

Next-Generation SONET/SDH- Technologies and Applications

Executive Summary

Innovation, the lifeline to survival in the telecommunications market, has spurred the telecommunications industry to adopt next-generation synchronous optical network/synchronous digital hierarchy (SONET/SDH) as the most economical and technologically feasible solution for transmitting both voice and data over carrier networks.

Designed to optimize time domain multiplexing (TDM)-based traffic, SONET/SDH is very robust and reliable, containing built-in mechanisms to provide 99.999 percent network availability. However, SONET/SDH rings, which are the primary connection to the metropolitan area network (MAN), are not designed to efficiently negotiate bursty packet data efficiently.

Additional constraints on performance result from the overly complex, multiple layers of poorly integrated technologies of MANs that limit flexibility. Further compounding these difficulties is the immense quantity of data traffic generated from local area networks (LANs), digital subscriber loop (DSL)-based broadband connections, storage area networks (SANs), and the local caching of Internet service providers (ISPs). The stress that these applications place on the infrastructure puts carriers at financial risk when they are unable to deliver services or levels of performance the marketplace demands.

Without enhancements to the MAN, carriers do not have the flexibility to manage bandwidth or the ability to quickly provision services and ensure network scalability and operational efficiency. However, they also realize that their economic survival depends upon the ability to optimize the transport technology of the existing SONET/SDH-based network without exorbitant spending or decommissioning any of the existing infrastructure.

The Advantage of Next-Generation SONET/SDH Over Ethernet

Next-generation SONET/SDH is an umbrella term describing a range of proprietary and standards-based developments that are built on the available SONET/SDH infrastructure. First deployed by long-distance carriers as a way to support new services such as Ethernet, Fibre Channel (FC), Enterprise System Connection (ESCON), and digital video broadcast (DVB), next-generation SONET/SDH enables the delivery of high-speed, high-bandwidth data within very tight budget constraints.

Properties of the Data Services	Properties of SONET/SDH
Asynchronous transport	Synchronous transport
Dynamic bandwidth	Constant bandwidth
Connectionless	Connection-oriented

The proliferation of Ethernet in LANs is largely due to its simplicity and cost-effectiveness. Standard Ethernet line rates are 10/100/1000 Mbps with 10 G contending for a significant presence in the MAN. Because Ethernet is based on a best-effort principle, meaning the unguaranteed transfer of data, concerns remain that Ethernet cannot fully provide the quality of service, security, redundancy, and restoration capabilities required for both data and voice traffic. Not only is 10 Gigabit Ethernet (GE) 10 times faster than its predecessor, it promotes the convergence of networking technologies.

When sending a 10 G signal directly to a legacy SONET/SDH add/drop multiplexer (ADM), the Ethernet line termination equipment must buffer the incoming signal and convert it into a signal that SONET/SDH supports.

Although GE provides a common frame from the desktop to the backbone, it lacks the technology that serves as a transport service for storage, raw data, and audio/video, independent of the protocol. FC was designed to remove many performance barriers that exist in legacy LANs and channels providing scalable gigabit technology, control, self-management, and reliability at distances up to 10 kilometers.

	Gigabit Ethernet	Fibre Channel
Applications	Data networks	SAN, audio/video, data
Line rates	1.25 Gbps	1.06, 2.12, 10 Gbps
Frame Sizes	Variable, 0 – 1.5 kB	Variable, 0 – 2 kB
Connection-oriented	No	Yes

However, when FC leaves the SAN and interacts with SONET/SDH, errors and packet losses occur. Although Transmission Control Protocol (TCP) correct for these errors and losses, delays and reduced bandwidth still cause performance problems.

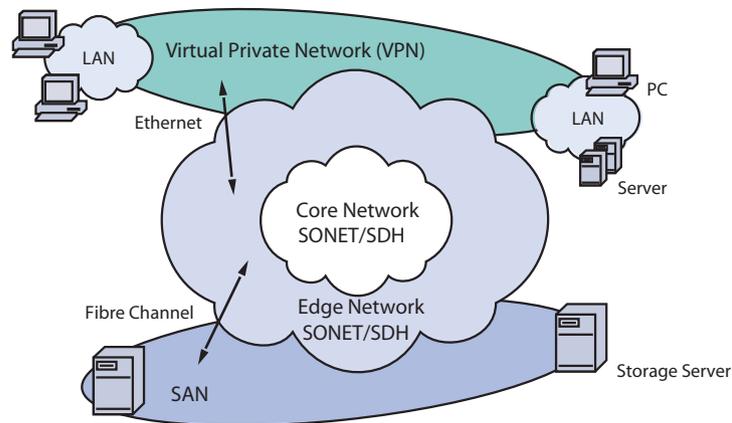


Figure 1. New services put new requirements on legacy SONET/SDH

Next-generation SONET/SDH extends the utility of the existing SONET/SDH network by leveraging existing Layer 1 networking and including technologies such as virtual concatenation (VC), generic framing procedure (GFP), and the link capacity adjustment scheme (LCAS).

Components of Next-Generation SONET/SDH

Next-Generation SONET/SDH has three primary components: virtual concatenation, generic framing procedure (GFP), and Link Capacity Adjustment Scheme (LCAS). These components are reviewed in the following subsections.

Virtual Concatenation

The traditional method of concatenation is termed "contiguous," meaning adjacent containers are combined and transported across the SONET/SDH network as one container. Contiguous concatenation limitations include the requirement that all network nodes that are part of the transmission path must be capable of recognizing and processing the concatenated container and the related lack of bandwidth granularity, which makes transporting many data signals inefficient.

Virtual concatenation, as defined in standards, such as International Telecommunications Union (ITU-T) G.707/American National Standards Institute (ANSI) T.105, addresses the drawbacks associated with the contiguous method. Virtual concatenation maps individual containers into a virtually concatenated link. Any number of containers can be grouped together, providing better bandwidth granularity than that attained using traditional techniques. In addition, it enables network operators to adjust the transport capacity to the required customer service for greater efficiency. Because the intermediate network nodes treat each container in the link as a standard, concatenated container, only the path originating and path terminating equipment must recognize and process the VC signal structure, meaning that each link can take its own path through the network, which can lead to phase differences between containers arriving at the path terminating equipment, requiring the equipment to buffer delays.

Service	Transport Capacity Efficiency without VC	Transport Capacity Efficiency with VC
Ethernet (10 Mb)	VC-3 --> 20%	VC-12-5v --> 92%
Fast Ethernet (100 Mb)	VC-4 --> 67%	VC-12-46v --> 100%
ESCON (200 MB)	VC-4-4c --> 33%	VC-3-4v --> 100%
Fibre Channel (1 Gb)	VC-4-16c --> 33%	VC-4-6v --> 89%
Gigabit Ethernet (1000 Mb)	VC-4-16c --> 42%	VC-4-7v --> 85%

Today's transport granularities are defined by the standard line rates STM-1/4/16 and STM-64 (OC-3/12/48 and OC-192). For example, the table above shows us that 1 G service is currently transported via an STM-16 channel. In this case, the actual transport capacity efficiency is about 42 percent. The group VC-4-7v is a virtual concatenated group (VCG), where VC-4 defines the basic granularity and 7v defines the number of members in the group, for nearly an 85-percent gain in efficiency.

The information required for VC is transported in the path overhead of the individual containers.

	SDH	SONET
High-order path	H4	H4
Low-order path	K4	Z7

The parameters required for VC are the frame counter multi-frame integration (MFI) and the sequence number (SQ). Because members of a VCG can travel through the network via different paths, they may not arrive at the destination port simultaneously. To eliminate this differential delay and guarantee the integrity of all the members in a group, an SQ is assigned to each member.

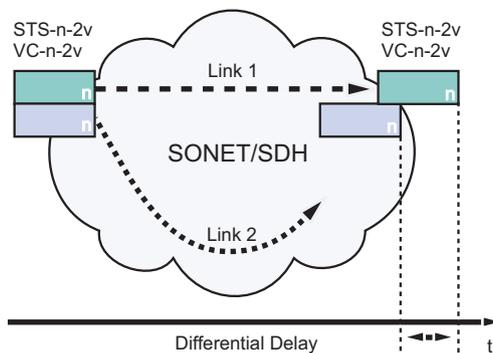


Figure 2. Causes of differential delay throughout the network

The MFI can detect and compensate for differential delays between VCG members up to 512 ms. The parameters describing the frame counter and sequence number are summarized in the following table.

Path	Number of Frames	Sequence Number
High-order path	0 – 4095	0 – 255
Low-order path	0 – 4095	0 – 63

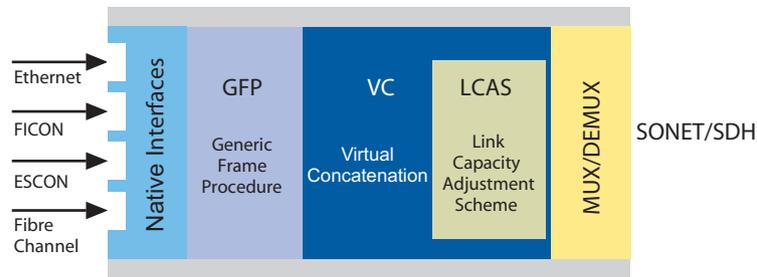


Figure 3. Overview of next-generation SONET/SDH

Generic Framing Procedure

Encapsulation techniques, such as the generic framing procedure (GFP), must be applied to adapt asynchronous, bursty traffic and variable frame sizes before data service traffic, such as Internet Protocol/Point-to-Point Protocol (IP/PPP), Ethernet media access control (MAC), FC, ESCON, and fiber connection (FICON) are transported over SONET/SDH networks. GFP adapts a frame-based data stream to a byte-oriented data stream by mapping the diverse services into a general-purpose frame, which is then mapped into the well-known SONET/SDH frames. This framing structure better detects and corrects errors and provides greater bandwidth efficiency than traditional encapsulation procedures.

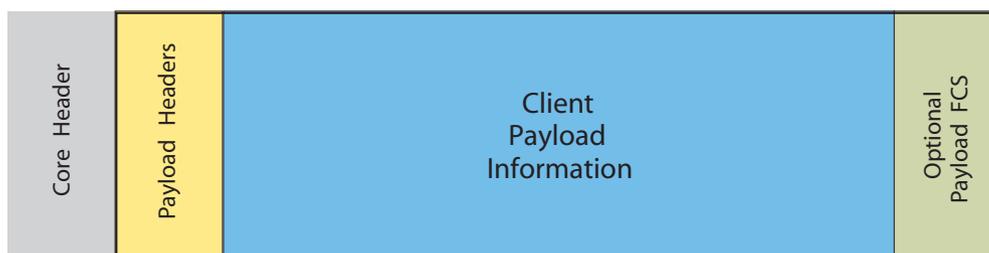


Figure 4. GFP frame

- The core header, payload header, actual payload area, and optional error detection field comprise the GFP frame.
- Core header defines the GFP frame length and detects CRC errors
- Payload header defines the type of information transported, either management or client frames as well as the content of the payload
- Client payload information defines the actual transport payload
- Optional FCS detects errors
- Currently two modes of client signal adaptation defined for GFP exist:
 - GFP framed (GFP-F), where one data signal frame is mapped in its entirety into one GFP frame
 - GFP transparent (GFP-T), where data signal block codes are mapped into periodic GFP frames
 - GFP as defined in ITU-T G.7041/Y.1303

The mode used depends upon the service being transported. However, to date, Ethernet is the data client signal defined for GFP-F. GFP-T maps any data client signal, but is mainly needed today to carry FC. The services mapped via GFP-F consume the least amount of overhead to guarantee the greatest bandwidth efficiency, whereas the priority of those mapped via GFP-T is the fast, efficient transport of data.

In addition to GFP as an adaptation mechanism, other methods exist. Of these, the link access protocol (LAP) and the high-level data link control (HDLC) are the two predominant framing mechanisms. However, GFP supports multiple services, and has higher flexibility, affording its use in combination with optical transport network and higher stability, which offers the possibility of introducing GFP multiplexing structures; therefore, GFP is the adaptive mechanism for the future.

Mode	Description	Application
GFP-F	Service is mapped frame-by-frame into the GFP frame Minimal overhead Variable GFP frame length	Fast Ethernet, Gigabit Ethernet, and IP
GFP-T	Service is mapped byte-by-byte into the GFP frame Optimized transfer delay Constant GFP frame length	Fibre Channel, FICON, ESCON, Ethernet, and DVB

Link Capacity Adjustment Scheme

ITU-T G.7041/Y.1305 define the Link Capacity Adjustment Scheme (LCAS) protocol, which runs between two network elements (NEs) connected at the customer interface to the traditional SONET/SDH network. Each H4/K4 byte transports a control packet, which consists of information regarding VC and parameters of the LCAS protocol.

By determining which members of a VCG are activated and how they are used, LCAS enables the originating equipment to dynamically change the number of containers in a concatenated group in response to a real-time change in bandwidth requirement. This increase or decrease in the transport bandwidth can be accomplished without negatively influencing the service. For example, a company that is supported by a 500 Mbps link between branches during normal business hours needs a higher bandwidth to perform updates during off hours. With LCAS, 1 G of additional bandwidth is automatically provisioned without any adverse impact to the service.

The following parameters in the control packet are relevant for the LCAS protocol:

- Control commands (CTRL) synchronize the source and receiver and transport information regarding the status of the individual members of a VCG
- Source identifier (GID) tells the receiver to which VCG a particular member belongs
- Resequencing acknowledgment (RS-Ack) notifies the source that the receiver received initiated changes
- Member status (MST) transfers the status of the link from the sink to the source for each individual member of the VCG (OK=0, FAIL=1).

- Error protection cyclic redundancy check (CRC), detects errors and discards errored control packets for individual members of the VCG

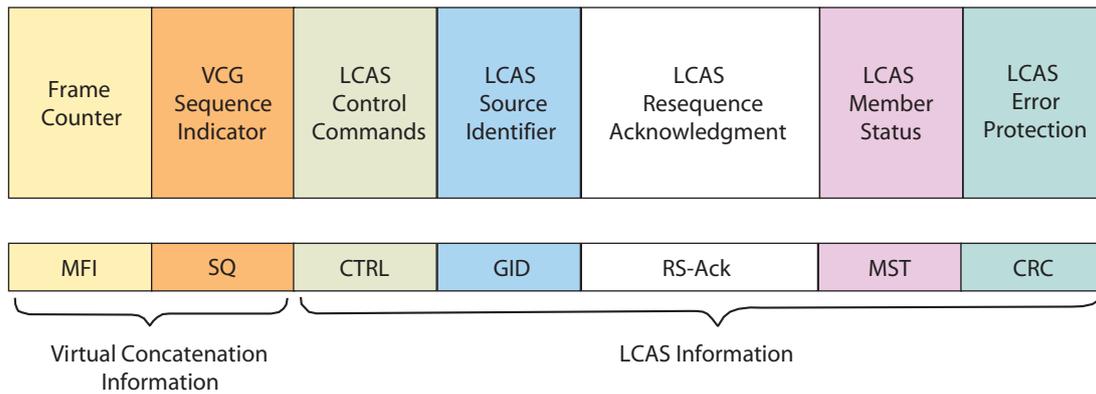


Figure 5. VC/LCAS control packet

Interworking Testing—The Key Component in Service Assurance

Testing is a key component in overcoming the challenges of delivering asynchronous services over continuous synchronous SONET/SDH networks. It is not only the first step, but it is also a necessary ongoing process to guarantee that all layers, from the service layer to the GFP layer as well as VC and LCAS, function properly.

Service Transparency

Testing on packet-oriented services such as Ethernet must be performed on all NEs, including legacy SONET/SDH and plesiochronous digital hierarchy (PDH) interfaces between customers, the MAN, and the core network. In addition:

- Analyze each received Ethernet frame for errors and alarms
- Generate traffic profiles of network utilization to indicate how new end users are behaving and to determine if traffic is constant or bursty
- Perform worst-case analysis on the mapping and demapping of a large number of short Ethernet frames or other abnormal conditions, such as oversized frames

Bandwidth Adaptation

To accommodate Ethernet client bandwidth demand, which has grown from 10 to 30 Mbps, GFP (as the adaptation layer) fills up the current available bandwidth of the transport network. When more bandwidth is needed, virtual containers are added to the VCG, which GFP automatically recognizes, triggering it to release additional bandwidth.

By testing the NEs, their ability to add and remove virtual containers is verified, and confirmation that GFP can appropriately respond to any changes is provided.

Compensation Mechanism for Differential Delay

When the network supports VC, the payload is split and sent via different paths through a long-haul network. Because these two paths are not the same length and contain a different number of NEs, the VCG members do not reach the termination point at the same time. Before reassembling the payload, the terminating equipment must compensate for this differential delay. However, because this process consumes computing power and memory space, it must be checked thoroughly to ensure it was implemented properly.

To prevent poor throughput, the loss of the payload, or the complete collapse of the connection, it is important to test for:

- The ability of the NE to store members of a group to compensate for differential delays
- The reassembly of the members of a group to the complete VCG

Dynamic Bandwidth Adaptation

If LCAS is used, simulating the increased and decreased use of bandwidth by manipulating the LCAS state machine can verify if the protocol was implemented correctly. Because LCAS is not symmetrical, both its forward and backward directions must be tested simultaneously by generating the right control commands in the control packet and monitoring the response of the NE. Performing tests on equipment with handshake capability is important because it can validate bandwidth adaptation without interrupting service.

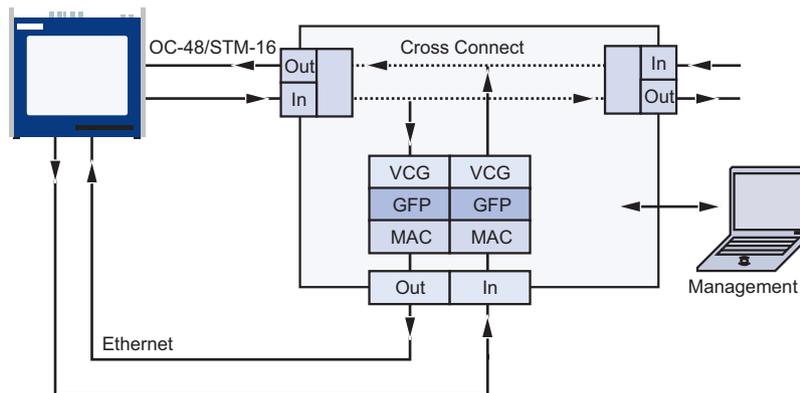


Figure 6. Interworking test using the Viavi Solutions OLT-50

Integrity of the NE Interfaces

After next-generation NEs are integrated into a legacy SONET/SDH network, they must be tested for compliance with ITU-T/ANSI/Telcordia recommendations. In particular, the tests are designed to verify the correct implementation of error and alarms reaction, trace identifiers, and path overhead content. Although today's client payload of VCGs is transported by one large congruous concatenated container that provides for overcapacity, VCGs combine a number of small virtual containers to provide individual transport capacity. Therefore, to verify compliance with ITU recommendations, all tests must be performed on each small container. In addition to the SONET/SDH interfaces, all client interfaces must be tested.

Conclusion

The biggest advantage of next-generation SONET/SDH is that it allows network operators to introduce new technology into their traditional SONET/SDH networks by replacing only the edge NEs. With this capability, both TDM and packet-oriented services are accommodated efficiently on the same wavelength. In addition, significant improvement is realized in how SONET/SDH networks manage packet bandwidth and greater granularity while maintaining the critical functions of traditional TDM networks.

Next-generation SONET/SDH flexibility enables network operators to either build a network using hybrid TDM/packet multiservice provisioning platforms or to provide only the underlying transmit bit stream framing.

Next-generation SONET/SDH not only is cost-effective, it enhances legacy networks' capabilities and capacity to levels that surpass other options. Integrating next-generation SONET/SDH technology into legacy networks achieves significant gain in throughput, quality, and service availability as long as testing and monitoring are employed to verify that new and existing technology can accommodate increasing bandwidth demands.

Operators who overlook these important steps will not save money in the long term. Without constant verification that the NEs are performing appropriately, service quality is not only jeopardized, the long-term costs associated with constant service disruptions, downtime, and unnecessary maintenance prevent network operators from operating profitably or building a base of loyal customers.



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