DigiPoints Volume 1

Leader Guide

Module 5 – Growing Capacity Through Technology

Summary

In Module 4, TDM was introduced and explained. The technology focus was on T1, the first TDM type system deployed in the US. It was practical because the technology available allowed engineers to make use of "empty space" on the cable pair. As technology advanced, engineers were able to find more of this "empty space" available in the transmission media. Simply put, solid state technology pushed the speeds at which digital signals could be sent and received. In this module, the discussion will start with the digital systems that followed T1 and make up the North American Digital Hierarchy (NADH). Module 5 will end with a description of SONET (Synchronous Optical Network).

Outcomes

This module covers the North American Digital Hierarchy (NADH), the European Digital Hierarchy (EDH), digital signals at levels higher than T1, the concept of "bit stuffing", and how multiplexers are designated or named. This module also covers the Synchronous Optical Network (SONET), including why SONET was developed, how it differs from TDM systems, the format of the SONET frame, and the functions of the Section, Line, and Path Overheads. It will also cover Virtual Tributaries (VT), how VTs are used and mapped, VT Overhead, VT Groups, and SONET STS Multiplexing.

Objectives

Upon successful completion of this module, the student will be able to:

- Name the digital signal levels of the North American Digital Hierarchy.
- Contrast and compare the NADH with the EDH.
- Explain why "bit stuffing" is used when multiplexing lower level digital signals into higher levels.
- Describe the disadvantages of "bit stuffing" as it impacts the economies of a network.
- Describe the technique used to designate multiplexers.
- Describe why SONET was developed.
- Explain the advantages of SONET over the TDM systems studied.
- Describe the SONET frame.
- Explain the functions of the overheads used in SONET:

- Section Overhead
- Line Overhead
- Path Overhead
- Explain the function of the DCC.
- Explain the function of the K bytes.
- Explain the purpose of the J1 and G1 bytes.
- Explain the function of the pointer bytes, H1 and H2.
- Describe what a VT is.
- Describe how VTs are used.
- Name the four types of VTs.
- Know the purpose and use of a VT Group.
- Explain the advantages of byte vs. bit stuffing, and where each is used.
- Describe what a STM-1, STC-3c, and STS-3 signals are, and how they are related.

Prerequisites

Students should have read Chapter 5 of *DigiPoints, Volume 1*.

Length

3 –3 ½ hours

Materials/Preparation for Instructor

- One workbook per student
- Visual Aids
- Instructor should read Chapter 5 of *DigiPoints, Volume 1*.

Supplies/Equipment

- Dry erase board with markers and eraser
- Easel flip chart
- Masking tape
- Pointing tool, e.g., laser or pointer
- Tent cards for students' names

Audience

The intended audience will be mid- to senior-level technicians or other associates who are seeking an understanding of digital basics.

Module Outline

This is an introductory level module that will provide a review of the following topics:

Objectives 1
Introduction 2
Digital Signal Multiplexing Above T1 5
Synchronous Optical Network (SONET) 12
Summary 32
Appendix 33

Objectives

EXPLAIN

REFER TO WB 5.1 AND WB 5.2

Tell students that when they have completed this module, they will be able to accomplish these objectives.

- Name the digital signal levels of the North American Digital Hierarchy.
- Contrast and compare the NADH with the EDH.
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- Explain the functions of the overheads used in SONET:
  - ◊ Section Overhead
  - ◊ Line Overhead
  - ◊ Path Overhead
- Explain the function of the DCC.
- Explain the function of the K bytes.
- Explain the purpose of the J1 and G1 bytes.
- Explain the function of the pointer bytes, H1 and H2.
- Describe what a VT is.
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- Name the four types of VTs.
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Introduction

Introduce this module with some basic thoughts about multiplexing with rates greater than T1. Why?

To bring the price of an item down, it is necessary to decrease the per unit production costs.

In communications, one method used to do that is to increase the amount of information that could be carried on the media used for a particular form of transmission.

REFER TO WB 5.3

WRITE ON BOARD

The FDM concept used in CATV was first used in the telephony industry in 1917. The objective was to carry more information, more conversations, on a pair of copper wires.

FDM - 1917

Over the next 60+ years, more elaborate schemes were developed using copper wire, coaxial cable, and microwaves.

In the late 1960s a new technology was deployed: TDM. This digital technology separated messages by time versus frequency.

T1 – late 1960s

TDM

The first deployed application was T1 systems. In a T1 system, 2 copper pairs were used to carry 24 conversations. That was a significant improvement in usage of the installed cable plant.

What technology allowed this to occur?

Answer:

◊ *Semiconductors*

Semiconductors

The same technology that brought about the revolution in computers, and is impacting the TV and CATV industry.

Here is an opportunity to review Module 4:

How often does a voice channel have to be sampled to capture all the information in the message?

Answer:

◊ *8000 samples/sec*

What is the theory behind that?

Answer:

◊ *Nyquist Theorem*

ASK

If you sample 8000 times a second, how often is a sample taken?

Answer:

◊ *Every 125 microseconds*

If there are 24 different signals being sampled, what is the maximum time allowed per sample?

Answer:

◊ *~5.2 microseconds*

How many pairs of wire does the T1 system use?

Answer:

◊ *2 pair*

When the telephone companies began deploying T1, the initial applications were the trunks between the switches in central offices in urban areas.

Take two trunks (read 2 pairs), add the T1 electronics at either end, remove the repeaters and other devices on these trunks, add T1 compatible equipment, and, you have not 2 voice grade trunks, but 24 TDM trunks.

Needless to say, customers, management, and stockholders received this with glee. Imagine a cable TV system in which every channel needed its own DEDICATE coaxial cable; there would not be a lot of affordable CATV available.

This development in the telephony industry also led the way for some very significant price reductions AND service improvements…and value added services too.

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ASK

What is the rate of a T1 line?

Write on board

Answer:

- ◊ *1.544 Mbps*

T1 – 1.544 Mbps

24 Channels

Needless to say, this just "whetted the appetite" of those engineers. Consider, what is a 286 processor compared to a Pentium II.

Digital Signal Multiplexing Above T1

Digital Rates Above T1

So, the engineers looked at the T1 systems and found that the speed COULD BE **DOUBLED** if just a few things were done to "condition" the line.

Write on board:

Conditioning

What this meant was that after removing the load coils, there were still impairments on the line. Perhaps bridge taps, perhaps capacitive coupling between pairs.

The engineers established a set of parameters that could be used to identify which pairs would be capable of carrying higher speed digital signals.

Cable pairs could be tested end to end to ascertain if their impedance fell into the range of acceptable limits.

If they passed the test, then equipment could be added to allow transmission of speeds twice the T1 rate, or 3.152 Mbps. These systems were called T1C systems; they carried 48 voice grade channels.

T1C – 3.152 Mbps

48 Channels

2 T1s

Improvements in electronics and the ability to build better cables allowed the rate to be doubled again to 6.312 Mbps.

This is known as a T2 signal.

T2 – 6.132 Mbps

96 Channels

4 T1s

This was approaching the limits for twisted pair. The next step was to use coaxial cable to provide T3 systems.

ASK

How fast is a T3 system and how many voice channels does it carry?

T3 – 44.736 Mbps

672 Channels

28 T1s

Answer:

- ◊ *44.736 Mbps and 672 channels. This is 28 T1s.*

The next system was the T4 system at 274.176 Mbps and 4032 voice grade channels or 168 T1s or 6 T3s.

T4, 274.176 Mbps, 168 T1s or 6 T3s.

Sounds fast.

EXPLAIN VA 5.1
REFER TO WB 5.4

North American Digital Signal Hierarchy

This visual shows us the North American Digital Signal Hierarchy.

The first Digital Signal Number is DS0. This is the 64,000 bps voice grade channel. Recall the 8 bits per PCM encoded PAM sample and 8000 samples per second.

That equates to 64 kbps or .064 Mbps.

The other rates, DS1, DS1C, DS2, DS3 and DS4 follow.

Prior to the NADH standard coming into existence, there was a de facto T1 standard created by the BELL SYSTEM for its T1 product.

That meant that if a company wanted to buy the equipment that supported this T1 technology, the equipment would have to be purchased from an American manufacturer, AT&T.

While this was okay for the AT&T company and its subsidiaries, there was a different feeling in other nations…and at other companies.

The desire for an open standard was strong outside the US. Also, Europeans were implementing digital technology differently. So, the NADH standard was developed for the US market.

Then, a European Digital Hierarchy was developed to handle the digital products used in Europe.

This made it possible for manufacturers and service providers to obtain equipment from different vendors AND allow networks from different countries and network service companies to “talk” to each other.

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Look at this table again. Note the number of channels starting at the T1 level.

Write on Board

As the Digital Signal (DS) number increases, so do the number of channels at multiples of "24", the number of channels on a T1.

T1, 1.544 Mbps
X 4
= 6.176 Mbps

HOWEVER, when you look at the bit rates at each DS level, you see that they are not multiples of the T1 rate.

In other words, 4 – T1s is 6.176 Mbps. But, a T2, which carries the equivalent of 4 T1s, requires 6.312 Mbps, or an extra 136,000 bits.

T2, 6.312 Mbps

ASK Where do these bits come from?

Extra bits
0.136 Mbps

Answer:

- ◊ *Stuff bits*

How Multiplexing Works

So, how do we multiplex these signals? Specifically, how do we move from a DS1 to a DS1C to a DS2, et cetera, and why are the total number of bits greater then the sum of the parts?

Our T1 signal is 1.544 Mbps.

But, there is some variance given in the standards, so that the signal is acceptable if it is between 1.5404 and 1.5458 Mbps.

This means that 2 – T1s can be coming in at slightly different rates. This impacts the synchronization that is carried in the framing bits.

If 2 – T1 signals are being combined into 1 – T1C signal, then that means the bits for the 2 T1s can be arriving at slightly different moments in time.

EXPLAIN VA 5.2
REFER TO WB 5.5

Bit Stuffing

The problem is how to compensate for this discrepancy. The solution is bit stuffing.

Bit stuffing allows the multiplexer, a T1C mux in this case, to add non-information bits into the output bit stream in order to build out the bits of the input stream.

This has the effect of having each input stream output the same number of bits per second to the output stream. It helps to maintain synchronization.

How does this work? The multiplexer compares the input registers to determine if one register is being depleted faster than the other. If it is, it means that the register being depleted faster is receiving fewer bits of input.

The multiplexer then knows to "stuff" a non-information bit into the output line instead of using an input line bit. This stuff bit compensates for the lack of sufficient input line bits.

(This is a place to point out, JOKINGLY, that this is where the robbed bits are recovered. Make sure everyone knows this is a joke. Bit robbing has to do with using information bits for signaling – Module 4)

At the receiving end, the demultiplexer must remove these stuffed bits.

How does it know which bits to remove?

Answer:

- ◊ *Also added to the bit stream are control bits to indicate the presence or absence of stuffed bits.*

Of course, framing bits, parity check bits, and maintenance bits are also added to the bit stream. Thus, the extra bits we saw above.

Bit stuffing was a useful way to take two, four or more multiplexed bit streams, such as T1s coming in at different clock rates, and form a higher speed bit stream without having to demultiplex the original signals.

However, this technique makes it impossible to recover the lower level signals (such as DS0 channels) in the higher bit rate stream without demultiplexing the entire bit stream.

This capability, known as *add/drop multiplexing*, is a cost-effective way to get at the individual channels.

Bit stuffing technology prevents add/drop multiplexing.

Thus, with bit stuffing techniques, the entire signal has to be demultiplexed; this adds to the costs since additional multiplexers and demultiplexers must be in the network.

EXPLAIN VA 5.3
REFER TO WB 5.6

Multiplexer Designations

Write on board

This visual shows how digital multiplexers are usually designated or named.

Mnn

The designator starts with the letter M and is then followed by two numbers or letters.

The character after the M indicates the speed of the lower speed DS level being multiplexed, such as 1, C, 2, 3, or 4.

If a DS1 were to be multiplexed to a higher level, we would write: M1n.

M1n

The last character is the speed that the multiplexer is going to output, that is, the DS level that the input signal has been output too.

In our example, if the output for the DS1s input was to be a DS3, we would write M13.

M13

As you look at the different multiplexer designations, notice that there is an MX3 type device.

MX3

This is a device that could take as input DS1s, DS1Cs, and/or DS2s, and multiplex them up to a DS3 level.

Equipment does exist that can take all three inputs simultaneously and convert the inputs into one DS3 signal.

By the way, the visual summarizes the North American Digital Hierarchy and the multiplexer designations.

EXPLAIN VA 5.4
REFER TO WB 5.7

European Digital Hierarchy

Write on board

CEPT

This visual shows what the **C***onference of* **E***uropean* **P***ostal and* **T***elecommunications* administrations were doing while the NADH was being developed. Here, too, a hierarchy is defined.

Like our T1, the voice rate analog signals are converted into 8 bit PCM signals, and then transmitted as 64 kbps channels on a CEPT1 system.

Unlike the North American T1, bits are not "robbed" for the purpose providing signaling information.

Instead, there are two 64 kbps channels used to take care of the signaling and framing functions.

Thus, while a CEPT1 has 30 voice channels or circuits operating at 64 kbps, there are a total of 32 – 64 kbps channels, which gives the CEPT1 a rate of 2.048 Mbps.

The other two channels carry the signaling and framing bits.

(NOTE: You may want to compare the T1 vs. CEPT1 frames.

The T1 frame has 24, 8-bit channels for 192 bits plus 1 framing bit, or 193 bits per frame.

193 bits/frame x 8000 frames/sec = 1,544,000 bit/sec.

The CEPT1 frame has 32, 8-bit channels for 256 bits per frame. No framing bit.

256 bits/frame x 8000 frames/sec = 2,048,000 bits/sec.

The above would show the differences between the two types of systems.)

This visual shows the CEPT level number (1 through 5), the number of voice circuits at each level, the multiplexer designation, and the bit rate of the different levels.

Synchronous Optical Network (SONET)

ASK

Why Another Standard?

What was the limitation on getting lower order signals out of the higher level signal under the NADH standard?

Answer:

◊ *Had to demultiplex the signal to get to lower level signals. NO Add/Drop capabilities.*

Why?

Answer:

◊ *Bit stuffing*

SONET removes this limitation. SONET is an American National Standards Institute (ANSI) standard for the transmission of information over an OPTICAL network.

EXPLAIN VA 5.5
REFER TO WB 5.8

Why SONET?

The Bell System was broken up in the early 80s.

Bell Labs was also broken in two; part of Bell Labs stayed with AT&T and Western Electric. The other portion, named Bellcore, went with the "Baby Bells" to be their "labs" arm.

These 'Baby Bells' were, of course, part of the vertically integrated Bell System.

As such, they purchased much of their equipment from Western Electric.

With the break up of AT&T, it became possible for these companies to look at other manufacturers. This was a new area to them.

This was important to them because of the economies involved. Prior to this, the manufactures designed their equipment to take a standard signal, such as T1, and output that standard signal at the far end.

In between, the manufacturers had proprietary techniques and methods to carry the signal. They also designed proprietary maintenance, monitoring, and testing systems.

This meant that a manufacturer could "lock" a customer into a technology. The customer could not interface different vendors' equipment on their network except where the signal was back to the interface it originated at. NO MID-SPAN meets.

EXPLAIN VA 5.6

The impetus to change was strong.

REFER TO WB 5.9

In 1985 ANSI accredited the T1X1 committee to begin working on developing standards for transmission systems that used fiber-optic technology.

The concept was that lightwave equipment from different companies would communicate with each other.

Thus, a company could buy equipment from Lucent, Nortel, Alcatel, Fujitsu, Siemens, etc., and the different terminals would be able to communicate with each other, exchange information, and allow the service providers to perform operations, administration, maintenance, and provisioning (OAM&P) through a variety of vendors' equipment. Open standards. Do not get locked into any one vendor's technology.

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EXPLAIN VA 5.7
REFER TO WB 5.10

The SONET standard was to be phased in. In Phase One, the basic STANDARDIZED capabilities were:

- Rates and formats (line rates, formats, and multiplexing structure),
- Mapping hierarchical signals,
- Performance monitoring,
- Automatic protection switching,
- Synchronization requirements, and
- Optical parameter specifications.

Phase 2 established the following:

- Short reach (INTRA-office (central office)) specifications for OC-1 to OC-12 rates.
- Electrical intra-office specifications from EC-1 to EC-12.
- Intra-office LAN topology.
- Data communications channel protocol using a seven layer stack.
- Asynchronous Transfer Mode (ATM) and Fiber Distributed Data Interface (FDDI) signal mapping
- Core OAM&P.
- Synchronization specifications.
- Payload and interface jitter and wander specifications.

EXPLAIN VA 5.8
REFER TO WB 5.11

SONET Line Rates and the SONET Frame

How fast is SONET? Real fast. And getting faster.

Remember when using the NADH standard that when you put two lower level DS signals together, such as 2 T1s, the output rate was higher than the sum of the two subrates?

Do you remember why? It was due to bit stuffing.

Write on Board

We do not have that in SONET.

The basic rate for SONET is 51.840 Mbps.

OC-1/EC-1 = 51.840 Mbps

The optical signal is known as "OC" or Optical Connection.

When it is available as an electrical signal, it is called an "EC" or Electrical Connection.

OC-3 = 3 x OC-1 rate or 3 x 51.840 = 155.520 Mbps

OC-1/EC-1 is 51.840 Mbps

OC-3/EC-3 is 3 x 51.840 or 155.520 Mbps

If the signal is an OC-*N* it is N x 51.840 Mbps

OC-N is N x 51.840 Mbps

Note: There is no bit stuffing. The bytes, or channels, keep their integrity.

ASK

What does this suggest that we can do?

Answer:

- ◊ *Add/Drop multiplexing*

The common rates in use are OC-3, OC-12, OC-48, and now OC-192. The other rates are defined, but are not commonly used.

EXPLAIN VA 5.9
REFER TO WB 5.12

Our SONET frame is 9 x 90 bytes. 810 bytes. It is sent 8000 times per second.

Write on board

So, an OC-1 is 810 bytes/frame x 8 bits/bytes x 8000 frames/second = 51,840,000 bps

810 bytes/frame x 8 bits/bytes x 8000 frames/sec= 51,840,000 bps

Now OC-1 is fast. But, an OC-48 is not fast enough for certain communication needs today. That is one reason OC-192 systems are deployed.

Consider this. No bit stuffing is taking place as the speeds are increased.

The bits stay grouped in their words or bytes.

Thus, it is possible in SONET to do Add/Drop multiplexing. Our individual channels are intact and can be identified.

In our asynchronous TDM environment, the bit stuffing caused us to lose sight of these lower subrates.

Now, with the SONET standard, these bytes, these individual channels, are still visible in the system because they are intact.

What does this Add/Drop capability mean for a provider?

Answer:

- ◊ *Do not have to demultiplex an entire signal to get at a lower speed signal. Can do it on the fly…add/drop. Less equipment is needed.*

Path, Line, and Section Overhead

Look closer at the SONET frame.

Notice it has three columns devoted to Transport Overhead. Transport overhead refers to **SECTION** and **LINE** Overhead.

EXPLAIN VA 5.10

It has one column in the STS Synchronous Payload Envelop (SPE) used as PATH overhead.

REFER TO WB 5.13

The overheads are Section, Line, and Path.

These overhead bytes are determined by function NOT by equipment.

And, because of the ANSI T1X1 committee's work on standards, these overhead bytes have specific functions defined.

Manufacturers cannot vary the amount or location of overhead bytes provided in the SONET frame.

Look at the amount of overhead that is being added to the payload. Of the 810 bytes in the frame, 36 bytes, or 4.4% is overhead.

KEEP THE MODULE 5 VISUAL AIDS HANDY. YOU MAY NEED TO FLIP BACK AND FORTH BETWEEN THEM TO CLARIFY POINTS FOR THE STUDENTS.

Also, note that the SECTION and LINE overhead are grouped together as Transport Overhead (TOH).

The PATH overhead is associated with the payload itself, called the Synchronous Payload Envelop (SPE). This is important since the PATH overhead stays with the SPE from the beginning of the SONET frame until the SONET frame reaches its destination and is disassembled.

EXPLAIN VA 5.11
REFER TO WB 5.14

Section Overhead

Look at this picture. We can see the SECTION, LINE, and PATH overheads areas of responsibility.

The Section Overhead (SOH) is 9 bytes in size. It monitors the activities in each of the links of a SONET system; each SONET network element is monitored.

Thus, each terminal, each regenerator, is being monitored.

The SOH provides for performance monitoring of the STS-*n* signal, a local orderwire, and a Data Communication Channel (DCC) that carries OAM&P, parity checking, and framing.

ASK

How were these functions handled in the NADH?

Answer:

- ◊ *Bit robbing, superframes, & extended superframes.*

How were these functions handled in the EDH (CEPT)?

Answer:

- ◊ *Extra channels carry this information. Bit robbing not required.*

EXPLAIN VA 5.12
REFER TO WB 5.15 THROUGH WB 5.17

This visual shows the use of the overhead bytes.

Our SOH uses framing bytes which are designated A1 and A2.

Each SONET frame in an STS-*n* system has its own framing bytes.

Write on board

Thus, in an OC-3 system, each of the OC-*n* signals would use these framing bytes. Each OC signal has:

8000 frames/sec

8000 frames/sec x 2 bytes/frame or 16,000 bytes/sec for framing. If each has that, then an OC-3 has 48,000 bytes/sec being used for framing.

x 2 bytes/frame = 16,000 bytes/sec for framing.

The 2nd important function of the SOH is the DCC.

The DCC information is carried in 3 Bytes, D1, D2, and D3.

That is 24 bits of information per frame, or,

8000 x 24 bits/sec = 192,000 bps.

The information is maintenance as well as message-based network management information being carried between each network element.

EXPLAIN VA 5.10
REFER TO WB 5.11

Line Overhead

The LINE Overhead (LOH) has 18 bytes. It is part of the Transport Overhead (TOH).

The LOH is provided to monitor conditions between the terminal multiplexers. The two end terminals on a particular line can communicate with each other across the network.

If there are no intermediate regenerators, if there are only end terminals, then the section and line overhead (SOH & LOH) originate and terminate on the same network elements, that is, the end terminals.

These two overheads are known together as Transport Overhead.

How are end terminals determined? End terminals are those terminals that provide protection switching of the line. The LOH is where this information is carried and it is at the end terminals where protection switching takes place.

LOH provides performance monitoring of the STS-1 signal, express orderwire (terminal to terminal) OAM&P information, line Alarm Indication Signal (AIS), Far End Receive Failure (FERF) indication, and pointer information.

The pointer bytes are used to indicate exactly where the STS-1 SPE is in the data stream.

Write on board

In other words, where exactly does the SPE start in the stream of bits on the line.

H1 and H2: Connects TOH to SPE Payload

The pointer bytes, H1 and H2, tell the system how many bytes are between the pointer bytes and the actual start of the SPE.

Thus, the pointer bytes tell the multiplexer exactly where the STS-1 frame begins.

The second key function of the LOH is to provide Automatic Protection Switching (APS).

K1 and K2 are the bytes used to provide APS. Protection switching takes place at the line level.

K1 & K2: APS, 50 ms.

In the case of a problem, the terminal network elements responsible for protection switching are required to determine and EXECUTE a switch within 50 ms (0.050 seconds).

The only STS-1 frame which carries these bytes in an STS-*n* system is the very first frame.

EXPLAIN VA 5.10, VA 5.11, VA 5.12

The third key function of the LOH is yet another DCC.

This is a 9 byte channel, D4 to D12.

This 576 kbps DCC makes it possible to update routing tables in Digital Cross-Connect Systems (DCS), change and/or update software at remote locations, and all the information that is being passed at the line level for administration, maintenance, alarms, monitoring, and control.

Only the first STS-1 frame in a STS-*n* system carries this data. Also, this DCC permits single ended operations (SEO).

Path Overhead

Path Overhead (POH) is carried end to end on the STS-1 SPE frame.

It is part of the payload itself. It stays with that payload until reaching an end terminal, switch, or cross connect system that is acting as a Path Terminating Equipment (PTE).

The POH provides performance monitoring of the SPE. It reports signal indication (equipped/unequipped for each signal), path status, and path trace. POH is built into the frame as it is built.

The first byte, J1, is the Path Trace byte. This allows the receiving terminal to verify an end-to-end connection.

The Path Status byte, G1, is used to send the terminating status and performance of the signal to the ORIGINATING equipment for the path.

Thus, the SPE can be monitored at both ends or at any point along the path itself.

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Virtual Tributaries (VT)

The SONET signal carries large payloads. Very large. Without the overhead bits, the SONET payload is

ASK

49.536 Mbps = (51.840 Mbps – (4 x 9 x 8 x 8000)).

This is a larger payload than the DS3 we studied earlier.

What is the size of the DS3 frame?

EXPLAIN VA 5.13
REFER TO WB 5.18

Answer:

◊ *44.736 Mbps*

Also, there are three levels below the DS3 level: DS1, DS1C, and DS2. The SONET standards require that these three sub-rates PLUS the CEPT1 rate be carried.

EXPLAIN VA 5.14
REFER TO WB 5.19

Looking at this visual, we see that there are 4 VT types:

VT1.5, VT2, VT3, and VT4.

As can be seen, the VT rate is higher than the DS*n* or CEPT1 rate being carried.

These lower level signals are mapped into the STS-1 SPE by columns.

This shows how the different signals are mapped into the SPE. In each case, 8 rows are used for the information; the 9th row is the VT overhead that is added for each lower level signal.

The STS-1 SPE has 87 columns; 86 of those columns are available to map in the lower level signals.

The SPE is large enough to carry any of these payloads.

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WRITE THIS TABLE ON BOARD:

DS-1, VT1.5, 3 columns x 28 DS-1 = 84 columns

CEPT1, VT2, 4 columns x 21 CEPT1 = 84 columns

DS-1C, VT3, 6 columns x 14 DS-1c = 84 columns

DS-2, VT4, 12 columns x 7 DS-2 = 84 columns

Since no framing bits from the DS1 signals are being carried, the 8-bit words can readily be mapped into the SONET frame.

Since framing and control bits for the CEPT1 are carried in separate 64 kbps channels, these two channels are mapped easily into the SONET frame.

For our DS1C and DS2 signal, the 48 and 96 voice grade channels being carried have “stuff bits” and other control and framing bits in the signal.

If the DS1C or DS2 is mapped directly into the SONET frame, the area provided, 9 rows x 6 columns for the DS1C and 9 rows x 12 columns for the DS2 provides all the room that is needed to hold these signals.

The SPE frame is divided into 7 (seven) VT groups.

Each of these groups consists of 12 columns (7 x 12 = 84).

This is the same number as the total number of columns to carry a full load of each of the sub-rates.

By establishing “groups” it is possible per the standards, to map the sub-rates into groups.

Each group will carry 1 category of sub-rate. That is, a group can carry ALL DS1s, or ALL CEPT1s, or ALL DS1Cs, or ALL DS2s. Since there are 7 groups, the SONET frame can be subdivided to carry different signals.

EXPLAIN VA 5.15
REFER TO WB 5.20

The next visual shows some possible combinations.

By mapping the signals into their respective VT Groups, the SONET signal can be utilized to carry many types of different signals simultaneously.

But each group can carry only one type of signal.

The total number of VT Groups cannot exceed 7 in the SONET frame.

Notice it is not necessary to fill a VT Group completely in order to use it.

(*NOTE: Review the module and talk through this VA, also shown as Table 5-6 in Chapter 5 of* DigiPoints, Volume 1*).*

EXPLAIN VA 5.16
REFER TO WB 5.21

In the SONET architecture, the bits are not interleaved or stuffed. Our channels stay together as 8-bit words, bytes.

However, these are asynchronous signals coming into the SONET system. How is that to be handled?

Consider how the SONET signal is transmitted on the high-speed output.

Each byte is transmitted serially.

If the frame is an OC-3, the first byte from the 1st frame ($A1_1$) is transmitted. Then the first byte of the 2nd frame ($A1_2$) is transmitted. Then the first byte of the 3rd frame ($A1_3$) is transmitted. Next, the 2nd byte of the 1st frame is transmitted, and so on.

So the bytes are being interleaved, not the bits.

Also, since the incoming signal is asynchronous, and the clocking is NOT the same as the SONET clock, stuffing must be used. But this is not bit stuffing. This is byte stuffing.

Remember the two columns not being used. 87 columns, one used for POH, and 84 used for the VT groups.

This leaves two columns of bytes that can be used for stuffing. These are columns 30 and 59.

Since bytes are being stuffed, the signal is still very readable. The channel bytes of a DS1 are available to be read. Thus, the add/drop capability exists.

The interleaving of these bytes is not a problem. In fact, the columns of the VT Groups are also interleaved. None of this is a problem BECAUSE the bytes are kept intact.

This allows the Add/Drop multiplexing capability to be retained and used.

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There are two distinct modes in which the SPE can be operated: Locked and Unlocked Mode

Write on board

Locked Mode

LOCKED

Locked Mode makes it easier to distribute and extract DS0 channels (these are the 64 kbps channels).

This mode would be used if DS0s were to be available to all multiplexers.

It is important to note that this mode is limiting. It is only efficient if ONLY DS0s are being used for Add/Drop.

Add/Drop DS0s

Floating Mode

FLOATING

Floating Mode speeds VT switching at all the NEs.

Floating Mode

Switch VT at all NEs

The use of VT path overhead and VT path payload pointers makes it possible for the system to drop all types of signals, not just DS0s.

Other signals mapped into SONET frame:

This is a more complex way of operating; but it is more flexible.

DS3

Additional SONET Payloads

Other signals mapped into SONET frame:

DS3

DS3 signals can be mapped directly into the SONET frame without using a VT Group of any sort.

The DS3 is a 44,736,000 bit per second signal.

This consists of:

8000 sample/sec (44,736,000/8000 = 5592 bits per frame) and

699 bytes (=5592/8) per SONET frame.

How many bytes are available in a 9 x 86 frame?

Answer:

◊ *774*

Sufficient bytes are available to map the DS3 into the SONET frame.

If the DS3 consists of DS1s or other sublevels in the NADH, the DS3 would have to be demultiplexed completely in order to gain access to the DS0s.

Bringing 28 DS1s into the SONET frame would be more efficient.

There is also a SYNTRAN signal that can be mapped into the SONET frame.

SYNTRAN

SYNTRAN is a synchronized DS3 signal built from DS1s.

Since it is synchronized, the individual DS1s are visible in the Syntran signal. When this signal is mapped and transported on the SONET system, the DS1s are visible and available.

SONET STS Multiplexing

Write on Board

Standard up to 255 STS-1

In addition to building STS-1 frames from lower level asynchronous signals, higher level STS frames are built from STS-1 frames.

This is STS multiplexing.

The current standard defines a STS-255 signal, that is,

255 STS-1 frames operating at 13.210 Gbps.

As we multiplex up the SONET signals, this is done WITHOUT bit stuffing. The integrity of the bytes is maintained.

SONET also has the ability to handle user information requiring more than one SONET STS-1 SPE.

EXPLAIN VA 5.17

REFER TO WB 5.22

When this condition exists, multiple SONET frames can be concatenated together.

Concatenated frames

That is, the frames are logically associated with each other end to end.

These frames are identified as STS-*n*c frames.

If *n*=3, then the designation is STS-3c.

It is similar to an STS-3 in that both have a data rate of 155.520 Mbps. The STS-3c will be carried across the network as a single item on the network.

How does an STS-1 signal get multiplexed up to a higher level?

The standards call for this to be done in stages.

The first stage is to multiplex 3 STS-1s up to an STS-3 signal. This is done without any bit or byte stuffing of the STS-1 signals.

Thus, the total number of bits at the end of this multiplexing is

3 x STS-1 or 3 x 51.840 = 155.520 Mbps.

Thus, each STS-1 is visible as it is multiplexed up to a higher rate bit stream.

The first stage of multiplexing takes the signal up to an STS-3.

This signal has SOH, LOH, and POH. It is also equivalent to the CCITT's Signal Digital Hierarchy (SDH) STM-1 signal.

STM-1 and STS-3 have the same bit rate, 155.520 Mbps.

If the multiplexing continues up to the STS-9 level, the bytes of each frame are interleaved as shown in VA 5.17.

Again, a higher level TOH is created to handle the information required for this higher bit rate line.

Again, there is no bit stuffing, although the bytes are interleaved. The synchronized signal is such that each STS-1 byte can be identified.

The ability to identify individual bytes makes Add/Drop multiplexing possible.

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EXPLAIN VA 5.18
REFER TO WB 5.23

Standards

This visual lists some of the primary standards that have been written for SONET.

There are three bodies working on this: ANSI, ITU-T, and Bellcore.

EXPLAIN VA 5.19

This visual shows SONET and the NADH interface.

The numbers between the vertical lines indicate how many lower level signals can be multiplexed up to the next level.

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Summary

REFER TO WB 5.24 THROUGH WB 5.27

Have students answer the study questions at the end of Module 5. Review the answers.

Answers in Appendix

Appendix

Answers to the questions at end of student workbooks.

1. What is the benefit of digital rates above T1?

   More conversations on the media being used.

2. What is the NADH?

   The North American Digital Hierarchy.

3. What are the levels in the NADH?

   DS1, DS1C, DS2, DS3, DS4

4. Why are the bit rates of each level NOT a simple multiple of the rates below it? That is, if a DS3 contains 28 DS1s, or 14 DS1Cs, or 7 DS2s, why is not a DS3 just a multiple of the lower rate?

   Bit Stuffing

5. What is the purpose of Bit Stuffing? Why is it needed?

   The low rate inputs to a multiplexer can be arriving at slightly different rates since the standard allows some variation (less then 1%) in the bit rate. Because each of the inputs may be on a different "clock" it is necessary to do bit stuffing so that the high-speed output will be synchronized. Also, the high-speed output needs to have its own framing and control bits.

6. What is made more difficult by this bit stuffing technique? How is it overcome?

   As signals are multiplexed upwards, it becomes impossible to identify the lower level signals, such as DS0s, in the overall bit stream. Thus, we are unable to add or drop a specific DS0 voice channel. To get to that channel requires that the ENTIRE signal be demultiplexed. This adds equipment to the network. This is expensive.

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7. What type of multiplexer is a M34?

   In the NADH, it is a multiplexer that takes 6 DS3 level signals and combines them into one DS4 level signal.
   In the European Digital Hierarchy, the M34 represents a multiplexer that takes 4 - CEPT3 level signals, each with 480 voice grade channels, and multiplexes these up to the CEPT4 level, which carries 1920 voice grade channels.

8. How are multiplexers designated/named?

   M – for the word multiplexer
   n – the DS level of the input signal
   n - the DS level of the output signal

   Mnn: M1C, M12, M13, MX3, M34 NADH

9. Why was SONET developed?

   To provide open standards that would allow a service provider to purchase compatible equipment from different vendors without getting "locked" into any one vendor's architecture.

10. What are the three types of overhead?

    SOH & LOH = TOH.
    POH

11. What is the purpose of the pointer bytes? Where are they found?

    Pointer tells where the SPE begins…how many bytes away. Pointers are found in the LOH.

12. How many bytes in the TOH? How are they divided?

    9 x 3 = 27. SOH 3 x 3 = 9 bytes, and LOH 18 bytes.

13. What percent of the SONET frame is devoted to overhead?

4.4% for LOH, SOH, & POH.

14. What does SOH allow?

Communications between NEs. Also has DCC capability and framing bytes.

15. What does LOH provide?

Pointer bytes, DCC bytes, and APS (K1, K2) bytes.

16. Name two things the POH provides.

End-to-end monitoring between both end terminals. Confirms that the path has continuity.

17. How many Virtual Tributary rates are available? What are they?

4 – VT1.5, VT2, VT3, and VT4.

18. How big is the VT1.5?

1.728 Mbps, 27 8-bit channels.

19. What is a VT Group? How big is it?

A VT Group is 12 columns by 9 rows or 108 bytes.

There are 7 groups, 84 columns, in a SONET SPE.

20. How many columns in the STS-1 SPE are not used by the VTs. What are these used for?

2 – Col 30 and 59. Used for byte stuffing.

21. What is the advantage of SONET multiplexing over TDM?

    No bit stuffing.

22. What is the first stage in SONET multiplexing?

    STS-1 to STS-3

23. How is the STM-1 different from the STS-3?

    STM-1 is a 155.520 Mbps signal in the SDH; it is the same bit size of the STS-3 in the SONET standard.

24. What is the difference between Locked Mode and Floating Mode?

    Locked mode is used to quickly get to DS0 signals. It is limited. Floating Mode is used to get to any of the DS level signals. It is the most flexible.

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