Packet-over-SONET/SDH

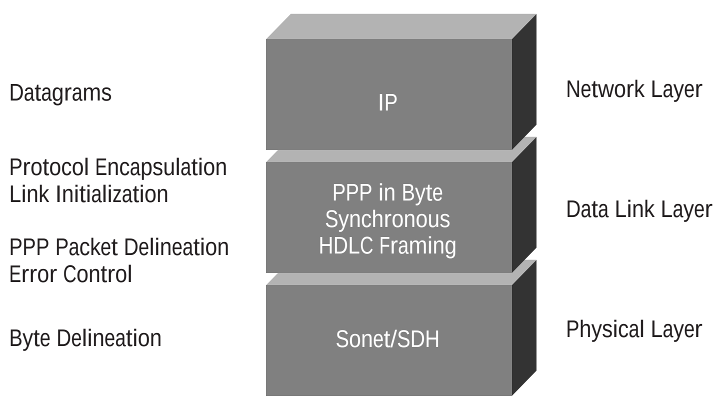
Introduction

Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) and optical fiber have emerged as significant technologies for building large-scale, high-speed, Internet Protocol (IP)-based networks. Even though SONET/SDH is frequently labeled as "Old World" because it is a time division-multiplexing (TDM) technology optimized for voice traffic, its capability to provide high-bandwidth capacity for transporting data is the primary reason for ubiquitous use in the Internet and large enterprise data networks. Packet over SONET (PoS) technology, which allows efficient transport of data over SONET/SDH, has certainly been a major player in accommodating the explosive growth on the Internet. Cisco Systems helped pioneer PoS technology and has been at the forefront in delivering high-performance and cost-effective PoS solutions for use in service provider and enterprise networks.

PoS provides a flexible solution that can be used in a variety of transport applications. Well known applications include use in network backbone infrastructures and data aggregation or distribution on the network edge and in the metropolitan area. Router PoS interfaces are frequently connected to Add Drop Multiplexers (ADMs), terminating point-to-point SONET/SDH links. Direct connections over dark fiber or via dense wave-division multiplexing (DWDM) systems is becoming increasingly popular.

PoS line cards are very popular on the Cisco gigabit switch router (GSR) series routers. Other Cisco products such as the Cisco 7500 and 7200 series routers also feature PoS interfaces. The Catalyst® 6500 and 8500 series enterprise switches are potential candidates for PoS interfaces in the future.

Figure 1   PPP over SONET



The current Internet Engineering Task Force (IEFT) PoS specification is RFC 2615 (PPP over SONET), which obsoletes RFC 1619. PoS provides a method for efficiently carrying data packets in SONET/SDH frames. RFC 1661 (Point-to-Point Protocol) and RFC 1662 (PPP in HDLC-like framing) are related. High-bandwidth capacity coupled with efficient link utilization make PoS largely preferred for building the core of data networks. PoS overhead, which averages about 3 percent, is significantly lower than the 15 percent average for the asynchronous transfer mode (ATM) cell tax.

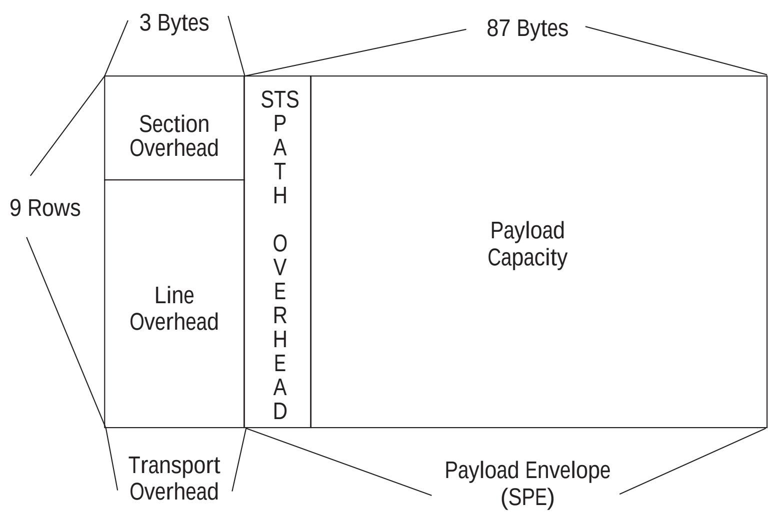
The Cisco GSR 12000 series routers support both channelized and concatenated PoS interfaces with speeds ranging from OC-3 to OC-48 to STM-16. An OC-192/STM-64 interface is under way. Cisco Systems is the market leader for state-of-the-art PoS solutions, offering reliable and high-performance PoS interfaces. Deployment is worldwide, with over 20,000 interfaces installed today. Extensive field experience, feeding back into the development and production cycles for improved product quality, has largely been behind the success and wide deployment of Cisco PoS solutions.

SONET/SDH and PoS Technology

SONET/SDH Frame Format

SONET/SDH is a high-speed TDM physical-layer transport technology, inherently optimized for voice. PoS provides a means for using the speed and excellent management capabilities of SONET/SDH to optimize data transport. A SONET/SDH frame is 810 bytes and is normally represented as a two-dimensional byte-per-cell grid of 9 rows and 90 columns. (See Figure 2.) The SONET/SDH frame is divided into transport overhead and payload bytes. The transport overhead bytes consist of section and line overhead bytes, while the payload bytes are made up of the payload capacity and some more overhead bytes, referred to as path overhead. The overhead bytes are responsible for the rich management capabilities of SONET/SDH.

Figure 2 SONET Frame Format



SONET/SDH Data Rates

The basic transmission rate of SONET (51.840 Mbps), referred to as Synchronous Transport Signal level 1 (STS-1), is obtained by sampling the 810-byte frames at 8000 frames per second. Developed by Bellcore (now Telecordia), SONET features an octet-synchronous multiplexing scheme with transmission rates in multiples of 51.840 Mbps. Even though several other rates were originally specified, only the transmission rates in Table 1 have emerged as practical and only these have been implemented in real networks. Also shown in the table are corresponding transmission rates and terminology for SDH. SDH is the SONET-equivalent specification proposed by the International Telecommunications Union (ITU). SDH supports only a subset of SONET data rates, starting from 155.520 Mbps, and it seems to be most popular in Europe.

Table 1 SDH Data Rates

SONET	SDH	Data Rates
STS-1		51.840 Mbps
STS-3	STM-1	155.520 Mbps
STS-12	STM-4	622.080 Mbps
STS-48	STM-16	2,488.320 Mbps
STS-192	STM-48	9,953.280 Mbps

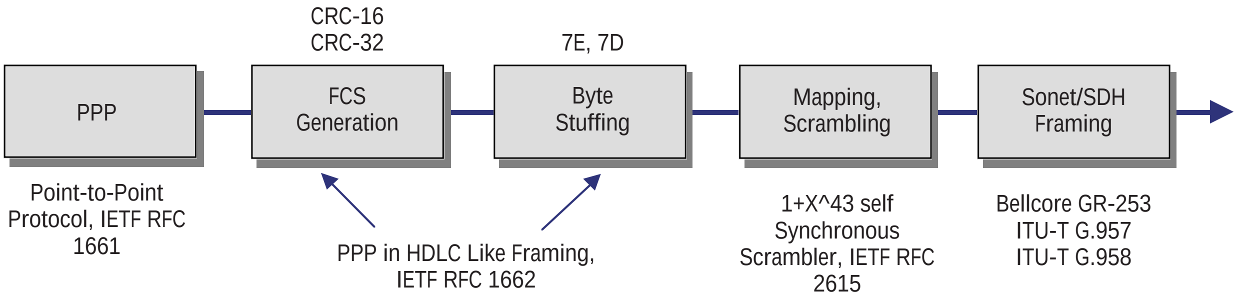
PoS Framing

PoS uses PPP in High-Level Data Link Control (HDLC)-like framing (as specified in RFC 1662) for data encapsulation at Layer 2 (data link) of the Open System Interconnection (OSI) stack. This method provides efficient packet delineation and error control. The frame format for PPP in HDLC-like framing is shown in Figure 3.

Figure 3 PPP in HDLC-Like Framing

RFC 2615 specifies the use of PPP encapsulation over SONET/SDH links. PPP was designed for use on point-to-point links and is suitable for SONET/SDH links, which are provisioned as point-to-point circuits even in ring topologies. PoS specifies STS-3c/STM-1 (155 Mbps) as the basic data rate, and it has a usable data bandwidth of 149.760 Mbps. PoS frames are mapped into SONET/SDH frames and they sit in the payload envelop as octet streams aligned on octet boundaries. Figure 4 shows the framing process. RFC 2615 recommends payload scrambling and a safeguard against bit sequences, which may disrupt timing. PoS payload scrambling is further discussed in the section “Synchronization.”

Figure 4 PoS Framing Sequence



PoS Bandwidth Efficiency

Figure 5 shows the PoS percentage efficiency for various packet sizes based on the following formula:

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Average Efficiency (%) = 1/[1.008 + (9/N)] x 100, where is N refers to the
multiplexing scheme as in STS-N.
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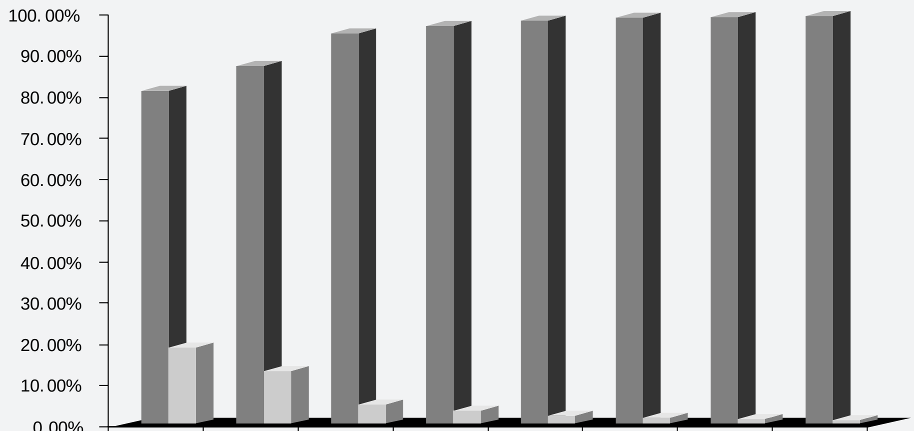
OC-3/STM-1 data rates are used with provisions made for a 7-byte PPP header and a 90-byte SONET overhead. The payload is 2340 bytes. The PoS bit efficiency is approximately 96 percent for 300-byte packets, compared to 80 percent with ATM for a similar packet size. The ATM adaption layer 5 (AAL5) is assumed to have 8 bytes, the Logical Link Control/Subnetwork Access Protocol (LLC/SNAP) header 8 bytes, and the ATM cell header 5 bytes.

Figure 5 PoS Efficiency Chart

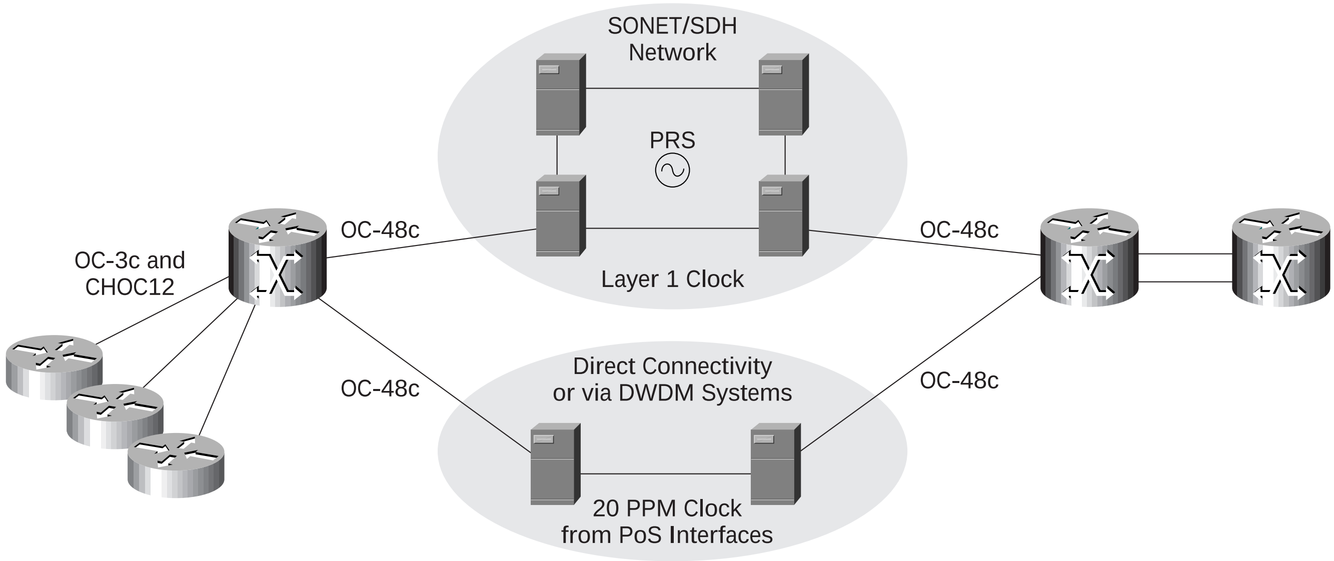


	40 Bytes	64 Bytes	200 Bytes	354 Bytes	750 Bytes	1500 Bytes	3000 Bytes	4470 Bytes
Efficiency (%)	81.10%	87.06%	94.97%	96.77%	98.04%	98.62%	98.91%	99.01%
Overhead (%)	18.88%	12.93%	5.02%	3.22%	1.94%	1.36%	1.07%	0.97%

Synchronization

PoS interfaces are usually connected over carrier SONET/SDH networks, where timing is synchronized to a reference Layer 1 clock running at 0.000001 parts per minute (ppm). The PoS interfaces derive timing information from the incoming data stream. This information may be distributed and synchronized throughout the rest of the whole network. A PoS interface retrieving timing in this fashion is said to be loop (or line) timed.

Figure 6 PoS Synchronization



When PoS interfaces are not connected to carrier SONET/SDH networks, such as in cases of direct router-to-router connectivity over dark fiber, the links are independently timed by 20-ppm internal clock sources built into the Cisco PoS interfaces. This type of timing, referred to as “internal,” is sufficient for simple point-to-point connections where network timing distribution is not required. Internal timing is suitable for situations with less rigorous timing requirements, including connectivity over DWDM systems. Cisco Systems has demonstrated the feasibility of 20-ppm internal timing in numerous field deployments and interoperability testing.

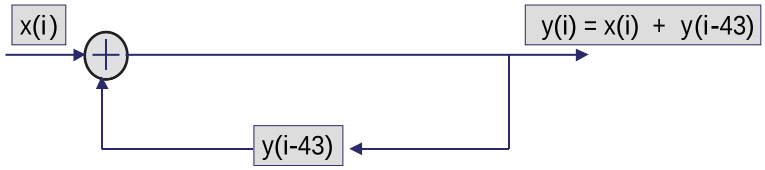
PoS Security

In addition to high-bandwidth efficiency, PoS offers secure and reliable transmission for data. Reliable data transfer depends on timing integrity. SONET/SDH timing information is obtained by filtering state transitions through a phased-locked loop (PLL). Since effective synchronization of the PLL depends on the density of “one” bit received, a long continuous sequence (about 80 or more) of “zero” bits could distort the expected density of “one” bits, impacting synchronization and resulting in loss of timing. A severe drift of the receiving clock will cause signal or data loss. Although the probability that this scenario will occur is very low under normal circumstances, it is prudent to guard against accidental or possibly malicious payload bit sequences that could cause it to happen.

PoS has adopted the ATM-style, self-synchronous payload scrambler which is based on the polynomial, x^43+1. This scrambler is specified in RFC 2615 and supported on Cisco PoS interfaces. When in use, the signal label in the path overhead (C2) is set to 0x16 to indicate scrambled payload. ATM-style payload scrambling is also recommended in updates to the Telecordia GRE-253 for SONET[1] and also the ITU SDH specification[2]. A graphical representation of the self-synchronous scrambler is shown in Figure 7.

1. Bellcore GR-253, Issue 2, Revision 2, Section 3.4.2.3, “HDLC-over-SONET Mapping,” Jan. 1999, pp. 3–57
2. ITU SDH specifications G.707 and G.783

Figure 7 ATM-Style Self-Synchronous Scrambler



Operation, Administration, Management, and Provisioning

SONET/SDH provides numerous alarms and error messages that are sent via the overhead bytes in SONET/SDH frames. Alarms, which are also known as defects, are associated with complete failures. Errors pertain to incomplete failures such as parity errors. Errors are also referred to as anomalies. Figure 8 elaborates on the placement of overhead bytes in SONET/SDH frames. SONET/SDH management facilities enable easy troubleshooting, failure detection, fault isolation, centralized maintenance, and remote provisioning. Network elements detect events at various SONET/SDH layers (section, line, and path) and notify other devices of pending adverse network conditions.

Figure 8 SONET/SDH Overhead Bytes

Transport Overhead

Section Overhead	Framing A1	Framing A2	STS-1 ID C1
	BIP-8 B1	Orderwire E1	User F1
	Data Com D1	Data Com D2	Data Com D3
Line Overhead	Pointer H1	Pointer H2	Pointer H3
	BIP-8 B2	APS K1	APS K2
	Data Com D4	Data Com D5	Data Com D6
	Data Com D7	Data Com D8	Data Com D9
	Data Com D10	Data Com D11	Data Com D12
	Grow/FEBE Z1	Grow/FEBE Z2	Orderwire E2

Path Overhead
Path Trace J1
BIP-8 B3
Signal Label C2
Path Status G1
User Channel F2
Multiframe Indicator H4
Path Trace Z3
Growth Z4
Growth Z5

The Cisco SONET/SDH compliance document provides extensive information regarding Cisco support and compliance with SONET/SDH standards. PoS-equipped Cisco routers act as terminal equipment (TE) for SONET section, line And path segments of a link and can detect and report the following SONET/SDH errors and alarms:

- Section—loss of signal (LOS), loss of frame (LOF), threshold crossing alarms (TCA) B1
- Line—alarm indication signal (AIS), (line and path) remote defect indication (RDI), (line and path) remote error indication (REI), threshold crossing alarms (TCA) B2
- Path—AIS, RDI, REI, B3, new pointer events (NEWPTR), positive stuffing event (PSE), negative stuffing event (NSE)

Other reported information includes:

- SF-ber—signal fail bit error rate
- SD-ber—signal degrade bit error rate
- C2—signal label (payload construction)
- J1—path trace byte

B1, B2, B3 are categorized as performance monitoring parameters, while others such as LOS, LOF, and L-AIS fall under alarms. Performance monitoring pertains to advance alerts, while alarms indicate failures. K1/K2 byte status is also reported for SONET automatic protection switching (APS) or SDH multiplex switching protection (MSP).

Restoration

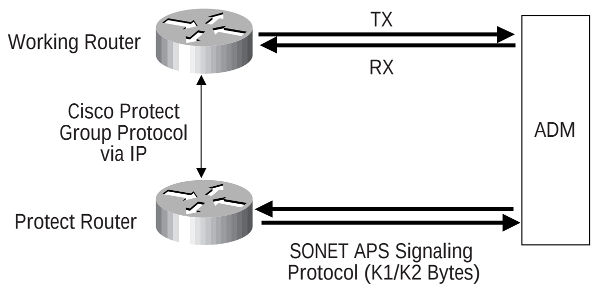
SONET APS and SDH MSP

Failure recovery in communications networks is possible at multiple layers, typically at the physical or network layers. Network-layer restoration, also known as Layer 3 restoration, essentially involves routing protocol convergence with alternate route selection. SONET/SDH provides protection schemes for physical-layer restoration. A key attribute of SONET/SDH is inherent failure restoration, which is specified to occur with 60 ms from the time of detection. In contrast, layer 3 restoration could take up to several seconds, typically 6 to 10 seconds for IP routing protocols such as Open Shortest Part First (OSPF), Intermediate System-to-Intermediate System (IS-IS) and Border Gateway Protocol (BGP). Cisco Systems has been researching into methods for improving Layer 3 convergence times that will not compromise routing stability. One direction could be to tightly couple routing convergence with events that trigger SONET/SDH restoration.

The network survivability schemes used in SONET/SDH are known as automatic protection switching (APS) for SONET and multiplexed switching protection (MSP) for SDH. APS and MSP are fundamentally similar and depend on protection signaling via the K1/K2 line overhead bytes. Cisco routers with PoS interfaces can receive and send appropriate protection signals to connecting ADMs. Cisco routers also use a proprietary protocol, known as the Protect Group Protocol, between working and protect routers to complement SONET/SDH protection signaling that occur with ADMs. The Protect Group Protocol is IP-based and uses User Datagram Protocol (UDP) transport (UDP port 172). Cisco currently implements 1 + 1 linear APS and MSP, which require the ADMs to forward the same data signal to both protect and working circuits. In the 1 + 1 protection scheme, the working PoS interface selects the data signal when there are no failures or severe errors. Signal selection is at a protected interface when there are problems on the working circuit.

The Cisco PoS protection scheme can be set up for situations where protect and working interfaces are different ports on the same router or even on the same line card in the same router. These scenarios, however, provide protection for only router interface or link failure. Most production deployments have working and protect interfaces on different routers, as shown in Figure 9.

Figure 9 Protection Switching

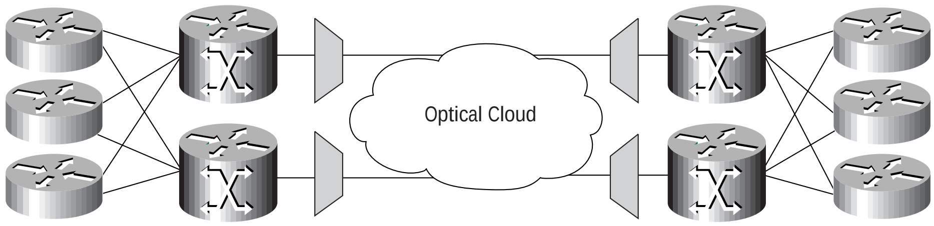


Optical Restoration over DWDM

In situations where the PoS connection is over an optical infrastructure such a DWDM network, restoration of physical-layer failures is achieved via optical protection mechanisms between underlying systems, such as Optical ADMs (OADMs). As an example, Pirelli Cables and Systems[3] recently announced addition of new protection features to its 128-channel capable TeraMux DWDM system, aimed at taking over monitoring functions usually performed at the SONET layer. Figure 10 shows a network with optical transport, geared for optical restoration.

3. http://www.pirelli.com

Figure 10 Optical Restoration



Restoration at Layer 3

Even though SONET/SDH and DWDM optical-restoration procedures guarantee restoration at the physical layer in less than 50 ms, IP routing protocols with elaborate timing mechanisms to guarantee routing stability are unable to keep up, they would typically converge in several seconds after an alternate physical path has been selected.

This network-layer lag in restoration has attracted significant interest and active research and field trials are currently going on to bridge this gap. One approach is studying stability effects with smaller routing protocol timers that hinge on the reliability of today's digital and optical circuits. Another direction is looking at building direct dependency of routing protocols on lower-layer protection schemes. Cisco Systems has been actively pursuing both directions.

Packet-over-SONET Applications

SONET/SDH has been most successfully used for high-speed IP transport in wide area networking (WAN) applications. In most WAN applications today, routers with PoS interfaces are connected to carrier SONET rings via ADMs. With the proliferation of PoS in the wide area, available bandwidth in the local area network (LAN) severely lagged as the traditional solutions for point-of-presence (PoP) intraconnectivity, such as Fiber Distributed Data Interface (FDDI) and Fast Ethernet were unable to keep up. Therefore, service providers adopted PoS for PoP LAN connections.

In recent times the emergence of DWDM, as a viable technology for bandwidth multiplication, has further promoted the significance of PoS in the quest for more bandwidth to meet insatiable demand by emerging data applications such as voice over IP and video streaming. DWDM allows the use of multi-channel (multiwavelength) signaling on a single strand of fiber increasing its bandwidth capacity in multiples of OC-48, up to 128 today and possibly more in the future. Another growing application for PoS is connectivity over dark fiber for metro and long-haul links. This section reviews various PoS applications and discusses the strengths and significance of PoS as a transport technology.

The use of PoS interfaces for network connectivity could be broken down into the following three application categories:

- Core
- Edge
- Metro

The core refers to backbone infrastructure for interconnecting distribution or aggregation points in a large network. Aggregation points in Internet service provider (ISP) networks are frequently referred as network access points (NAPs) or points of presence (PoPs). Customer access to the service provider network, which is normally at OC-3 and lower speeds, is terminated at PoPs. Data transport between customer premises and PoPs as well as intra-PoP connectivity can be classified as edge applications. Metro application normally refers to interbuilding connections such as in a small city downtown area or university campus.

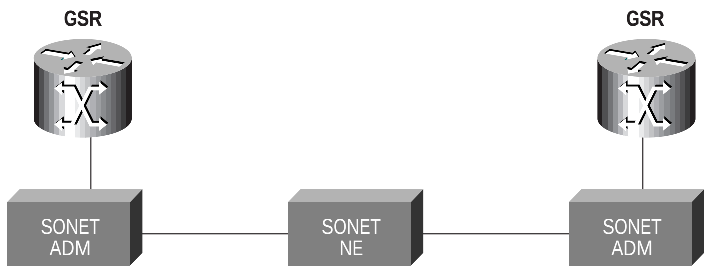
Core Application of PoS

A very common application of PoS is WAN connectivity over SONET/SDH networks. This application was the primary motivation for development of PoS interfaces on routers. This section looks at three primary methods for connecting routers with PoS interfaces: connectivity to SONET/SDH networks, connectivity over DWDM systems, and router-to-router connectivity over dark fiber.

Connectivity to SONET/SDH Networks

WAN PoS links are provisioned as point-to-point circuits over carrier SONET/SDH networks and the circuits are dropped off from ADMs. Routers are connected to the ADMs via PoS interfaces. (See Figure 11.)

Figure 11 PoS-ADM Connection

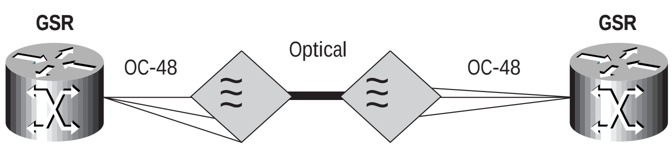


As discussed in the section “Synchronization,” router PoS interfaces derive timing from the received data stream and synchronize with the higher timing hierarchy of the carrier network.

Connectivity over DWDM Systems

The dramatically increasing levels of IP data traffic in public networks, in comparison to voice traffic, is driving the need for data-optimized networks. Data-optimized networks will use optical-data-transport facilities in place of TDM infrastructures, which are optimized for voice. This setup removes complexity, framing overhead and capital costs associated with SONET/SDH and ATM solutions for data transport. The all-optical internet model uses on the capabilities of SONET/SDH by employing PoS solutions for connecting to DWDM transponders instead of ADMs. PoS interfaces provide efficient means for framing data onto the DWDM fiber channel. Figure 12 shows connectivity over DWDM channels.

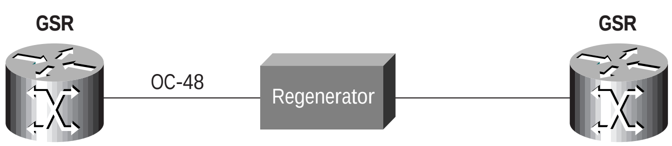
Figure 12 DWDM Connection



Dark-Fiber PoS connectivity

In dark-fiber PoS connectivity, IP routers are connected directly to dark fiber using PoS interfaces. If such connectivity is to be used to haul data over significantly long distances, regenerators are inserted into the link to maintain signal integrity and provide appropriate jitter control. Figure 13 shows a long haul “router-to-router” OC-48 POS connection using an optical regenerator.

Figure 13 PoS over Dark Fiber Connection



Metro Application

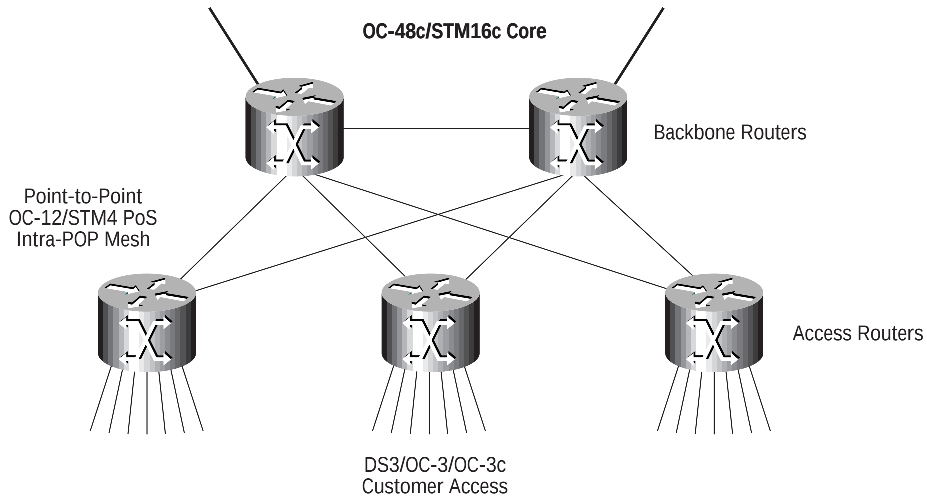
Unidirectional SONET/SDH rings are popular for high-speed connectivity between office buildings in metro areas. This type of ring is normally part of a carrier infrastructure and features ADMs for bandwidth drop-off to routers equipped with PoS interfaces. DWDM or dark fiber can be used with PoS in a similar fashion. Using PoS rather than Gigabit Ethernet to provide framing and data transport between connecting routers allows the use of rich management and other capabilities of SONET/SDH.

Using PoS on the Network Edge

The edge of the network is associated with traffic aggregation or distribution. It is also the point of convergence of regional traffic housed in facilities referred to as network PoPs. Access links from customer premises to PoPs are typically OC-3 and below. Channelized PoS solutions such as the OC-12-to-DS3 line card provide easy-to-manage DS3 customer access.

A key component of the network edge is intra-PoP connections between aggregation routers. Until recently, LAN technology used for intra-PoP connectivity in service provider networks, Fast Ethernet and FDDI, had bandwidth capability pegged at 100 Mbps. The huge bandwidth requirements for server-farm deployments and corresponding applications frequently required service providers to use multiple parallel 100 Mbps connections. To keep up with the huge bandwidth available in the wide area, most service providers have adopted PoS as an alternative for high-speed intra-PoP connectivity. Using PoS for intra-PoP connectivity provides numerous benefits, the most significant being flexible design using mixed-bandwidth links from OC-3/STM-1 to OC-48/STM-16 (available today) and OC-192/STM-64 (in the near future). (See Figure 14.)

Figure 14 Intra-POP PoS Connectivity



Interoperability

The Cisco SONET/SDH Compliance document[4] spells out compliance of Cisco PoS interfaces to related SONET/SDH standards and RFCs. In addition to the compliance paper are also various datasheets[5], which summarize features and power budget requirements for Cisco PoS solutions. Cisco has conducted extensive testing with both vendors and customers to ensure interoperability with other vendor devices and to guarantee smooth operation in special customer environments.

Interoperability Testing

The Cisco Optical Internetworking Business Unit home page at http://wwwin.cisco.com/ispbu has an interoperability section that fields a long list of ADM and DWDM systems vendors whose equipment has been tested with Cisco PoS interfaces on the GSR series routers. Testing has been done with service providers to verify operational interoperability and standards compliance. The extensive list of ADMs and DWDM transponders tested include equipment from NEC, Alcatel, Nortel, Lucent, Tyco Submarine and many others. Cisco also cooperated with Pirelli, Cienna, Optical Networks, Monterey, and Corvis at SuperComm 99 and successfully demonstrated interoperability with DWDM systems from the respective vendors. See details in the brochure titled “SuperComm Interoperability Demo” at the mentioned page.

4. http://wwww.pirelli.com
5. http://wwwin.cisco.com/ispbu/ (see the line card information section)

Customer Deployments

Cisco PoS interfaces have been deployed in a very large number of service provider and private enterprise networks. More than 20,000 PoS interfaces have been deployed in more than 170 GSR customer networks worldwide. Numerous joint press releases with customers can be located at the Optical Internetworking Business Unit Home Page at http://wwwin.cisco.com/ispbu.

Summary of PoS Benefits

- *Proven reliability and performance*—shipping since 1997
- *Large field deployment*—More than 20,000 total interfaces deployed in some of the largest and most advanced networks in the world today
- *Efficient utilization of available bandwidth*—up to 97 percent of available bandwidth is used
- *Scalable solutions*—Bandwidth from OC-3 to OC-192/STM-64
- *Flexible solution*—Usable in traditional SONET/SDH infrastructures as well as in emerging all-optical network infrastructures based on DWDM and dark-fiber connectivity
- *Cost effective*—Lowest cost per bit metrics for high-speed interfaces
- *OAM&P*—Performance monitoring and fault detection via SONET/SDH framing
- *Fast restoration (50 ms)*—using SONET APS and SDH MSP
- *Standards-based* multivendor solution
  - Bellcore (Telecordia) GR-253
  - ITU-T G.957
  - ITU-T G.707
  - RFC 2615, Point-to-point Protocol over SONET/SDH
  - RFC 1662, PPP
  - RFC 1661, Packet over SONET/SDH
- *Several Applications*
  - Core—ADM, DWDM, dark fiber
  - Edge—Customer access, intra-PoP, data center
  - Metro—ADM, DWDM, dark fiber
- *Optimized for both IP and Multiprotocol Label Switching (MPLS)*

References

- Bellcore GR-253, Issue 2, Revision 2, Jan 99. Section 3.4.2.3 HDLC-over-SONET Mapping pp.3-57.
- ITU SDH specification, G.707, G.783, and G.957
- http://www-tac/Support_Library/Internetworking/Sonet/SDH_compliance2.html
- Data Sheets (http://wwwin.cisco.com/ispbu/, Linecard information section)

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