

NEXT GENERATION SDH SYSTEMS

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Abstract

The time is approaching when Telecom carriers will need to invest in a new range of more efficient equipment that are more adaptable to the Data protocols and traffic churn. Despite the downturn in Optical Transmission there continues to be growth in Data transmission and Storage. This white paper claims that the existing SDH infrastructure is here to stay and will present the 'Next generation SDH' standards showing how they can provide new sources of revenue and make efficient use of Telecom Carrier's installed infrastructure by the addition of plug in cards without the need to build overlay systems.

Introduction

Next generation Synchronous Digital Hierarchy (SDH) protocols will provide new sources of revenue. They will provide new service interfaces, enabling Local Area Networks (LAN) and Storage Area Networks (SAN) to be directly connected into multi site metropolitan, national or global wide area networks (WAN) without the need for including Packet on SONET/SDH (POS) equipment in the Data equipment. They will also maximize efficiency of Telecom Carriers' valuable installed fibre-optic transmission networks, and simplify operations, so that savings in both OPEX and CAPEX will be achieved.

The new protocols are:-

- VCAT Virtual Concatenation
- LCAS Link Capacity Adjustment Scheme
- GFP Generic Framing Procedure
- RPR Resilient Packet Ring
- TSI Time slot interchange
- ASTN Automatic Switched Transport Network
- Autodiscovery
- IP based management

The advantages of SDH are:-

- Standard Optical interfaces for inter-operability.
- Embedded communications channels for OAM & P.
- Cross Connects and ADMs that switch the payload regardless of the Optical Line rate. This solved the problem of 'multiplexer mountains' and jitter gain suffered by the preceding asynchronous or PDH transmission systems.

The Next generation SDH protocols will provide even more benefits such as:-

- Flexible mapping of any new service interface
- More efficient use of installed infrastructure.
- Transparency
- Better Connection management;
- Faster service turn-up/tear down
- Simpler OAM communications

At the turn of the millennium during the 'dot-com bubble' analysts were predicting the demise of SDH, saying it would be swept away by the Optical Transport Network (OTN) 'all optical' networks with 'huge' capacity IP systems directly carried on optical wavelengths. But the bubble burst and the enormous predictions for traffic growth did not materialise. It is now widely recognised that Carriers' installed SDH networks are here to stay and it will be the infrastructure for new growth and services. But legacy SDH was designed to serve voice networks and is poorly matched to Data transport and Storage protocols.

The new protocols, such as Virtual Concatenation (VCAT) and Link Capacity Adjustment Scheme (LCAS) take advantage of spare strands of bandwidth in the network that need not be contiguous and dynamically scale them into end-to-end managed transport channels. Generic Framing protocol (GFP) will provide the flexible frame format for Data and Storage protocols, such as Ethernet, Fibre Channel, Escon etc. without the need for the time consuming standardization process. Equipment supporting the new protocols will provide a convergence of Layers 1 (transmission) and 2 (Link).

Vendors will need to discuss with their customers how services will be sold. In particular how they will manage the Service level Agreements with the end customers. Correlation of transport failure or degradation to the impact upon actual Data services may be required. The present mode of operation with legacy systems provides performance reports and alarms at the SDH and Optical layers with no indication in the transport layers of the affect upon the services being carried. Should the converged Layer 2 and Layer 1 be treated as ethernet with SDH capability or optical nodes with ethernet capability.

The Synchronous Digital Hierarchy

Since the early 1990s the frame format for Telecom transmission has been the Synchronous Digital Hierarchy (SDH/SONET). The SDH format is very similar to the North American SONET format, but with some modifications to accommodate the different legacy PDH transmission schemes used in Europe. For example, the international primary multiplex is 2Mbit/s E1, while in North America it is 1.5M DS1.

Transmission rates have been doubling roughly every 2 years from 140M in 1980 through to 10Gbit/s in 1995. Transmission rates rapidly increased in the late 90s as the number of wavelengths capable of being multiplexed into a single fibre increased from 1 to over 160 by 2000. Because the rapid growth of Bandwidth demand and optical ability appeared to be outstripping the capability of SDH new standards for the transport layer were being hurried into place. This was the 'Optical Transport network' (OTN). The OTN would provide transparent transport of any client interface, optical switching, managed layers and ultra long haul reach with Forward Error Correction (FEC).

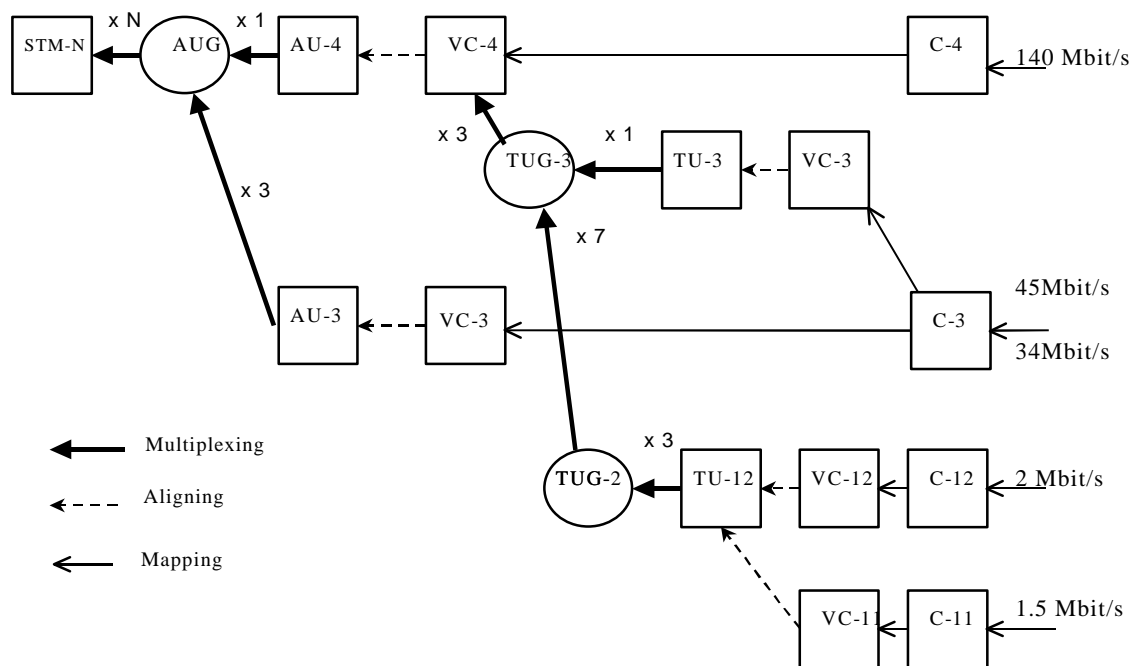
Experts were confidently predicting the demise of SDH as it would be swept away by the OTN, Notwithstanding the major challenge the optical switching presented to engineers, especially in long haul amplified networks, the downturn in the Telecom market has replaced that confidence with realism.

It is highly unlikely that any carrier would now consider replacing their valuable SDH infrastructure. The emerging OTN standards retreated into a niche application for transparent point-to-point reach and carrying only SDH as its payload. The extra reach is very valuable as it eliminates costly regeneration in long haul networks. An amplified 10 Gbit/s SDH typically supports 600km between electrical regeneration sites, while the same signal carried in an OTN frame can travel 1500km or more between regenerators.

The major point to note about SDH is that every node is synchronized to a National reference clock that is distributed via the SDH signal or by satellite. The synchronization allows any container to be added, dropped or cross-connected at an SDH switching node without having to demultiplex through every interface rate. This maximizes layer efficiency and minimizes jitter.

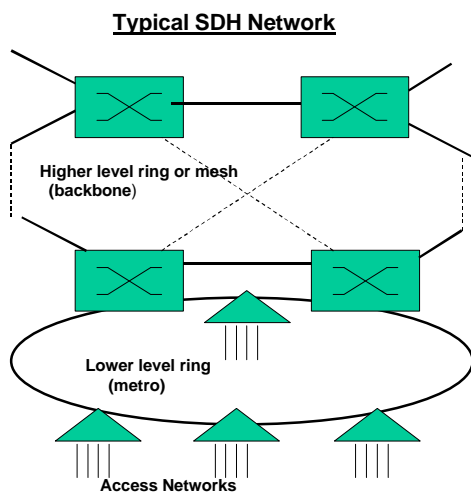
The SDH multiplexer maps the incoming signal into a Virtual Container, VC, and adds overhead bytes for end-to-end management and in service monitoring. There is a standardized virtual container for each service. For lower rate services low order VCs are used. For example the E1 signal is mapped into a VC12. A higher rate signal, such as 140M is mapped into a high order VC, the VC-4.

SDH Multiplexing Structure



Low order VCs are multiplexed into a high order VC. The high order VC-4s are multiplexed into one of the SDH transmission Synchronous Transport Modules (STM-N). The standardized STM-N range between STM-1 (155 Mbit/s) through to STM-256 (40 Gbit/s) in multiples of 4. The VC-4s are mapped into an STM-N frame with multiplex (MS) and regenerator section (RS) overheads. These transport overheads are used to monitor the connection and performance of sections, provide management data communications, protection and synchronisation signalling, user channels and voice orderwire.

One VC-4 with can be transmitted at 155 Mbit/s as an STM-1. 64 VC-4s multiplexed together into an STM64 are transmitted at 10 Gbit/s. To maintain synchronisation for the VC-4 paths within the STM frame, each VC-4 has a pointer in the STM overhead that indicates where the start of the VC-4 is in the frame. Each pointer is incremented or decremented as the VC-4 moves within the frame. These pointer movements occur very infrequently and are used to accommodate differences in network clocks between nodes. If there is a network synchronisation problem then the pointer movements will occur more frequently, in order to ensure the payload is not lost. The network planner designs the network to minimise pointer movements because pointer movements can cause jitter and wander of the payload.



SDH provides a layered network, typically low order VCs are switched near the edges and high order VCs are switched near the core. The layering ensures an efficient network and simplifies operations.

Customers' traffic is collected via rings or point-to-point links in the access network and sent via low order VCs to Add/Drop Multiplexers (ADM) on metro rings. Customers with high demand may use high order virtual containers or multiples of them. The metro rings multiplex

low order virtual containers into higher order virtual containers and transport the traffic to hubs where the traffic is switched at Large ADMs or Cross Connects either back into the metro or onto regional or long haul backbone networks. Interconnection between rings is typically via Matched Node Ring Hubs to avoid single points of failure.

The main types of protection used in SDH are:

- Dedicated Protection, DPRing. Mainly used in the access networks and metro rings.
- Shared Protection Ring, SPRing. Mainly used in Regional and Long Haul backbone networks. Traffic in rings share reserved protection bandwidth.
- Matched nodes are used to interconnect rings reliably
- Mesh protection. Several mesh protocols have been tried. Unlike DPRing and SPRing none of them are standardized. The protocols use spare capacity in the network to provide protection in the event of failure.

In the metro transmission is typically via un-amplified STM1 155 Mbit/s to STM4 622Mbit/s, but STM-16 2.5Gbit/s is not uncommon.

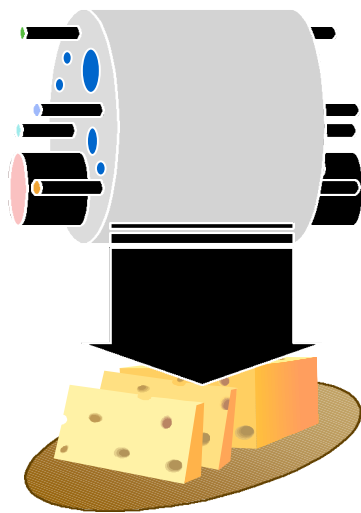
Typically in large regional and long haul backbone networks amplified DWDM STM16 2.5Gbit/s or STM64 10Gbit/s are used. The amplifiers at typical spacing of 80km eliminate the need for expensive electrical regeneration until over 600km.

SDH limitations

SDH networks were put under severe strain by the explosive growth of demand in the late 90s during the 'dot-com bubble' as carriers raced to stay ahead of the predicted growth in new services. Networks built from legacy SDH equipment took days to months to plan, turn up or change services. It could not provide the optimum service for emerging new services. High bandwidth services required contiguous blocks of VC-

4s to be reserved, for example Packet on SDH/SONET (POS). They also required the Data, Storage or Video equipment to include the SDH mapping and electro-optics within the equipment. Those POS interfaces were far more costly options on the client equipment than the standard Ethernet, Storage or Video interfaces the equipment would normally use. It was difficult to plan new services in large networks where a contiguous set of VCs needed to be found through all intermediate network elements. It was even harder for protected services where same contiguous set of VCs had to be reserved on both the working and protected paths.

The result was stranded VC channels left behind in SDH networks. The VCs between network elements were added and removed haphazardly due to the unpredictable customer churn. For example if VC-4 #1 connects NE1 to NE3 and VC-4#2 connect NE2 to NE3. The next VC-4 available to connect NE1 to NE4 is VC-4 #3. VC-4#2 between NE1 and NE2 is unused, and may be un-useable.



It is difficult to route high bandwidth services through the fragmented network. It is sometimes compared to a swiss cheese. There are plenty of holes in it that could be filled. But do they may not go all the way through and they are not straight.

The result is a very inefficient fragmented network, with bandwidth bottlenecks in places and under-use elsewhere. The useable system fill became exhausted well before 100% of VCs were connected.

The solution was expensive addition of overlay networks on extra wavelengths, but after the Telecom downturn Carriers needed to take care to solve the problem more economically.

Dedicated protection is wasteful of bandwidth. Shared protection is less wasteful, but more complicated and difficult to interoperate between vendors.

The differences between SDH and SONET made it difficult to engineer global networks. For example SONET STS1 (high order VC3) was designed to carry the 45Mbit/s DS3 signal and is not the same as the European equivalent (low order VC3). The North American SONET high order path is the STS1 (high order VC3) while in Europe the high order path is the VC-4

The Bandwidth granularity of the standardized SDH mappings are based upon legacy PDH systems and do not fit the requirements for new data services. For example Gigabit/s Ethernet (GE) at 1Gbit/s is a poor fit to STM-16 at 2.5 Gbit/s. There are no standard mappings for new service interfaces. Proprietary solutions were implemented, but this leads to interoperability and scale-ability issues.

Packet on SONET/SDH (POS) is difficult to Route in the transport layer. Typically requires an entire 2.5G or 10G wavelength with concatenated VC timeslots. For example a Router with 2.5G POS maps transmitted data into a VC-4-16c., contiguous block of 16 VC-4s.

Ethernet protocols are based on decade multiples - 10Mbit/s , 100Mbit/s, 1Gbit/s, 10Gbit/s. Storage protocols such as Fibre Channel include 200Mbit/s, 2Mbit/s, 4Mbit/s. However SDH was designed to have service interfaces around PDH interfaces of 2.048Mbit/s, 45 Mbit/s etc.

SDH provides poor transparency for the entire SDH signal (STM-N). It is transparent to the Virtual containers and the payloads within them, but legacy SDH cannot carry an entire STM-N transparently. SDH was designed to be transparent to legacy PDH services, but nobody foresaw a requirement for SDH to carry an entire STM-N frame transparently. But that is exactly what the Carrier's Carrier market of leased 'dark fibre' and Bandwidth swapping required in the late 1990s as carriers sold bandwidth to other carriers. Proprietary solutions were developed. None of these solutions was totally transparent, even though they carried the more common standard overhead bytes there were interoperability problems where the service required transport of STM-N that had proprietary use of overheads for example where extended protection control bytes were in use. They were also not transparent to timing. The client STM-N would need to take timing from the server network. This is not easy where the two carriers have their own primary clocks. The first truly transparent solution to the problem to emerge was the OTN digital wrapper as defined in ITU-T G.709. However it was only properly designed for point-to-point links. Because it was an asynchronous multiplexing scheme It had all the networking issues of the old PDH systems. Apart from transparency the other major benefit of the OTN digital wrapper was strong FEC, enabling far greater reach (typically 6 to 11dB gain depending upon the FEC scheme and amount of overhead). So for point to point schemes requiring transparency or extra reach the OTN will probably be used, with the signal returning to SDH when it needs to be switched.

Present Mode of Operation

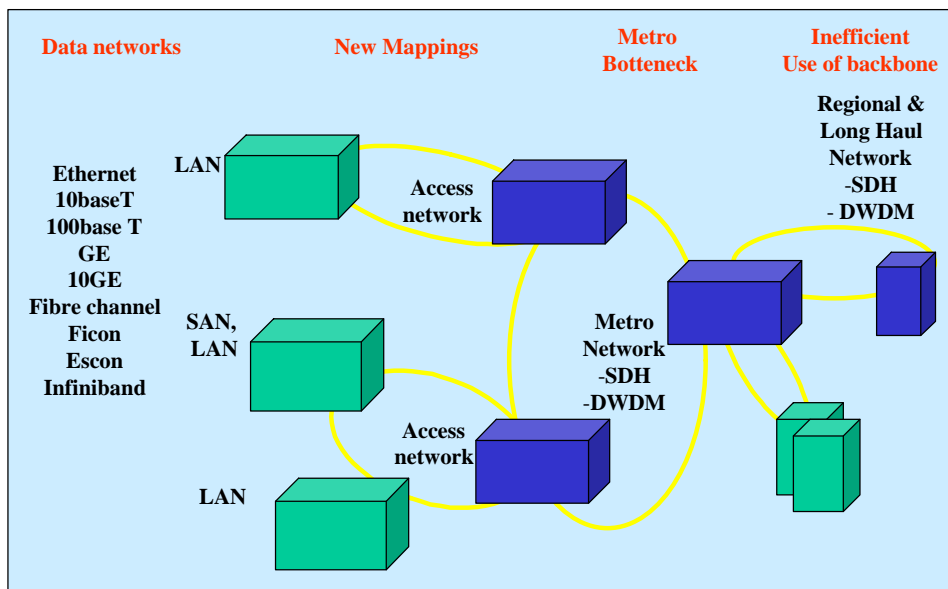
The problem facing Telecom carriers varies. There is un-predictable future growth. Shorter contract cycles and competition cause high connection churn. Customer demands are provisioned in small increments. So the network is not provisioned as efficiently as it would be if all connections are made and fixed on day one. But the legacy SDH and optical solution is fairly static. Circuits can take days to month plan and provision, Sometimes the available bandwidth is stranded or it may not be contiguous. It is difficult to re-provision an existing service to a new application.

Market Needs

Carriers want to get the maximum revenue out of their existing SDH networks. They want evolution of their networks, and not a costly revolution, overlay or replacement. They require small incremental costs and the functionality can be progressively introduced to the network without disruption to existing services. The traffic will be allocated dynamically when required, and can be increased or decreased depending on the customer demand. This contrasts to the previous mode of operation where the network was static.

New Services

There is still strong growth in data services to interconnect LANs into wide area virtual networks. There is also growing demand from corporations and financial institutions to interconnect SANs create wide area storage networks. Cable operators are looking for more efficient ways to transmit video, for example for VOD. While for the present there is overcapacity in much of the long haul network, there are bottlenecks in the metro and access networks, and growth with legacy SDH or DWDM is proving too costly.



There is strong demand for high capacity broadband access. Many potential broadband subscribers live beyond the reach of ADSL. A more efficient SDH could provide stepping stones to clusters of domestic subscribers beyond reach of broadband.

Data storage demand is doubling every year in large corporations and financial institutions. They need to be able to back-up and restore their storage rapidly to secure remote locations. Banks and Insurance companies are evolving to totally paperless operations. For example all paper correspondence will be scanned at the post room. Legislation requires financial data records to be stored for 5 years and to be recovered within a short fixed period. Using tape and transportation is not satisfactory. A fast economical solution using telecommunications is required.

Corporations require Wide Area Networking of high bit rate client-server interfaces. The transport network needs to be able to connect to these Ethernet and Storage interfaces in their native form, to avoid adding costly interfaces between the

transport and data equipment and requiring the data equipment to have costly plug-in cards with transport interfaces.

SMEs, government, schools, colleges, universities, hospitals and regional development are driving demand for broadband services. Cable operators requiring VOD and a multitude of interface options, integrated switching, and drop-and-continue capabilities for digital video broadcast applications.

Ethernet interfaces are well understood and have standardized interfaces. They are cost effective with cheap components that are widely used in LANs. There is low operation and service costs. Bandwidth scales incrementally and customer only needs to pay for the bandwidth used. Bandwidth can be increased or decrease in minutes. Ethernet Can link enterprises into multi site networks into VPNs.

Next Generation SDH Transmission protocols

Next generation SDH protocols are being developed that will allow customers to provide new services. For example transport of Ethernet or storage protocols by the addition of plug in cards on installed systems rather than a new overlay network. The protocols will also allow the customer to maximise efficiency as spare timeslots can be used. The signal is partitioned into smaller virtual containers that can be routed separately through the network. This compares well with the legacy Packet on SDH protocols that require large contiguous groups of VCs on all the sections that the circuit traverses.

Efficient Scale-ability

- Match transport bandwidth to the service requirements
- Better performance /cost ratio
- Better granularity for efficient growth
- Re-use of existing infrastructure
- Avoid costly overbuilds
- Bandwidth re-use



Enabling New Services

- Multi-Service capability
- Ethernet, Storage, Video ..
- No delays for standardization of new service interfaces

Resilient and Reliable

Whether you call it, a digger, a Back-Ho or whatever, the affect on a glass fibre is the same. Reliable services need to be carried on a transmission system that can tolerate fibre cuts.

- Shared or Dedicated protection
- Restoration to automatically discovered or pre-planned spare bandwidths
- No need to dedicate whole fibres or contiguous timeslots for protection.
- Next generation SDH protocols can use spare channels whether they are on different paths, fibres, wavelengths or discontinuous VCs.
- Can protect against multiple outages & node failures
- Planned switchover to spare bandwidth for maintenance or for daily or weekly operations such as backups.



Operational efficiency

A new signalling and control plane will enable the 'Automatic Switched Transport Network' (ASTN).

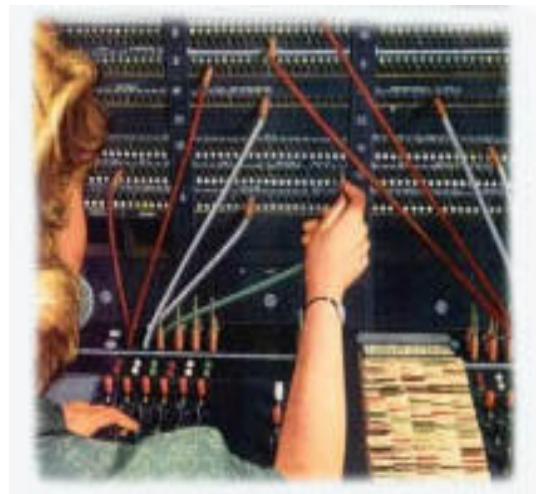
The ASTN will automate provisioning of circuits. Planning and circuit turn-up / tear-down will now be in real time.

ASTN will also support restoration of service onto spare bandwidth during failure conditions or for maintenance.

Churn Management

The new SDH and signaling protocols will provide Auto-discovery of the Network Elements, connectivity and capability in the networks.

The protocols will defragment the under utilized fragmented infrastructure. Provisioning will be fast and there will be automated connection management. This will lead to huge CapEx & OpEx savings.



Constant Bit Rate Transparency

Entire STM-N transparency including payloads, overheads and timing is required for carrier-carrier services and to solve vendor interoperability issues.

Two classes of constant bit rate transparency are required:-

- Lower capacity STM-N transported over higher capacity STM-N. For example 4 x STM-16 transported on one 10 Gbit/s wavelength.
- Arbitrary bit rate transparency of non-SDH. For example 2.3 Gbit/s multiplexed video signal transported in STM-N.

Virtual Concatenation (VCAT) provides the solution to these problems as the whole signal can be mapped to a set of Virtual containers e.g. VC-4. These VC-4s need not be contiguous and can traverse the network separately. They come together again at the network element that reconstructs the original signal.

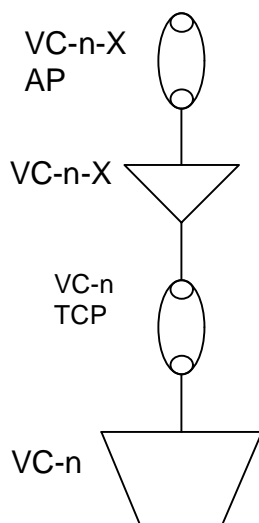
VCAT can even be used to transport OTN signals for carriers that may have SDH infrastructure, with areas of OTN needing interconnection. This form of VCAT is standardized in ITU-T G.707 and is also called g.modem.

Packet data Transparency

To create wide area networks there is a requirement for Transparency of Data protocols across transport networks. The data protocols such as Ethernet and Fibre channel have formats like 8B10B, 64B65B etc. Generic Framing Procedure (GFP) together with Virtual concatenation provide the solution to this problem as GFP will frame any of these formats.

Virtual Concatenation, VCAT

SDH Virtual Concatenation (VCAT) is standardized in ITU-T G.707. (The OTN also has a type of virtual concatenation that is standardized in G.709, but that would only be used in all OTN networks and where very high capacity multiples of transparent 2.5Gbit/s or 10Gbit/s are required).



ITU-T VCAT model

The service is transported via 'X' independent Virtual Containers (VC). Each VC is called a 'member'. The virtually concatenated container is referred to in the SDH standards as VC-n-Xv where n indicates the Virtual Container type (e.g. for example VC-4), and X indicates the number of VC-n members that are virtually concatenated to transport the service, for example X could be set to 7 to transport Gigabit Ethernet, GE.

In order to monitor the end-to-end quality of service of the VCAT signal a trail trace and BIP is applied across the whole VC-n-X.

The SDH equipment is required to compensate for differential delay at the trail termination sink. This is because VC-n that may have traversed a different path to reach the termination will have experienced different delays. Hitless Restoration is feasible because the next generation SDH equipment can select working VCs from the buffers used to compensate for differential delay.

Link Capacity Adjustment Scheme

LCAS is standardized by the ITU-T in G.7042. The scheme controls capacity increase or decrease for a service over a Virtual Concatenated channel. Capacity can be adjusted to match the service need, restore failed circuits or adjust capacity during failure.

VCAT with LCAS provides Scale-able expansion. For example a 1 GE signal connected to an SDH NE may only require 100 Mbit/s of bandwidth day 1, and so only one VC-4 will connect across the network. Later as the customer's requirement grows additional VC-4s can be connected up to the maximum bandwidth of the GE interface.

Commands to provision, delete or change the service may come from Network Manager or ASTN control. They may be triggered by customer demand, protection or restoration plans.

The scheme allows temporary removal of failed VC members, allowing automatic decrease of capacity during network failures and automatic increase after recovery. This feature can be used to plan a service that can tolerate a defined minimum bandwidth during failure conditions, but under normal conditions will have higher bandwidth provisioned.

LCAS control packets

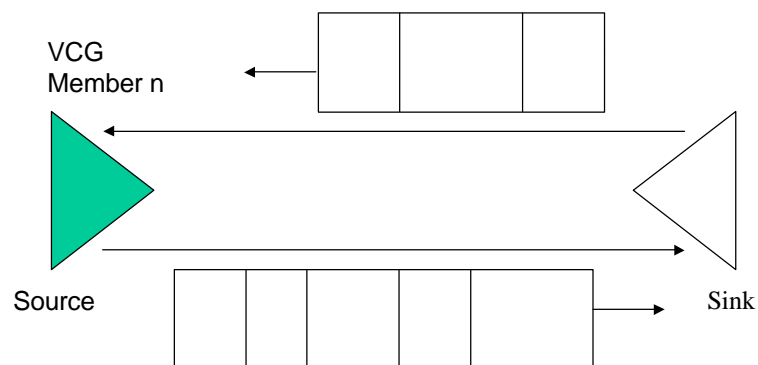
LCAS Control packets describe the status of link. The control packets are used to synchronize status at the VCAT trail termination Source and Sink. Status change packets are sent in advance of the service adjustment. The signalling channel is unidirectional and sent in the VC overhead of each VC member. The H4 overhead byte is the signalling channel for high order VCs (e.g. VC4 or SPE-1). The K4 byte is used for signalling in low order VCs (e.g. VC12 or VT1). Each control packet has a cyclic redundancy check. Hence the signalling is very fast and reliable compared to using external IP networks.

Information sent from Source to Sink:

MFI	Multiframe, 0-4095
SQ	Sequence Number, 0-255
CTRL	control information
GID	Group ID
CRC	Cyclic Redundancy Check

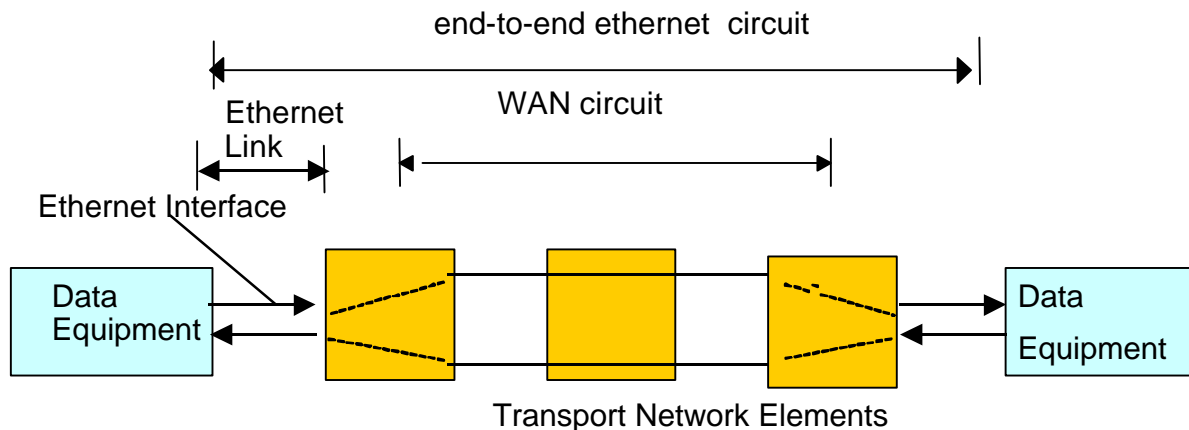
Information is sent from Sink to Source:

MST	Member status, 0= OK, 1= Fail
RS-Ack	Acknowledge
CRC	Cyclic Redundancy Check



Generic Frame Procedure

Generic Framing Procedure (GFP) is standardized in ITU-T G.7041. GFP is a flexible efficient framing scheme that can be used for transparent transport of any packet data protocol. For example Ethernet (GE etc.), Storage (Fibre channel etc.) or Video. These protocols typically use formats where data is transmitted in formats such as 8B10B, 64B/65B etc. For example 8B10B is a format where a block of 8 data bits is transmitted with 2 overhead bits.



The scheme requires signalling conversion between the Ethernet and transport systems. For example, if the Ethernet signal fails then the SDH equipment at the trail termination source needs to signal that failed status to the remote SDH equipment at the trail termination sink. The SDH equipment must then fail the outgoing Ethernet signal (e.g. by turning off the laser) so that the remote Data equipment can detect the failure. If this is not done then it takes far longer for the Data network to detect that the link is down, because the data equipment may not be using a protocol that can detect failure by the absence of incoming packets.

The system must also control latency and throughput to ensure that end-to-end delays do not exceed time-outs in the Data equipment. Some of the Data protocols were developed for use on a single site without long haul transport in mind.

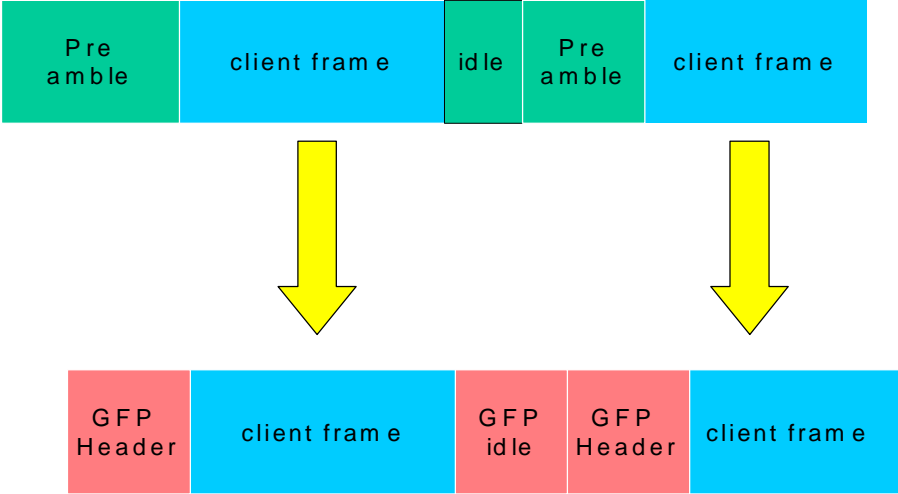
Enterprise Data and Carrier transport management systems are different. They use different protocols and collect different statistics. For example Transport management systems monitor for error-ed seconds, while network management systems for Data equipment monitor for missing or corrupted Ethernet frames. So the SDH equipment needs to report to Enterprise network management systems (e.g. SNMP) as well as Carrier transport network management systems (e.g. TL-1 or TMN).

There are two types of mapping standardized for GFP. Frame mapped GFP-F and transparent mapped GFP-T.

GFP- F. Frame Mapped

Frames from the client data equipment are transmitted as a unit. The whole frame is encapsulated so there is delay as the frame is being stored prior to encapsulation and transmission. All the information in client frames is encapsulated in the GFP frame, but the preamble and inter-frame gaps are discarded. Preamble and inter-frame gap is re-created at the SDH equipment at the trail termination.

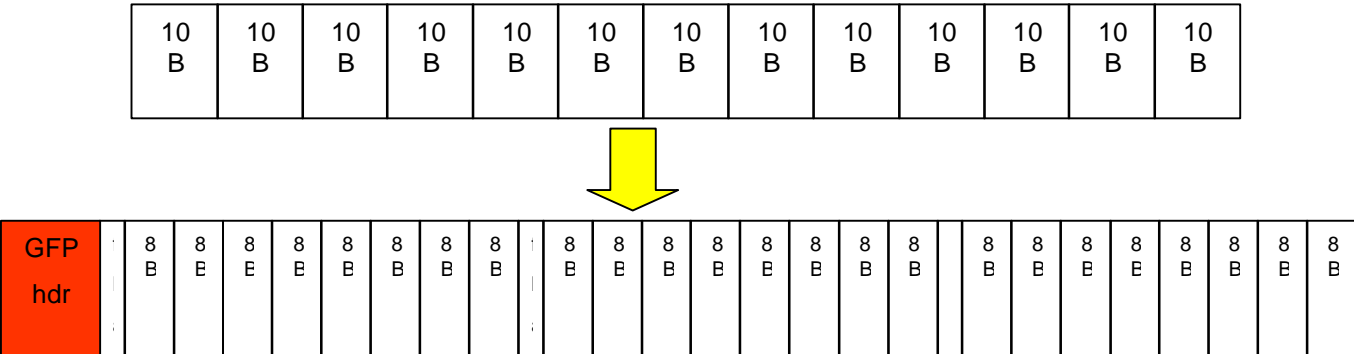
Mapping from packet data frames to GFP-F



GFP-T. Transparent Mapping

GFP-T is totally transmitted and the data is transmitted immediately, rather than waiting for reception of the whole data frame. All data including the control information is transferred. The GFP header is transmitted followed by all the data and control in octets. Every 8 octets is followed by a flag. Unrecognised/invalid codes are translated to a standard invalid code. Pad code is inserted for rate matching. The advantage of the transparent mapping is its low latency. For example Escon requires low latency.

Mapping from packet data frames to GFP-F

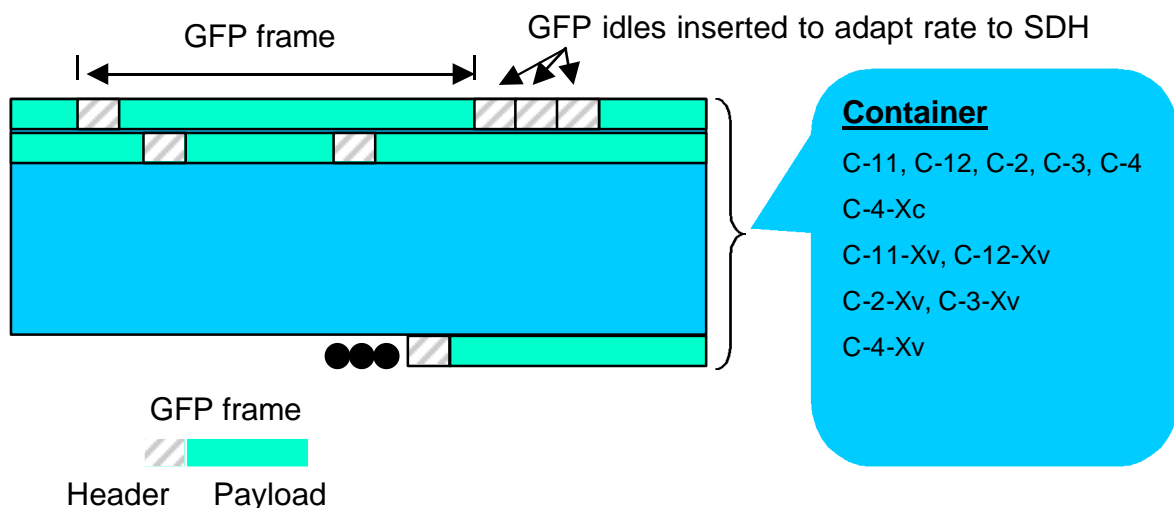


Comparison of GFP mappings	
Frame-mapped	Transparent-mapped
Store client frame before forwarding	Low latency
Client protocol specific mappings	Common to all 8B/10B protocols e.g ethernet & SANs
Control codewords discarded	Control code-words forwarded transparently e.g. GE auto-negotiation
Can map to sub-rate paths	Fixed path bandwidth
Can map to variable path bandwidth e.g. failures on VCAT/LCAS members	Fixed path bandwidth

GFP to SDH mapping

GFP frames map into an SDH virtual container, e.g. VC-4. The choice of container depends on the amount of data expected to be transmitted. Typical containers are VC-12 for lower rate channels that would have traditionally required a 2M or E1, while VC-4s would be used for higher capacity services.

GFP idle codes are inserted to adapt the data rate to the continuous constant rate bit stream of the SDH container and to pad out the rate to the rate of the container during periods of lower activity.



Time-slot interchange

SDH Networks evolved inefficiently, they could now be described like a fragmented swiss cheese. Circuits were connected as required and especially in rings many stranded VCs were left on links. Time Slot Interchange (TSI) enables improved provisioning flexibility by allowing a path to interchange timeslots as it transits the network. This makes planning easier. The customer gets improved system fill and greater provisioning lifetime for the SDH section. It is especially needed for services such as POS, 'Packet on SDH' or 10 GE WAN where the data is required to be carried via a contiguous set of Virtual Containers (e.g. VC4-16c). It is difficult to find a set of spare contiguous VCs that use the same timeslots at each node in the ring.

However TSI is not simple to implement, especially on SDH rings protected using Shared protection protocols (MS-SPRing, BLSR) that require network maps of all virtual channel connections in the ring to be stored at each network element in the ring. Changing the VC used by a circuit in a ring at intermediate network elements can make it very difficult for the correct switching decision during failure of a fibre or node.

With protocols that can be carried via Virtual Concatenation there is less need for TSI as the individual VCs will use whatever spare VCs that are available, whether they are contiguous or not.

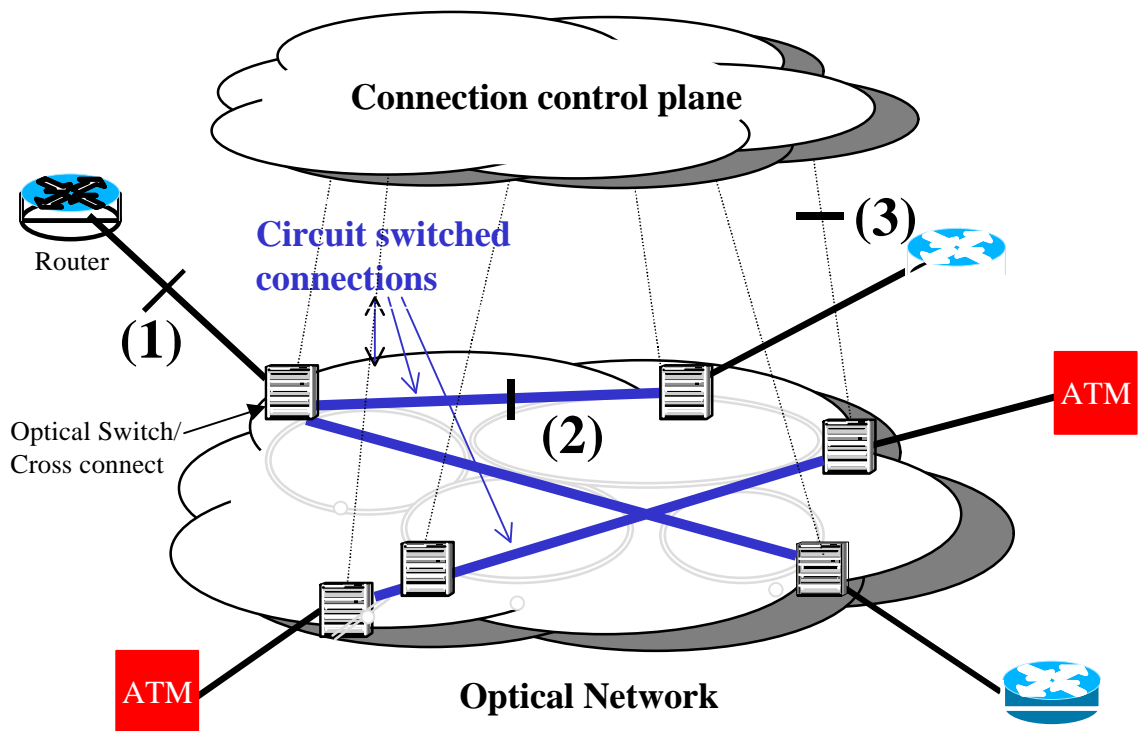
RPR, Resilient Packet Ring

RPR is a new version of Ethernet defined in IEEE 802.17 that addresses the problem of resilience of the Ethernet protocol. RPR can co-exist with SDH rings. RPR provides layer 2 restoration. It uses the Ethernet MAC for fault location and fast switchover to new route. It supports similar ring protection performance as SDH, but all the protection is controlled using packets in layer 2 rather than fault detection and K byte signalling in layer 1.

All RPR aware nodes in ring aware of the destination so they can route traffic to the correct node over the restoration route Advantages of Ethernet are retained, for example Packet stat-muxed add/drop and spatial re-use . RPR equipment can re-use the existing fibre ring topology. RPR is resilient with fast protection comparable to SDH protocols (<50ms). It supports 4 priority levels, VLAN and Multicast.

ASTN, Automatic Switched Transport Network

ASTN is being standardized in the ITU in ITU-T G.8070, G.8080. ASTN signalling could be thought of as the transport equivalent of signalling system number 7 used for switching voice circuits as the subscriber dials telephone number. It is also analogous to the PNNI system used for provisioning broadband circuits in ATM networks. There will be a hierarchical numbering plan for a global ASTN numbering scheme.



ASTN is a control and signalling layer which will enable:-

- Fast provisioning of end to end circuits
- Fast turn up and tear down of services
- Dynamic allocation of network resources
- Restoration of service during network failure conditions
- Restoration of high priority part of the service during network failure conditions.
- Periodic re-optimization of the system

Auto-discovery

Auto-discovery is being standardized in ITU-T G.7714. It is the means that the management systems and signalling systems, such as ASTN, will discover what equipment, circuits and capability is available in the network. With legacy networks a major problem with many customers is the difference between what the customer has in the network and what the management system believes is in the network. The divergence between the real network and the management views occurred because the equipment was added to the management databases manually and because systems from different vendors were employed. This is especially a problem after reconfigurations.

Auto-discovery will aid planning decisions. With auto-discovery the management systems will have an accurate database of the real network, its capability, system fill, its spare capacity, single points of failure and restoration routes.

This will enable:

- Improved Connection Management
- Improved Inventory management
- Better knowledge of Service and equipment capabilities

Signalling for auto-discovery between nodes and management systems will be via SDH overheads and/or the DCN. The protocol will discover adjacency of the physical equipment and adjacency of nodes connected via a transmission layer.

Physical Media Adjacency Discovery

Physical Media Adjacency Discovery (PMAD) will discover the physical connectivity between adjacent Network Elements. For example that ADMs are connected together, or an ADM is connected to a Regenerator, or the connectivity between amplifiers on an Optical line system.

This is used for:-

- Service capability exchange
- Inventory
- Equipment Capability
- Verification of port characteristics

Layer Adjacency Discovery

Layer Adjacency Discover (LAD) discovers the connectivity in a layer between equipment. For example a pair of ADMs may have regenerators and amplifiers between them, but at the VC-4 layer they are considered to be adjacent. In this layer, knowledge of the physical connectivity beyond the fact that it is working, degraded or failed is of no interest. LAD builds a layer network topology for each layer and Identifies link connection end points for connection management This aids routing decisions The layer connectivity is valid while the trail supporting link is valid.

Service Type Signalling

Legacy SDH networks are unaware of the services that they transport. Service Layer management enables carriers to manage and monitor the service as it traverses the transport network, even as it passes between different carriers. The impact of fibre cut, failure or degradation of SDH channels can be correlated to the impact upon the actual service in terms that are understood by the end customer systems.

A means of correlating the service with the transport layer is required. So that the carrier will know the impact upon end customer services when an SDH container fails.

Service information may be signalled using packets via the VC and section overheads e.g. in K4, H4 or D bytes.

Information within the packet could include:-

- Trail Termination Source and Sink
- Layers of Tandem connection information
- Service type e.g. Packet Data, Constant bit rate ...
- Service encoding e.g. GFP-T, GFP-P
- Service priority : e.g. for congestion or delay control
- QoS requirement: Protected, Best effort or pre-emptable

Thus a carrier can monitor: The content of the paths flowing through a node

- The % fill of the switches transport sections
- The impact of node and section degradations
- At each node where VC switching occurs the node shall broadcast packets using UDP over the LPOH (K4) , HPOH (H4) and RS (D1-D3 DCC)
- Unused VCs will be indicated by an 'unused' packet

Since the packets will be UDP datagrams they need not be acknowledged. But to ensure that information is not lost when there is transmission degradation the datagrams will be retransmitted at regular intervals. The interval needs to be chosen to balance speed versus Comms, CPU, memory usage.

When a change of service through the VC is required a new packet will be sent. This could be a change to 'unused'

Thus all connected nodes and sections can be aware of the contents of the paths flowing through it.

Conclusion

Whereas the pre Telecom downturn view was that Data protocols and the OTN would drive out SDH, it is now evident that Data protocols will be a driver for future SDH systems. While there is overcapacity in most of the Long Haul Networks – apart from a few pinch points – there is a bottleneck in the metro networks, where use of the fibre has been inefficient and DWDM too costly. The new protocols will allow far more efficient use of the metro networks, and bring the SDH network to the Data equipment.

SDH is here to stay and new growth, efficiency and services will be built upon existing networks. The growth will be steady and scaleable with plug in cards. Initially the next generation cards will plug into existing SDH or DWDM equipment that is already in service. The standards developed for the OTN will not replace SDH, but it will find a major role in point to point systems where the extra reach achieved by FEC will enable cost reduction by the elimination of regenerators.

Operational costs will reduce as the new protocols such as LCAS, ASTN, Autodiscovery and IP management reduce the cost of connection management and OAM&P. VCAT will enable efficient use of the installed infrastructure.

To simplify nodes and to enable better correlation of transport degradation to service problems Layer 2 and Layer 1 protocols may converge. A system that is Ethernet with SDH optical capabilities requires overlay networks or extra wavelengths. An SDH optical system with ethernet protocols can be built into existing networks with plug in cards.

References

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The Author

Chris Purse obtained his honours degree in Electronics from Cardiff University in 1981, and became a Member of the IEE and Chartered Engineer in 1987.

As a student researching quaternary semiconductor Lasers in 1980 he was involved at the '*birth*' of commercial fibre optic transmission industry, and he was there when it almost went to its '*deathbed*' in 2003 following the Telecom downturn. He was Senior Manager at Nortel Networks Harlow laboratories responsible for the System Design requirements of the High Capacity OPTera optical and SDH/SONET range of products. Along the way he developed optical and satellite transmission systems from 2Mbit/s to 1.6 Tbit/s. He is now developing ideas and applications for next generation SDH and investigating solutions for extending broadband access.

Glossary

ADM	Add/Drop Multiplexer
ASTN	Automatic Switched Transport Network
BIP	Bit Interleaved Parity
CRC	Cyclic Redundancy Check
DCC	Data Communications Channel e.g. D1-D12 embedded data bytes in STM-N
DCN	Data Communications Network
DWDM	Dense Wavelength Division Multiplex
DPRing	Dedicated Protection Ring
FEC	Forward Error Control
GE	Gigabit Ethernet
GFP	Generic Framing Procedure
GID	Group ID
IP	Internet Protocol
LAD	Layer Adjacency Discovery
LAN	Local Area Network
LCAS	Link Capacity Adjustment Scheme
OAMP	Operations, Administration, Management and Provisioning.
OTN	Optical Transport Network
PDH	Plesiochronous Digital Hierarchy (2 Mbit/s, 8 Mbit/s, 34 Mbit/s etc..)
PMAD	Physical Media Adjacency Discovery
QOS	Quality of Service
RPR	Resilient Packet ring
SAN	Storage Area Network
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical NETwork
SPRing	Shared Protection Ring
STM	Synchronous Transport Module
TSI	Timeslot Interchange
VC	Virtual Container
VCAT	Virtual Concatenation
VOD	Video on Demand