# L03 - TDM Techniques

## TDM Techniques

Time Division Multiplexing (synchronous, statistical)
Digital Voice Transmission, PDH, SDH

## Agenda

- **Introduction**
- **Synchronous (Deterministic) TDM**
- **Asynchronous (Statistical) TDM**
- **Digital Voice Transmission**
- **PDH**
- **SDH**

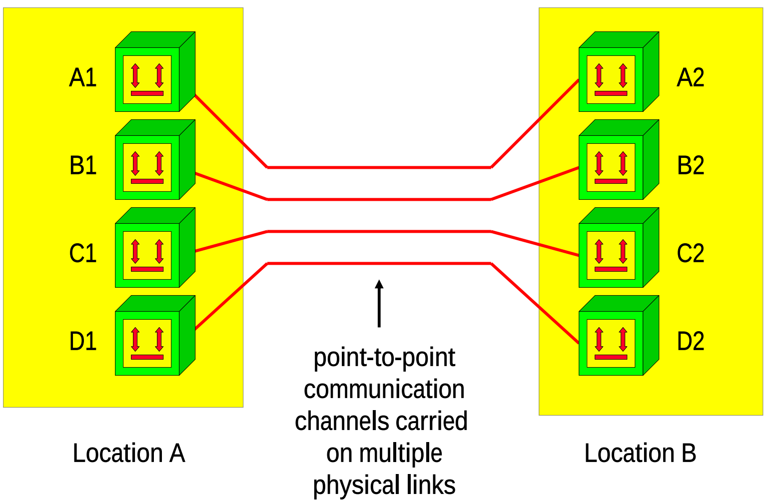
**L03 - TDM Techniques**

## Introduction

- **line protocol techniques (data link procedures)**
  - were developed for communication between two devices on one physical point-to-point link
  - bandwidth of physical link is used exclusively by the two stations
- **in case multiple communication channels are necessary between two locations**
  - multiple physical point-to-point are needed
  - expensive solution
- **in order to use one physical link for multiple channels**
  - multiplexing techniques were developed



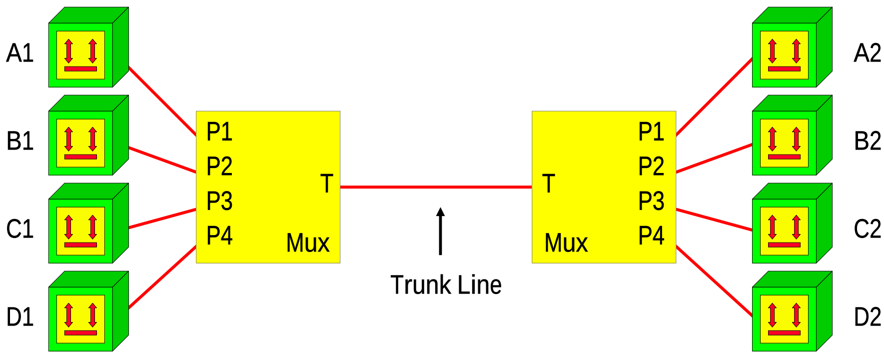
## Point-To-Point Channels



# L03 - TDM Techniques

## Multiplexing / Demultiplexing

- **multiplexer is a device**
  – which can take a number of input channels and, by interleaving them, output them as one datastream on one physical trunk line






## Time Division Multiplexing (TDM)

- **time division multiplexer**
  – allocates each input channel a period of time or timeslot
  – controls bandwidth of trunk line among input channels
- **individual time slots**
  – are assembled into frames to form a single high-speed digital datastream
- **available transmission capacity of the trunk**
  – is time shared between various channels
- **at the destination demultiplexer reconstructs**
  – individual channel data streams

# L03 - TDM Techniques

## Types of TDM

- **depending on timing behavior two methods**
  - synchronous TDM
    - timeslots have constant length (capacity) and can be used in a synchronous, periodical manner
  - asynchronous (statistical) TDM
    - timeslots have variable length and are used on demand (depending on the statistics of channel communication)

## Synchronous TDM Standards

- **TDM framing on the trunk line**
  - can be vendor dependent
    - proprietary TDM products
  - can be standard based
- **two main architectures for standardizing synchronous TDM for trunk lines**
  - **PDH - Plesiochronous Digital Hierarchy**
    - e.g. E1, E3, E4, T1, T3
  - **SDH - Synchronous Digital Hierarchy**
    - e.g. STM-1, STM-4, STM-16

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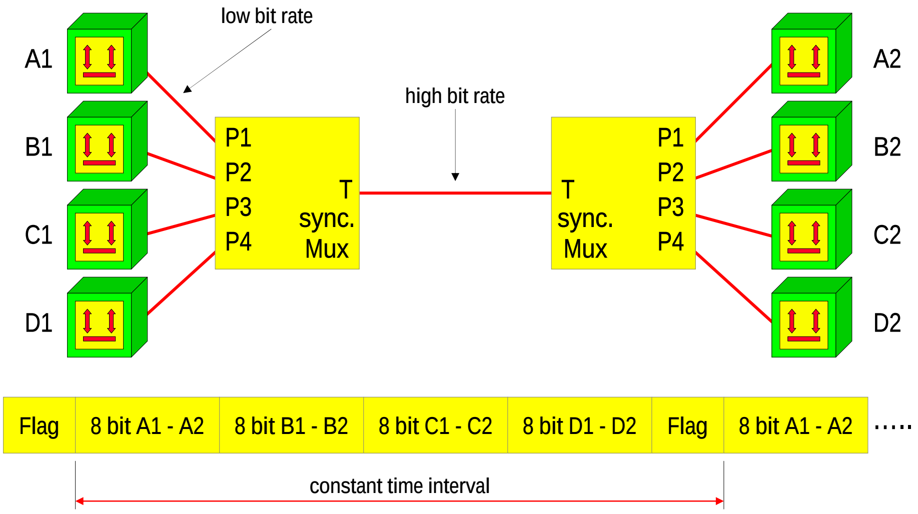
## Synchronous Time Division Multiplexing

- **synchronous TDM**
  - periodically generates a frame consisting of a constant number of timeslots each timeslot of constant length
  - timeslots can be identified by position in the frame
    - timeslot 0, timeslot 1, ....
- **every input channel is assigned**
  - a reserved timeslot
  - e.g. timeslot numbers refer to port numbers of a multiplexer
    - traffic of port P1 in timeslot 1 for A1- A2 channel
    - traffic of port P2 in timeslot 2 for B1- B2 channel
    - ......

# L03 - TDM Techniques

## Synchronous Time Division Multiplexing

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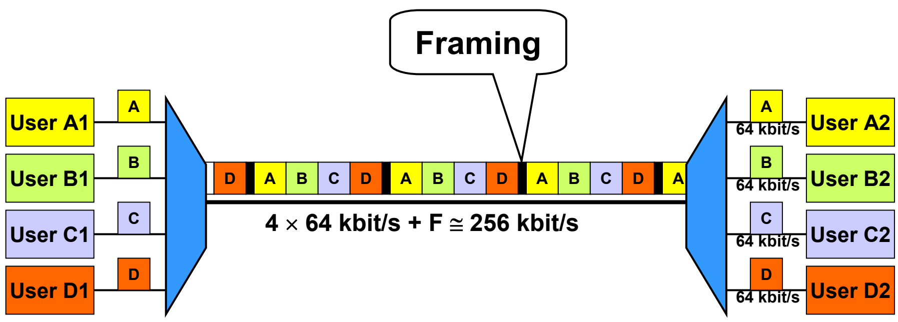
## Trunk Speed with Synchronous TDM




- **Trunk speed = Number of slots × User access rate**
- **Each user gets a constant timeslot of the trunk**

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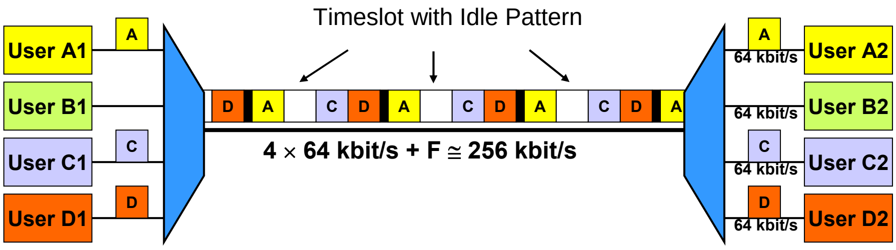
# Idle Timeslots with Synchronous TDM




- **If a communication channel has nothing to transmit**
- **-> Idle timeslots -> Waste of bandwidth**



# Advantages

- **compared to pure point-to-point physical links**
  - synchronous multiplexing adds only minimal delays
    - time necessary to packetize and depacketize
    - transmission/propagation delay on trunk
- **any line protocol could be used between devices**
  - method is protocol-transparent
- **to endsystems**
  - channel looks like a synchronous physical point-to-point line

## Disadvantages

- **bitrate on trunk line T**
  - sum of all port bitrates (P1-P4) plus synchronization (flag)
  - high bitrate is required
  - hence expensive
- **if no data is to be sent on a channel**
  - special idle pattern will be inserted by the multiplexer in that particular timeslot
  - waste of bandwidth of trunk line
- **asynchronous (statistic) time division multiplex avoids both disadvantages**
  - making use of communication statistics between devices

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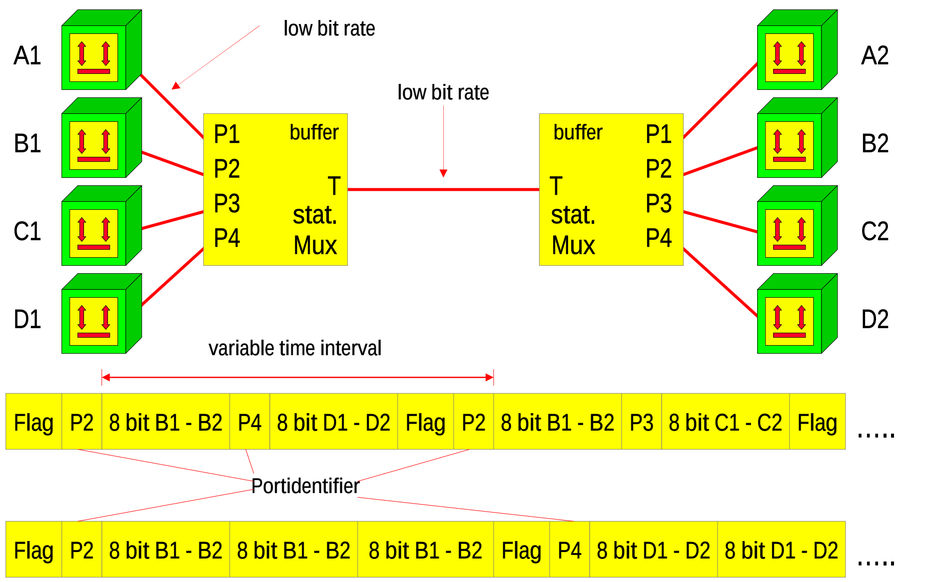
## Asynchronous Time Division Multiplexing

- **usually devices communicate in a statistical manner**
  - not all devices have data to transmit at the same time
- **therefore it is sufficient**
  - to calculate necessary bitrate of the multiplexer trunk line according to the average bitrates caused by device communication
- **if devices transmit simultaneously**
  - only one channel can occupy trunk line
  - data must be buffered inside multiplexer until trunk is available again
  - statistics must guarantee that trunk will not be monopolized by a single channel



## Asynchronous Time Division Multiplexing



## ATDM Operation

- **multiplexer only generates a transmission frame**
  - if data octets are present at input ports
- **source of data**
  - must be explicitly identified in transmission frames
  - addressing
- **reason for addressing**
  - there exists no constant relationship between timeslot and portnumber as with synchronous TDM
- **port identifier**
  - is used as address of source and sent across the trunk

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## ATDM Operation / Facts

- **transmission frame can be assembled using**
  - either a single channel octet by frame
    - suitable for character oriented terminal sessions
  - or multiple channel octets per frame
    - suitable for block oriented computer sessions
- **in case of congestion**
  - buffering causes additional delays compared to synchronous TDM
- **delays are variable because of statistical behavior**
  - hence asynchronous

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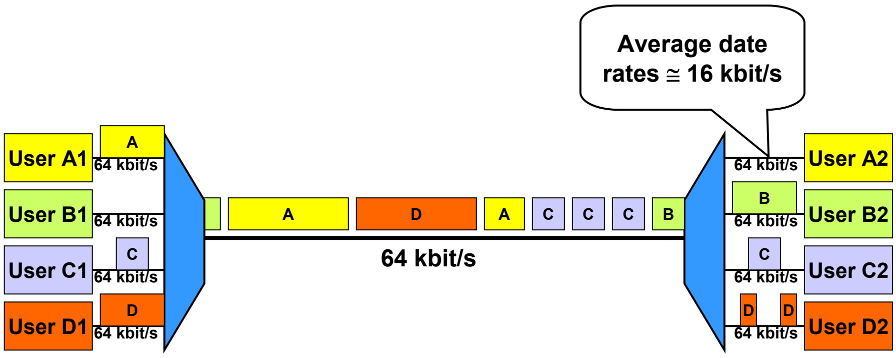
# Asynchronous / Statistical TDM




- Trunk speed dimensioned for average usage
- Each user can send packets whenever he wants
- Buffering necessary if trunk already occupied

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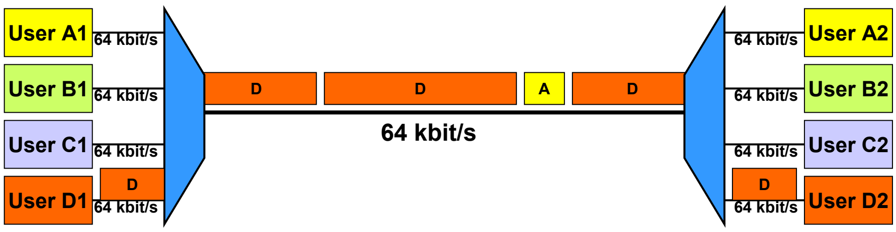
# Asynchronous / Statistical TDM




- If other users are silent, one user can fully utilize his access rate

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## ATDM Facts

- **ATDM can be used protocol transparent**
  - however in case of buffer overflow transmission errors will be seen by devices
    - FCS errors
- **to avoid FCS errors**
  - a kind of flow control between multiplexer and device should be used
  - examples for flow control
    - HW flow control based on handshake signals (e.g. RTS, CTS)
    - SW flow control (e.g. XON/XOFF or connection oriented line protocol with START/STOP flow control e.g. HDLC RNR)



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**L03 - TDM Techniques**

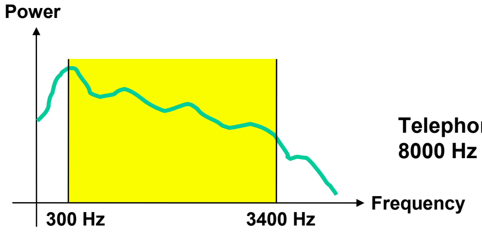
## Voice Transmission

- **digital voice transmission**
  - based on Nyquist´s Theorem
  - analogous voice can be digitized using pulse-code-modulation (PCM) technique requiring a 64kbit/s digital channel
    - voice is sampled every 125usec (8000 times per second)
    - every sample is encoded in 8 bits
  - used nowadays in the backbone of our telephone network
  - today analogous transmission only between home and local office -> so called local loop
- **synchronous TDM**
  - originated from digital voice transmission

## Sampling of Voice

- **Nyquist´s Theorem**
  - any analogue signal with limited bandwidth $f_B$ can be sampled and reconstructed properly when the sampling frequency is $2 \cdot f_B$
  - transmission of sampling pulses allows reconstruction of original analogous signal
  - sampling pulses are quantized resulting in binary code word which is actually transmitted



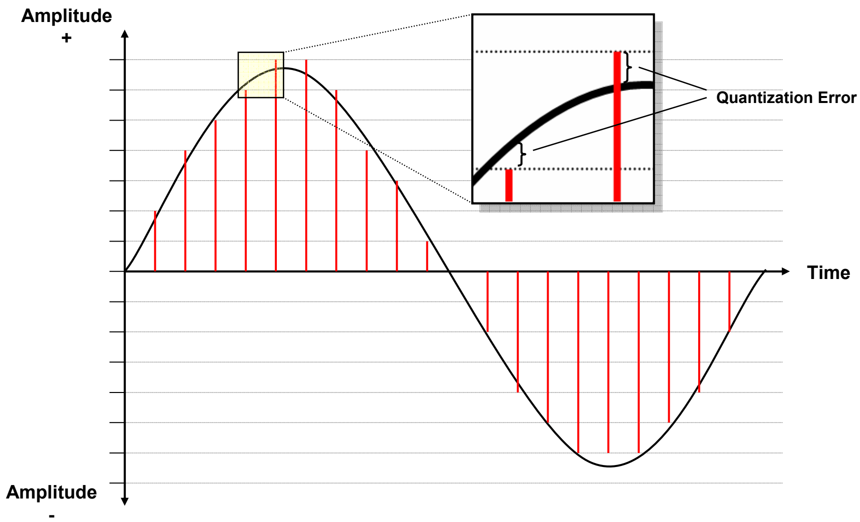

$$R = 2 * B * \log_2 V$$

**Telephone channel: 300-3400 Hz**
**8000 Hz x 8 bit resolution = 64 kbit/s**

# L03 - TDM Techniques

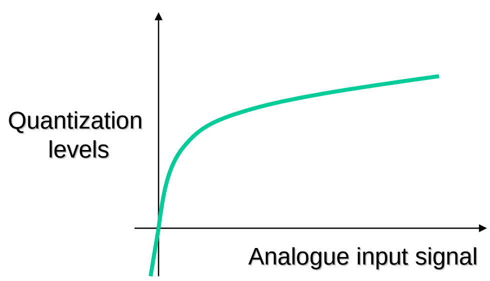
## Linear Quantization





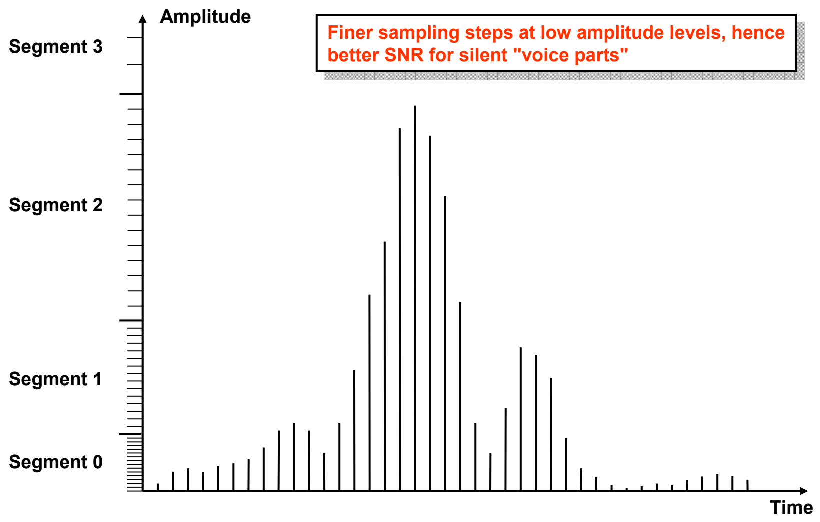

## Improving SNR (Signal Noise Ratio)

- **to improve the SNR of speech signals**
  - lower amplitudes receive a finer resolution than greater amplitudes
- **a nonlinear function (logarithmic) is used for quantization**
  - USA: μ-law (Bell)
  - Europe: A-law (ITU)



# L03 - TDM Techniques

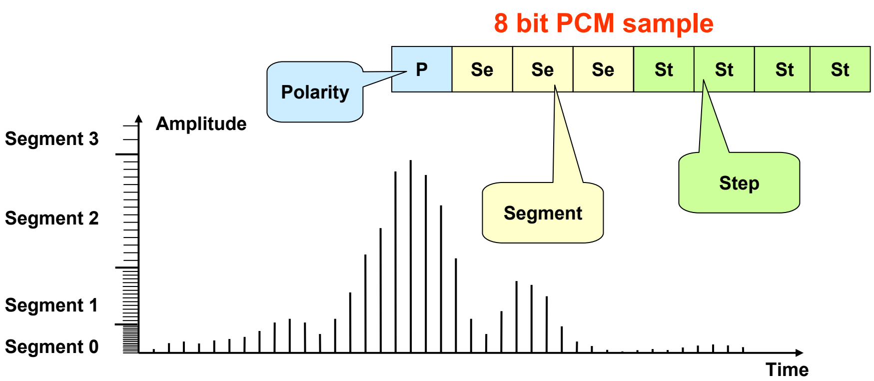
## Log. Quantization






## Encoding (PCM)

- Putting digital values in a defined form for transmission



# L03 - TDM Techniques

## Voice Compression

- **Waveform Coders**
  - Non-linear approximation of analog waveform
  - PCM (no compression), ADPCM
- **Vocoders**
  - speech is analyzed and compared to a codebook
  - only codebook values are transmitted and speed synthesizer at the receiver
- **Hybrid coders**
  - Combination of waveform coders and vocoders
  - 4.8 kbps to 16 kbps
  - Used for mobile phones
  - CELP, GSM



## Standardized Codecs

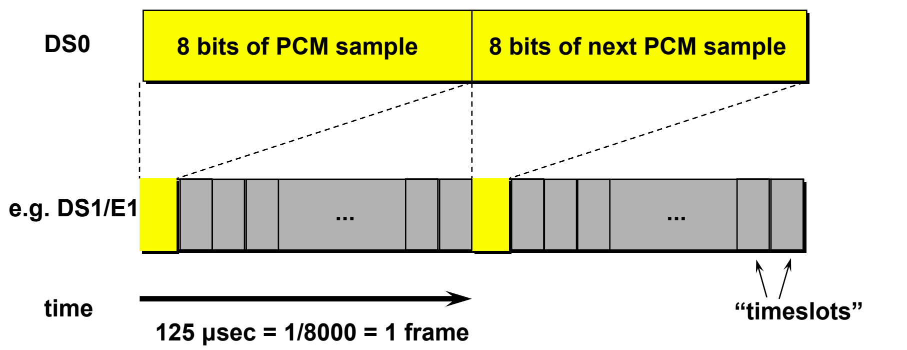
- PCM
  - G.711 (64 kbps)
- Adaptive Differential Pulse Code Modulation (ADPCM)
  - only the difference from one sample pulse to the next will be transmitted
  - fewer bits used for encoding the difference value
  - G.726 (16, 24, 32, 40 kbps)
- Low Delay Code Excited Linear Predictor (LD-CELP)
  - G.728 (16 kbps)
- Conjugate Structure Algebraic Code Excited Linear Predictor (CS-ACELP)
  - G.729 (8 kbps)

## Digital voice channel

- DS0 = Digital Signal, Level 0
  - 1 timeslot in multiplexing frames
- Base for hierarchical digital communication systems
- Equals one PCM coded voice channel
  - 64 kbit/s
- Each samples (byte) must arrive within 125 μs
  - To receive 8000 samples (bytes) per second
  - Higher order frames must ensure the same byte-rate per user(!)



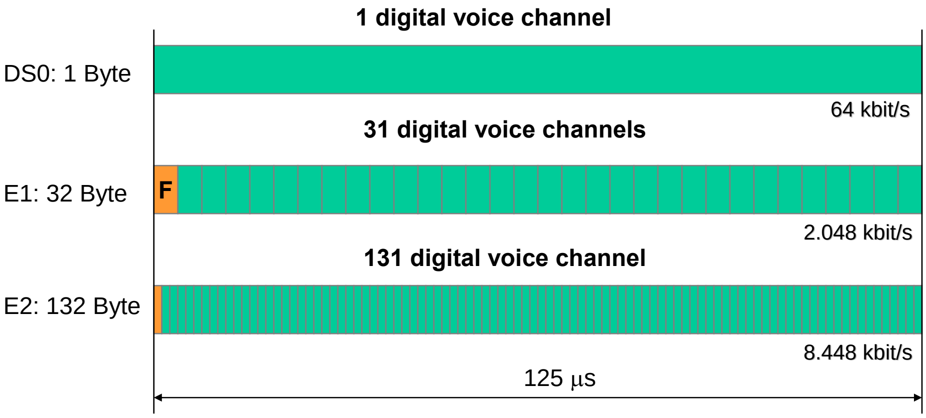
## Multiplexing Basics




- frame rate is always 8000 frame per second at all levels of the hierarchy
- byte interleaved multiplexing

# L03 - TDM Techniques

## Multiplexing Basics




– note: DS0 and higher rates can be used for any transport digital information -> data transmission



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## Multiplexing Hierarchies

- **why hierarchy and standardization?**
  - only a hierarchical digital multiplexing infrastructure which is standardized
    - can connect millions of (low speed) customers across the city/country/world
- **two main architectures**
  - PDH - plesiochronous digital hierarchy
    - plesio means nearly synchronous, clock differences are compensated by bit stuffing techniques / overhead bits
    - PDH is still used for low-speed lines
  - SDH - synchronous digital hierarchy
    - overcomes deficits of PDH
    - in North America SONET is used
    - telecommunication backbones move very quickly to SONET/SDH



## PDH Hierarchy

**North America / ANSI**

| Signal | Carrier | Channels | Mbit/s |
|---|---|---|---|
| DS0 | | 1 | 0.064 |
| DS1 | T1 | 24 | 1.544 |
| DS1C | T1C | 48 | 3.152 |
| DS2 | T2 | 96 | 6.312 |
| DS3 | T3 | 672 | 44.736 |
| DS4 | T4 | 4032 | 274.176 |

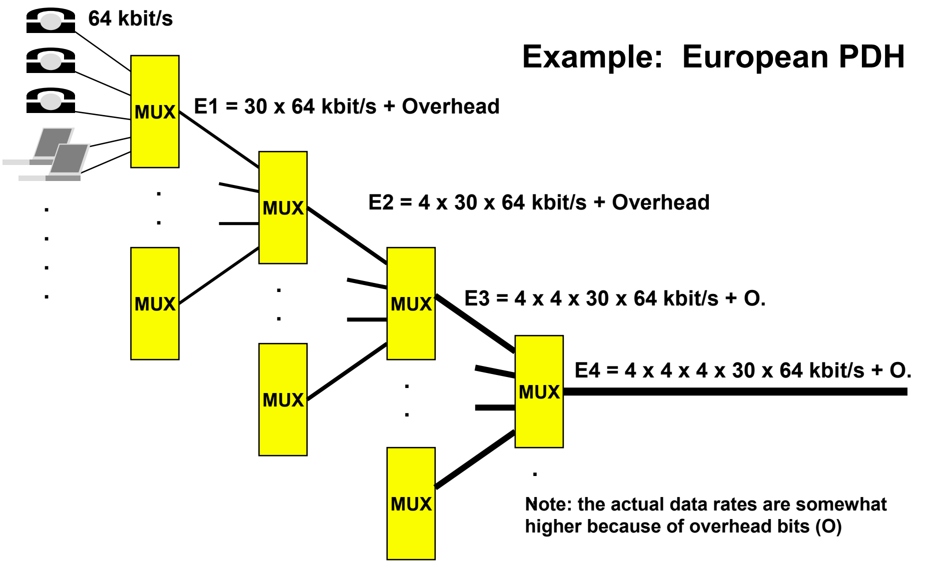
**Europe / ITU**

| Signal | Carrier | Channels | Mbit/s |
|---|---|---|---|
| DS0 | "E0" | 1 | 0.064 |
| CEPT-1 | E1 | 32 | 2.048 |
| CEPT-2 | E2 | 128 | 8.448 |
| CEPT-3 | E3 | 512 | 34.368 |
| CEPT-4 | E4 | 2048 | 139.264 |
| CEPT-5 | E5 | 8192 | 565.148 |

- **Incompatible MUX rates**
- **Different signalling schemes**
- **Different overhead**
- **$\mu$-law versus A-law**

# L03 - TDM Techniques

## Digital Hierarchy of Multiplexers

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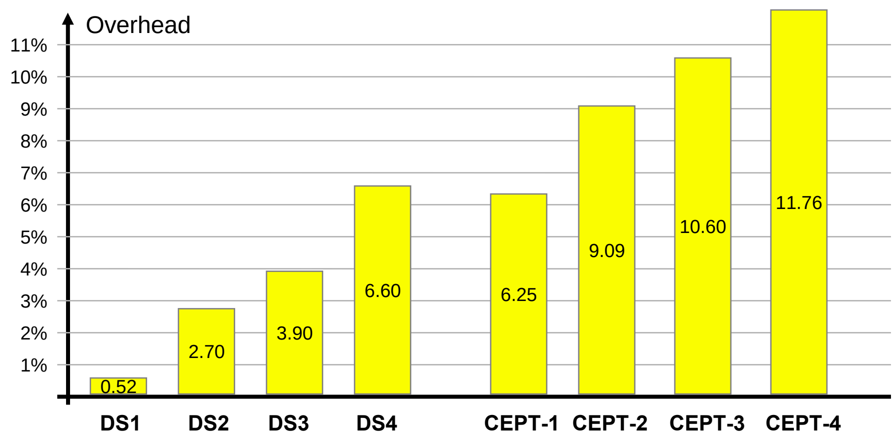
## PDH Limitations

- PDH overhead increases dramatically with high bit rates

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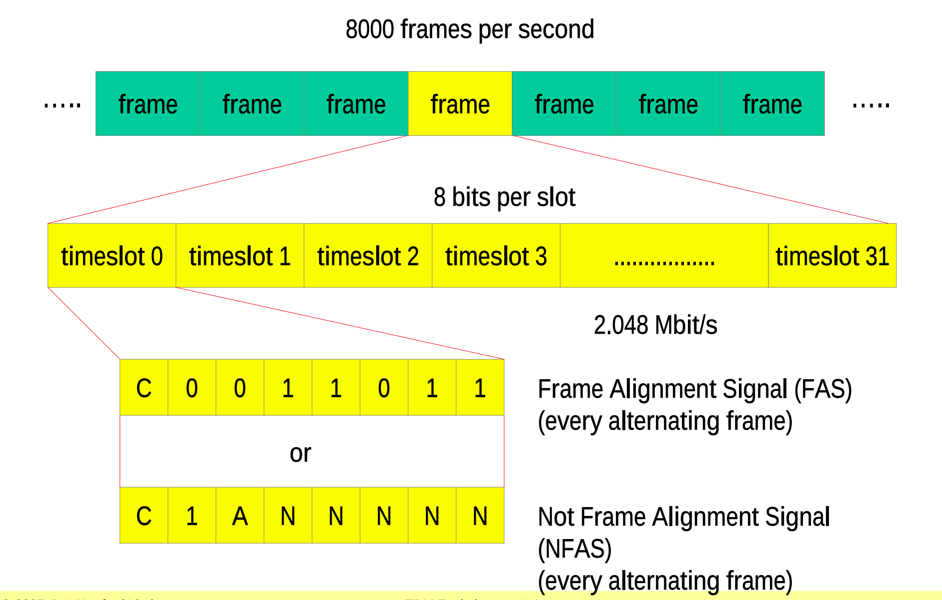
## E1 Frame Structure






## E1 Frame Structure

- **every second frame**
  - timeslot 0 contains FAS used for frame synchronization
- **C (CRC) bit**
  - is part of an optional 4-bit CRC sequence
  - provides frame checking and multiframe synchronization
- **A (Alarm Indication) bit**
  - so called Yellow (remote) alarm
  - used to signal loss of signal (LOS) or out of frame (OOF) condition to the far end
- **N (National) bits**
  - reserved for future use

## CRC Multiframe Structure Timeslot 0

| | timeslot 0 | | timeslot 1 ........... timeslot 31 |
|---|---|---|---|
| frame 0 | C1 | FAS | semimultiframe 1 |
| frame 1 | 0 | NFAS | |
| frame 2 | C2 | FAS | |
| frame 3 | 0 | NFAS | |
| frame 4 | C3 | FAS | |
| frame 5 | 1 | NFAS | |
| frame 6 | C4 | FAS | |
| frame 7 | 0 | NFAS | |
| frame 8 | C1 | FAS | semimultiframe 2 |
| frame 9 | 1 | NFAS | |
| frame 10 | C2 | FAS | |
| frame 11 | 1 | NFAS | |
| frame 12 | C3 | FAS | |
| frame 13 | Si | NFAS | |
| frame 14 | C4 | FAS | |
| frame 15 | Si | NFAS | |

CRC Multiframe Sync - bits: 0 0 1 0 1 1



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## Reasons for SONET/SDH Development

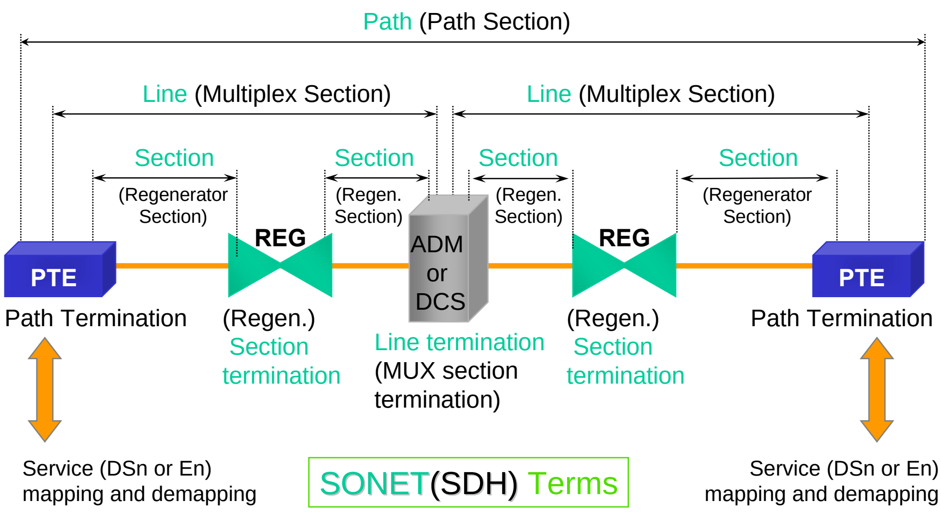
- **Incompatible PDH standards !!!**
- **PDH does not scale to very high bit rates**
  - Increasing overhead
  - Various multiplexing procedures
  - Switching of channels requires demultiplexing first
- **Demand for a true synchronous network**
  - No pulse stuffing between higher MUX levels
  - Phase shifts are compensated by floating payload and pointer technique
- **Demand for add-drop MUXes and ring topologies**



## SDH History

- After divestiture of AT&T
  - Many companies -> many proprietary solutions for PDH successor technology
- In 1984 ECSA (Exchange Carriers Standards Association) started on SONET
  - Goal: one common standard
  - Tuned to carry US PDH payloads
- In 1986 CCITT became interested in SONET
  - Created SDH as a superset
  - Tuned to carry European PDH payloads including E4 (140 Mbit/s)
- SDH is a world standard
  - SONET is subset of SDH
- Originally designed for fiber optics

# Network Structure






# SONET/SDH Line Rates

| SONET Optical Levels | SONET Electrical Level | Line Rates Mbit/s | SDH Levels |
|---|---|---|---|
| OC-1 | STS-1 | 51.84 | STM-0 |
| OC-3 | STS-3 | 155.52 | STM-1 |
| OC-9 | STS-9 | 466.56 | STM-3 |
| OC-12 | STS-12 | 622.08 | STM-4 |
| OC-18 | STS-18 | 933.12 | STM-6 |
| OC-24 | STS-24 | 1244.16 | STM-8 |
| OC-36 | STS-36 | 1866.24 | STM-12 |
| OC-48 | STS-48 | 2488.32 | STM-16 |
| OC-96 | STS-96 | 4976.64 | STM-32 |
| OC-192 | STS-192 | 9953.28 | STM-64 |
| OC-768 | STS-768 | 39813.12 | STM-256 |

**Defined but later removed, and only the multiples by four were left!**

**(Coming soon)**