# Digital Carrier Systems

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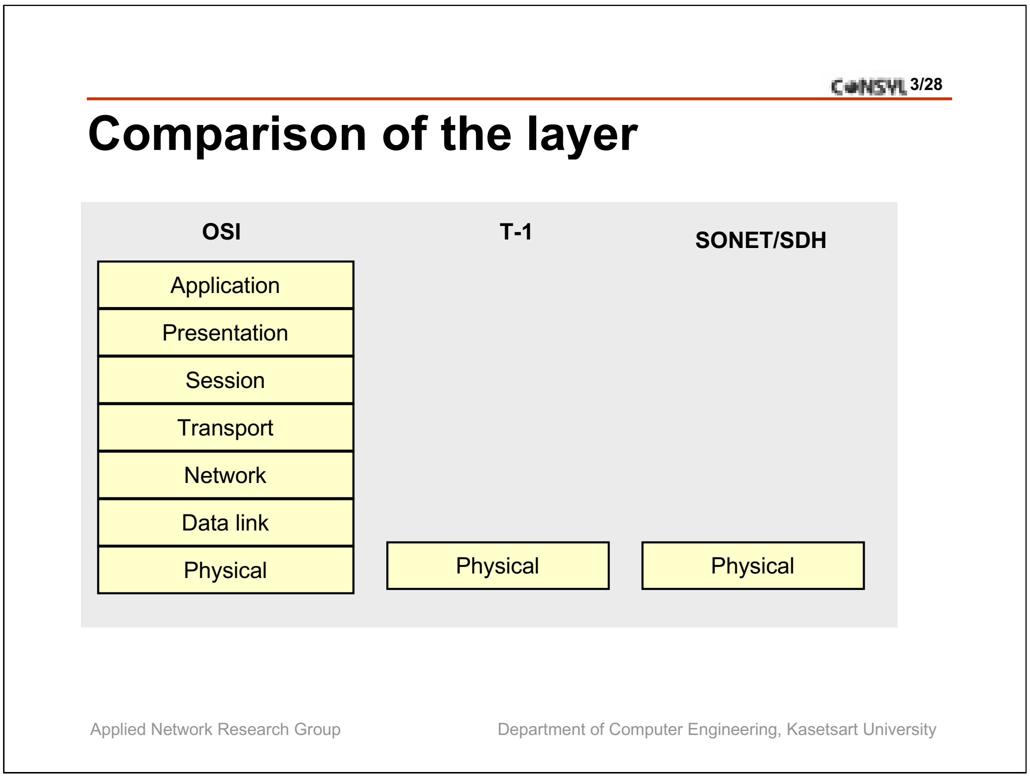
# Digital carrier standard

- **T-carrier**
  - North America, Japan
- **E-carrier**
  - Europe, South America
- **SONET/SDH**
  - world-wide new standard

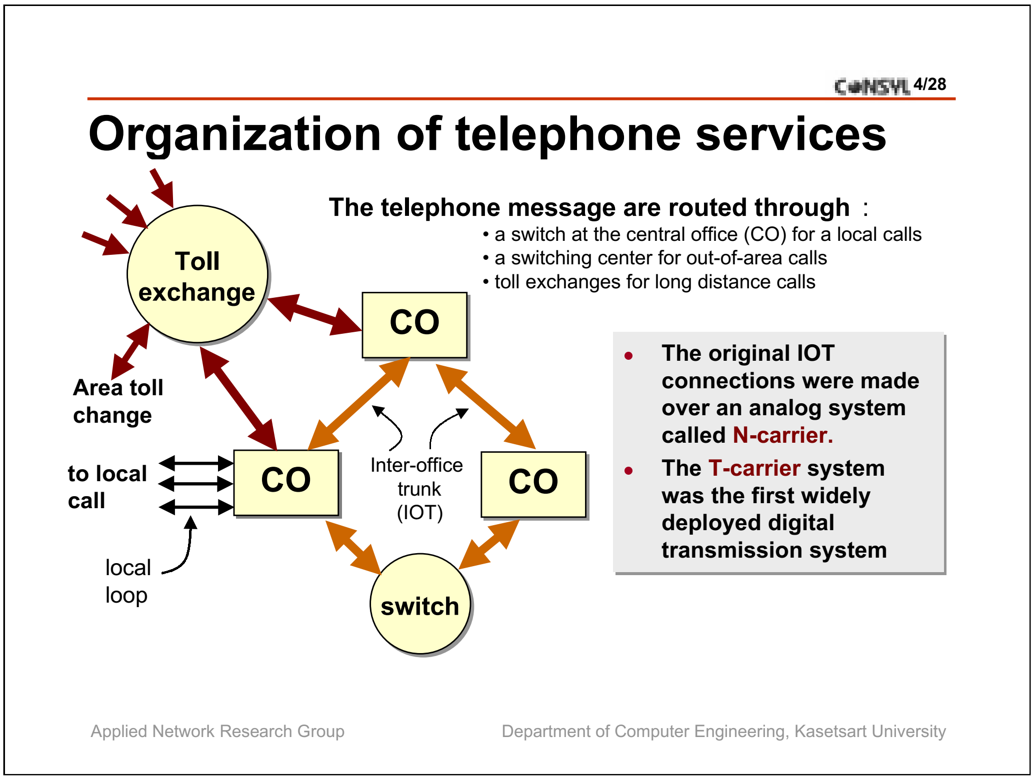


Telephone companies make uses of multiplexing long-distance calls onto high-speed trunks. International standards bodies issue multiplexing rates that from the *digital transmission hierarchy*. *Digital carrier* is a digital signaling represent a telecommunications service. The base level in the hierarchy is the equivalent of a single 64Kbps digitized voice. The hierarchy differs from region to region.

Digital service in North America defines a four level transmission hierarchy called T-carrier, range from T1, T2, T3 and T4. In Europe and South America, there is five-level transmission hierarchy called E-carrier, range from E1, E2, E3, E4 and E5. Both systems use PCM to encode an analog signal in digital from. The signal is sampled 8000 times per second, and each sample valve is encoded in an 8-bit valve. The signal transmission uses TDM. SONET and SDH is intended to provided a specification for taking advantage of high-speed digital transmission capability of optical fiber

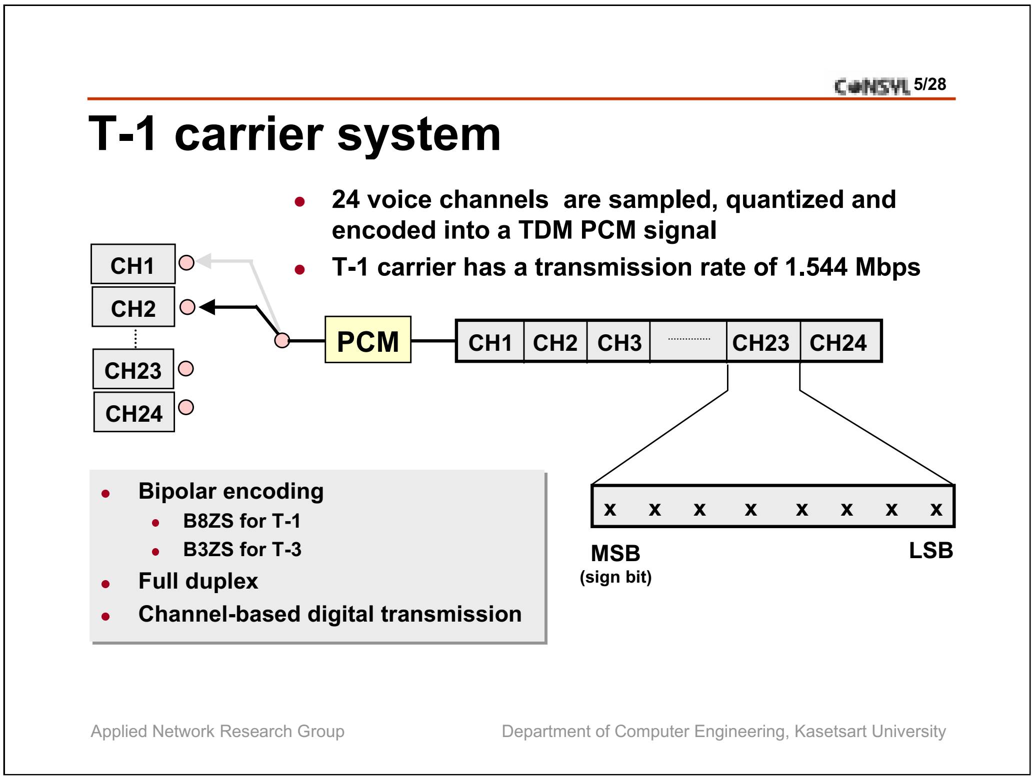



T-1 and SONET/SDH standard define the rates and formats, the physical layer, network and the network operational criteria



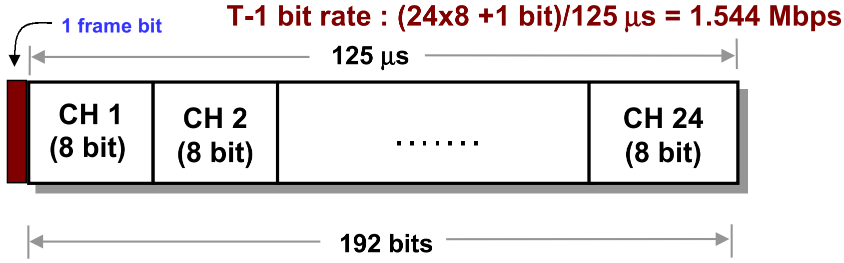

The non-local calls are routed between central office through inter-office trunks (IOT). The original IOT connections were made over an analog system called the N-carrier. The N-carrier system deployed an analog transmissions, allowing 12 voice calls to share the same line. The L-carrier system was designed in the late 1960s for handling much higher capacity. The system can carry up to 6000 calls on the coaxial cable. However, the repeater were needed to improve signal periodically along the line. The system was very expensive for investment.

The new digital transmission called T-carrier system was later developed.The T-1 version can handle 24 calls on two pairs of copper wire.




The Bell system has established time division multiplexed PCM systems in North America. The transmission system is known as the T-carrier system. The T1 carrier is the fundamental building block of the multiplexing hierarchy. The T1 carrier consists of 24 voice channels that are sampled, digitized and encoded to a PCM signal. The transmission rate onto the T1 carrier is 1.544 Mbps. The designations T1 and DS1 refer to the circuit and signal respectively. Pulse trains in T carrier rely on the B8ZS (Bipolar with 8 Zero Substitution) coding.

# T-1 frame

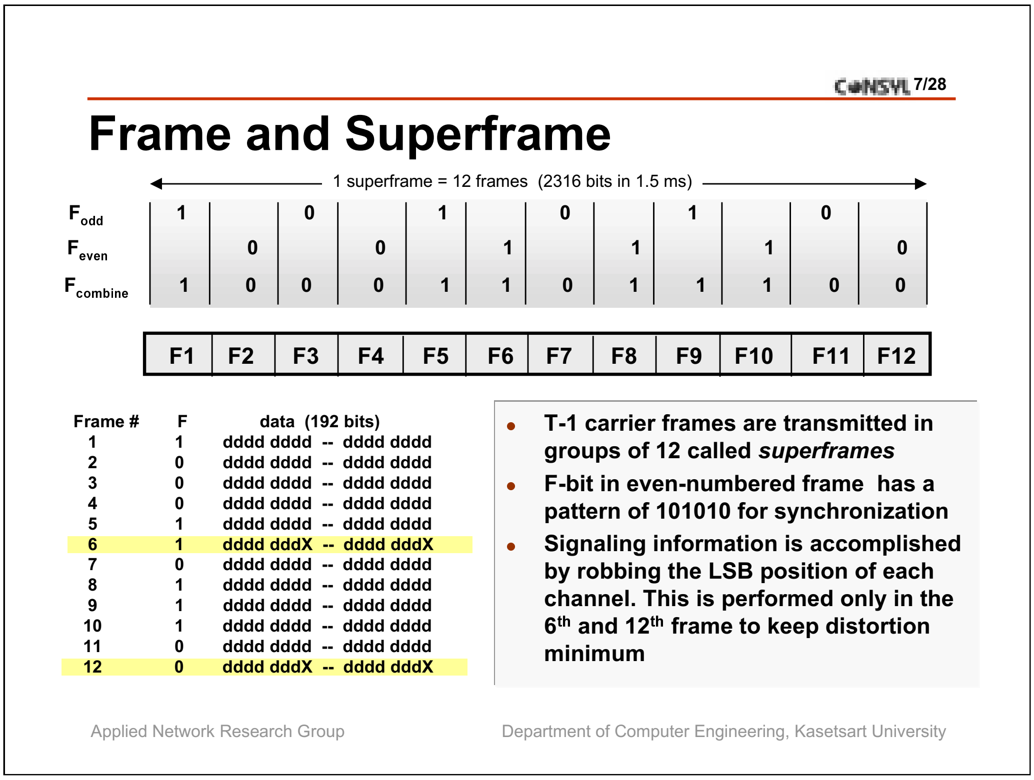



- The early frame standard called D1, D2 and D3 were used.
- There are two framing standard for the T-1, called D4 (superframe) and extended superframe (ESF)
- The T-3 used the M13 framing



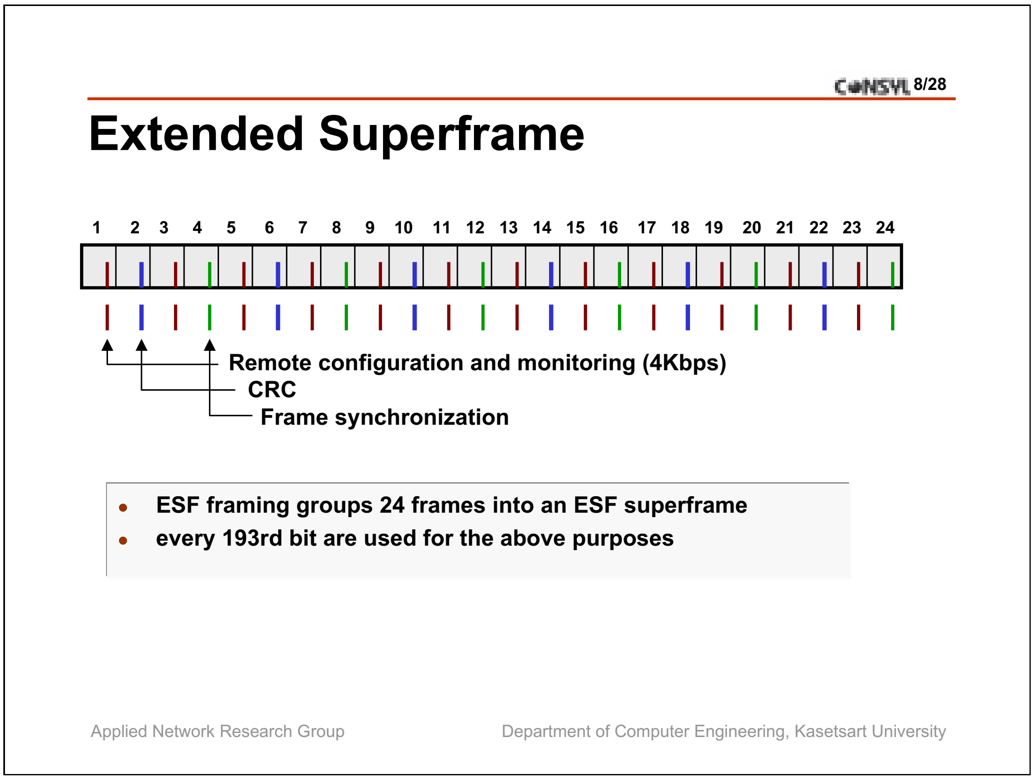
A DS1 frame contains 193 bits divided into 24 slots (one for each voice channel) of 8 bits and one extra bit called a *framing bit* (F-bit), which is used for synchronizing.

Eight-bit voice samples are taken from each of 24 channels at a rate of 8000 times per second (64 Kbps rate). To support this speed, T1 must transmit a DS1 frame every 1/8000 of a second (125 µs). This yields the bit rate of (24x8+1) bits/125 µs = 1.544 Mbps.




12 consecutive frames comprise a superframe (also called D4 framing). The 12 framing bits in this superframe (one framing bit per frame) goes through the 12-bit pattern 100011011100.

The synchronization pattern occurring in the odd-numbered frames is 101010. These are the synchronization bits for the channel banks. The voice clock synchronization pattern occurring in the even-numbered frames has a pattern of 001110. The combined Fs bit pattern is 100011011100 for the superframe. It is call the S bit because it is shared between framing and signaling.

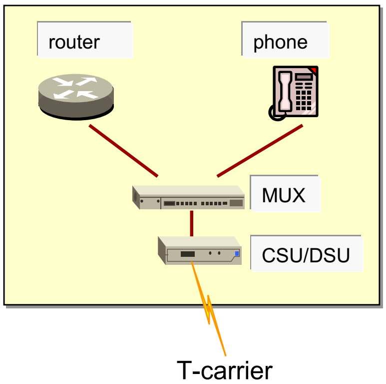



Extended Superframe extends this to not only provide frame synchronization, but also error detection and a data channel, all using the framing bit. The value in every 193rd bit (in bits 193, 386, and so on) are used for three purposes :

- Every fourth bit of this 24-bit cycle (that is, the framing bits for frames 4, 8, 12, 16, 20, and 24) goes through the pattern 001011. This provides the frame synchronization.
- The framing bits for frames 2, 6, 10, ..,22). are used to send a 6-bit CRC, generated from the data in the previous 24 frames. This provides error detection. The receiving CSU can then track the error rate and generate an alarm if it gets too high. (This error checking is done constantly while the link is in service and for any type of data.
- The remaining framing bits (for frames 1, 3, 5, 7, ..,23) provide a 4kbps supervisory data channel that is used for other functions such as remote configuration and monitoring of CSUs.

The eighth bit in every channel of frames 6,12,18 and 24 is used for signaling between central offices.

# Multiplexing




- **CSU (Channel Service Unit)**
  - performs several protective and diagnostic functions
- **DSU (Data Service Unit)**
  - convert the digital data from a (for example) router to T1 voltages and encoding.

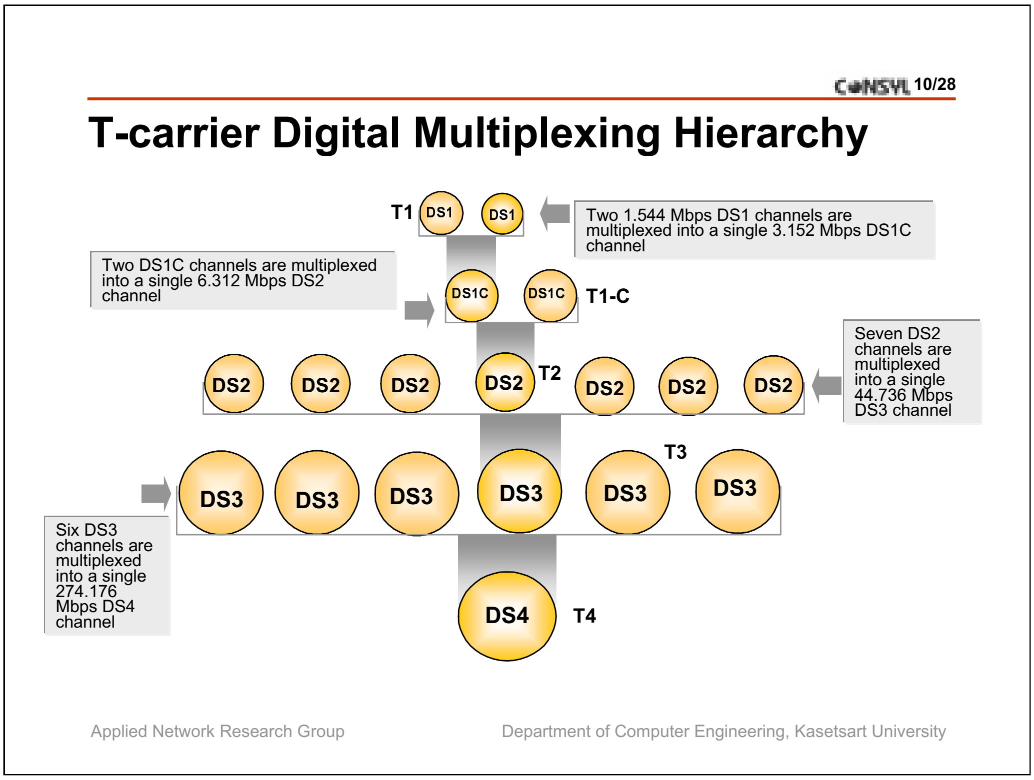


CSU is a device usually required on a T1 (or FT1 or T3) line that performs several protective and diagnostic functions, such as the following:

- Lightning protection (protect the user's equipment from damage)
- "Ones density" enforcement (if the user equipment transmits more than 15 consecutive zeros, then the CSU either alarms and stuffs
- Loopback (for diagnostic testing)

For data applications, often integrated with the DSU, so the unit is then called a CSU/DSU.

DSU is a device required to convert the digital data from a (for example) router to T1 voltages and encoding. Usually uses a V.35 interface to the router. Because of proprietary extra features, such as multiplexing and diagnostics, units from the same manufacturer must usually be used at both ends of a link.



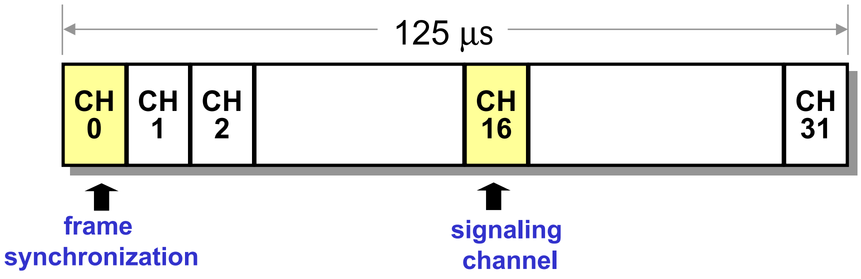

To achieve higher aggregate link bit rates, several DS1 channels are multiplexed together.

| carrier | frame | # channels | Rate (Mbps) | Media |
|---|---|---|---|---|
| T-1 | DS1 | 24 | 1.544 | Wire pair |
| T-1C | DS1C | 48 | 3.152 | Wire pair |
| T-2 | DS2 | 96 | 6.312 | Wire pair, fiber |
| T-3 | DS3 | 672 | 44.376 | Coax, microwave, fiber |
| T-4 | DS4 | 4032 | 274.176 | Coax, microwave, fiber |

**Note**:
(1) In both T1 and E1 systems, the lower bit rates are known as fractional T1/E1.
(2) T2 is used in Japan, but is not offered to the public in the United States.
(3) T4 is now obsolete, and used only in a few rare instances.

# E1-frame

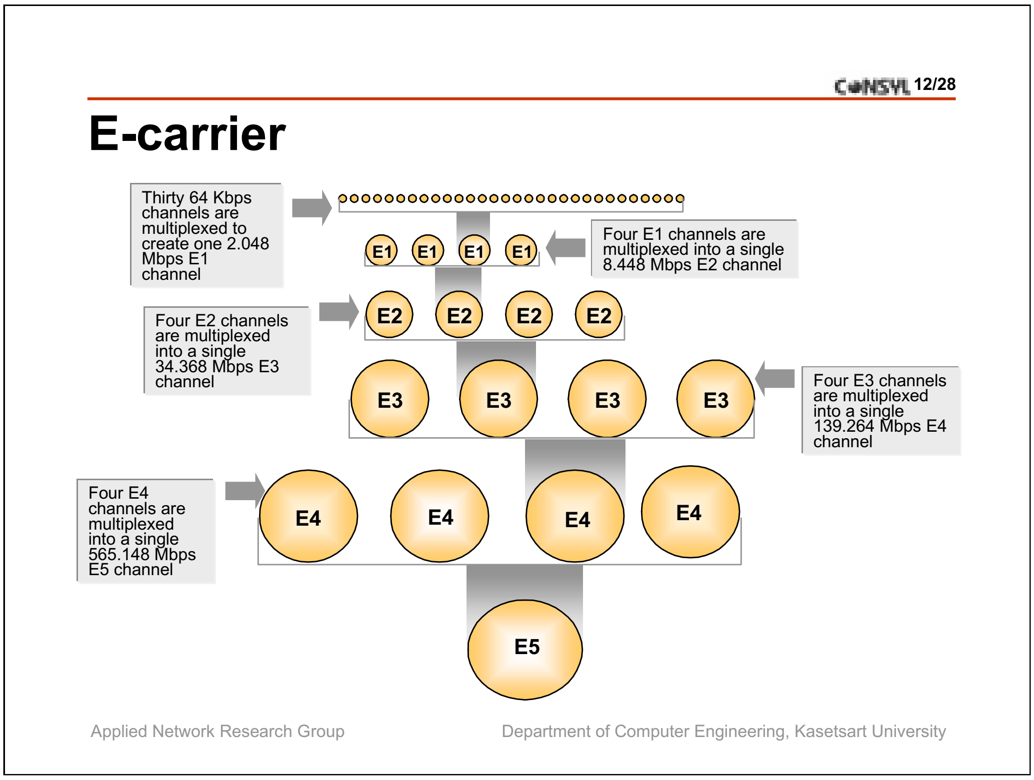
**30 voice channels+2 control channels**




**E1 bit rate : (32x8 bit)/125 μs = 2.048 Mbps**



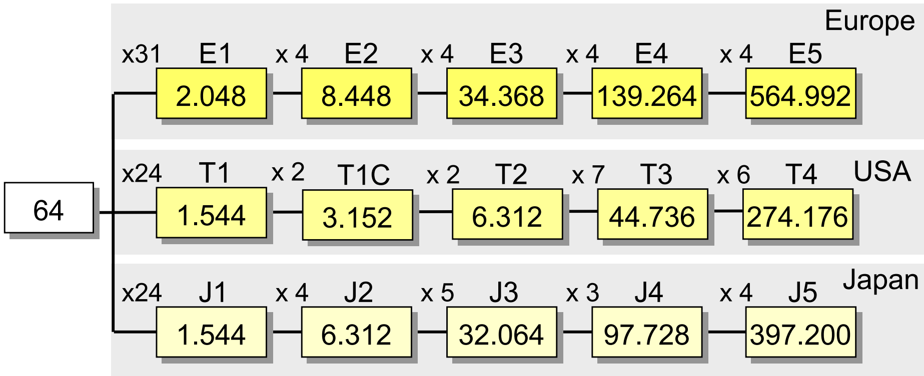
E1 is a carrier channel configuration defined by ITU-T. The E1 carrier channel is built up of 64 Kbps voice channels and two 64 Kbps signaling channel. This yields bit rate : 32x8 bits/125 μs = 2.048 Mbps




To achieve higher bit rate, several E-1 channels are multiplexed together :

| Circuit | no. of channels | Data rate (Mbps) |
|---|---|---|
| E1 | 30 data +2 control | 2.048 |
| E2 | 120 | 8.448 |
| E3 | 480 | 34.368 |
| E4 | 1920 | 139.264 |
| E5 | 7680 | 565.148 |

# Digital carrier comparison






Traditional digital hierarchy in United States, Japan and Europe.

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# PDH

almost synchronous

- **PDH = Plesiochronous Digital Hierarchy**
- **Digital transmission systems (T-carrier, E carrier) combine lower order multiplex stream to get higher bit rate**
- **Each device runs its own free-running clock**
- **Different streams have small differences in clock signals.**
- **Solve by adding justification bit**

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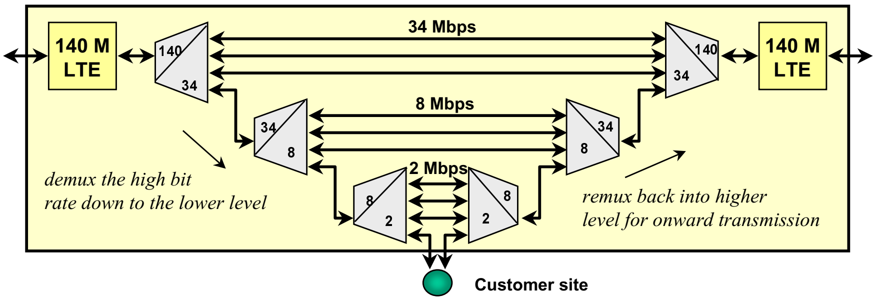
All telecommunication traffic has until recently been carried over equipment based on PDH. The term Plesiochronous came from Greek language, and means- *almost synchronous*. An examples would be two alarm clocks, both of which keep good time. But over a period, the two clocks would start to drift part.

In the same way, digital signals from different places typically have their own clocks. All operating at almost (but not quite) 1.544 Mbps (T1). If the first source runs at 1.545 Mbps and the second runs at 1.543 Mbps, the output contains more bit from the first source than the second. The naive multiplexer must drop bits from the first source, otherwise there must be a way to distinguish bits arriving bits from difference sources. This requires the packets scheme, which is not possible in the circuit-switched telephone network. The solution is the use of *justification* or *bit stuffing*.

# PDH deficiencies (I)

- **Lack of flexibility**
  - impossible to identify a lower bit rate channel from the higher-order bit stream.

Extraction of 2 Mbps channel from 140 Mbps channel







The demultiplexing/multiplexing operation is performed by a device known as a "drop-and-insert" or add-drop multiplexer (ADM).

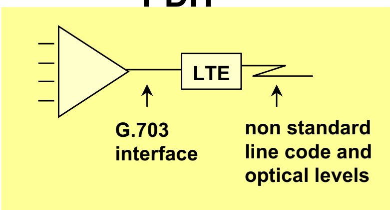
It's difficult, using PDH based equipment, to drop and insert a low rate channel from a high rate channel, without the use of a 'multiplexer mountain'. The normal example given is that of dropping out a 2 Mbps channel from a passing 140 Mbps stream. The cause of this particular problem lies in the amount of information processing necessary to locate and extract the required traffic channel. The basic PDH multiplexer process involves a bit interleaving operation which obscures knowledge of the individual byte boundaries, and thus leads to an inflexible system.

With all the different levels of plesiochronous traffic, it is impossible to find and directly demultiplex a higher order bit rate, This is need to demultiplex the high bit rate down to the lower level. This stream must then be remultiplexed back into higher level for onward transmission.

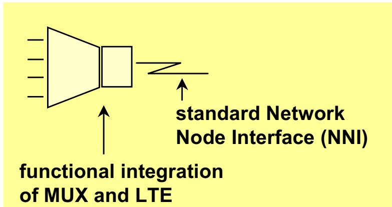
# PDH deficiencies (II)

- **Lack of performance**
  - No standard for monitoring the performance of traffic channel
  - No management channel
- **Lack of 'Mid-Fibre meet'**
  - undefined interface specification on the line side of a line transmission

**PDH**




**SDH**






The PDH does not currently have any internationals standardized ways of monitoring the performance of traffic channels. The PDH does not have any agreed management channels or protocol stacks

Although the PDH specifies the exact format of the bit stream at the aggregate port of any PSH multiplexer, it puts no such constraints on the bit stream on the line side of a line termination. Consequently, every manufacture has used his own proprietary line code and optical interface specification, making it impossible for a PTO to interconnect line terminals from two different manufactures.

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## SDH & SONET

- **What is SDH/SONET ?**
  - Standard interface developed for using in the public network
  - multiplexing standard for optical fiber transmission
- **SONET = Synchronous Optical Network**
  - refers to the system used within the U.S. and Canada
- **SDH = Synchronous Digital Hierarchy**
  - international community term (ITU-T recommendations)

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SDH (Synchronous Digital Hierarchy) was developed initially by Bellcore in the USA under the title of Synchronous Optical Network (SONET). ITU-T sets a SDH standard with series of recommendations G.707, G.708 and G.709 as well as other relevant recommendations.

SONET is a new transmission system designed for use over new fiber optics links. It is a more intelligent framing and transmission system which has many advantages over the older PDH systems. SONET consists of a hierarchy of physical data transmission rates.

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# SDH/SONET goals

- **Goals**
  - make it possible for different carrier to interwork
  - unify the U.S., European and Japanese digital system
  - Provide a way to multiplex multiple digital signal together
  - provide support for operations, administration, and maintenance
- **Characteristics**
  - use single master clock to synchronize
  - Bit stream can be a added or extracted directly
  - Basic transmission rate = 155.52 Mbps

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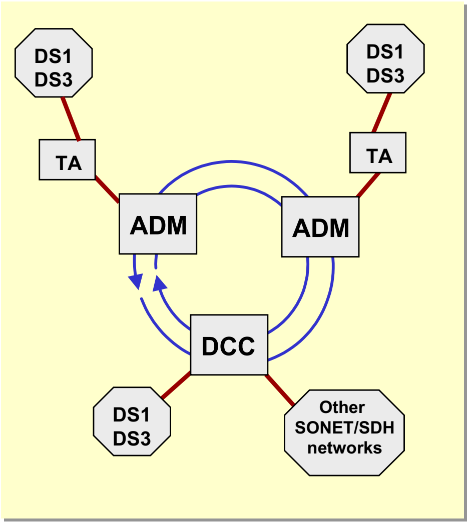
Design Goals :
(1). Defines a common signaling standard with respect to wavelength, timing, framing structure and others.
(2) Digital system in U.S., European and Japan were based on 64 Kbps PCM channels, but all of which combined them in different and incompatibility ways.
(3) Part of SDH/SONET's mission was to continue the hierarchy to gigabits/sec and beyond.
(4) Previous PDH system did not do this OAM (Operation, Administration, Management) very well.

# SDH/SONET topology



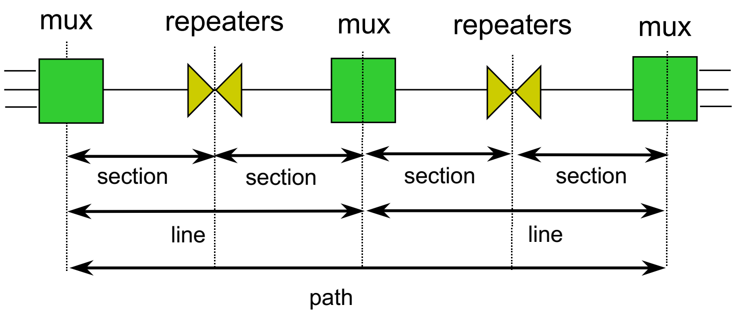

- Typical SDH/SONET topology is a dual ring (fiber optics)
- One ring is the working facility, and the other ring is the protection facility (standby)
- End-user devices operating on LANs or other transport systems are attached through terminal adapter



The SONET/SDH topology can be a mesh, but often a dual ring. The ADM can add or drop payload onto one of the two channels. Remaining traffic that was not dropped passes straight through the multiplexer without additional processing. The DCS acts as a hub. It can add and drop as well as operate with different carrier rates such as DS1, OC-n and so on.

# SDH/SONET System

- consists of switches, mux and repeaters






In SONET/SDH terminology, a fiber going directly from any device to any other device, with nothing in between, is called a **section**. A run between two multiplexers (possibly with one or more repeaters in the middle) is called a **line**. Finally, the connection between the source and destinations is called a **path**.

The SONET/SDH topology can be a mesh, but often a dual ring.

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## Multiplexing level

| SONET | SDH | Bit rate (Mbps) |
|---|---|---|
| STS-1/OC-1 | (Not defined) | 51.84 |
| STS-3/OC-3 | STM-1 | 155.52 |
| STS-9/OC-9 | STM-3 | 466.56 |
| STS-12/OC-12 | STM-4 | 622.08 |
| STS-18/OC-18 | STM-6 | 933.12 |
| STS-24/OC-24 | STM-8 | 1244.16 |
| STS-36/OC-36 | STM-12 | 1866.24 |
| STS-48/OC-48 | STM-16 | 2488.32 |

STS = Synchronous Transport Signal
OC = Optical Carrier
STM = Synchronous Transport Module

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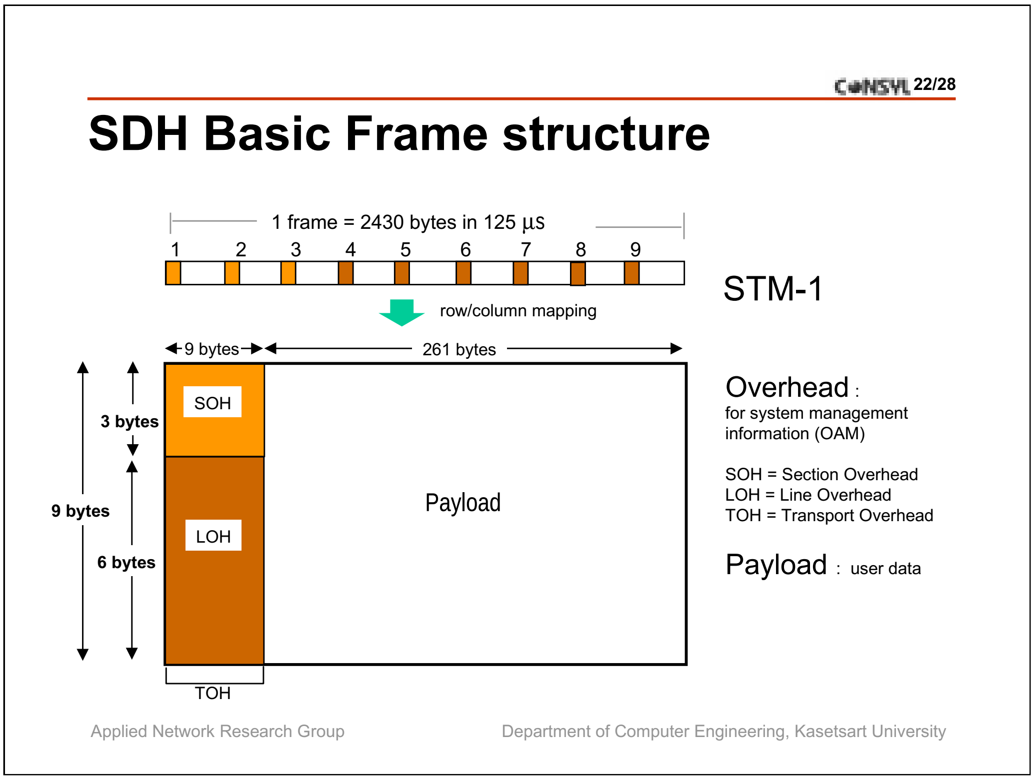
SONET is a signaling hierarchy based on a basic signaling structure called *Synchronous Transport Signal* (STS). The STS signaling system provides a basic signaling structure that built upon to implement higher line rates.

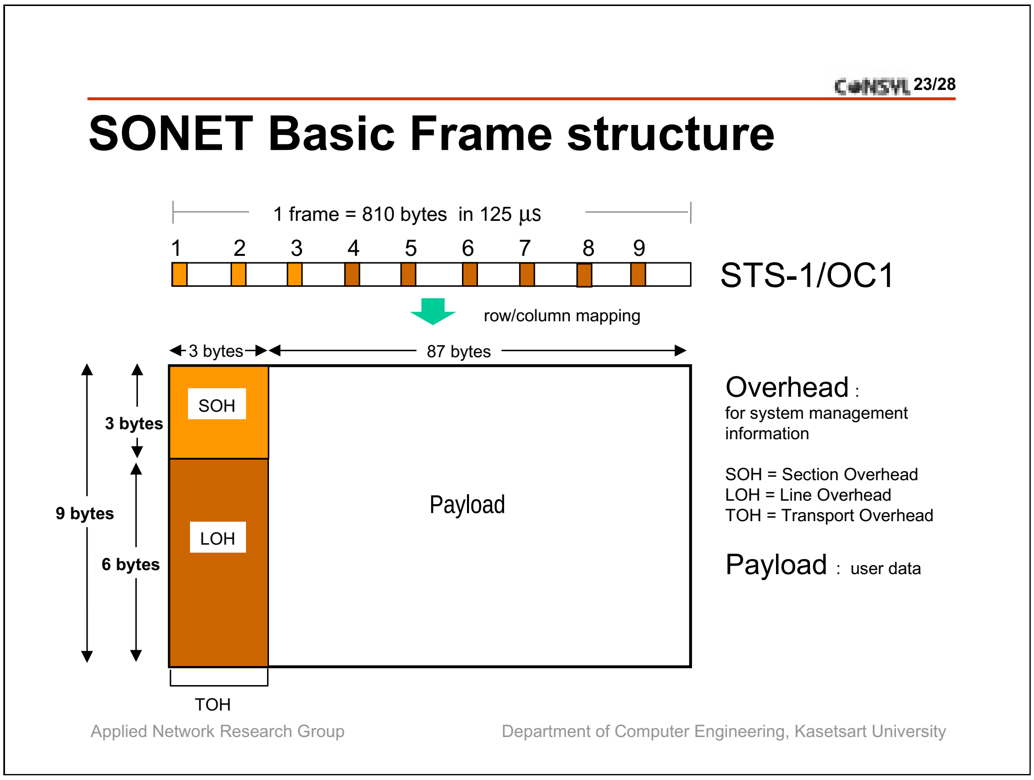
STS is also called *Optical Carrier* (OC) signaling. Optical carrier is used to denote light signaling over fiber rather than electrical signaling over copper.

The STS/OC signaling hierarchy is based on a basic signaling rates of 51.84 Mbps. The higher signaling rate is a multiple of the STS/OC number times the basic rate of 51.84 Mb/s. The STS-3 line rate is three times the line rate of STS-1. There are rates for STS/OC-2,4,5,7,8 etc. within this hierarchy. However, these rates not used.

Note that the basic rate of SDH starts with a signaling rate of 155.52 Mbps called *STM-1* (Synchronous Transport Module) which is equivalent to STS-3/OC-3




A STS-3 frame has 9 column of overhead and 261 bytes of payload, results 270x9= 2430 bytes. The 2430x8 bites are transmitted 8000 times per second, for a gross data rate of 155.52 Mbps.




A SONET frame can be viewd logically as 9 rows of 90 bytes each. Therefore, an STS-1 frame is a unit of 810 bytes of information. SONET frame is transmitted serially bit-by-bit beginning with the first bit of the first byte. Each frame

The 810 bytes frame are best described as a rectangular of bytes, 90 column wide by 9 rows high. Thus 810x8 =6480 bits are transmitted 8000 times per second, for a gross data rate of 51.84 Mbps.

The first three column of each row are reserved for system management information. the first three rows contain *section overhead.* The next six contain the *line overhead.* Section overhead and line overhead are called *transport overhead.*

The remaining 87 column hold 87x9x8x8000 = 50.112 Mbps of user data called *Synchronous Payload Envelope* or *Information Payload* or *Payload.*

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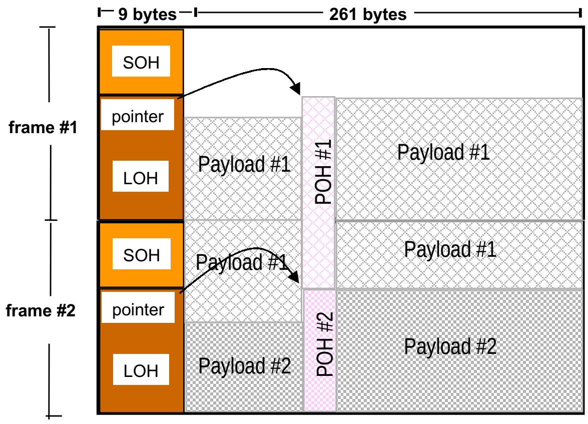
# STM-1 Frame

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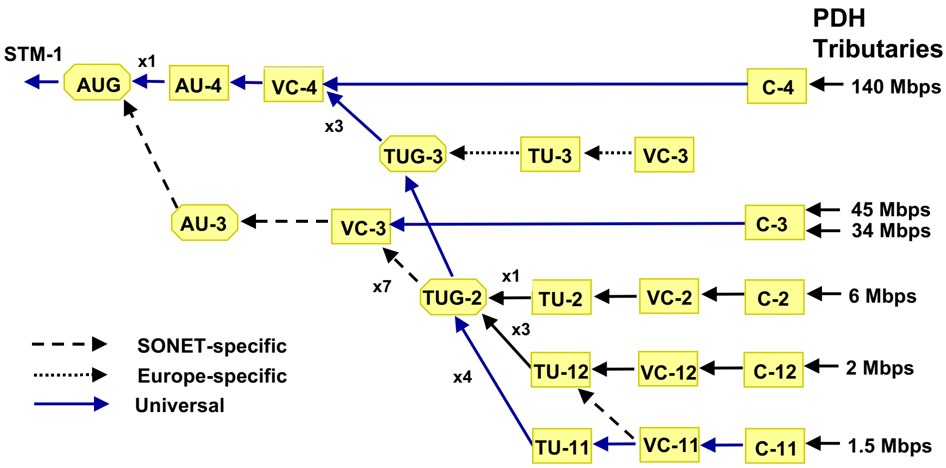
This user data do not always begin at row1 column 4. The SPE can begin everywhere with the frame. The first row of line overhead contain a *pointer* to the first byte of user data. The first column of the SPE is called the *path overhead***.** The pointer mechanism is at the very heart of the SDH standard. This mechanism allow us to easily locate each traffic channel, together with its associated management and control information.

The SPE is allowed to begin anywhere with in SDH frame, and even to span two frames for flexibility. For example, if a payload arrives at the source while a dummy frame is being constructed. It can be inserted into the current frame, instead of being held until the start of the next one. This feature is also useful when the payload does not fit exactly in one frame, as in the case of a sequence of 53-byte ATM cells. The first row of line overhead can point to the start of the first full cell, to provide synchronization.

# SDH mux scheme

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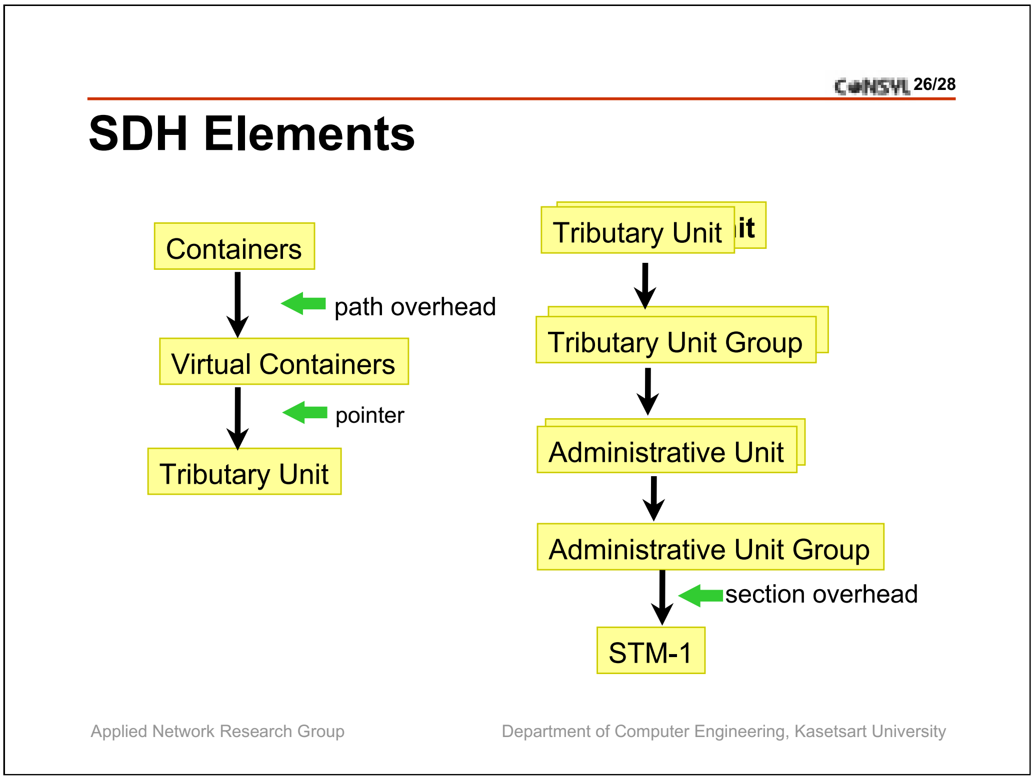
PDH tributaries streams is carried in different containers. Note that the first digit of the lowest level container is a 1 and the second digit indicates whether it contains 1.5 Mbps (C11) or 2 Mbps (C12)




The container and its path overhead collectively forma virtual container (VC). The VCs and its pointer are known as a tributary unit (TU) if the VC carriers a lower-order tributary or a tributary group if it carries a number of lower-order tributaries. The largest VC in an STM-1 frame is known as and administrative unit (AU).

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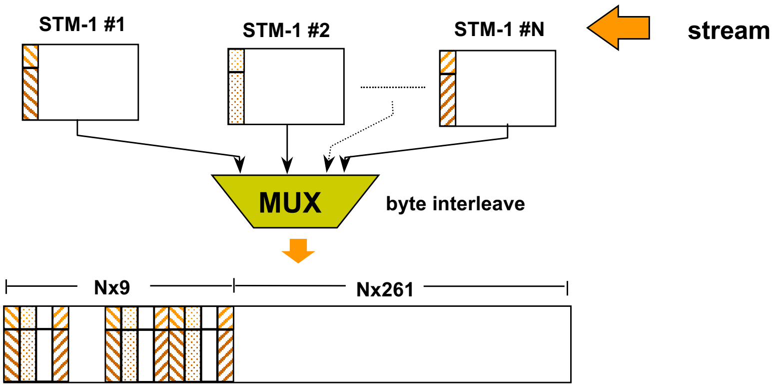
# High order mux

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The multiplexing of multiple data stream, plays an important role in SONET/SDH. Multiplexing is done byte for byte. For example, when three STM-1 are merged into one STM-3 stream at 466.56 Mbps, the multiplexer first outputs 1 byte from tributary 1, then 1 from tributary 2 , and finally from tributary 3, before going back to 1.

# 1xOC3 and 3xoC1

- **OC3 = 3xOC1**
  - a 155.52 Mbps carriers consisting of 3 separated OC3 carriers
- **OC3c = 1X155.52Mbps carriers**
  - a data stream from single source of 155.52 Mbps
- **Higher-order frames also exist (e.g. OC12c).**
- **The amount of actual user data in an OC3c stream is slightly higher than in an OC-3 stream!**



The amount of actual user data in an OC3c stream is slightly higher than in an OC-3 stream (149.760 Mbps and 148.608 Mbps) because the path overhead column is included inside the SPE only once, instead of the three times it would be with the three independent OC-1 streams. In other words 260 columns of the 270 columns are available for user data in OC3c, whereas only 258 columns are available for user data in OC-3.