The Broad (and Surprising?) Future of SONET
Introduction
In the early 1990s, SONET emerged as the clear winner for general-purpose transport in North American telecom networks. SONET offered significant benefits in operations, network protection, performance monitoring, alarm surveillance, provisioning ease and multi-vendor interoperability.

In the mid to late 1990s, as packet and frame-based services and transport mechanisms emerged, SONET technology appeared on its way to becoming outdated. Concerns were raised about SONET’s bandwidth granularity, the cost of redundancy, multiservice capability, the efficiency of transport overhead and other issues. These issues led equipment vendors and metro carriers to experiment with a number of non-traditional transport network approaches and implementations—including ATM transport, hybrid ATM/TDM transport and switched optical Ethernet overlays. [1–5]

However, continued advances in SONET technology radically drove down networking equipment costs while addressing bandwidth granularity and multiservice concerns. At the same time, the cost of reinventing packet or frame technologies to replace crucial SONET transport operations functionality had been wildly underestimated or the costs of packet technologies had not been well understood.[6] SONET has proven indispensable in serving revenue-critical TDM-based private line services and is well positioned to provide the broad enterprise marketplace with a wide range of fractional rate services, which complement high-end WDM-based access approaches.

The advancement of SONET technology, embodied in what are known today as MSPPs, continues to promise future substantial benefits for network providers by extending the life of familiar operations methods and procedures, thereby leveraging existing operational investments. Continued enhancements in SONET technology further facilitate the ongoing deployment of the highest volume, most interoperable optical networking technology, paving the way for ongoing network Capital Expense (CAPEX) reduction and continued Operational Expense (OPEX) savings.

This paper outlines the broad future of SONET technology—highlighting significant advances being made by SONET and related technologies and explaining the impact of those advances on future service profitability, transport network cost reduction and metro network infrastructure direction in the following areas:

- **Enabling New Services** – The ability to use SONET network technology, including Generic Framing Protocol (GFP), Virtual Concatenation (VCAT), Link Capacity Adjustment Scheme (LCAS) and other technologies, as a foundation for multiservice delivery
- **Innovative SONET Access** – Reaching more customers for new and traditional services at dramatically lower price points while maintaining the power of SONET operations
- **Scalability and Integration** – The ability for a single network element to replace functionality formerly requiring multiple network elements or network elements of different types
- **Optical Networking Integration** – The ability to integrate appropriate levels of photonic technology into SONET platforms to build highly scalable metro Dense Wavelength Division Multiplexing (DWDM) core networks
- **Network Management and Control** – The ability to more thoroughly manage and control large-scale optical networks
SONET for Multiservice Delivery
SONET provides an inherently superior fit for multiservice needs, private line-based needs and access to switched services. No other technology provides the unique combination of bandwidth flexibility, deterministic performance, survivability, operations power and cost performance. Over the near term, SONET technology will continue to evolve to provide fully interoperable data and video service transport and will continue to expand to support additional types of customer handoff interfaces and functionality.

While the telecom industry focuses on profitability and new revenue generation, a key emphasis for service providers is reaching the large enterprise customer with new, innovative services with the ability to deliver those services in a capital efficient and operationally efficient manner. While consolidation and bankruptcy have narrowed the field of competitors, the battle remains intense with ILECs, major Interexchange Carriers (IXCs) and Multiple System Operators (MSOs) all vying for enterprise service dollars.

Some of the important and emerging enterprise services include:
- SAN connectivity across the MAN/WAN for business continuance and disaster recovery
- Ethernet port services
- Enhanced Ethernet services – Layer 2 (L2) Virtual Private Network (VPN), transparent Local Area Network (LAN) services
- Layer 3 (L3) VPNs
- Video transport services
- Internet access
- Legacy private line, frame relay and ATM services
- Voice
- Voice Over Internet Protocol (VoIP)
- Private line services
- Private transport services
- Shared transport services

For the above critical services, SONET technology-based systems play a vital role as a service delivery vehicle or efficient access to high layer service networks.

SONET as a Native Service Delivery Vehicle
SONET-based systems today fulfill native service delivery for a wide variety of services. Native service delivery means that the SONET/MSPP network itself provides the service without relying on any other switching or routing products. Of particular importance are dedicated ring services offered to large enterprises by most carriers. These rings are a good value to enterprises that need to interconnect a number of sites in a metro area with a large number of survivable circuits and play an important role in the carrier’s ability to retain and satisfy the largest corporate customers.
Traditionally, these rings have provided DS1 and DS3 service to customer sites but are now beginning to provide private line Ethernet service. In the future, these rings will provide statistically multiplexed Ethernet transport, as well as storage area network interfaces, as shown in Figure 1.

Statistically multiplexed Ethernet ports provide additional value for some enterprise users because a number of Ethernet ports can be delivered while the overall ring bandwidth—a considerable price element in most dedicated ring tariffs—can be conserved. While the ports themselves will be more costly than private line Ethernet ports, the enterprise, under certain traffic demand scenarios, will ultimately save money by deferring the cost of a ring upgrade.

This statistically multiplexed Ethernet approach will never replace pure private line Ethernet over SONET approaches as some enterprises have application and bandwidth needs that will always require dedicated channels. Figure 2 describes the enhancements over time to dedicated ring service portfolios.
Some issues must be carefully considered regarding statistically multiplexed Ethernet in dedicated SONET rings—the statistical multiplexing technology itself and the network management approach. While some statistical multiplexing schemes such as IEEE 802.17 are good fits for single ring networks, they are not easily extensible to networks requiring more than a single ring and may only occupy a niche in the network. Other schemes based on IEEE 802.1w and other IEEE 802.1 series standards are more extensible, but may be more difficult to manage.

Additionally, the network management approach for these enhanced private rings requires carriers to rely on more than just traditional OSSs that sometimes cannot accommodate the management of enhanced data functionality and their more sophisticated SLAs.

Adding SAN or mainframe channel extension ports to these networks provides additional value and allows the enterprise to connect data center locations to either:

1) consolidate data center locations thereby allowing for additional sharing of storage resources across multiple locations
2) provide connectivity to backup storage facilities for business continuity and disaster recovery purposes
SONET as an Access Transport Solution

In addition to providing native service delivery, SONET-based technology plays a vital role in providing access transport and service demarcation for a variety of higher layer switched services. In these cases, the service and SLA is fulfilled in a switched or routed network and the SONET platforms merely provide underlying transport. [7]

Along with SONET-based DS1 tail circuit delivery for frame relay access, SONET has emerged as a vital technology for economical access to a variety of switched or routed Ethernet-based services like L3 VPN services, transparent LAN services and Internet access.

While simple Ethernet-based media converters may provide cost-effective access to closely located L2 and L3 networks, SONET-based solutions expand the service footprint and the ability to provide economical transport to users who may not be physically located near the serving central office as shown in Figure 3.

![Figure 3: SONET-based Access to Switched or Routed Network Services](image-url)

Not only do SONET-based MSPPs provide access to the switched or routed network services, they also pick up private line data services or traditional DS1 and DS3 circuits from the end user and deliver those services from a common platform and operations environment.

When providing access to switched and routed services, the access network must provide QoS that is both uniform and higher in quality than the highest quality service that is provided by the switched or routed network. This process is critical to ensure that:

1) The service experience of each end user is identical regardless of the access method or access vendor
2) The access network does not interfere with the ability of the network provider to guarantee SLAs from the switched or routed network.
For these reasons, private line-based Ethernet transport is the simplest fit for Ethernet over SONET access to data networks. Some limited aggregation and statistical multiplexing capabilities can be used in the SONET network, but these attributes must be carefully defined to both add value and to ensure that service uniformity and SLA management are maintained.

**Historical SONET Limitations and their Remedies**
First-generation SONET implementations were limited in their ability to handle service delivery or access for Ethernet, video and general data services that are dominating today's landscape. Limitations existed in the ability to handle bandwidth that didn't map neatly into the TDM hierarchy, restricting the choices of enterprises to 1.5 Mbps, 50 Mbps, 150 Mbps, 600 Mbps and 2.4 Gbps bandwidth granularities. The VCAT standard has been significant in broadly expanding the available granularities for private line types of services and for core access and transport. VCAT allows for bandwidth granularity options of 50 Mbps or 1.5 Mbps even across a legacy transport environment.

Furthermore, the initial SONET standards did not describe the encapsulation methodology to be used for mapping a variety of service interfaces into a SONET payload. While existing Internet RFCs were often leveraged to achieve a standards-based mapping technique, the result was a series of non-uniform implementations that were not generally interoperable. The GFP standard ITU-T G.7041 has specified a standard mapping methodology for frame-based and 8B/10B encoded signals and lays the fundamental foundation for multi-vendor interoperability. Although the GFP standard itself is sufficient for basic interoperability, additional standards and implementation agreement work needs to be done so that advanced SONET services can achieve the same level of interoperability as DS1 and DS3 services.[8,9]

With the advent of new types of network interfaces such as Ethernet, DVB-ASI for video [10] and Fibre Channel for SAN, carriers now have the ability to provide a variety of transport bandwidth services from the same physical customer interface. This process results in the theoretical ability of the service provider to flexibly increase the available bandwidth to the enterprise by performing simple provisioning steps with no technician dispatch to the customer site. The LCAS standard specified in ITU-T G.7042 enables the client signal mapping/demapping end points to signal one another based on a provisioning command to increase or decrease the available transport bandwidth. While the basic framework for LCAS is completed, additional standardization and implementation agreement work is still needed to ensure full interoperability.

**The Future of SONET-Based Service Delivery**
There are a breadth of requirements for large enterprise optical service delivery, including—entry cost, operations richness, service reliability, QoS flexibility, capacity/cost options, multiservice flexibility and Infrastructure interworking.

The future of SONET service delivery is bright and compares well with other technologies for a variety of enterprise needs as shown in Figure 4.
Figure 4: Optical Services Delivery Spectrum (Performance increases as you move out from the center of the chart).

The three most significant issues facing the future of SONET service delivery are to:

- Lower initial capital cost of service delivery
- Define the interface between client data services and the SONET infrastructure
- Evolve toward a more sophisticated OSS infrastructure
Lowering Capital Cost
Traditional SONET implementations were top-of-the-line, chassis-based systems designed primarily for interoffice transport and hardened loop infrastructure applications. As SONET technology has matured, and innovative ASIC approaches have emerged, SONET is now appearing in radically new packaging with dramatically lower price points and unprecedented management ease. With higher component integration, these new packaging innovations often result in a much higher maintainability factor than in traditional systems.

This benefit allows carriers to rethink their access network approaches by, bringing optical services to new customers, using low-cost SONET to complement and add new services to a large embedded base, and lowering operational costs by rolling customers from unreliable copper to the highly robust and easy-to-maintain SONET fiber network.

As the cost of SONET-based end-terminal equipment continues to plummet, these low cost access approaches now allow for SONET-based access networks to compete favorably on cost with PON architectures. As Figure 5 shows, there are a number of possible choices for implementing an access network. With PON-based systems, there is a savings in fiber, but with the advent of new SONET access packaging, the customer-located equipment is now less expensive than packet-based PON systems.

Figure 5: Low-Cost Business Access Options

Alternative architectures include traditional ring- and hub-based approaches. Ring-based approaches are less fiber intensive while hub-based systems offer lower cost optical terminations. There are a number of complex trade-offs when assessing the suitability of the above approaches for access network deployment. However, SONET-based ring or hub architectures allow carriers to provide TDM and data services over a low capital cost infrastructure using the same operations tools that manage most of the existing network infrastructure.
Defining the Operations Interface
For traditional DS1 and DS3 transport services and for general infrastructure transport, an extremely well defined interface exists between DS1 and DS3 signals and their respective SONET containers. Well-established standards, such as ANSI T1.105 and Telcordia GR-253 for fault management, alarm escalation/de-escalation and client fault handling also exists. Furthermore, DS1 and DS3 signals themselves—having migrated from core transport carriers to client interfaces—also come with a rich set of performance monitoring and fault management capabilities including AIS and RDI.

For example, the failure of an incoming DS1 or DS3 signal generates a PDI-P or PDI-V indication in the SONET overhead that ultimately results in the generation of DS1 or DS3 AIS at the far end egress of the SONET network. For emerging types of client interfaces such as Ethernet and Fibre Channel, the analogous behaviors remain largely undefined and there are numerous proprietary implementations. Standards activity in ITU and ANSI standards bodies is moving toward solving these issues.

Evolving Toward a Sophisticated OSS Structure
For many carriers, reliance upon a top-heavy provisioning and surveillance model at the NMS layer of their OSS environment has allowed TDM-based networks to scale dramatically and reliably. However, placing all the provisioning and alarm surveillance intelligence into a small set of third-party NMS platforms results in significant limitations including:

- Limitations in flexibility
- Increased time to market
- Costly OSS integration cycles
- Sluggish provisioning times

The flexibility of limitations derive from the fact that these third-party systems are responsible for understanding all the detailed NE functionality, including alarm hierarchy and equipment and facility dependencies, as well as the precise provisioning model across five significant dimensions:

1) Multiple NE vendors
2) Multiple product lines
3) Specific products
4) Multiple releases and options of those products
5) Technology advances within those products

To make the integration problem tractable, given this complex, five-dimensional problem, fundamental restrictions must be placed on the capabilities of the OSS. These restrictions stifle vendor and carrier service innovation and may place those carriers at significant competitive disadvantage when new capabilities cannot be accommodated.

Similarly, since multiple vendors, products, and product releases are in queue for OSS integration, the long integration cycle time causes inevitable time to market increases. In addition to the basic cycle time issues, occasionally new features and capabilities require fundamental enhancements to the OSS. These fundamental enhancements are costly and must be jointly engineered among a number of vendors, carriers and the OSS supplier(s), compounding the time to market and cost issues.
An improved approach, depicted in Figure 6, is to shift this detailed network element knowledge down into the network elements themselves and to vendor-provided EMSs. In this way, because each equipment vendor deeply understands the unique features of the various product lines, products, releases and options, the vendor can build that knowledge into their EMSs and then extract that information to higher layer systems and older, embedded OSSs.

Figure 6: Evolving Toward a Sophisticated OSS Structure

In addition, the network elements themselves can leverage certain aspects of the GMPLS protocol suite, especially in areas of topology and connectivity discovery, to assist the EMS in obtaining accurate inventory and network resource information. In this way, the new OSS infrastructure can continually update and rectify accurate inventory and assignment information from the network. This process will greatly speed network provisioning.

In summary, this type of approach will facilitate full equipment flexibility and carrier service differentiation, improve time to market for critical features and lower costs of network solutions.
Scalability and Integration for Infrastructure Consolidation

In addition to providing exciting new service capabilities and bringing those services to new enterprise customers, advances in SONET technology are allowing carriers to reinvent their approach to the core metro infrastructure, thereby realizing tremendous CAPEX and OPEX savings.

One of the initial infrastructure networking problems solved by original SONET implementations was the elimination of unnecessary stacked boxes performing back-to-back multiplexing and demultiplexing functions in central offices.

As Figure 7 shows, SONET add/drop technology brought a significant improvement by consolidating multiple boxes into one. However, as metro traffic continued to grow exponentially in the late 1990s and SONET dominated core IOF networks, carriers began to build stacked rings again, resulting in congestion within the office and difficulty in interconnecting these stacked rings. In some offices where DCS equipment could not be afforded, the ring interconnection was accomplished via DSX cables or optical fiber jumpers. While an obvious improvement over asynchronous transport days, this type of solution left substantial room for improvement.

![Figure 7: SONET-Based Enhancements Transform the Infrastructure](image-url)
As next-generation SONET equipment became available, it became possible to collapse multiple ADMs into single NEs. This enhancement generates obvious savings in a number of areas and several available examples illustrate the savings that MSPP approaches have over ADM implementations for real network configurations [11,12]. Carriers are now beginning to take advantage of these new infrastructure enhancements and substantially reduce cost, floor space and power. [13]

**Paving the Way for the All-Photonic Core**

As metro interoffice bandwidth scales up, the IOF network will migrate to an all-optical core. Some carriers now require this level of scalability and deploying these types of infrastructure solutions. This all-optical core will be optimal for carrying large amounts of traffic—particularly traffic that does not require grooming or rearrangement. With an all-optical core, carriers can rethink their IOF architectures to allow for more optical connections, eliminating unnecessary, expensive Optical-to-Electrical-to-Optical transitions.

A critical aspect of making these networks cost effective for general-purpose transport is the tight integration of the SONET/MSPP base with the new photonic core—in particular the integration of transponder optics directly into the SONET/MSPP elements as shown in Figure 8. By integrating the optical interconnection, tens of thousands of dollars per IOF wavelength can be removed from the network.

For these networks to be cost effective, the integrated SONET-layer grooming must be non-blocking across the entire bandwidth. Studies imply that segmented bandwidth management, or grooming that is confined across a small portion of client bandwidth, can be cost effective in metro networks. However, once the reality of circuit churn sets in, networks based on these types of structures quickly become operational nightmares.
Figure 8: Migration to an All-Photonic Core
Summary
A few years ago, SONET technology was considered dead as carriers and vendors experimented with a variety of packet- or frame-based transport approaches in an attempt to better serve growing data transport needs. While packet-based transport schemes largely fell by the wayside, SONET technology remains vibrant as a multi-purpose, highly granular and operationally elegant service delivery vehicle, as well as a highly integrated large capacity infrastructure consolidation tool.

In particular, the future of SONET lies in these areas:
- Innovative, low-cost optical access solution empowers carriers to bring optical services to new customers, generating additional revenue while lowering OPEX
- Fully interoperable multiservice transport where the provisioning of the data circuit is as simple as the provisioning of a DS1 or DS3 private line circuit
- Sophisticated, integrated packet management functionality for enhanced private ring networking when coupled with the appropriate OSS approach
- Additional infrastructure consolidation as ADMs evolve to MSPPs that grow to approach traditional DCS sizes
- Integrated transponder optics and full bandwidth grooming will make all-photonic networks the most economical approach to high-capacity networking
- A new OSS approach that relies on CORBA-enabled EMSs to improve time to market for a new generation of rich and flexible services

When considering the breadth of requirements for large enterprise optical service delivery—entry cost, operations richness, service reliability, QoS flexibility, capacity/cost options, multiservice flexibility and infrastructure interworking—the future of SONET is bright as the appropriate foundation for the breadth of service delivery and infrastructure consolidation needs.
References


### Acronyms

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<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
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<tr>
<td>ASIC</td>
<td>Application-Specific Integrated Circuit</td>
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<td>ATM</td>
<td>Asynchronous Transfer Mode</td>
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<td>CAPEX</td>
<td>Capital Expense</td>
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<td>CORBA</td>
<td>Common Object Request Broker Architecture</td>
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<td>DCS</td>
<td>Digital Cross-connect System</td>
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<td>DSX</td>
<td>Digital Signal Cross-connect</td>
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<td>DVB-ASI</td>
<td>Digital Video Broadcast – Asynchronous Serial Interface</td>
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<td>DWDM</td>
<td>Dense Wavelength Division Multiplexing</td>
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<td>EMS</td>
<td>Element Management System</td>
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<td>GFP</td>
<td>Generic Framing Protocol</td>
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<td>GMPLS</td>
<td>Generalized Multiprotocol Label Switching</td>
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<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<td>ILEC</td>
<td>Incumbent Local Exchange Carrier</td>
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<td>IOF</td>
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<td>LCAS</td>
<td>Link Capacity Adjustment Scheme</td>
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<td>Metropolitan Area Network</td>
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<td>MSO</td>
<td>Multiple System Operator</td>
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<td>MSPP</td>
<td>MultiService Provisioning Platform</td>
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<td>NE</td>
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<td>OSS</td>
<td>Operational Support System</td>
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<td>PDI-P</td>
<td>Payload Defect Indicator – Path</td>
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