Synchronous Digital Hierarchy (SDH)

Definition

Synchronous digital hierarchy (SDH) and synchronous optical network (SONET) refer to a group of fiber-optic transmission rates that can transport digital signals with different capacities.

Overview

This tutorial discusses synchronous transmission standards in world public telecommunications networks. It will cover their origins, features, applications, and advantages, as well as their impact on network design and synchronous signal structure.

This tutorial concentrates on the most common form of SDH, that defined by the European Telecommunications Standards Institute (ETSI) for Europe but now used everywhere outside of North America and Japan. The Japanese version of SDH differs only in details that are touched on here but are not significant for the purposes of this tutorial. SONET was defined by the American National Standards Institution (ANSI) and is used in North America. This tutorial refers to SONET where appropriate; a more detailed discussion is available in the International Engineering Consortium's (IEC's) SONET Web ProForum tutorial.

The reader is assumed to be comfortable with the basic concepts of a public telecommunications network, with its separate functions of transmission and switching, and is assumed to be aware of the context for the growth of broadband traffic. No specific prior knowledge is assumed about hardware or software technologies.

This material is based on an article first published in the *IEE Electronics & Communication Engineering Journa*l, June 1994, and the copyright to that article is owned by the (UK) Institution of Electrical Engineers.

Topics

1. Introduction: Emergence of SDH
2. SDH Standards

1. Introduction: Emergence of SDH

Since their emergence from standards bodies around 1990, SDH and its variant, SONET, have helped revolutionize the performance and cost of telecommunications networks based on optical fibers.

SDH has provided transmission networks with a vendor-independent and sophisticated signal structure that has a rich feature set. This has resulted in new network applications, the deployment of new equipment in new network topologies, and management by operations systems of much greater power than previously seen in transmission networks.

As digital networks increased in complexity in the early 1980s, demand from network operators and their customers grew for features that could not be readily provided within the existing transmission standards. These features were based on high-order multiplexing through a hierarchy of increasing bit rates up to 140 Mbps or 565 Mbps in Europe and had been defined in the late 1960s and early 1970s along with the introduction of digital transmission over coaxial cables. Their features were constrained by the high costs of transmission bandwidth and digital devices. The multiplexing technique allowed for the combining of slightly nonsynchronous rates, referred to as plesiochronous, which lead to the term plesiochronous digital hierarchy (PDH).

The development of optical fiber transmission and large-scale integrated circuits made more complex standards possible. There were demands for improved and increasingly sophisticated services that required large bandwidth, better

performance monitoring facilities, and greater network flexibility. Two main factors influenced the form of the new standard:

1. Proposals in Comité Consultif International de Telegraphique et Telephonique (CCITT) (now International Telecommunications Union–Telecommunications Services Sector [ITU–TS]) for a broadband integrated services digital network (BISDN) opened the door for a new, single-world multiplexing standard that could better support switched broadband services.

2. The 1984 breakup of the Bell operating companies (BOCs) in the United States produced competitive pressures that required a standard optical interface for interexchange carriers' use and new features for improved network management.

It was widely accepted that the new multiplexing method should be synchronous and based not on bit interleaving as was the PDH, but on byte interleaving, as are the multiplexing structures from 64 kbps to the primary rates of 1,544 kbps (1.5 Mbps) and 2,048 kbps (2 Mbps). By these means the new multiplexing method was to give a similar level of switching flexibility both above and below the primary rates (though most SDH products do not implement flexibility below primary rate). In addition, it was to have comprehensive management options to support new services and more centralized network control.

2. SDH Standards

The new standard appeared first as SONET, drafted by Bellcore in the United States, and then went through revisions before it emerged in a new form compatible with the international SDH. Both SDH and SONET emerged between 1988 and 1992.

SONET is an ANSI standard; it can carry as payloads the North American PDH hierarchy of bit rates: 1.5/6/45 Mbps, plus 2 Mbps (known in the United States as E-1). SDH embraces most of SONET and is an international standard, but it is often regarded as a European standard because its suppliers—with one or two exceptions—carry only the ETSI–defined European PDH bit rates of 2/34/140 Mbps (8 Mbps is omitted from SDH). Both ETSI and ANSI have defined, detailed SDH/SONET feature options for use within their geographical spheres of influence.

The original SDH standard defined the transport of 1.5/2/6/34/45/140 Mbps within a transmission rate of 155.52 Mbps and is being developed to carry other types of traffic, such as asynchronous transfer mode (ATM) and Internet protocol (IP), within rates that are integer multiples of 155.52 Mbps. The basic unit of transmission in SONET is at 51.84 Mbps, but in order to carry 140 Mbps, SDH is

based on three times this (i.e., 155.52 Mbps [155 Mbps]). Through an appropriate choice of options, a subset of SDH is compatible with a subset of SONET; therefore, traffic interworking is possible. Interworking for alarms and performance management is generally not possible between SDH and SONET systems. It is only possible in a few cases for some features between vendors of SDH and slightly more between vendors of SONET.

Although SONET and SDH were conceived originally for optical fiber transmission, SDH radio systems exist at rates compatible with both SONET and SDH.

In summary, the following are true:

- SONET is a digital hierarchy interface conceived by Bellcore and defined by ANSI for use in North America.

- SDH is (a) a network node interface (NNI) defined by CCITT/ITU–TS for worldwide use and partly compatible with SONET; and (b) one of two options for the user-network interface (UNI) (i.e., the customer connection), and formally the U reference-point interface for support of BISDN.

Future of SDH

Almost all new fiber-transmission systems now being installed in public networks use SDH or SONET. They are expected to dominate transmission for decades to come, just as their predecessor PDH has dominated transmission for more than 20 years (and still does in terms of total systems installed). Bit rates in long-haul systems are expected to rise to 40 Gbps soon after the year 2000, at the same time as systems of 155 Mbps and below penetrate more deeply into access networks.

3. SDH Features and Management

Traffic Interfaces

SDH defines traffic interfaces that are independent of vendors. At 155 Mbps they are defined for both optical and copper interfaces and at higher rates for optical ones only. These higher rates are defined as integer multiples of 155.52 Mbps in an n x 4 sequence, giving for example, 622.08 Mbps (622 Mbps) and 2488.32 Mbps (2.5 Gbps). To support network growth and the demand for broadband services, multiplexing to even higher rates such as 10 Gbps continues in the same way, with upper limits set by technology rather than by lack of standards as was the case with PDH.

Each interface rate contains overheads to support a range of facilities and a payload capacity for traffic. Both the overhead and payload areas can be fully or partially filled. Rates below 155 Mbps can be supported by using a 155 Mbps interface with only a partially filled payload area. An example of this is a radio system whose spectrum allocation limits it to a capacity less than the full SDH payload, but whose terminal traffic ports are to be connected to 155 Mbps ports on a cross-connect. Interfaces are sometimes available at a lower synchronous rate for access applications. North America has for some time used 51.84 Mbps SONET, and ETSI has defined a 34 Mbps SDH interface—now being deployed—whose data rate is identical to that of 34 Mbps PDH.

SDH Layers

In the multiplexing process, payloads are layered into lower-order and higher-order virtual containers, each including a range of overhead functions for management and error monitoring. Transmission is then supported by the attachment of further layers of overheads. This layering of functions in SDH, both for traffic and management, suits the layered concept of a service-based network better than the transmission-oriented PDH standards.

Management Functions

To support a range of operations, SDH includes a management layer whose communications are transported within dedicated data communications channel (DCC) time slots inside the interface rate. These have a standard profile for the structure of network-management messages, irrespective of vendor or operator. However, there has been no agreement on the definition of the message sets to be carried, so there is no interworking of management channels between equipment vendors at the SDH interface.

Elsewhere, at the network-management interface to each node, which is typically via a local-area network (LAN), there has been more agreement. ITU–TS standards define a Q3em interface between an SDH equipment and its manager; SDH vendors are migrating their software to be compatible with this interface.

4. Network Generic Applications

Evolutionary Pressures

The need to reduce network operating costs and increase revenues were the drivers behind the introduction of SDH. The former can be achieved by improving the operations management of networks and introducing more reliable equipment. SDH scores high on both.

Increase in revenues can come from meeting the growing demand for improved services, including broadband, and an improved response, such as greater flexibility and reliability of networks. For broadband services typically based on ATM, a number of techniques exist for high-quality routing over PDH networks. The characteristics of SDH, however, make it much more suitable for this application, because it offers better transmission quality, enormous routing flexibility, and support for facilities such as path self-healing.

SDH and ATM provide different but essentially compatible features, both of which are required in the network.
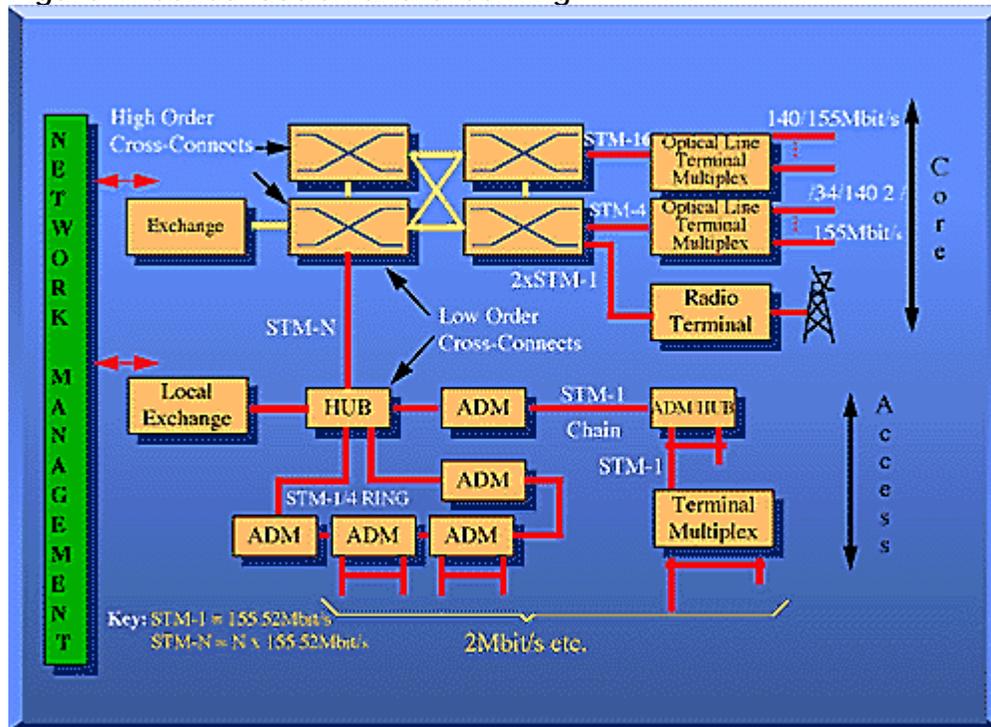
Operations

Managing capacity in the network involves such operations as the following:

a. protection, for circuit recovery in milliseconds

b. restoration, for circuit recovery in seconds or minutes

c. provisioning, for the allocation of capacity to preferred routes

d. consolidation, or the funneling of traffic from unfilled bearers onto fewer bearers in order to reduce waste of traffic capacity

e. grooming, or the sorting of different traffic types from mixed payloads into separate destinations for each type of traffic

The last two are explained in *Figure 1.*

Figure 1. Consolidation and Grooming

All of these functions were available in the switched network through the use of flexible switches for private circuits and for public telephony-based services, up to three times 64 kbps at most. Within the early broadband transmission network, however, all but (a) and to some degree (b) were provided almost entirely by rearranging cables on distribution frames across the network.

This was not satisfactory for frequent changes to a network. These frames are formed from masses of cable and connectors that are moved by hand. If they are disturbed frequently, these frames create a reliability hazard and management problem, such as trouble ensuring correct connection and the availability of staff to support them.

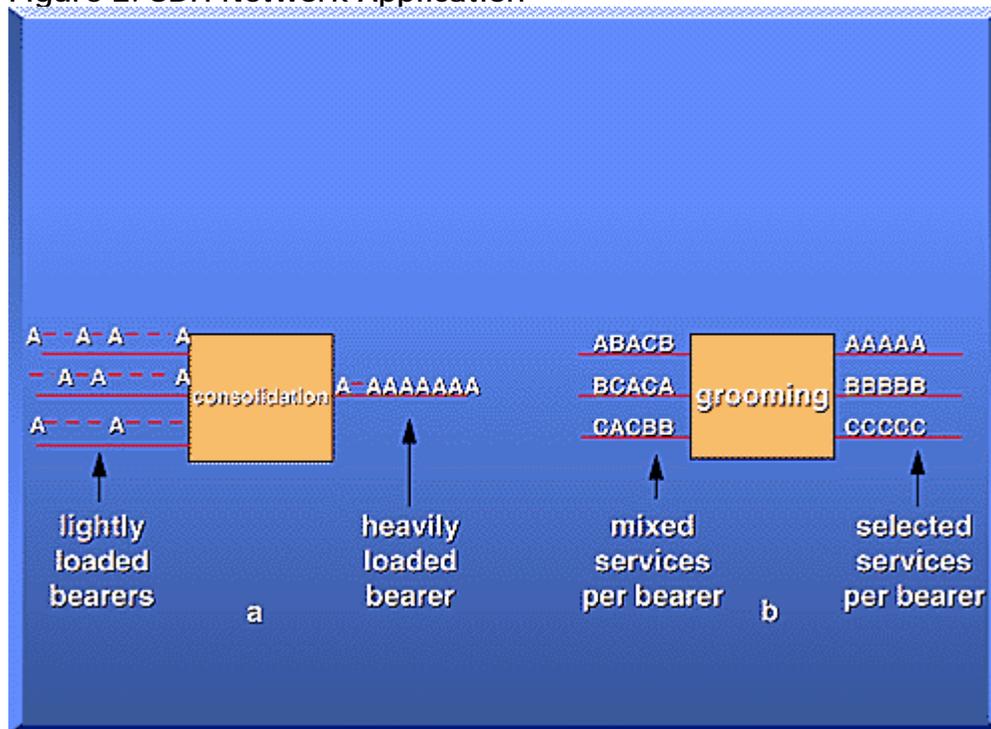# 5. Network Generic Applications: Equipment and Uses

SDH was designed to allow for flexibility in the creation of products for electronically routing telecommunications traffic. The key products are as follows:

- optical-line systems

- radio-relay systems

- terminal multiplexers

- add-drop multiplexers (ADM)

- hub multiplexers

- digital cross-connect switches

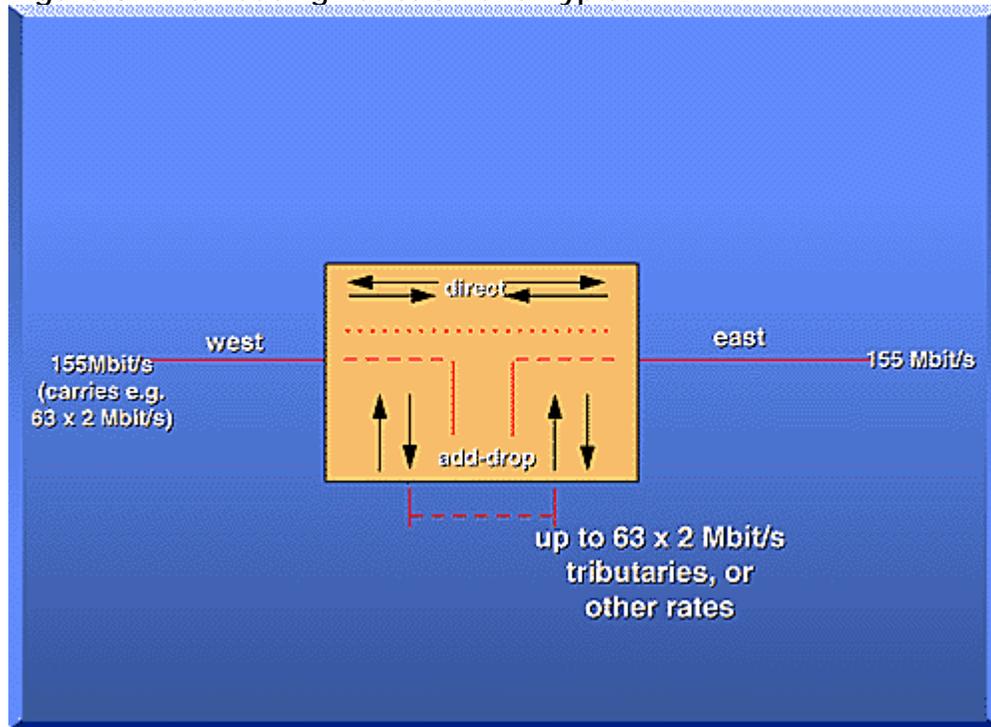A generic network using these products is shown in *Figure 2.*

Figure 2. SDH Network Application

Optical-line systems, and to a lesser extent radio-relay systems, provide the transmission-bearer backbone for the SDH network. Terminal multiplexers provide access to the SDH network for various types of traffic using traditional interfaces such as 2 Mbps G.703 or in data-oriented forms such as fiber distributed data interface (FDDI) via an appropriate bridge or router.

ADM can offer the same facilities as terminal multiplexers, but they also can provide low-cost access to a portion of the traffic passing along a bearer. Most designs of ADM are suitable for incorporation in rings to provide increased service flexibility in both urban and rural areas (spans between ADMs are typically 60 km). ADM ring design also employs alternative routing for maximum availability to overcome fiber cuts and equipment failures. A group of ADMs, such as in a ring, can be managed as an entity for distributed bandwidth management. The routing function of a typical ADM is outlined in *Figure 3.*

Figure 3. The Routing Function of a Typical ADM

Hub multiplexers provide flexibility for interconnecting traffic between bearers, usually optical fibers. A hub multiplex is connected as a star, and traffic can be consolidated or services managed while standby bearers between hubs provide alternate routing for restoration. Several rings of ADMs can converge on a single hub, providing interconnection of traffic between those rings and connection into the existing network.

Some designs of ADM also can be used as hub multiplexers, or they can combine the two functions to optimize network topology between ring and star for each application while still using a common base of equipment. A single unit can act as an ADM on a ring while serving as a hub multiplex for a number of fiber spurs off the ring, with each spur supporting a major business user.

A cross-connect allows nonblocking connections between any of its ports. An SDH cross-connect performs this function for SDH virtual containers (VC) that is, when connecting a PDH signal, the SDH cross-connect also connects the associated SDH path overhead (POH) for network management. In contrast with telephony exchanges (central offices [COs] in North America), which respond primarily to individual customer demands, cross-connects are the major flexibility points for network management.

6. Cross-Connect Types

Cross-connects are known in the United States as digital cross-connect switches (DCSs) and as DXCs elsewhere. They are classified as DCS p/q or DXC p/q, where p is the hierarchical order of the port bit rate and q is the hierarchical order of the traffic component that is switched within that port bit rate.

DXC/DCS can occur in two main types. Higher order cross-connects are generally used to route bulk traffic in blocks of nominally 155 Mbps for network provisioning or restoration (including disaster recovery). They are designated as DXC 4/4. The first "4" refers to 155 Mbps transmission ports on the cross-connect, and the second "4" indicates that the whole payload within the 155 Mbps is switched as an entity. Lower order cross-connects (DXC 4/1 or 1/1, the "1" denoting primary rate at 1.5 or 2 Mbps) are used for time switching leased lines, consolidation, and service restoration. They switch traffic components down to primary rate, usually having options to switch alternatively at the intermediate rate of 34 or 45 Mbps. The capabilities and applications of these two cross-connect families may overlap, with some designs capable of parallel operation, for example at 4/4, 4/1, and 1/1.

Those ADMs and hub multiplexers, which include time-slot interchange, also can be used as small nonblocking DCSs. A ring of several ADMs can be managed as a distributed cross-connect but typically will experience some blocking, which must be anticipated in network planning.

Some cross-connect designs allow all traffic interfaces to be in PDH form for compatibility with existing equipment. In particular, these designs might allow the p hierarchical level in a DXC p/q cross-connect to be at either 34 or 140 Mbps in PDH format, as an alternative to 155 Mbps, so that network flexibility becomes available where SDH infrastructure does not yet exist. In these cross-connects, a port at 34 or 140 Mbps can include an embedded PDH multiplex equipment for internal conversion to and from 2 Mbps, which provides a transmultiplexer function between PDH and SDH areas of the network.

ADMs conventionally allow traffic to be in PDH form, such as at 2 or 34 Mbps on their add-drop ports, and also may provide the transmultiplexer function. The through traffic ports are in SDH form.

7. Trends in Deployment

The general plan for services in a synchronous network is that the synchronous transport provides circuits that are managed by the operator in a time scale down to hours or fractions of an hour (apart from protection and restoration, which are faster). These circuits may be used, for example, to carry public-switched traffic or as private circuits, or even both, such as in the North American SONET

integrated digital loop carrier (IDLC) systems. Private circuits could be at multi-megabit rates, brought to the user via a local multiplexer.

The control of bandwidth on a time scale of seconds or less calls for other multiplexing technologies that have switching capability, such as ATM and IP. These typically employ SDH or SONET as their transport mechanism. SDH's unsuitability for independent fast switching applications is perhaps its only disadvantage.
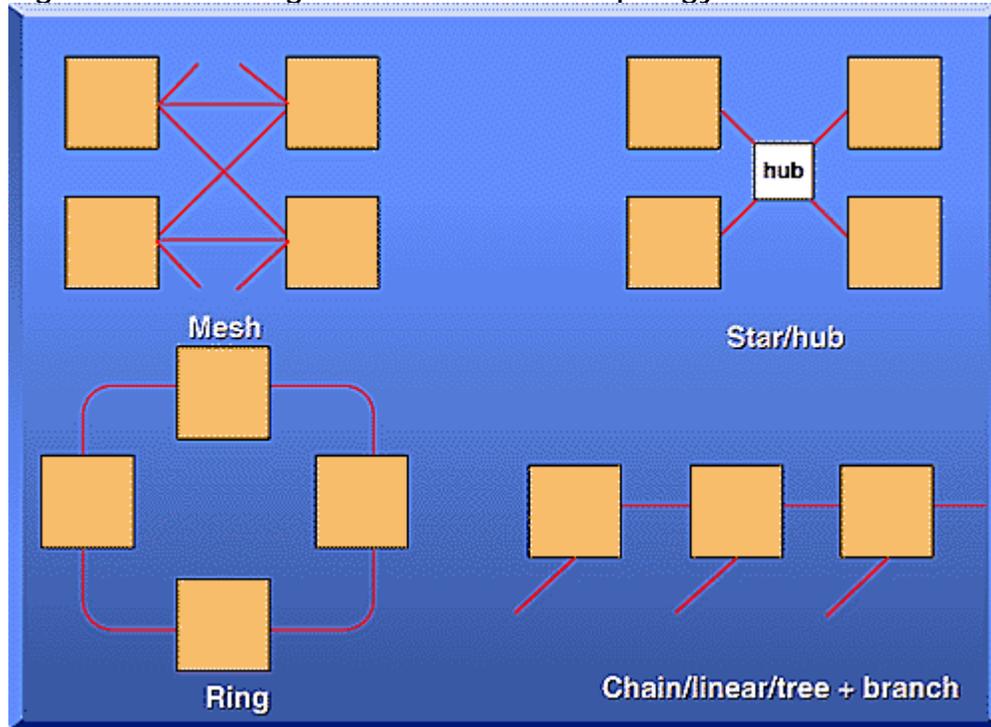
As SDH is introduced more widely, the management capability of the network gradually increases because of the comprehensive monitoring and high-capacity management channels throughout the network. Operated in unison by a common network-management system, the DXCs, ADMs, and hub multiplexers allow centralized control of items (b) to (e) in *Topic 4*, while the integration of monitoring functions for all of the elements provides operators a complete view of their resources and their performances. Protection—item (a) in *Topic 4*—is best implemented locally for a speedy response.

8. Network Design

Network Topology

The flexibility of SDH can be used to best advantage by introducing a new network topology. Traditional networks make use of mesh and hub (i.e., star) arrangements, but SDH, with the help of DXCs and hub multiplexers, allows these to be used in a much more comprehensive way. SDH also enables these arrangements to be combined with rings and chains of ADMs to improve flexibility and reliability across the core and access areas of a network. *Figure 4* shows the basic fragments of network topology that can be combined.

Figure 4. Basic Fragments of Network Topology

Rings could supply improved services to a high-density business area, a major science park, or a conference/exhibition center. In addition, they may displace multiple local exchanges by multiplexers and fiber connections to a single major exchange for lower costs.

Introduction Strategy for SDH

Depending on the regulatory position and the relative age and demands of different parts of an operator's network, SDH may be introduced first for the following reasons:

- for trunk transmission where line capacity is inadequate or unreliable, such as by introducing 2.5 Gbps optical-line systems

- to provide improved capacity for digital services in an area, such as by introducing rings of ADM

- to give broadband and flexible access to customers over optical fibers where provision of copper pairs is inadequate for the demand, such as by introducing IDLC–type systems (integrated digital loop carrier using remote multiplexers connected to a service switch via optical fibers)
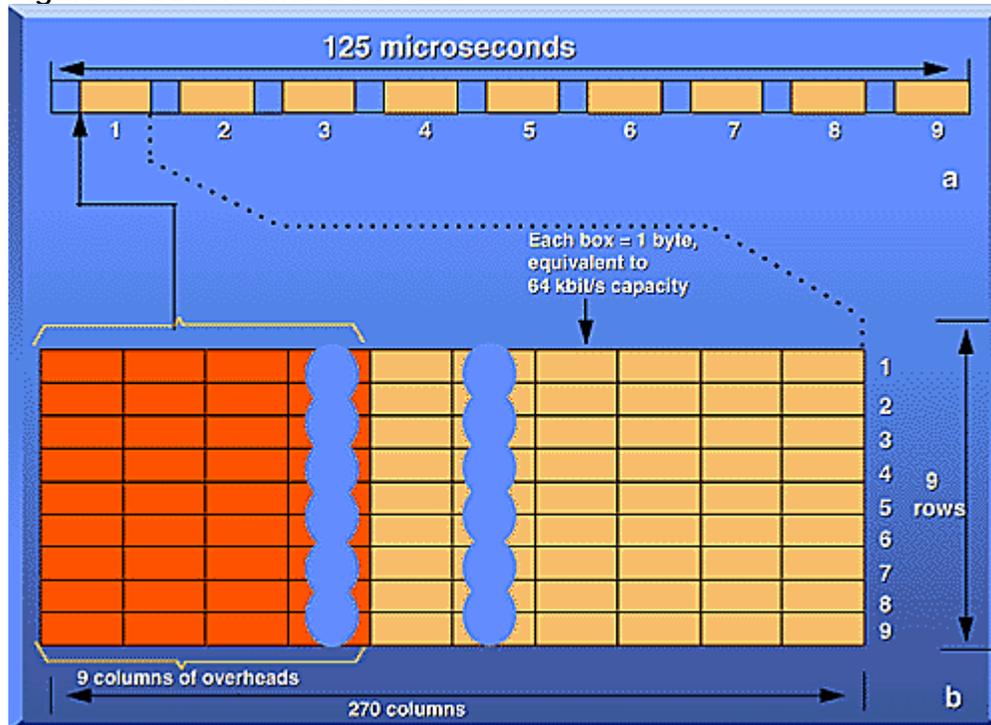
- to provide bandwidth flexibility in the trunk network for provisioning and restoration, by introducing DXC 4n/4 high-order cross-connect switches

- to give time-switched leased lines, other services, and improved utilization of the network or to maximize the availability of specific services; these applications would use ADMs, hubs, or low-order DXC– types such as 4/1 or 1/1
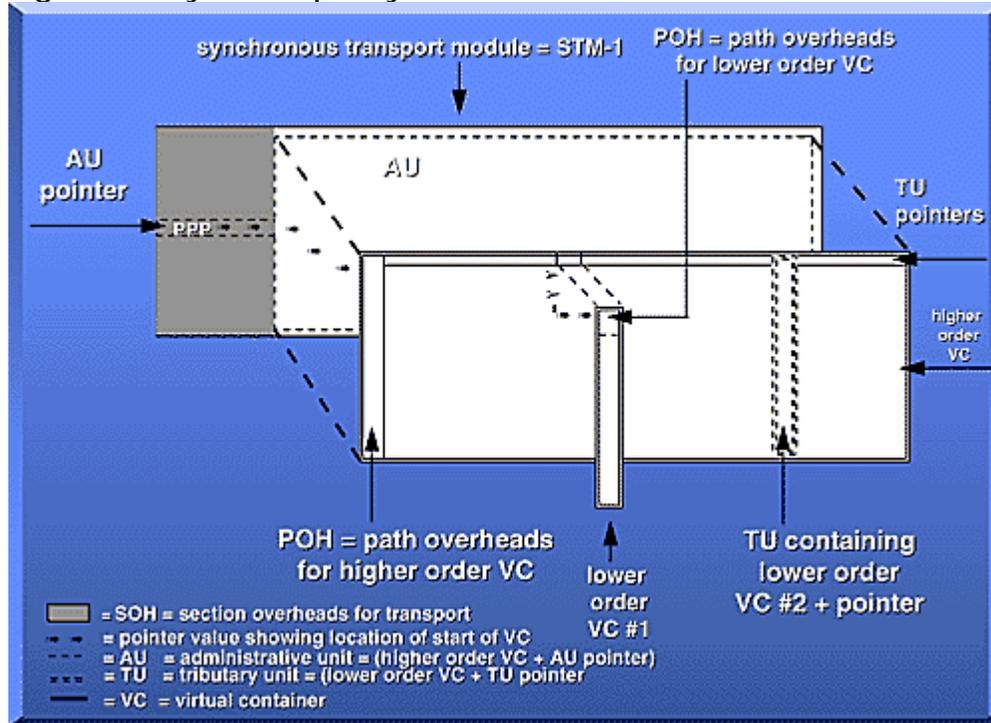
9. SDH Frame Structure

Outline

The frame has a repetitive structure with a period of 125 microseconds—the same as for pulse code modulation (PCM)—and consists of nine equal-length segments. At the gross transport rate of 155.52 Mbps for the base synchronous transport module (STM–1), there is a burst of nine overhead bytes at the start of each segment, as shown at the top of *Figure 5*. This figure also depicts how the SDH frame at STM–1 is conventionally represented, with the segments displayed as from nine rows and 270 columns. Each byte is equivalent to 64 kbps, so each column of nine bytes is equivalent to 576 kbps.

Figure 5. SDH Frame Structure

The first nine columns contain the section overhead (SOH) for transport-support features such as framing, management-operations channels, and error monitoring, with the first segment containing the frame word for demultiplexer alignment. The remaining columns can be assigned in many ways to carry lower bit-rate signals, such as 2 Mbps; each signal has its own overhead. For transporting PDH traffic signals, payload capacity is allocated in an integral number of columns, inside of which are management overheads associated with the particular signal, as *Figure 6* depicts.

Figure 6. Payload Capacity

The first level of division is the administrative unit (AU), which is the unit of provision for bandwidth in the main network. Its capacity can be used to carry a high bit-rate signal, such as 45 Mbps or 140 Mbps (for the two sizes of AU, AU–3 and AU–4, respectively). *Figure 6* shows an AU–4, which occupies all of the payload capacity of an STM–1. An AU can be further divided to carry lower-rate signals, each within a tributary unit (TU), of which there are several sizes. For example, a TU–12 carries a single 2–Mbps signal, and a TU–2 carries a North American or Japanese 6–Mbps signal.

A specific quantity of one or more TU's can be notionally combined into a tributary unit group (TUG) for planning and routing purposes. No overheads are attached to create this item, so its existence relies on network management tracking its path. For example, in Europe, ETSI proposes that a TUG–2 should carry 3 x 2 Mbps in the form of 3 x TU–12s.

10. Virtual Containers

At each level, subdivisions of capacity can float individually between the payload areas of adjacent frames. This individuation allows for clock differences and wandering as payloads traverse the network and are interchanged and multiplexed with others. In this way, the inevitable imperfections of network synchronization can be accommodated. Each subdivision can be readily located by its own pointer that is embedded in the overheads. The pointer is used to find the floating part of the AU or TU, which is called a virtual container (VC). The AU pointer locates a higher-order VC, and the TU pointer locates a lower-order VC. For example, an AU–3 contains a VC–3 plus a pointer, and a TU–2 contains a VC–2 plus a pointer.

A VC is the payload entity that travels across the network, being created and dismantled at or near the service termination point. PDH traffic signals are mapped into containers of appropriate size for the bandwidth required, using single-bit justification to align the clock rates where necessary. POHs are then added for management purposes, creating a VC, and these overheads are removed later where the VC is dismantled and the original signal is reconstituted.

PDH traffic signals to be mapped into SDH are by definition continuous. Each PDH signal is mapped into its own VC, and several VCs of the same nominal size are then multiplexed by byte interleaving into the SDH payload. This arrangement minimizes the delay experienced by each VC. Although, in theory, an ATM traffic signal is made up of discontinuous cells, each 53 bytes long, the gaps between used cells are filled by ATM idle cells that are inserted by ATM equipment when it is connected to a PDH or SDH interface, hence forming a continuous signal. This is then mapped into its own VC, just as for a PDH signal, and again multiplexed with other signals by byte interleaving.
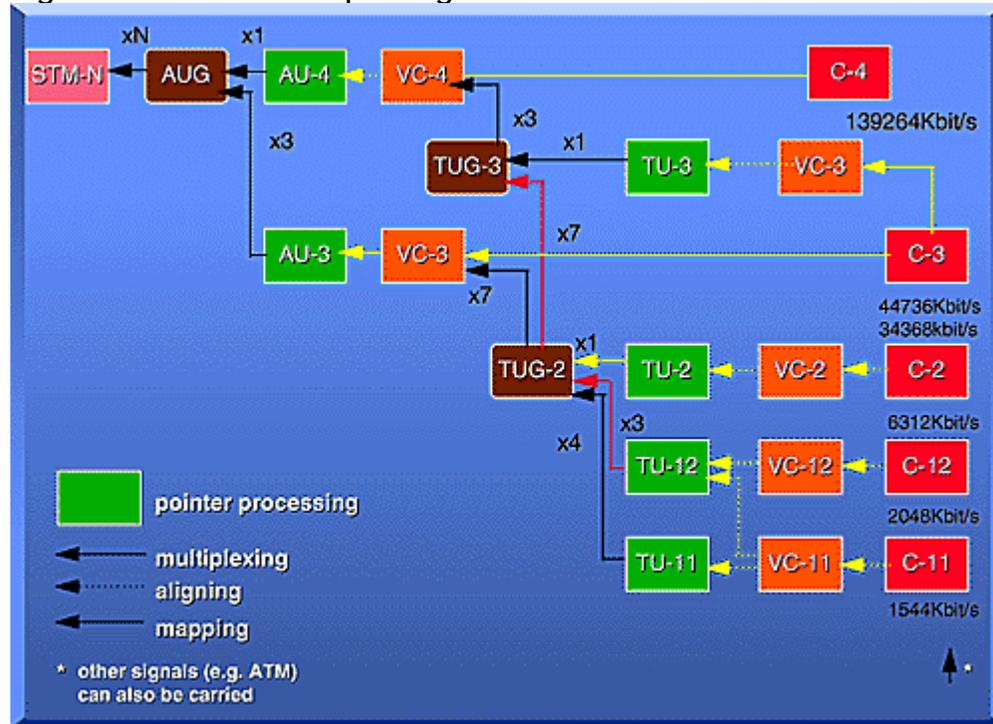
11. Supporting Different Rates

Higher levels of the synchronous hierarchy are formed by byte-interleaving the payloads from a number N of STM–1 signals, then adding a transport overhead of size N times that of an STM–1 and filling it with new management data and pointer values as appropriate. STMs created in this way range upwards from STM–1 at 155.52 Mbps by integer multiples of four with no theoretical limit. For example, STM–16 is at 2,488.32 Mbps and can carry 16 x AU–4. STM–N is the generic term for these higher rate transmission modules.

All of the above processes are summarized for the full range of PDH rates supported by SDH, as shown in *Figure 7*. Other rates and future services are expected to be supported by concatenation. This is a technique that allows multiples of either lower- or higher-order VCs to be managed as if they were a single VC. For example, a VC–4–4c is a concatenation of 4 x VC–4, giving an

equivalent circuit capacity of around 600 Mbps and is expected to be used for the transmission of ATM between major network nodes.

Figure 7. ITU–TS Multiplexing Structure

Before transmission, the STM–N signal has scrambling applied overall to randomize the bit sequence for improved transmission performance. A few bytes of overhead are left unscrambled to simplify subsequent demultiplexing. Broadband payloads such as ATM and IP are likely to occupy a large VC such as a VC–4, which when carried in STM–1 results in the SDH experiencing many successive bytes from each ATM cell. However, the unpredictable data patterns of ATM cells risk compromising the relatively short scrambler used in SDH. This could intermittently endanger the transmission of the whole SDH signal by affecting digit sequences and therefore the clock content needed for demultiplexing. For this reason, extra long scramblers are added for those payloads.

Self-Test

1. The removal of which constraints allowed the development of SDH and SONET features?

    a. shortage of optical fibers

    b. costs of digital devices

    c. cost of transmission bandwidth

    d. regulations on competition

    e. limitations of laser technology

    f. both b and c

2. SDH traffic interfaces are defined only for optical interfaces.

    a. true

    b. false

3. Standards for network management allow interworking of all management functions between vendors via the fiber.

    a. true

    b. false

4. How long does SDH circuit recovery take?

    a. microseconds

    b. milliseconds

    c. seconds

    d. minutes

    e. hours

    f. b, c, and d

5. Higher-order SDH cross-connects route what entity?

    a. 1.5 Mbps

    b. ATM cells

    c. management data channels

    d. payload within 155 Mbps

6. The installation of an SDH network requires that the network topology be changed.

    a. true

b. false

7. What is a TUG?

    a. a fiber interface on a multiplexer

    b. a managed group of tributary units

    c. a column of the payload structure

    d. part of the management overheads

8. Concatenation provides which benefit?

    a. interworking between vendors

    b. better system reliability

    c. management of very large payloads

    d. operation over radio systems

9. Scrambling is used in SDH for which reason?

    a. to randomize the bit sequence for better transmission performance

    b. to reduce the power consumption of equipment

    c. to allow for upgrades to higher bit rates

    d. to prevent unauthorized access

10. PDH is the predecessor of both SDH and SONET.

    a. true

    b. false

Correct Answers

1. The removal of which constraints allowed the development of SDH and SONET features?

    a. shortage of optical fibers

    b. costs of digital devices

c. cost of transmission bandwidth

d. regulations on competition

e. limitations of laser technology

f. both b and c

See Topic 1.

2. SDH traffic interfaces are defined only for optical interfaces.

a. true

b. false

See Topic 3.

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See Topic 4, items a and b.

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See Topic 9.

10. PDH is the predecessor of both SDH and SONET.

    a. true

    b. false

See Topic 2.

Glossary

ADM
add-drop multiplexer

ANSI
American National Standards Institute

ATM
asynchronous transfer mode; a form of fast short packet switching and multiplexing

AU
administrative unit; a managed entity within the SDH structure

BISDN
broadband integrated services digital network

CCITT
Comité Consultif International de Telegraphique et Telephonique; in English, Consultative Committee on International Telegraphy and Telephony; predecessor of ITU–TS

DCC
data communications channel; the main management channel inside SDH

DCS
digital cross-connect system; an electronic multiport switch for digital traffic

DXC
digital cross-connect; see DCS

ETSI
European Telecommunications Standards Institute

FDDI
fiber distributed data interface; a short range 100 Mbps interface used between large computing nodes

IDLC
integrated digital loop carrier; a North American system for connecting an exchange/central office to subscribers over a large area via fiber

IP
Internet protocol; a component of protocol for many computer links including the Internet

ITU–TS
International Telecommunications Union–Transmission Standards

LAN
local-area network; a linked group of computers

MAN
metropolitan-area network; an area network for public broadband traffic

NNI
network node interface; a defined interface between nodes in the public network

PDH
plesiochronous digital hierarchy; the widely deployed transmission system which predates SDH

POH
path overhead; a group of management communications facilities in SDH

SDH
synchronous digital hierarchy

SOH
section overhead; a group of management communications facilities in SDH

SONET
synchronous optical network; the North American variant of SDH

STM
synchronous transport module; the basic unit of transmission in SDH

TU
tributary unit; the basic unit of payload together with its management overheads and synchronisation data

TUG
tributary unit group; a managed group of TU

UNI
user-network interface; a defined interface between the user and the public network

VC
virtual container; the basic unit of payload together with its management overheads