Introduction to SDH/SONET


Cambyse Guy Omidyar


Anne Aldridge

Our readership covers all aspects of telecommunications, but no one is expert in everything. We have prepared this introduction to synchronous digital hierarchy/synchronous optical network (SDH/SONET) for two reasons. First, we hope to give those readers who are not well-versed in transmission technology a bit of background. Second, the SDH standards, since they include operations and maintenance, contain many protocols written by software and protocol experts. For the average transmission person, this is enough to give one a *S*plitting *D*ouble *H*eadache.

American National Standards Institute (ANSI) established standards for SONET rates, and ITU-Telecommunications sector, formerly CCITT, had adopted a set of interface standards as recommendation G.707, G.708, and G.709. (See the first article in this issue.)

The expectation of end users to be able to transfer a large volume of data other than the current DS-3 rate set at 44.736 Mb/s has changed the direction of technology towards SONET/SDH. This new technology is based on lessons learned from current transmission rates and was intended to take advantage of the high speed digital transmission capability of optical fiber.

What is the Plesiochronous Digital Hierarchy (PDH)?

In the early 1960s, all switching and all transmission systems were analog. In this period, transmission experts were working on pulse code modulation (PCM) to transform the analog voice signals into digital bit streams. Their main purpose was to solve the problem of too many copper wires in the streets and not enough space for new ones. Using four copper wires, a digital stream could transmit many voice signals with better quality than analog systems. And so, in Holmdel, New Jersey around 1965, the U.S. standard of 24 voice signals multiplexed together with one "framing" bit to form a 1.544 Mb/s signal called DS-1 was born. Each voice signal needs a 64 kb/s stream; this is the product of 8 kHz sampling (due to Nyquist's Law[1]) and 8 bit-per-sample coding, a choice which permits the voice signal to tolerate multiple analog-to-digital and digital-to-analog (A/D and D/A) conversions — an important requirement at the time.

A few years later, in 1968, Europeans devised a similar standard, with 30 voice channels plus a channel for "framing" and a channel for signalling, for a total of 32 x 64 kbit/s = 2.048 Mb/s. This is commonly called the E-l format.

What is framing? As shown in Fig. 1, it is a method of indicating where to begin counting channels so that the demultiplexer knows which is channel 1, 2, etc. A sequence of bits repeated in each frame (8000 frames per second) forms a pattern that is difficult for data to imitate. Thus, by observing the bit stream for a certain period of time, the framing mechanism can figure out where channel 1 is.

Because all switching was analog until 1975, all the digital transmission systems received analog signals, used an internal crystal clock to convert them to a digital stream, and reconverted them to analog. A few years later, technology permitted faster digital transmission on copper cables, then on coaxial cables.

Multiplexing means taking a certain number of DS-l or E-l signals and putting them together as shown in Fig. 2. One bit is taken from each "tributary" stream and put into a higher-order stream. The European hierarchy is:

- four E-1s make an "E-2" at around 8 Mb/s.
- four E-2s make an "E-3" at 34 Mb/s.
- four E-3s make an "E-4" at 140 Mb/s.
- four E-4s make an "E-5" (not standardized) at 565 Mb/s.

The North American hierarchy is similar but less regular. At each step, the multiplexer has to take into account the fact that the clocks of the tributaries are all slightly different. So the method called the "Plesiochronous Digital Hierarchy" (PDH) was developed. "Plesio," from Greek, means "almost." Each clock is allowed a certain range of speeds. The multiplexer reads each tributary at the highest allowed clock speed and, when there are no bits in the input buffer (because the bits are arriving according to a slower clock), it adds a "stuffing" bit to "stuff" the signal up to the higher clock speed. It also has a mechanism to signal to the demultiplexer that it has performed stuffing, and the demultiplexer must know which bit to throw out.[2]

This PDH method is the base for all currently installed digital transmission systems, except the field trials described in this issue.

What is a Synchronous Network?

In the last 15 years, digital switching has taken over from ana-

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[1] *Nyquist discovered that if an analog signal is sampled at discrete moments in time with frequency* N, *the entire signal can be reconstructed, except for all components above the frequency* N/2. *Analog telephone trunks have always cut off voice signals at 4 kHz (or lower) to limit the bandwidth required for frequency division multiplexing. Hence the choice of* N = *8 kHz.*

[2] *This is called "positive stuffing." There is also a method called "negative stuffing" and other variations.*

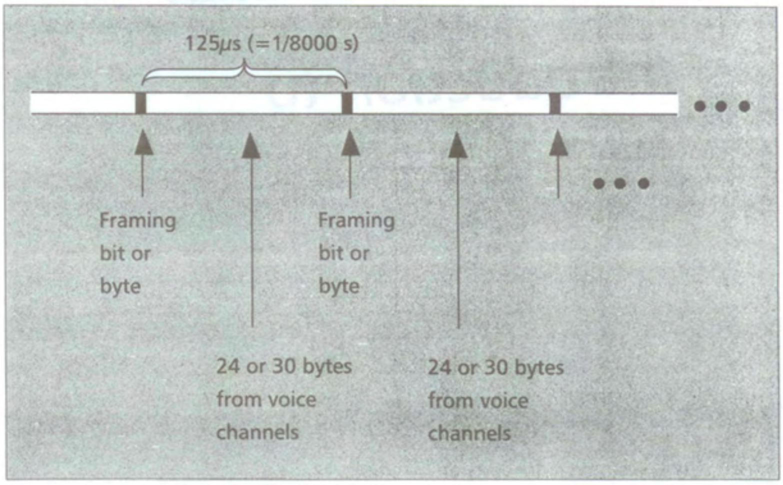
log switching. This means all digital systems can be connected and therefore synchronized with each other. (The concept of "synchronized" still allows for some variation clock speed.)

There are two problems with the PDH method, seen from the perspective of a synchronized network. One is that each time it is necessary to pick out or insert a stream (i.e., E-l) from a high-order stream (i.e., 140 Mb/s E-4), it is necessary to perform *all* the operations of the three multiplexers that created the E-4. This operation is called Add/Drop. Another problem is that these multiplexers create a network in which measuring performance, rerouting signals after network failures, and managing remote network elements from work centers are all extremely difficult.

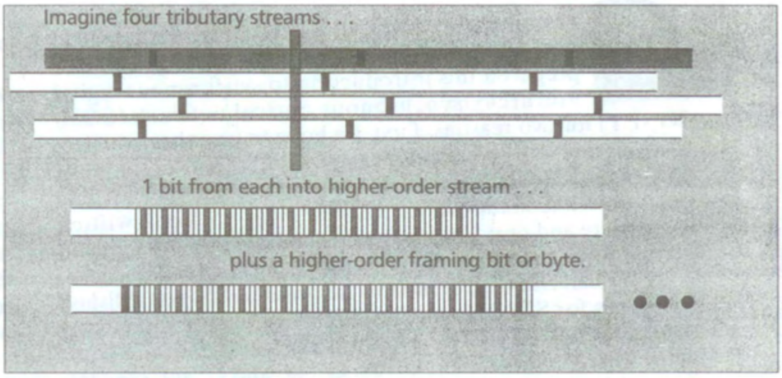
The new method of multiplexing, called the Synchronous Digital Hierarchy in Europe and the Synchronous Optical Network (SONET) in North America, was born from research begun in Holmdel, New Jersey in the early 1980s. What new methods could:

- take advantage of the totally synchronized network?
- unify the North American and European standards?
- be used on both optical fiber and radio?
- put some intelligence in the multiplexers for solving operations and maintenance problems, especially protection switching?
- make multivendor networks manageable?
- be compatible with existing PDH streams?

This enormous standardization task is not yet complete, but is far enough along that single-vendor field trials are already in operation. Future trials will demonstrate not only that streams from different manufacturers can be connected at the optical level (never possible with PDH) but also that such a network can be managed by a single network manager.



■ **Figure 1.** *Structure of a DS-1 or E-1 stream.*



■ **Figure 2.** *PDH multiplexing.*

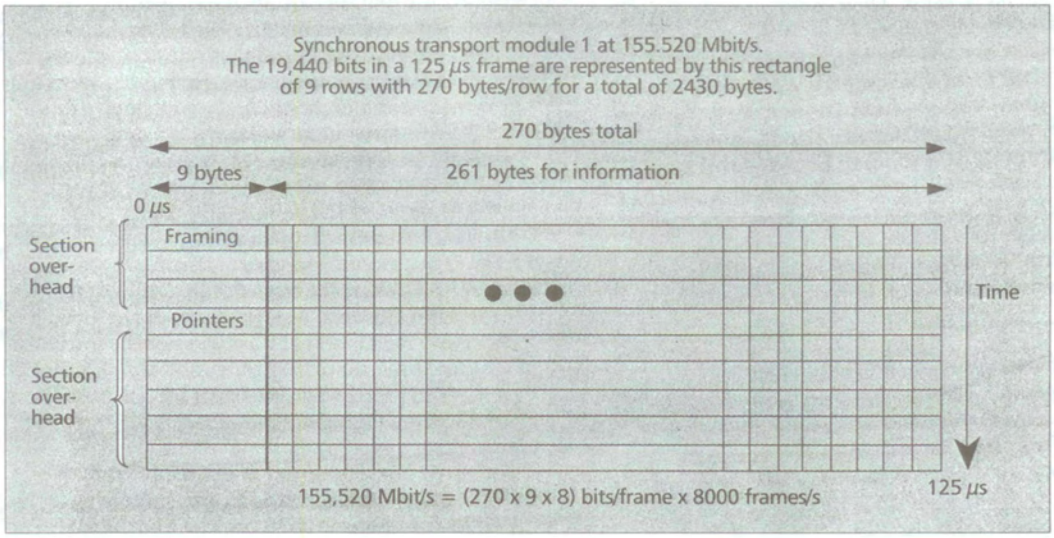
What is SDH?

The basic time constant of 8000 frames per second is preserved in SDH. What is transmitted in these 125 µs is represented in a rectangle as shown in Fig. 3, which describes the format of the first (lowest) level of the synchronous hierarchy. All information is collected in bytes (also called octets) and no longer in bits. The bytes are transmitted one row at a time starting from the point labeled "0 µs."

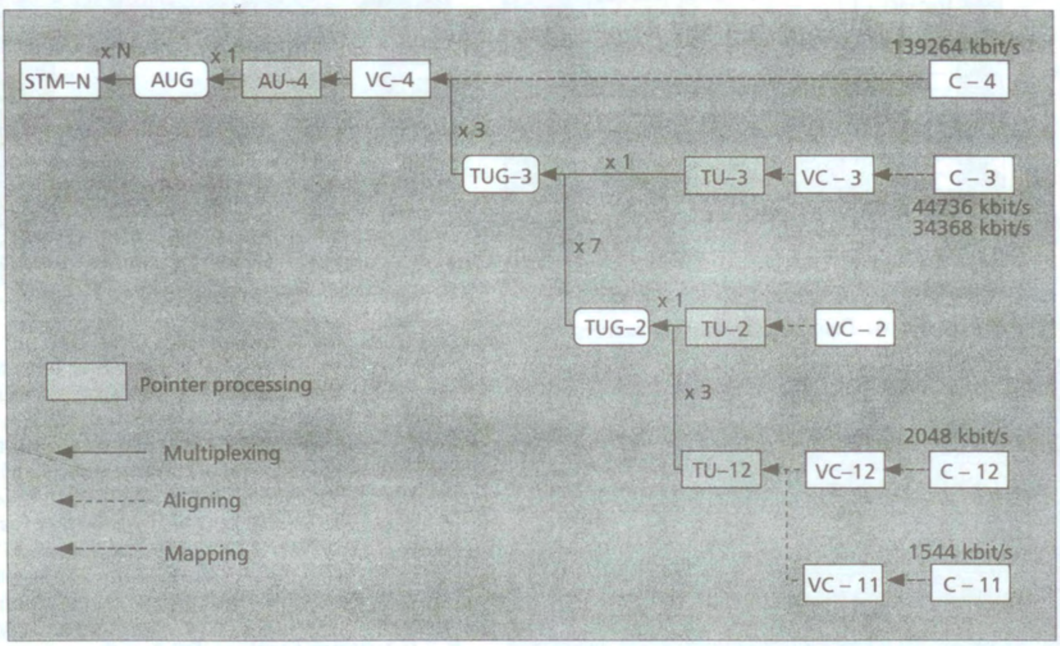
The largest part of the rectangle is for information transmitted (261 x 9 bytes) while the left-hand part is for various other information described below.

Pointers — The Secret to Success

The tributaries to a multiplexer each have a frame that is not aligned in time with the other tributaries, nor with the frame of the output stream. In PDH, the multiplexer does not even need to know where this frame is in time; that is the



■ **Figure 3.** *SDH structure.*



■ **Figure 8.** *SDH structure (ETSI).*

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Multiplexing up from 2 Mb/s

The 2 Mb/s stream is already a fine synchronous format. (Most Europeans won't say the same about the 1.544 Mb/s format, which has less space for signaling.) There are several ways to carry 2 Mb/s tributaries. Figure 7 shows the simplest multiplexing method: byte-synchronous, with one byte from one 64 kb/s channel in each box. This is useful when the "client" is dealing with 64 kbit/s channels, for example, a voice switch, but would be less useful for, say, video or ATM formats.

The E-4 format carries 64 streams at 2 Mb/s. But the STM-l does not: that would be too easy! In order to accomodate the North American format, it contains 3 x 7 x 3 = 63 of them. It uses an intermediate format at 3 x 2 Mb/s = 6 Mb/s.

ETSI Formats

SDH is a multplexing format for the whole world, thus uniting for the first time European and North American formats. The complexity of the standards derives from the necessity of handling all existing PDH formats in both systems. Figure 8 shows the subset of the standards used in countries which follow European Telecommunications Standards Institute (ETSI) recommendations. The European formats called C-12, C-3 (the 8 Mb/s C-2 is rarely used these days), and C-4 are mapped as shown in Fig. 8 into Virtual Containers. The TU are Tributary Units, and the TUG are Tributary Unit Groups, which are intermediate stages for reaching the final VC-4.

The previous Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) special issue was published in the *IEEE Communications Magazine* in August 1990. The November 1991 of *IEEE LTS: The Magazine of Lightwave Telecommunication Systems* also published a special issue on SONET/SDH. Since that time, significant progress has been made on the design of SONET/SDH transport systems, prototyping, management, and standardization.

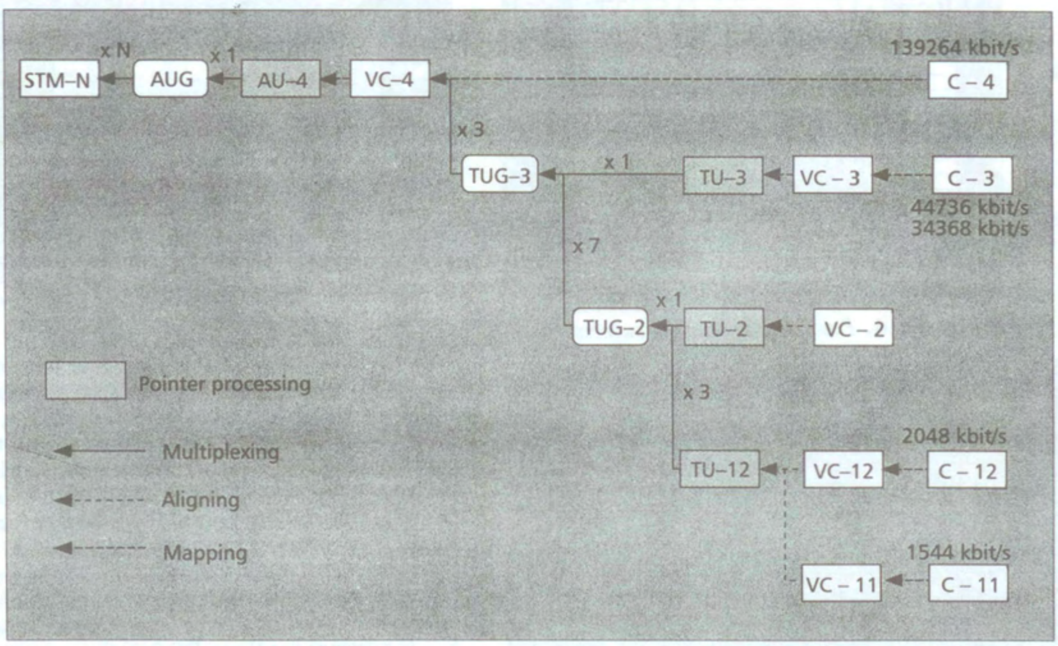
Two papers on SONET were written by authors from Bellcore. The first article, SONET Implementation by Yau-Chau Ching and H. Sabit Say, describes the status of SONET deployment and discusses the future direction of SONET. The second article, Network Synchronization—A Challenge for SDH/SONET by Michael J. Klein and Ralph Urbansky, addresses problems related to SDH/SONET synchronization and timing.

The third article, Implementing a Flexible Synchronous Network by Susanna Allmis, describes the SYNET technology based on the SDH and its implementation. The fourth article, The Impact G.826 by Mansoor Shafi and Peter Smith, evaluates error performance parameters in G.826 for higher rates at 155 Mb/s. The fifth article, Cost-effective Network Evolution by Tsong-Ho Wu, describes a cost effective three-phase network evolution path by using a proposed SARPVP architecture.

Biographies

CAMBYSE GUY OMIDYAR is a consulting engineer for Computer Sciences Corporation, Beltsville, Maryland. He has worked the last four years on future NASA Telecommunication networks including Space Station Freedom and Earth Observing Systems. In the early 1980s, he worked on a variety of projects, including analysis and evaluation of Strategic Defense Initiative (SDI) — battle management, command, control, and communications (BMC3) networking for Strategic Defense Initiative Office (SDIO) of the Department of Defense. In the late 1980s, he joined Bellcore, where he was a major contributor to the T1M1.5 Lower Layer working group for the Operations system and network equipment interface of T1 Standard Committee, and worked on the early development of Synchronous Optical Network and Switched Multi-Megabit data service. He received his D.Sc. in electrical engineering from George Washington University and has been an associate professorial lecturer there. He is on the technical editorial board of *IEEE Network* and an associate editor of *IEEE Communications Magazine*.

ANNE ALDRIDGE received B.A. and M.A. degrees in mathematics from U.C.S.B. in 1968 and a Ph.D. in mathematical statistics from Columbia in 1975. From 1968 to 1984, she was with AT&T Bell Laboratories in areas including switch and network maintenance, traffic engineering, No. 1 ESS software development, and fast packetswitching exploratory development. Since 1984 she has been with Italtel in Milan, Italy, working first in the development of the Linea UT and then in international-marketing. She is presently director of promotion in the international sales area. She has been active in IEEE Communications Society for many years.She has been Chairman of the Communications Switching Technical Committee and is currently senior editor for *JSAC*, associate editor for *IEEE Communications Magazine*, and member at large of the Board of Governors.



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