signal stream greater than STS-1 is needed to support an individual data source such as is required for DBDQ, ATM, or FDDI. The SONET signal structure, which ordinarily interleaves bytes from separate sources, uses a different approach for single high speed (>50M bps) inputs. This approach is called concatenation and allows mapping onto a higher payload capacity. This higher payload capacity is called the STS-3C frame and is, essentially, an STS structure three times larger than the STS-1. Instead of the ninety columns of the STS-1, the STS-3C has two-hundred seventy columns, of which nine columns are for transport overhead. This STS-3C frame also operates at 125 microseconds.
• **VT 6**—Twelve columns of nine bytes each. At 8,000 frames, this provides capacity of 6.912 M bps, sufficient for the 6.176 M bps of a DS2. Seven VT 6’s can be multiplexed onto the STS-1 signal.

**Virtual Tributary Operating Modes**

These Virtual Tributaries operate in two different modes.

- **Floating Mode**—The floating mode has been designed to minimize network delay and provide efficient cross connection of transport signals at the VT level. This occurs by allowing each VT to float about the STS-1 payload to avoid using unwanted buffer space at each cross connect point. Each VT has pointers that identify timing synchronization and other related issues. This improves the performance of the virtual tributary by eliminating unnecessary idle space.

- **Fixed Mode**—The fixed mode locks the VT into a fixed position in the STS-1 payload. Payload pointers are not required since there is no reconstruction needed at the receiving end. This arrangement reduces the cost and complexity of the multiplexing equipment at either end of the channel. It may result in some diminished performance as empty space is left in the signal stream.

**Transport Overhead**

The transport overhead of the STS-1 frame is partitioned into three areas to support the network maintenance at the Path, Line, and Section levels of the network span. Figure 5 illustrates these three elements.
A linear SONET architecture is configured in a point to point manner. Traffic moving from point A to point B has only one route to follow. If there is a backup cable, it invariably follows the same route. In the event of a break, the only way to get from A to B is to redirect the traffic along some other routes in the network, if possible. Service stops while restoration is implemented.

Surprisingly, the major carriers, with the exception of SPRINT, have built their networks using mostly linear connectivity on their long haul inter-city sections. Carriers are likely to do this because they build SONET over existing facilities that are already linear in nature. As a result, cable cuts in these sections have resulted in chronic catastrophic outages for thousands of users. This is being corrected as time goes on, but SPRINT has maintained a major service edge by its strategic decision to deploy only ring architectures throughout its North American network.

**SONET Ring Architecture**

A primary goal of SONET is survivability; to construct a self-healing network that can recognize a fiber cut and reroute traffic before a significant degradation in performance occurs. All carriers that deploy SONET follow the same set of standards. But there are differences in network architectures and equipment that significantly affect the success of the network. The right architecture allows a network to be self-healing and make survivability and restoration effective enough to provide constantly good service levels.

**Linear Deployment vs. Ring Deployment**

SONET operates in several different modes. A major distinction in operation is whether the service is deployed in a linear fashion or as one of several ring types. As shown in figure six, a linear deployment is vulnerable to interruption because the fiber cable has only a single path to the endpoints. Ring systems are relatively immune to interruption because of the multiple path access implied in the ring itself.

**Two Types of SONET Ring**

There are two types of SONET ring. One switches individual paths (path switched) and the other switches the entire optical line capacity (line switched).

A key difference is the number of fibers used. Path switched rings use only two fibers while line switching can use either two or four fibers.
Path Switching

Path switching, which is less efficient than line switching, sends traffic both ways around the two fiber ring for redundancy. The receiving end monitors both signals and selects the better one. Due to this dedicated use of the protection capacity, path switching systems have less fundamental capacity than line switched rings.

![Figure 7](image)

Figure 7

OSI Relationships

It should be clear that SONET is at the lowest level of the OSI protocol stack and provides the physical connectivity between locations. It is a method of providing a roadway, or path that can be used by a variety of traffic sources and protocols. In many ways, SONET is completely neutral to the content or higher level protocols in the traffic stream itself. Figure 9 shows the relationship of SONET to the OSI protocol stack.

![Figure 9](image)

Protocol Support

Because of its very high speed and high quality, SONET is the natural transmission medium for the new high performance protocols being implemented both in the carrier infrastructure and in private networks. These relatively new protocols; i.e. ATM, FDDI and DQDB, are all expected to deliver traffic in the 100 Mbps range and higher. In order for this to happen successfully, the medium must be inherently error free, fail safe, cleanly manageable, and fast.

Copper wire based networks can be provisioned to support high bandwidths and operate in a relatively trouble free manner, but the higher the performance demands, the more difficult it is to provision copper wire successfully. On the other hand, the fiber optics based SONET is just beginning to hit its stride as the demand for high quality escalates.

<table>
<thead>
<tr>
<th>Application</th>
<th>Unidirectional Pair Switched</th>
<th>Bi-directional Line Switched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Office</td>
<td>Future LEC Central Office</td>
<td></td>
</tr>
<tr>
<td>Backbone or Loop Plant</td>
<td>Backbone</td>
<td></td>
</tr>
<tr>
<td><strong>Number of Fibers</strong></td>
<td>2</td>
<td>2 or 4</td>
</tr>
<tr>
<td><strong>Typical Speed of Ring</strong></td>
<td>OC-3 or OC-12</td>
<td>OC-12 or OC-48</td>
</tr>
<tr>
<td><strong>Bellcore Spec</strong></td>
<td>TR-496</td>
<td>GR-1230</td>
</tr>
</tbody>
</table>

Figure 8
ATM

ATM, which has become the probable universal choice for supporting the performance driven applications of the future, is designed to work closely with the SONET standard. In fact, it has been designated by the ITU-T to operate with SONET as its basic standard configuration. Figure 10 shows the relationship of the ATM layers associated with SONET. The virtual channel and virtual path layers of ATM run on top of the SONET physical layer.

The physical layer is based on three essential components: transmission path, digital line, and regeneration. These layers correspond to the section, line, and path operations described earlier.

FDDI and DQDB

The Fiber Distributed Data Interface (FDDI) and the Distributed Queue, Dual Bus (DQDB) protocols are both intended as a Metropolitan Area Network (MAN) solution for high performance requirements.

Both FDDI and DQDB use a double ring topology. Both of these approaches impose no restrictive distance limitation, no terminal limits, and no limits on the total span of the network. FDDI is an ANSI standard that operates at the lower level within the OSI IEEE 802 architecture, as does DQDB, the 802.6 standard.

Within OSI, the data link layer is divided into two sublayers; the logical link control protocol (LLC), and

Operation and Maintenance (OAM)

The OAM functions of ATM and SONET are closely aligned and are intended to operate together. OAM is defined with five levels of functionality. Levels four and five are intended for ATM, while levels one, two, and three are for SONET.

Level three supports OAM information between network components that do the assembly and disassembly of the STS header and payload, control operations, and cell delineation. As described previously in figure 5, this corresponds to the SONET Path component.
Level two provides OAM information between elements that terminate section end points (the links in figure 5). This contains information on loss of frame synchronization and degraded error performance.

Level one, corresponding to the section components in figure five, reports on loss of synchronization and quality degradation between signal regenerators.

This OAM information is available to support Automatic Protection Switching (APS), which provided automated network recovery. It is this capability that allows the bi-directional line switching function of SONET rings to operate so successfully.

OAM information is also available to network managers for use in tracking quality and for constantly fine tuning the network so that errors and failures are kept to the absolute minimum.

The Contemporary View of Networking

As described earlier, SONET is certainly the most important medium for future carrier network provisioning. This will be needed if the forecasted tremendous increase in network traffic is to be successfully supported. And, in particular, SONET needs to be deployed using the very effective bi-directional line switching techniques that allow virtually ‘bullet proof’ networks that will keep running regardless of catastrophic network failures.

These SONET rings need to be deployed not just within the local loop, but at all levels of the network including the local telephone infrastructure and the backbone carrier network.

Interlocking Long Distance Rings

Building on the logical requirement for SONET Rings as the fabric for the nation-wide telecommunications infrastructure, it becomes clear that carriers must develop an architectural strategy that creates a set of interlocking rings that will cover not only local regions but the entirety of North America.

This nation-wide architectural concept, including the new service paradigm for fail safe operation, combined with the highest possible quality, consistent availability, and mega-bandwidth capability, is certainly the network fabric that will support all terrestrial based telecommunications far into the next centuries.

SPRINT, not inhibited by earlier, less flexible, architectural constraints, has been able to jump to the lead in providing fully interconnected ring arrangements that virtually assure their customers fail safe network operations. Other carriers certainly recognize the value of this approach and are moving as quickly as possible to catch up. Given the lead already developed by SPRINT, it seems unlikely, however, that this will happen soon.
The Future of the North American and International Infrastructure

It has become increasingly clear that SONET technology is a key component to the future network success of businesses, government, and academia. It closely supports the major protocols such as ATM, provides fail safe operation, service consistency, remarkable fast performance, universal standards, international acceptance, and the co-operation of the manufacturing community. When implemented using the bi-directional, line switched ring concept, it provides protection capacity that assures total transparent service quality at all levels.

The approach, extended architecturally across the continent in a matrix of interlocking rings, makes the North American infrastructure ready for the deployment of high powered, mission critical, telecommunications applications. It is the architectural fabric that the nation has been waiting for and it is here now. The phased deployment of nation-wide interlocking SONET rings is proceeding quickly and will soon be so ubiquitous as to eliminate all future concerns of network quality, capacity, or performance.

Appendix A: SONET Line Interfaces

SONET interfaces all use single mode fiber and are defined in three different ranges:

- **Short Reach (SR)**—Applies to sections of up to 2 km, with signal loss of no greater than 7 dB. Transmission is via light emitting diodes (LEDs) or multi-longitudinal mode (MLM) lasers at 1310 nanometer wavelength.

- **Intermediate Reach (IR)**—Applies to sections of up to 15 km, with signal loss of no greater than 12 dB. Transmission is via low power (50 mw) single longitudinal mode (SLM) or MLM at either 1310 or 1550 nanometer wavelength.

- **Long Reach (LR)**—Applies to sections of up to 40 km, with signal loss in the range of 10 to 28 dB. Transmission is via high power (500 mw) SLM or MLM at either 1310 or 1550 nanometer wavelength.

**Electrical Interfaces:**

For Intra-office applications, coaxial cable is used for distances up to 900 feet for STS-1 signals and 450 feet for STS-3 signals.
Case Study: California Fiber Cut

At 10:37 a.m. on June 28, 1995, a construction crew severed a major Sprint fiber-optic cable between Anaheim and San Diego, Calif. This cut normally would have knocked out service to thousands of Sprint customers— with partial service restoral in about five minutes, and complete restoral in several hours. However, this day would be different.

Instead of feeling the debilitating repercussion of service disruption and waiting for its repair, customers didn’t notice a thing. Their service quality continued at the high level they had come to expect from Sprint because of the company’s industry-leading deployment of four-fiber, bi-directional, line-switched ring (4-fiber BLSR) SONET technology.

The instant the construction crew severed normal transmission on the cable, 24 SONET DS3s were affected. Because one of the tremendous advantages of SONET is its inherent capability to enhance network monitoring, within 10 milliseconds alarms went off in Sprint’s Transmission Control Center.

Once the cut was detected, the 4-fiber, BLSR SONET system performed a ring switch in 50 milliseconds— literally the “blink of an eye.” All traffic was switched from the working channel to the protect fibers and rerouted around the other side of the SONET ring. After technicians located the fiber cut and spliced the cable later in the day, the SONET ring was switched back to its normal configuration.

Had this been a cut on an asynchronous or a linear-SONET network— like the networks of most of Sprint’s competitors— network managers would have had to electronically implement alternate pre-plans manually to reconfigure traffic patterns. Although a large percentage of the traffic would have been restored by this method in several minutes, a large percentage would have been out of commission for several hours.

During this incident, the advantages of Sprint’s 4-fiber BLSR network became apparent. The goal of service consistency was achieved.

Fortunately, Sprint engineers decided years earlier to tackle the issue of how to best deploy SONET to maximize its tremendous survivability characteristics. Contemplating the dozens of ways that a long-distance network can be harmed, these engineers designed the Sprint SONET network to protect it against more vulnerabilities than any other kind of known SONET deployment. In early 1994, Sprint began to leverage the original physical loop topology of its all-digital, fiber-optic network built in the mid- ‘80s and began to deploy SONET electronics on its network in a way unmatched by its competitors.

In June 1995, Sprint completed the first coast-to-coast 4-fiber, BLSR SONET telecommunications route. In April of 1996, the company completed the first international ring— between Canada and the U.S. Sprint plans to have approximately 120 SONET rings throughout the United States by the end of 1997, moving all customers to this unique deployment of a wonderful technology. As Sprint aggressively moves toward this goal, fiber cuts and many other types of outages are increasingly going unnoticed by Sprint customers.

Sprint’s SONET deployment is fast becoming a clear advantage to its customers. The California fiber cut illustrated the impact that Sprint’s SONET deployment is having on the telecommunications industry and, much more importantly, displayed the lack of impact that network failures are having on Sprint’s customers. Sprint is changing the world’s standard of network reliability with a technology that’s blink-of-an-eye beauty is, ironically, never more stunning than when it can’t be seen.
Service Consistency vs. Service Restoration

In a service restoration paradigm, a failure disconnects customers. The customer is at the mercy of the carrier, which reconnects service either in several minutes, or several hours. This service restoration paradigm is still in use by carriers that are deploying SONET in a linear, or point-to-point, configuration.

Four-fiber, bi-directional, line-switched ring (4-fiber BLSR) SONET offers customers something different and better—service consistency. Customers never notice when there has been a disruption on the network.

In mission critical applications, customers need service 24 hours a day—not 23 hours, 55 minutes. Sprint is the only long-distance carrier deploying 4-fiber, BLSR across its entire network.

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**Glossary**

**Add/Drop Multiplexer (ADM)**—A multiplexer capable of extracting or inserting lower-rate signals from a higher-rate multiplexed signal without completely demultiplexing the signal.

**Alarm Indication Signal (AIS)**—A signal to downstream equipment that there is a problem upstream. SONET defines four categories of AIS: Line AIS, STS Path AIS, VT Path AIS, DSn AIS.

**Asynchronous**—Referring to two or more signals which, though they have the same nominal rates, actually operate at different rates.

**Asynchronous Transfer Mode (ATM)**—A fast-packet switching technology allowing free allocation of capacity to each channel. The SONET synchronous payload envelope is a variation of ATM.

**Attenuation**—Reduction of signal magnitude or signal loss, usually expressed in decibels.

**Automatic Protection Switching (APS)**—The ability of a network element to detect a failed working line and switch the service to a spare (protection) line. 1 +1 APS pairs a protection line with each working line. 1:n APS provides one protection line for every n working lines.

**Bandwidth**—Information carrying capacity of a communication channel. Analog bandwidth is the range of signal frequencies that can be transmitted by a communication channel or network.

**Bidirectional**—Operating in both directions. Bidirectional APS allows protection switching to be initiated by either end of the line.
**Binary N-Zero Suppression (BNZS)**—Line coding system that replaces N number of zeros with a special code to maintain pulse density required for synchronization. N is typically 3, 6, or 8.

**Bit**—One binary digit; a pulse of data.

**Bit Error Rate (BER)**—The number of coding violations detected in a unit of time, usually one second.

**Bit-Interleaved Parity (BIP)**—A parity check that groups all the bits in a block into units (such as a byte) then performs a parity check for each bit position in a group. For example, a BIP-8 creates eight-bit (one byte) groups, then does a parity check for each of the eight bit positions in the byte.

**Bit-oriented channel**—A SONET overhead channel that codes the information it carries with simple protocols and binary coded bit patterns.

**Bit synchronous**—A way of mapping payload into virtual tributaries that synchronizes all inputs into the Vs but does not capture any framing information or allow access to subrate channels carried in each input. For example, bit synchronous mapping of a channelized DS1 into a VT 1.5 does not provide access to the DSO channels carried by the DS1.

**Bits per second (bps)**—The number of bits passing a point every second. The transmission rate for digital information.

**Byte-interleaved**—Bytes from each ST S-1 are placed in sequence in a multiplexed or concatenated ST S-N signal. For example, for an ST S-3, the sequence of bytes from contributing ST S-1s is 1, 2, 3, 1, 2, 3...

**Byte synchronous**—A way of mapping payload into virtual tributaries that synchronizes all inputs into the Vs, captures framing information, and allows access to subrate channels carried in each input. For example, byte synchronous mapping of a channelized DS1 into a VT 1.5 provides direct access to the DSO channels carried by the DS1.

**Channel**—The smallest subdivision of a circuit that provides a type of communication service; usually a path with only one direction.

**Circuit**—A communication path or network; usually a pair of channels providing bidirectional communication.

**Circuit switching**—Basic switching process whereby a circuit between two users is opened on demand and maintained for their exclusive use for the duration of the transmission.

**Coding Violation (CV)**—A transmission error detected by the difference between the transmitted and the locally calculated bit-interleaved parity.

**Concatenation**—Grouping multiple ST S-1 frames into a superframe to carry a single payload. For example, DS4NA service requires three concatenated ST S-1 signals, designated ST S-3c. A concatenated ST S-Nc is switched, multiplexed, and transported as a single unit.

**Craft**—Any personnel whose primary responsibility is the day-to-day operation and maintenance of a network.

**Cyclic Redundancy Check (CRC)**—A technique for using overhead bits to detect transmission errors.

**Digital Cross-connect System (DCS)**—An electronic cross-connect which has access to the lower-rate channels in higher-rate multiplexed signals and can electronically rearrange (cross-connect) those channels.

**Digital signal**—An electrical or optical signal that varies in discrete steps. Electrical signals are coded as voltages, optical signals are coded as pulses of light.
**Envelope capacity**—The number of bytes the payload envelope of a single frame can carry. The SONET STS payload envelope is the 783 bytes of the STS-1 frame available to carry a signal. Each virtual tributary has an envelope capacity defined as the number of bytes in the virtual tributary less the bytes used by VT overhead.

**Extended Superframe (ESF)**—A T1 framing format that groups 24 frames of 192 bits per frame with 24 overhead bits for frame synchronization, error checking, and network management.

**Far End Block Error (FEBE)**—A message sent back upstream that the receiving network element is detecting errors, usually a coding violation.

**Far End Receive Failure (FERF)**—A message sent back upstream that the receiving network element has received a failure condition or alarm indication. SONET uses the FERF message at the Line Layer.

**Fiber optical terminating system**—Network element which terminates the optical circuit. It serves such functions as mapping the service into the SONET carrier and making opto/electrical conversions.

**Fixed stuff**—A bit or byte whose function is reserved. Fixed stuff locations, sometimes called reserved locations, do not carry overhead or payload.

**Floating mode**—A virtual tributary mode that allows the VT synchronous payload envelope to begin anywhere in the VT. Pointers identify the starting location of the VT SPE. VT SPEs in different superframes may begin at different locations.

**Framing**—Method for distinguishing digital channels that have been multiplexed together.

**Frequency**—The number of cycles of periodic activity that occur in a discrete amount of time.

**Gigabit**—One billion bits.

**IEEE 802.6**—Standards being developed by IEEE to govern metropolitan area networking.

**Integrated Services Digital Network (ISDN)**—Method for carrying many different services over the same digital transmission and switching facilities.

**Isochronous**—All devices in the network derive their timing signal directly or indirectly from the same primary reference clock.

**Kilobit**—One thousand bits.

**Laser**—A device that produces highly coherent light using light amplification by stimulated emission of radiation; lasers are used in fiber optic communication systems as light sources.

**Line**—One or more SONET sections, including network elements at each end, capable of accessing, generating, and processing Line Overhead.

**Line Overhead (LOH)**—18 bytes of overhead accessed, generated, and processed by line terminating equipment. This overhead supports functions such as locating the SPE in the frame, multiplexing or concatenating signals, performance monitoring, automatic protection switching, and line maintenance.

**Line Terminating Equipment (LTE)**—Network elements such as add/drop multiplexers or digital cross-connect systems which can access, generate, and process Line Overhead.

**Local Area Network (LAN)**—Network permitting transmission and communication between hardware devices, usually in one building or complex.

**Locked Mode**—A virtual tributary mode that fixes the starting location of the VT SPE. Locked mode has less pointer processing than floating mode.
Mapping—The process of associating each bit transmitted by a service into the SONET payload structure that carries the service. E.g., mapping a DS1 service into a SONET VT1.5 associates each bit of the DS1 with a location in the VT1.5.

Megabit—One million bits.

Message oriented channel—A SONET overhead channel that codes the information it carries with complex protocols.

Multilongitudinal mode laser—A laser which transmits over a narrow range of wavelengths.

Multimode—Used to describe optical fiber that allows more than one mode of light signal transmission.

Multiplexer—A device for combining several channels to be carried by one line or fiber.

Multipoint service—Distribution of telecommunications services to two or more stations.

Network Element (NE)—Any device which is part of a SONET transmission path and serves one or more of the section, line, or path terminating functions.

Non-Return to Zero (NRZ)—A signal that does not return to the zero level between successive transmitted ones.

Non-revertive—A type of automatic protection switching which does not automatically switch the service back from the protection line after the working line has returned to service.

Orderwire—A craft voice communication channel. SONET provides both Section Layer and Line Layer orderwire channels in the Transport O overhead.

Packet switching—A transmission technique that segments and routes information into discrete units. Packet switching allows for efficient sharing of network resources as packets from different sources can all be sent over the same channel in the same bitstream.

Parity check—An error checking scheme which examines the number of transmitted bits in a block which hold the value one. For even parity, an overhead parity bit is set to either one or zero to make the total number of transmitted ones in the block data plus parity bit an even number. For odd parity, the parity bit is set to make the total number of ones in the block an odd number.

Path—One or more Sonet lines, including network elements at each end capable of accessing, generating, and processing Path O overhead. Paths provide end-to-end transport of services.

Path Overhead (POH)—Overhead accessed, generated, and processed by path terminating equipment. This overhead supports junctions directly related to assuring reliable end-to-end transport of services, including performance monitoring, access to virtual tributaries, and/or access to the service carried. Path overhead includes nine bytes of STS Path O overhead and, when the frame is VT structured, five bytes of VT Path O overhead.

Path Terminating Equipment (PTE)—Network elements such as fiber optic terminating systems which can access, generate, and process Path O overhead.

Payload—The service carried by a SONET carrier; the contents of an STS SPE or VT SPE.

Phase—In the context of framed digital signals, phase refers to the position of a frame in a sequence of frames.

Plesiochronous—Each device in the network deriving its timing signal from different primary reference clocks.
**Pointer**—A part of the SONET overhead that locates a floating payload structure. STS pointers locate the SPE. VT Pointers locate floating mode virtual tributaries. All SONET frames use STS pointers; only floating mode virtual tributaries use VT pointers.

**Protocol**—A formal set of rules.

**Regenerator**—Device that restores a degraded digital signal for continued transmission; also called a repeater.

**Repeater**—Device that restores a degraded digital signal for continued transmission; also called a regenerator.

**Return to Zero (RZ)**—A signal that returns to the zero level between successive transmitted ones.

**Revertive**—A type of automatic protection switching which automatically switches the service back from the protection line after the working line has returned to service.

**Scrambling**—Coding the output of a SONET transmitter to assure adequate density for the receiving end to detect the signal. SONET scrambling compares the current transmitted bit to several previously transmitted bits and changes its value based on the result of that comparison. The receiving end decodes the scrambled signal.

**Section**—The span between two SONET network elements capable of accessing, generating, and processing only SONET Section overhead. This is the lowest layer of the SONET protocol stack with overhead.

**Section Overhead (SOH)**—Nine bytes of overhead accessed, generated, and processed by section terminating equipment. This overhead supports functions such as framing the signal and performance monitoring.

**Section Terminating Equipment (STE)**—Network elements such as regenerators which can access, generate, and process Section Overhead.

**Signaling**—Method of communication between network components to provide control management and performance monitoring.

**Single Longitudinal Mode (SLM)**—A laser which transmits over a single wavelength.

**Single mode**—Used to describe optical fiber that allows only one mode of light signal transmission.

**Stuff opportunity**—A location in an STS-N frame which may be used to carry a stuff byte (or stuff it) if necessary for synchronization.

**Subframe**—Any one of the multiple frames that make up a superframe structure.

**Subrate**—Requires less than the full capacity available on a transport system’s basic frame.

**Superframe**—Any structure made of multiple frames. SONET recognizes superframes at the DS1 level (D4 and extended superframe) and at the VT (500u STS superframes).

**Superframe (D4) framing**—A T1 framing format that groups 12 frames of 192 bits per frame with 12 overhead bits for frame synchronization.

**Superrate**—Any service requiring more than a single STS-1, i.e., concatenated STS-Nc for transport. DS4NA is an example of a superrate service requiring STS-3c transport.

**Switched Multimegabit Digital Service (SMDS)**—A planned connection service between LANs for data transmission.

**Synchronous**—Operating at the same speed, all circuits in a synchronous network are constrained to operate at their nominal rates with no significant variation.
Synchronous optical networks (SONET)—A standard for fiber optics.

Synchronous Payload Envelope (SPE)—A SONET structure that carries the payload (service) in a SONET frame or virtual tributary. The STS SPE may begin anywhere in the frame’s payload envelope. The VT SPE may begin anywhere in a floating mode VT but begins at a fixed location in a locked mode VT.

Synchronous Transport Signal (STS)—A SONET frame including overhead and payload capacity. The basic SONET frame is the STS-1. STS-1s can be multiplexed or concatenated with no additional overhead.

Syntran—Synchronous transmission, a standard for synchronous transmission designed primarily for transmission of DS3 signals.

Unidirectional—Operating in only one direction. Unidirectional APS allows protection switching to be initiated only by the head-end of the line.

Virtual tributary (VT)—A payload structure that specifies where and how a sub-STS-1 signal will fit into an STS-1 SPE.

VT group—A structure for organizing virtual tributaries. Each STS-1 SPE may carry seven VT groups. The VTs in each group must all be the same size but each of the seven groups may carry different size VTs.

Workstation (WS)—A terminal or computer that provides craft access to a network element.

X.25—ISDN-defined protocol for packet switched transmission of data.

XOR—A binary logical operation used in logic and computer science. When two values are XORed, they are compared; the resulting value depends upon that comparison. In the table below, Values A and B are XORed to yield the resulting Value C:

<table>
<thead>
<tr>
<th>When A is:</th>
<th>And B is:</th>
<th>C will be:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Yellow signal—A message sent upstream, similar to a FERF, that a receiving network element has received a failure condition or alarm indication. There are X Sonet yellow signals, STS Path Yellow, VT Path Yellow, and DSn Yellow.

Zero Byte Time Slot Interpolation (ZBTSI)—A line coding scheme for ensuring sufficient pulses to synchronize transmitting and receiving network elements.
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“The significant problems we face cannot be solved
by the same level of thinking that created them.”

Albert Einstein
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