TDM Techniques

Time Division Multiplexing (synchronous, statistical)

Telco Backbones (Digital Voice Transmission, PDH, SDH)

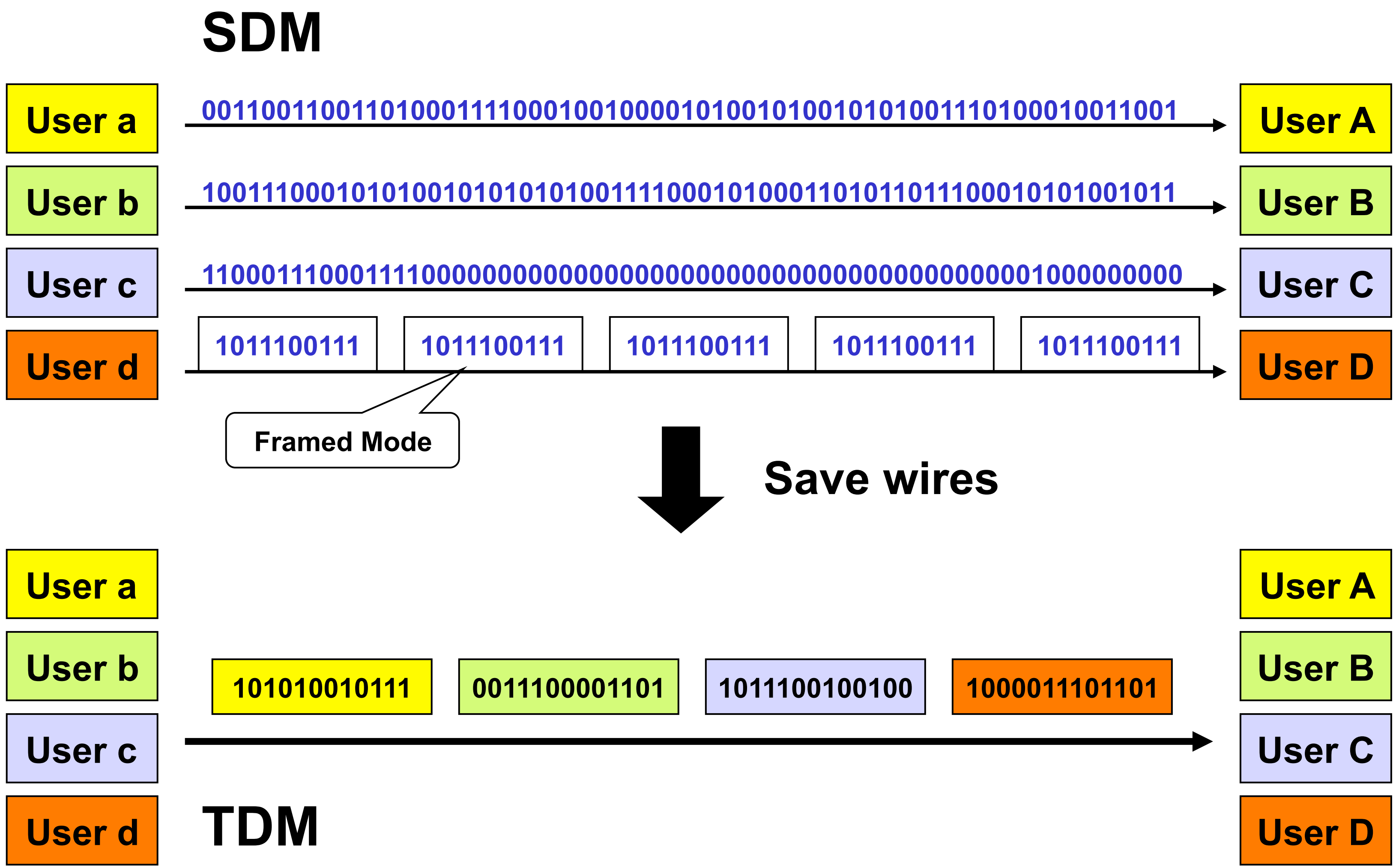
Agenda

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

Introduction

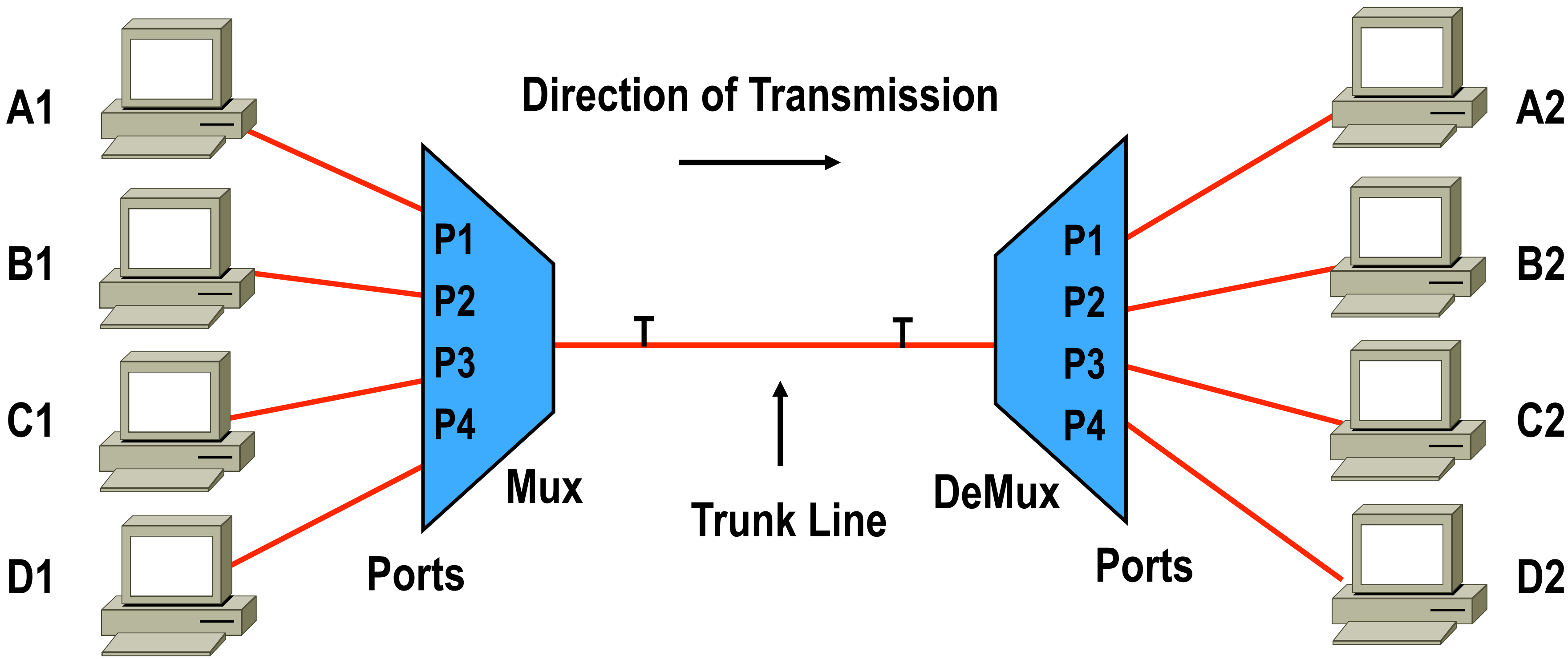
- **Line protocol techniques**
  - Were developed for communication between two devices over one physical point-to-point link
  - Bandwidth of physical link is exclusively used by the two stations
- **In case multiple communication channels are necessary between two locations**
  - Multiple physical point-to-point links are needed
  - Every point-to-point link is operated by line protocol techniques
  - SDM (Space Division Multiplexing)
  - Expensive solution
- **One method to use one physical link for multiple channels is**
  - TDM (Time Division Multiplexing)
  - Note: FDM, DWDM, CDM are other methods

TDM versus SDM



TDM Multiplexing / Demultiplexing

- **TDM multiplexer**
  - Take a number of input channels and - by interleaving them - output them as one data stream on one physical **trunk** line
  - Demultiplexer does the opposite



Types of TDM

- **Depending on timing behavior two basic TDM methods**
  - Synchronous (deterministic) TDM
    - Timeslots have constant length (capacity) and can be used in a synchronous, periodical manner
    - Examples: PDH (E1, T1), SDH (STM-1, STM-4), ISDN
  - Asynchronous (statistical) TDM
    - Timeslots have variable length and are used on demand (depending on the statistics of the individual channel communication)
    - Examples: X.25, Frame-Relay, ATM, IP, Ethernet, WLAN …

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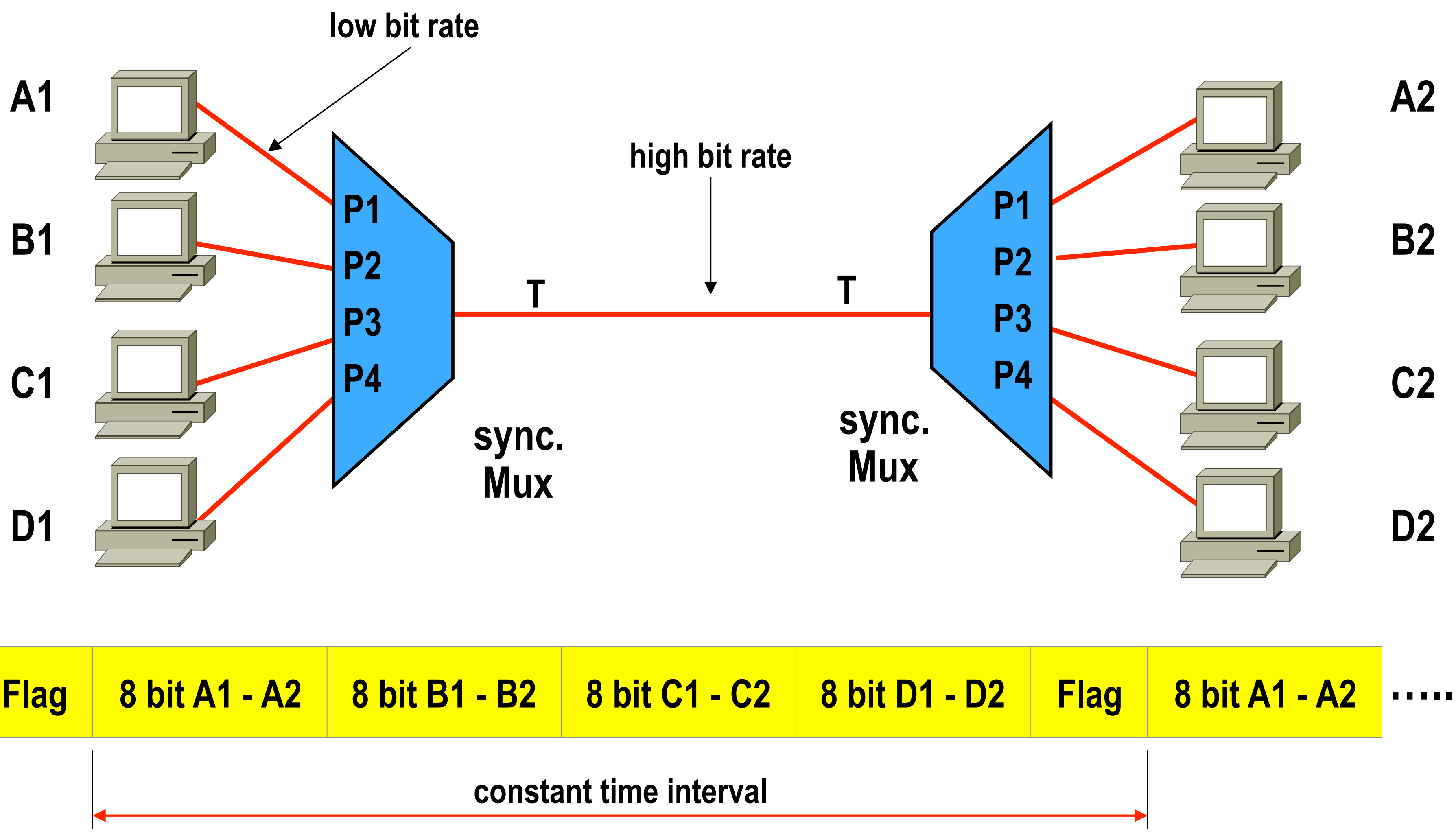
Synchronous (Deterministic) TDM

Implicit addressing given by the position of a timeslot in the frame



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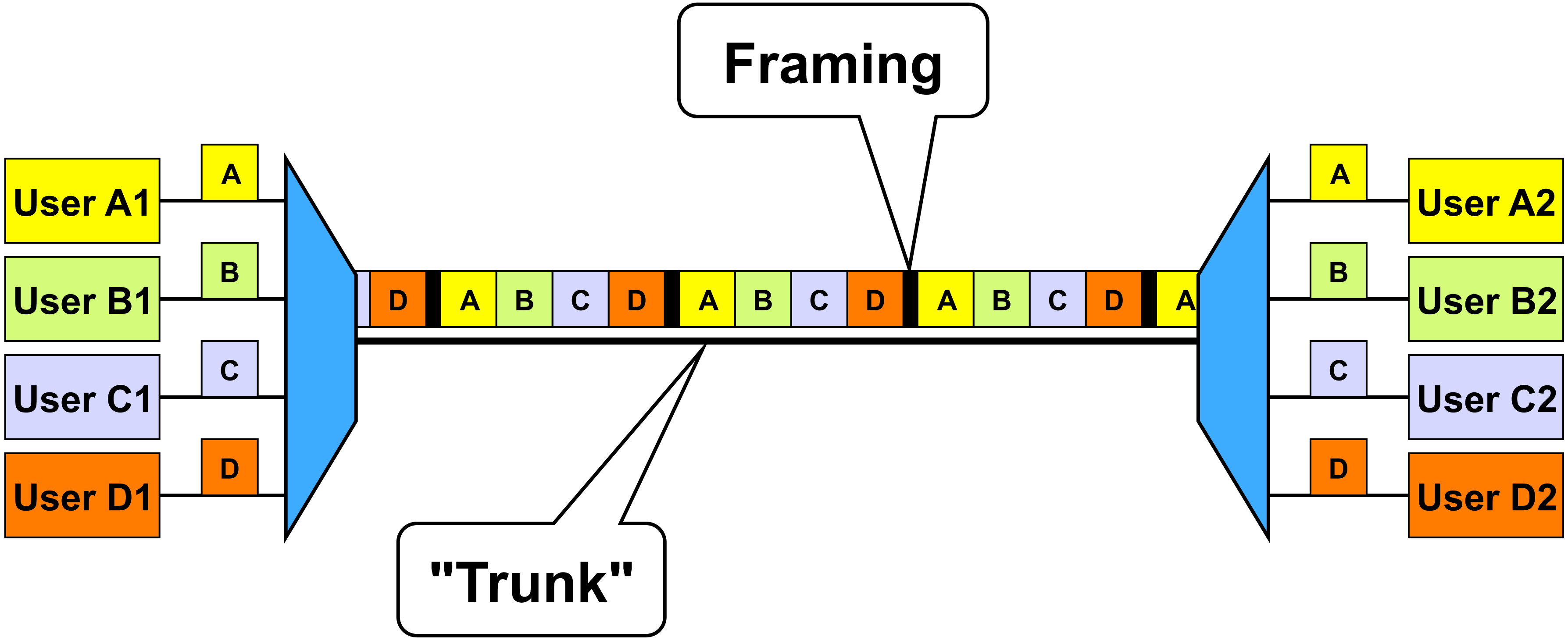
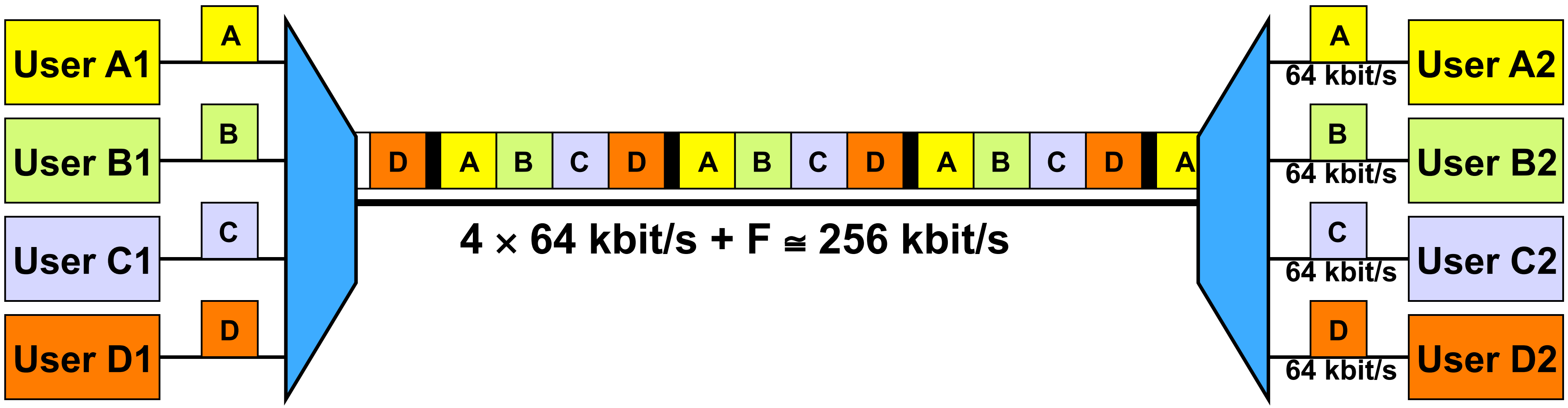
Synchronous (Deterministic) TDM

Implicit addressing given by the position of a timeslot in the frame

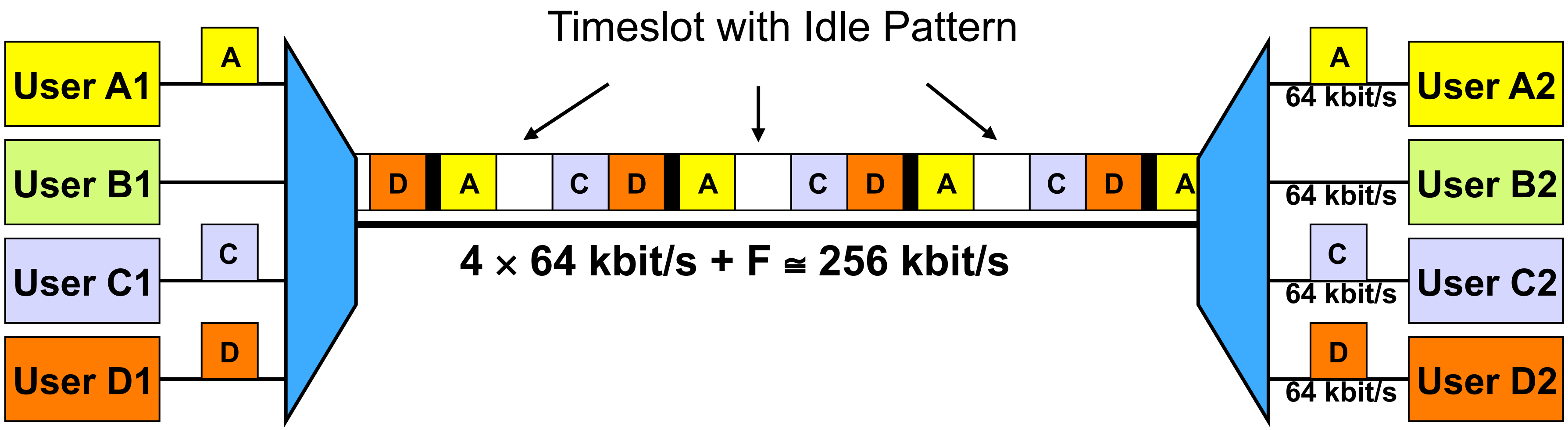


Trunk Speed with Synchronous TDM



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

Idle Timeslots with Synchronous TDM



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

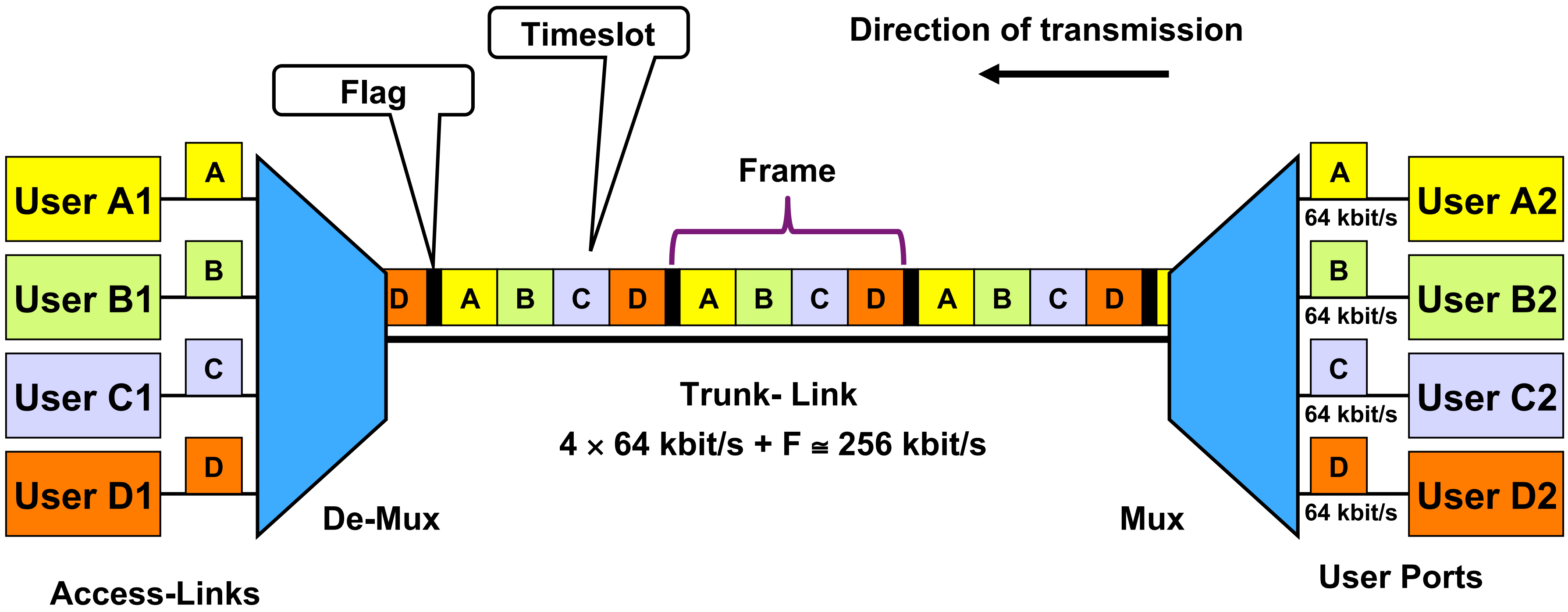
Deterministic TDM - Advantages

- **Compared to pure point-to-point physical links**
  - Synchronous multiplexing adds only minimal delays
    - Time necessary to packetize and depacketize a byte
    - Transmission/propagation delay on trunk
- **The end-to-end delay for transporting a byte is constant**
- **The time between two bytes to be transported is constant**
  - Hence optimal for isochronous transmission requirements like traditional digital voice
- **Any line protocol could be used between devices**
  - Method is protocol-transparent
- **To endsystems**
  - Channel looks like a single physical point-to-point line

Deterministic TDM - Disadvantages

- **Bitrate on trunk line T**
  - Sum of all port bitrates (P1-P4) plus frame 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) TDM avoids both disadvantages by**
  - Making use of communication statistics between devices

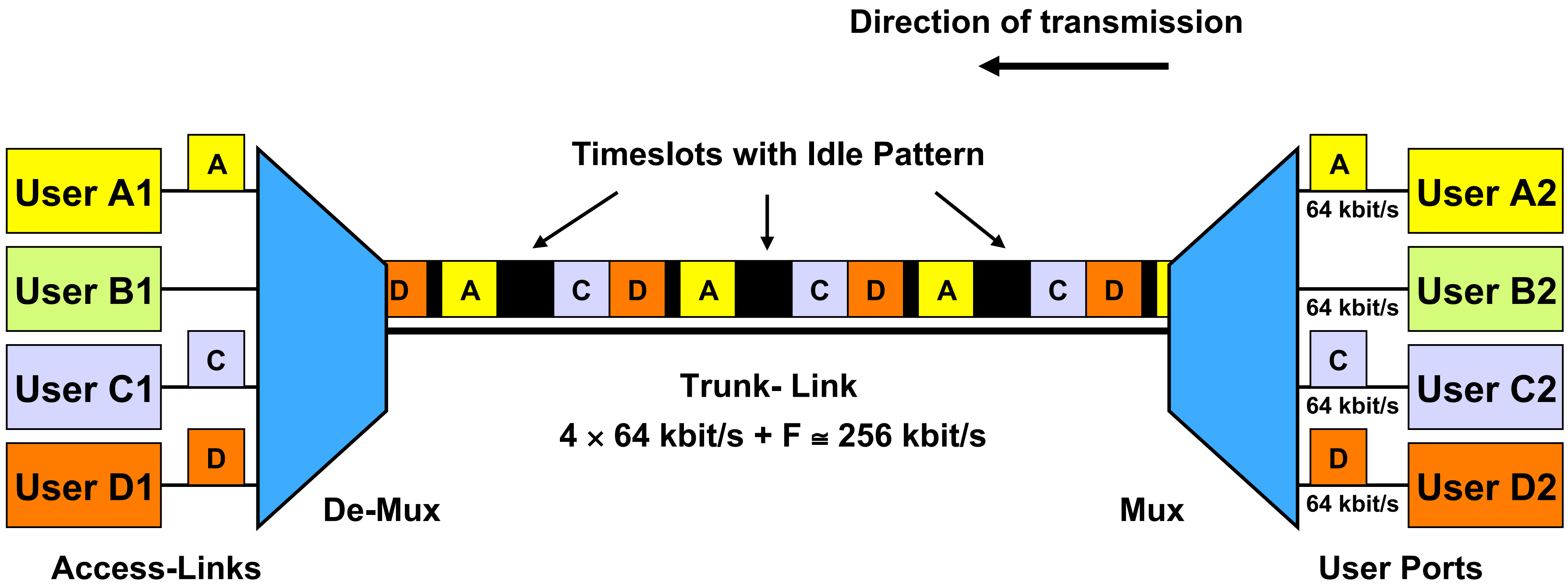
Summary: Synchronous TDM (1)



- Periodic frames consisting of a constant number of timeslots
- Every channel occupies a dedicated timeslot
- Implicit addressing given by the position of a timeslot in the frame
- Trunk rate = number of timeslots x access-link rate

<u>Each channel experiences constant delay and no delay variation (jitter)</u>

Summary: Synchronous TDM (2)



Timeslot can be used for any kind of communication
-> protocol transparency
But empty timeslots are not useable by other communication channels
-> waste of bandwidth during times of inactivity

<u>Lead to development of asynchronous/statistical multiplexing</u>

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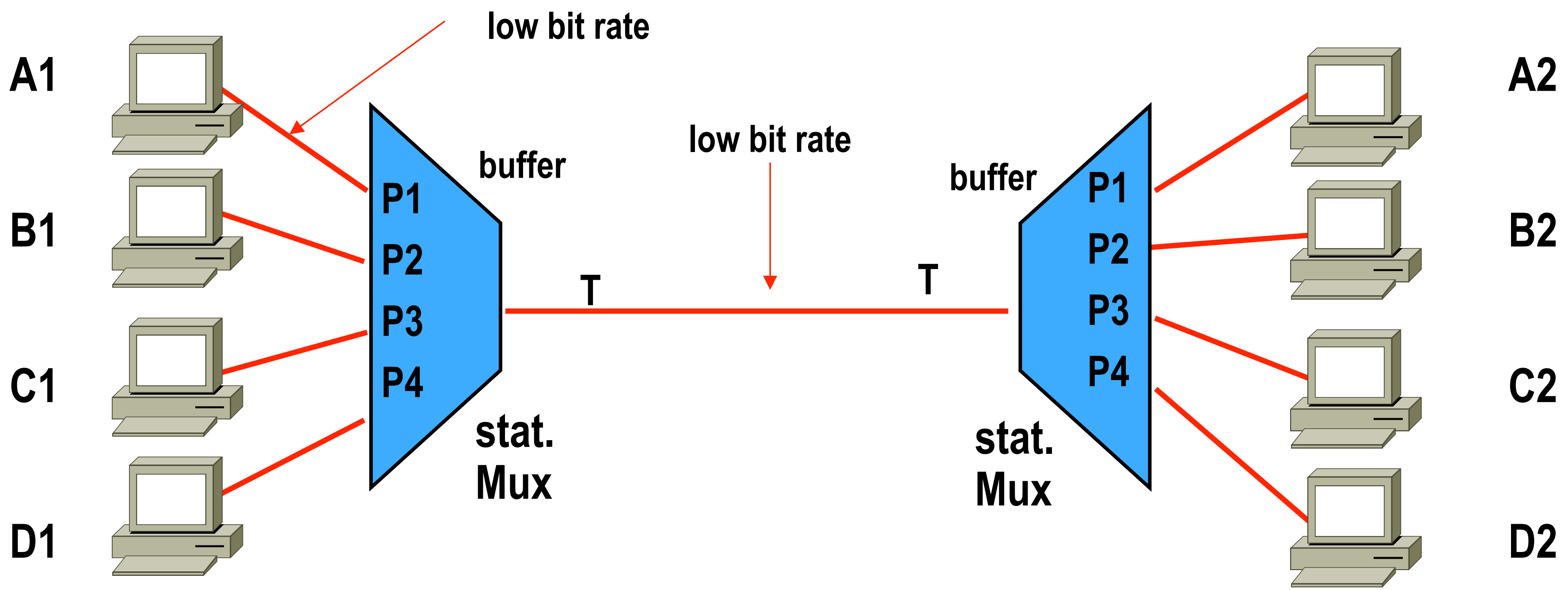
Asynchronous (Statistical) TDM



Variable time interval for a byte B1 –> B2

Method 1: Terminal Session

Flag	P2	8 bit B1 - B2	P4	8 bit D1 - D2	Flag	P2	8 bit B1 - B2	P3	8 bit C1 - C2	Flag	…..

Px = Port identifier – Address information !!!

Method 2: Computer Session

Flag	P2	8 bit B1 - B2	8 bit B1 - B2	8 bit B1 - B2	Flag	P4	8 bit D1 - D2	8 bit D1 - D2	…..

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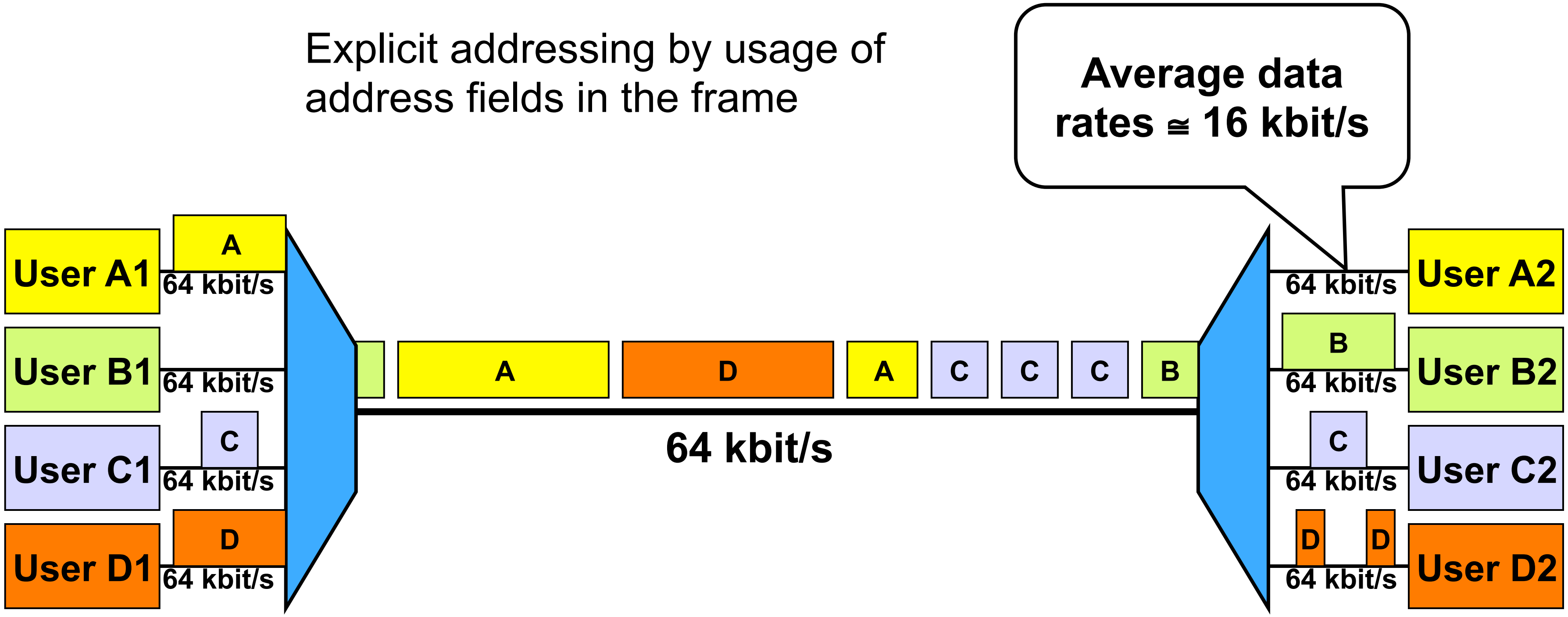
Asynchronous (Statistical) TDM

Method 2: Computer Session

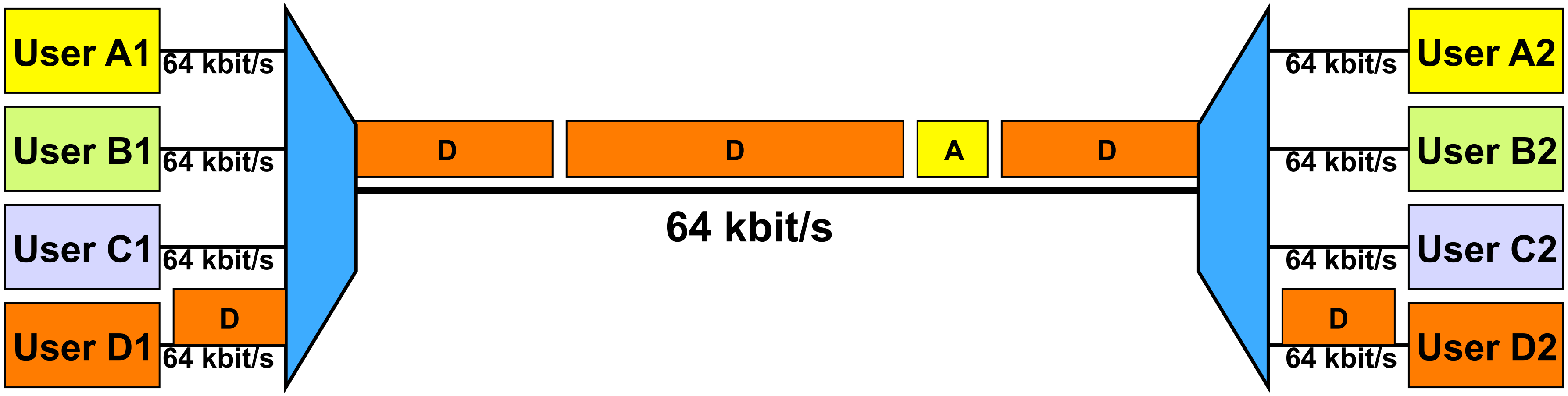
Explicit addressing by usage of address fields in the frame



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

Asynchronous (Statistical) TDM

Method 2: Computer Session



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

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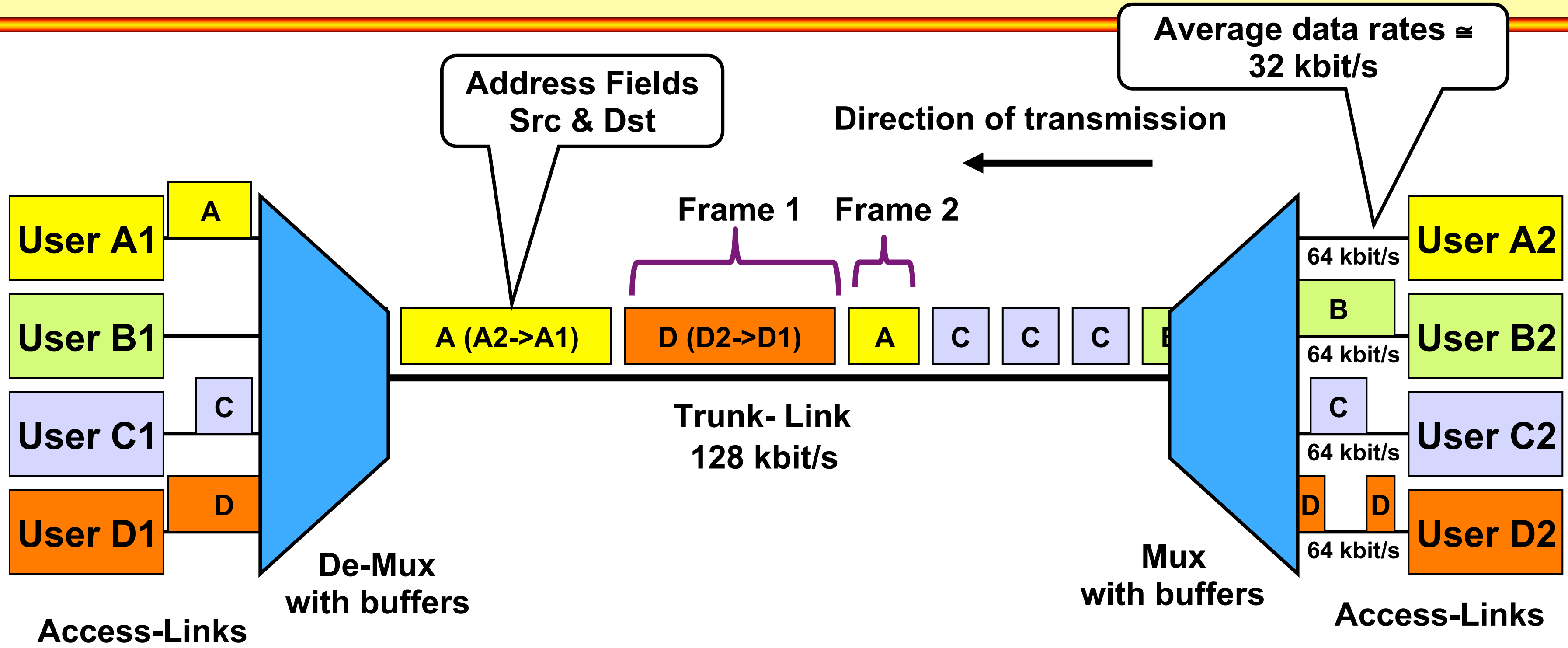
Asynchronous (Statistical) TDM Facts

- **Good utilization of trunk**
  - Statistically dimensioned
- **Frames can have different size**
- **Multiplexers require buffers**
- **Variable delays**
- **Address information required**
- **Usually not protocol transparent**
  - If protocol transparent buffer overflow would cause FCS error handled by the overlaying line protocol
  - Better to speak a protocol with flow control abilities between end system and multiplexer
    - That is a new element in our story
    - Until now flow control only end-to-end explained

Summary: Asynchronous TDM (1)



- Trunk rate is dimensioned for average usage in statistical manner
- Each user channels can send packets whenever he/she wants
- Frames have different lengths
- Buffering is necessary if trunk is already occupied by another channel
- Explicit addressing by usage of address fields in the frame
- Not protocol-transparent any more

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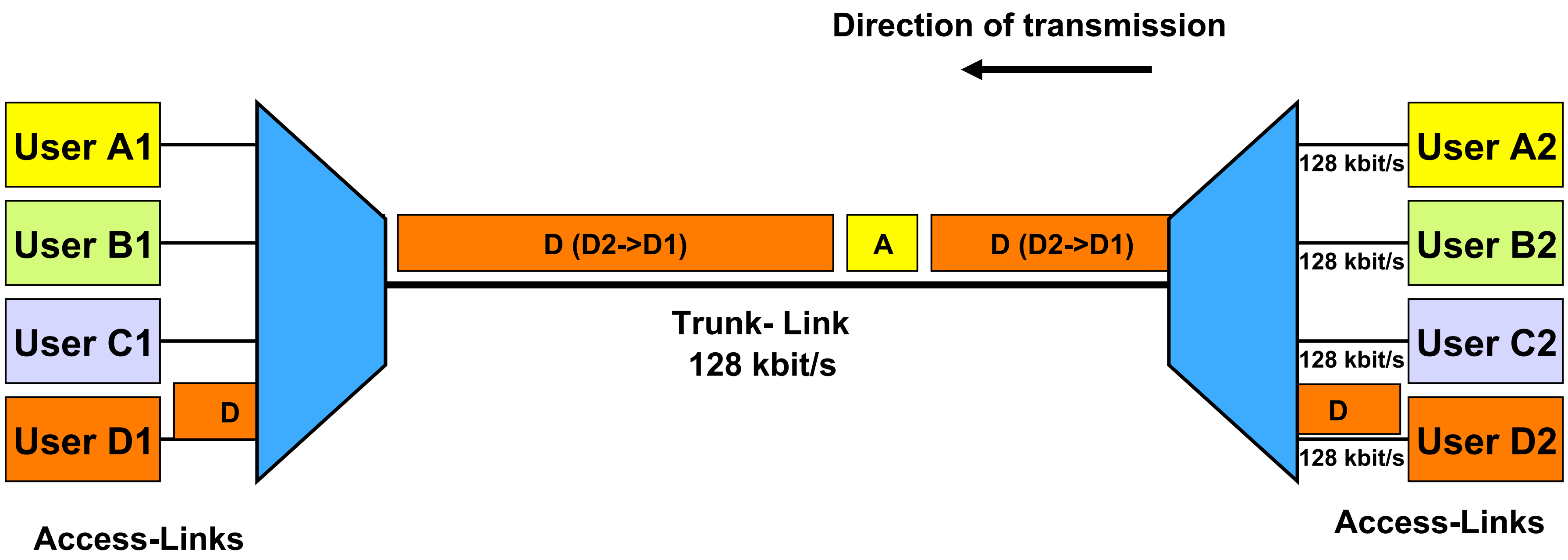
Summary: Asynchronous TDM (2)



If other channels are silent, one channel can fully utilize his/her access rate -> better usage of network bandwidth

Variable delay and variable delay variation (jitter)
Buffer overflow leads to loss of packets

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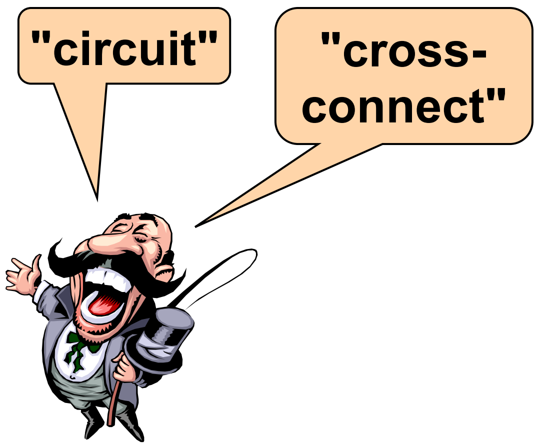
Telco Long History

- **Origins in late 19th century**
  - Voice was/is the yardstick
    - Same terms
    - Same signaling principles
    - Even today, although data traffic increases dramatically
    - Led to technological constraints and demands
- **General Goals**
  - Interoperability
    - Over decades
    - Over different vendors
    - World-wide!
  - Availability
    - Protection lines in case of failures
    - High non-blocking probability

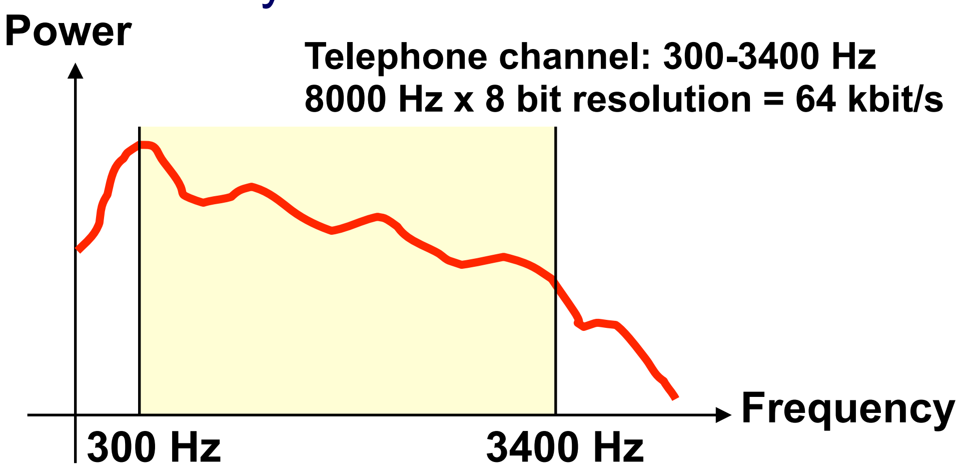


Digital Voice – Synchronous TDM

- **Digital voice transmission**
  - Based on Nyquist-Shannon 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 up to now in the backbone of our telephone network
- **Synchronous TDM**
  - Originated from digital voice transmission by multiplexing of several 64kbit/s voice channels over a common trunk line

Sampling of Voice

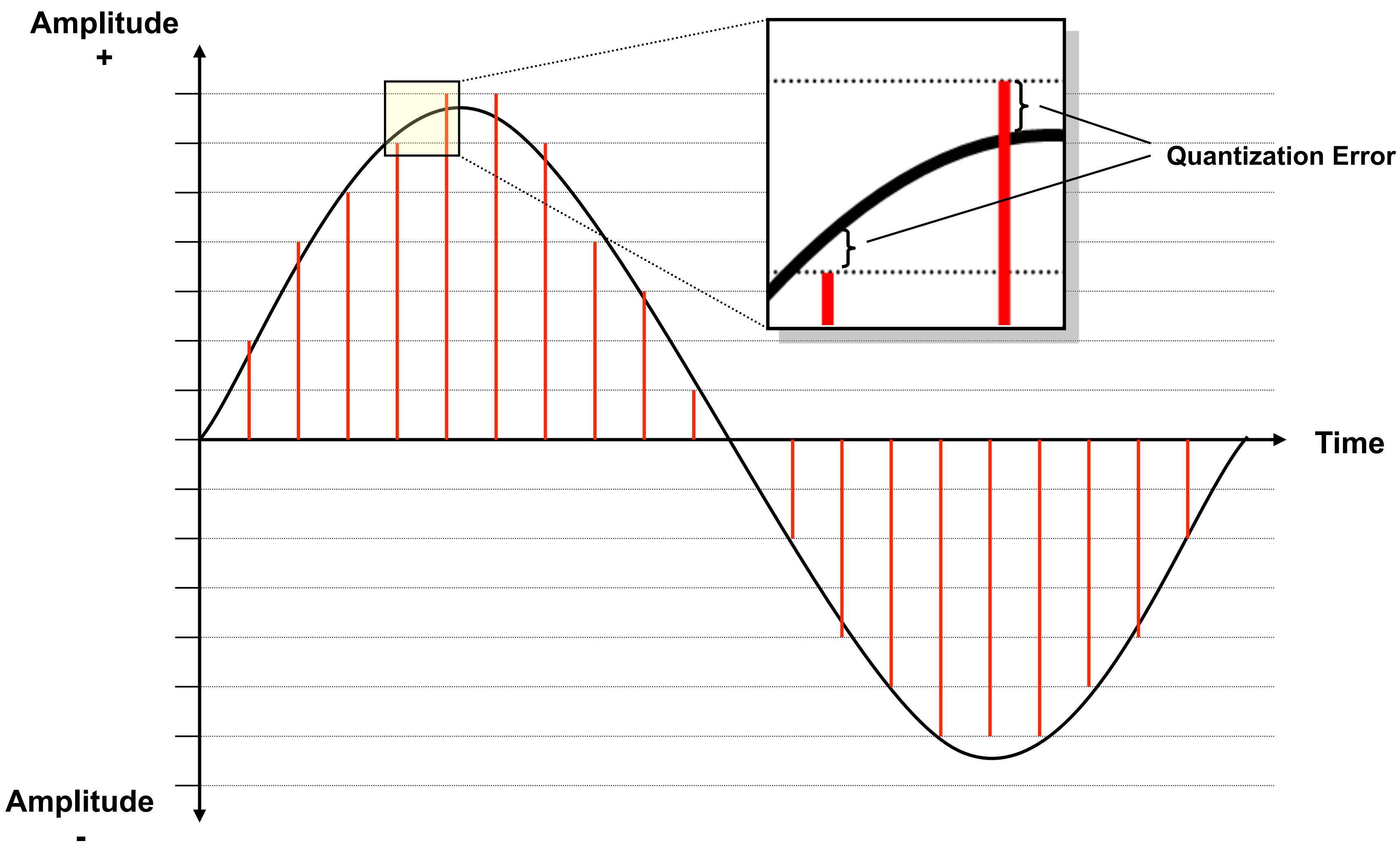
- **Nyquist - Shannon Theorem**
  - Any analogue signal with limited bandwidth f_B can be sampled and reconstructed properly when the sampling frequency is $2 \cdot f_B$
  - Speech signal has most of its power and information between 0 and 4000 Hz
  - Transmission of sampling pulses allows reconstruction of original analogous signal
  - Sampling pulses are quantized resulting in binary code word which is actually transmitted



Compare it to the formula giving the maximum information-rate of a noiseless but bandwidth-limited line

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

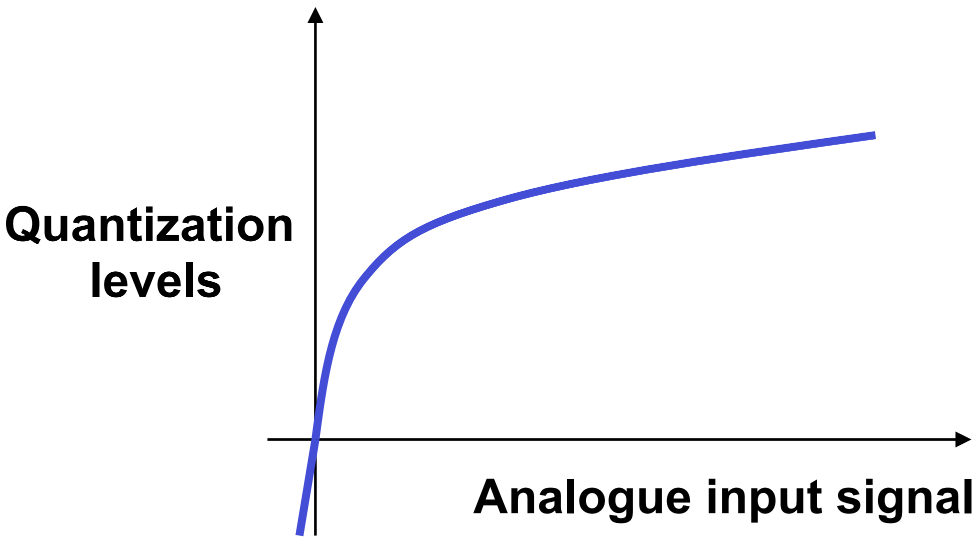
Linear Quantization



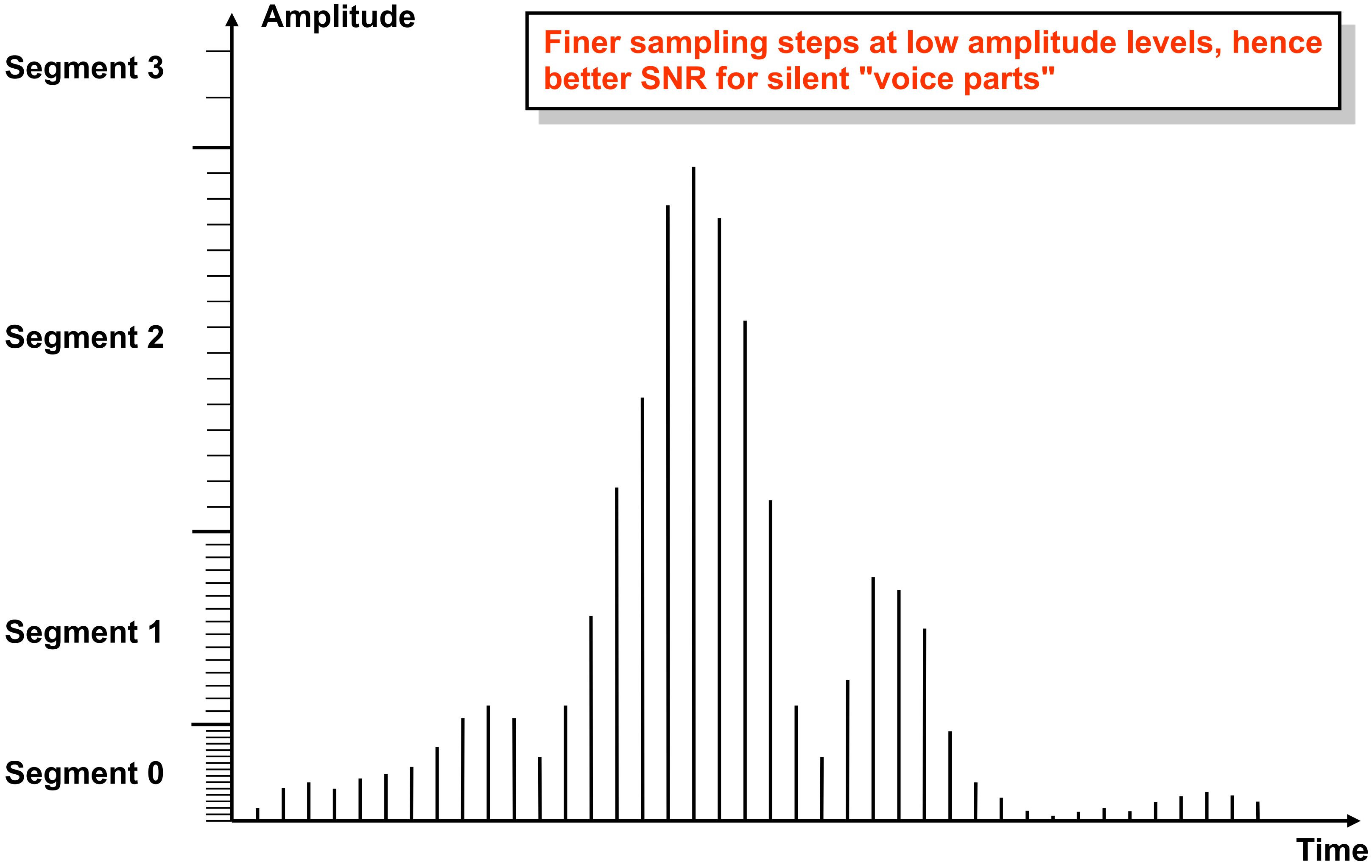
Improving SNR

- **SNR improvement of speech signals**
  - Quantize loud signals much coarser than quiet signals
  - Lower amplitudes receive a finer resolution than greater amplitudes
- **Expansion and compression specified by nonlinear function**
  - USA: μ-law (Bell)
  - Europe: A-law (CCITT)

Conversion is task of the μ-law world



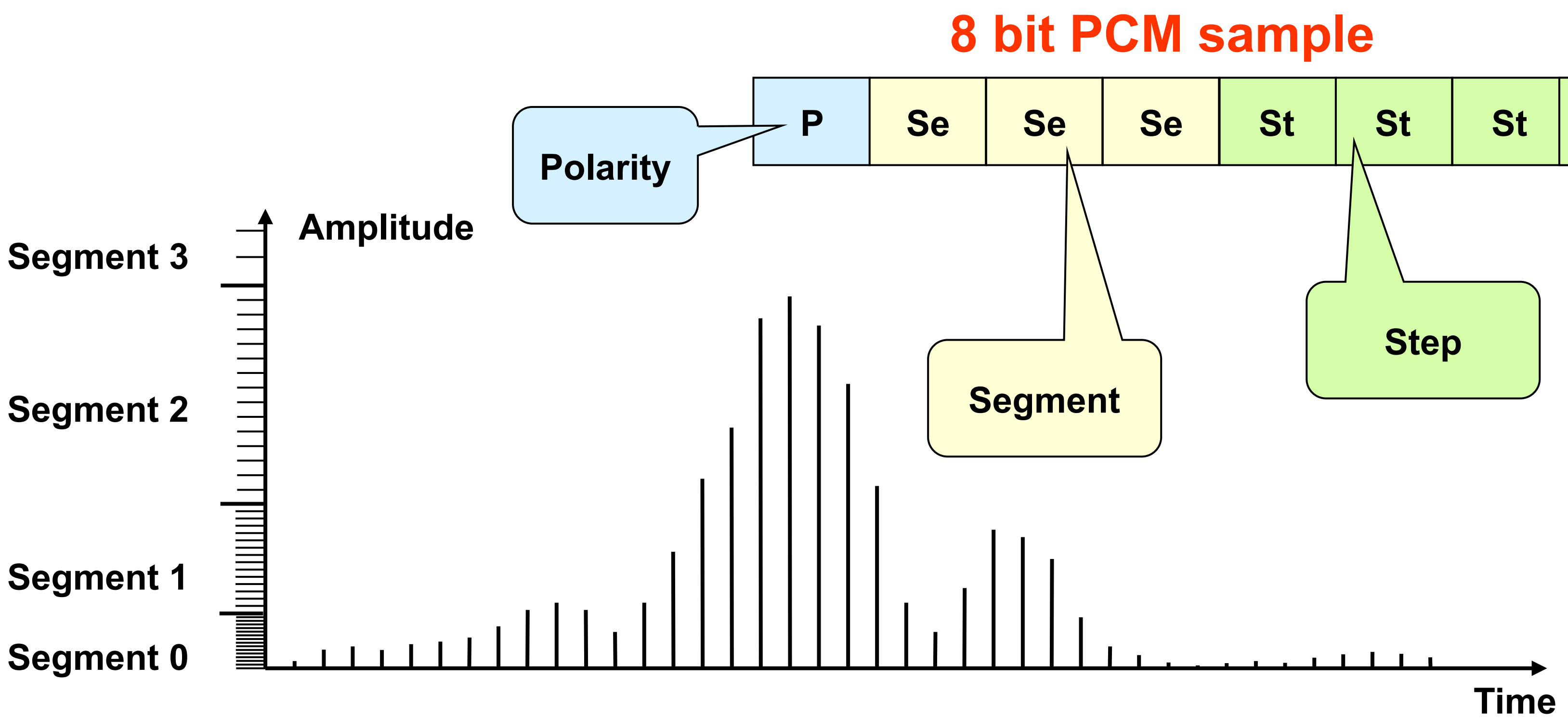
Log. Quantization



Finer sampling steps at low amplitude levels, hence better SNR for silent "voice parts"

Encoding (PCM)

- **Putting digital values in a defined form for transmission**



Codec Standards

- PCM
  - G.711 (64 kbps)
- ADPCM (Adaptive Differential Pulse Code Modulation)
  - 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)
- LD-CELP (Low Delay Code Excited Linear Predictor)
  - G.728 (16 kbps)
- CS-ACELP (Conjugate Structure Algebraic CELP)
  - G.729 (8 kbps)
- Dual Rate Speech Coding Standard (G.723)
  - Uses minimal data rate of 5,3K (ACELP) at fair quality or 6,3K (MP-MPLQ) with good quality
- All above standards are used for VoIP
  - Voice transmission over IP networks
- GSM uses LCP (Linear Predictive Encoding)
  - 6,5 – 13 kbps

Isochronous Traffic vs. Realtime Traffic

- **Isochronous Traffic**
  - Data rate end-to-end must be constant
  - Delay variation (jitter) is critical
    - To enable echo suppression
    - To reconstruct sampled analog signals without otherwise distortion
- **Realtime Traffic**
  - Requires guaranteed bounded delay "only"
  - Example:
    - Telephony (< 1s RTT)
    - Interactive traffic (remote operations)
    - Remote control
    - Telemetry

Solutions

- **Isochronous network**
  - Common clock for all components
  - Aka "Synchronous" network
- **Plesiochronous network**
  - With end-to-end synchronization somehow
- **Totally asynchronous network**
  - Using buffers (playback) and QoS techniques

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Plesiochronous Digital Hierarchy

- **Created in the 1960s as successor of analog telephony infrastructure**
- **Smooth migration**
  - Adaptation of analog signaling methods
- **Based on Synchronous TDM**
- **Still important today**
  - Telephony access level
  - ISDN PRI
  - Leased line

Why Plesiochronous?

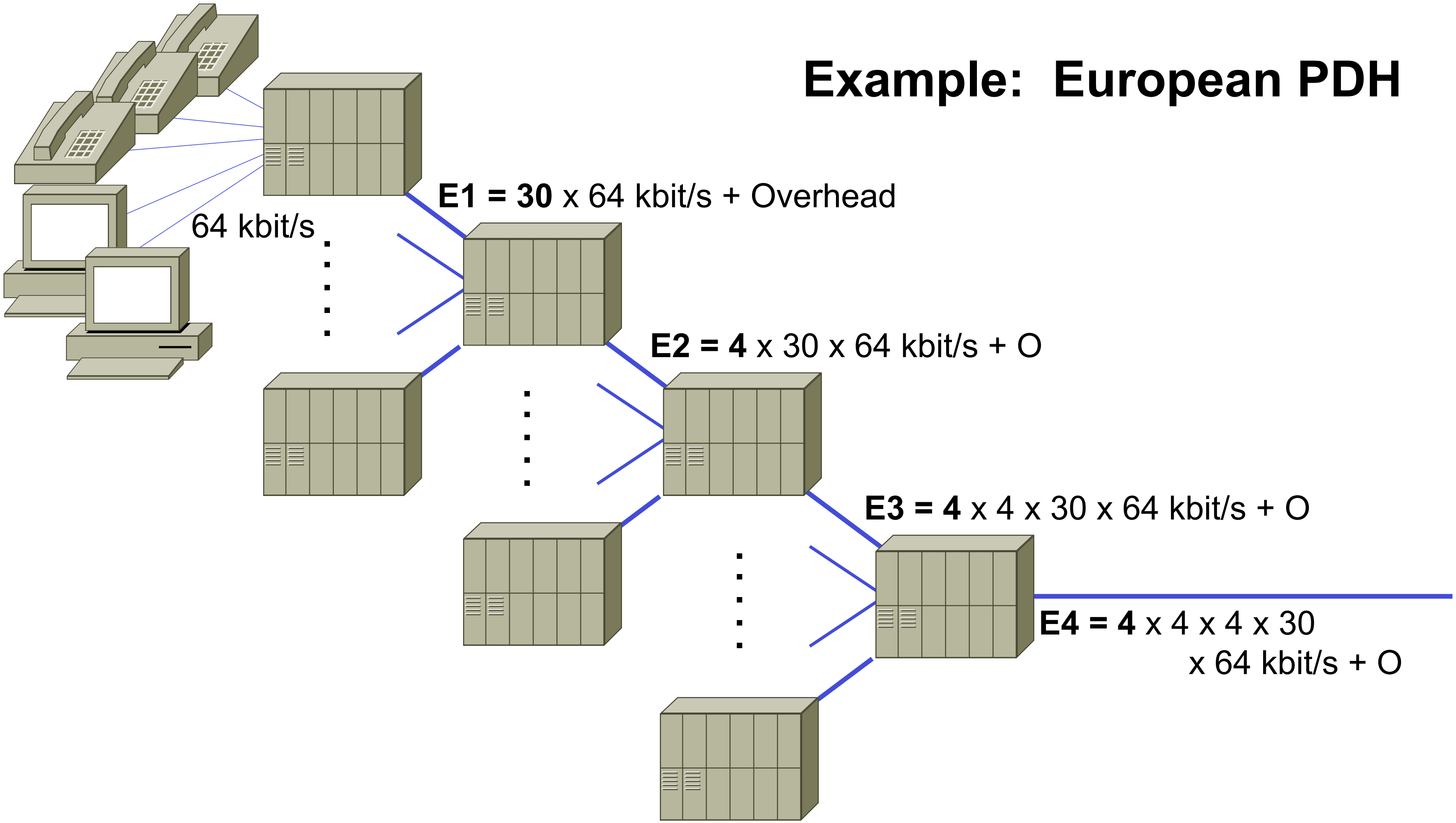
- **1960s technology: No buffering of frames at high speeds possible**
- **Goal: Fast delivery, very short delays (voice!)**
  - Immediate forwarding of bits
  - Pulse stuffing instead of buffering
- **Plesiochronous = "nearly synchronous"**
  - Network is not synchronized but fast
  - Sufficient to synchronize sender and receiver

Why Hierarchy?

- **Only a hierarchical digital multiplexing infrastructure**
  - Can connect millions of (low speed) customers across the city/country/world
- **Local infrastructure: Simple star**
- **Wide area infrastructure: Point-to-point trunks or ring topologies**
  - Grooming required

Digital Hierarchy of Multiplexers

Example: European PDH



Digital Signal Levels

- **Differentiate:**
  - Signal (Framing layer)
  - Carrier (Physical Layer)
- **North America (ANSI)**
  - DS-n = Digital Signal level n
  - Carrier system: T1, T2, ...
- **Europe (CEPT)**
  - CEPT-n = ITU-T digital signal level n
  - Carrier system: E1, E2, ...

Worldwide Digital Signal Levels

North America

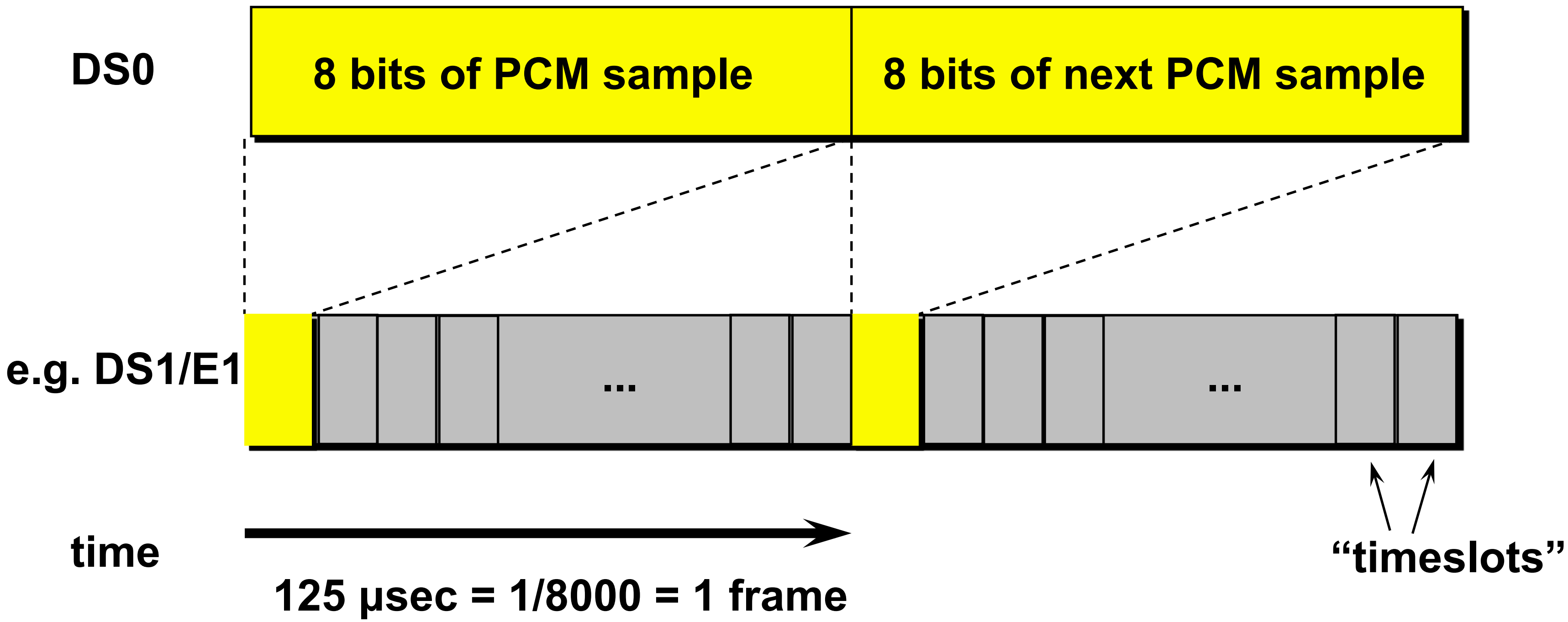
Signal	Carrier	Channels	Mbit/s
DS0		1	0.064
DS1	T1	24	1.544
DS1C	T1C	48	3.152
DS2	T2	96	6.312
DS3	T3	672	44.736
DS4	T4	4032	274.176

Europe

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

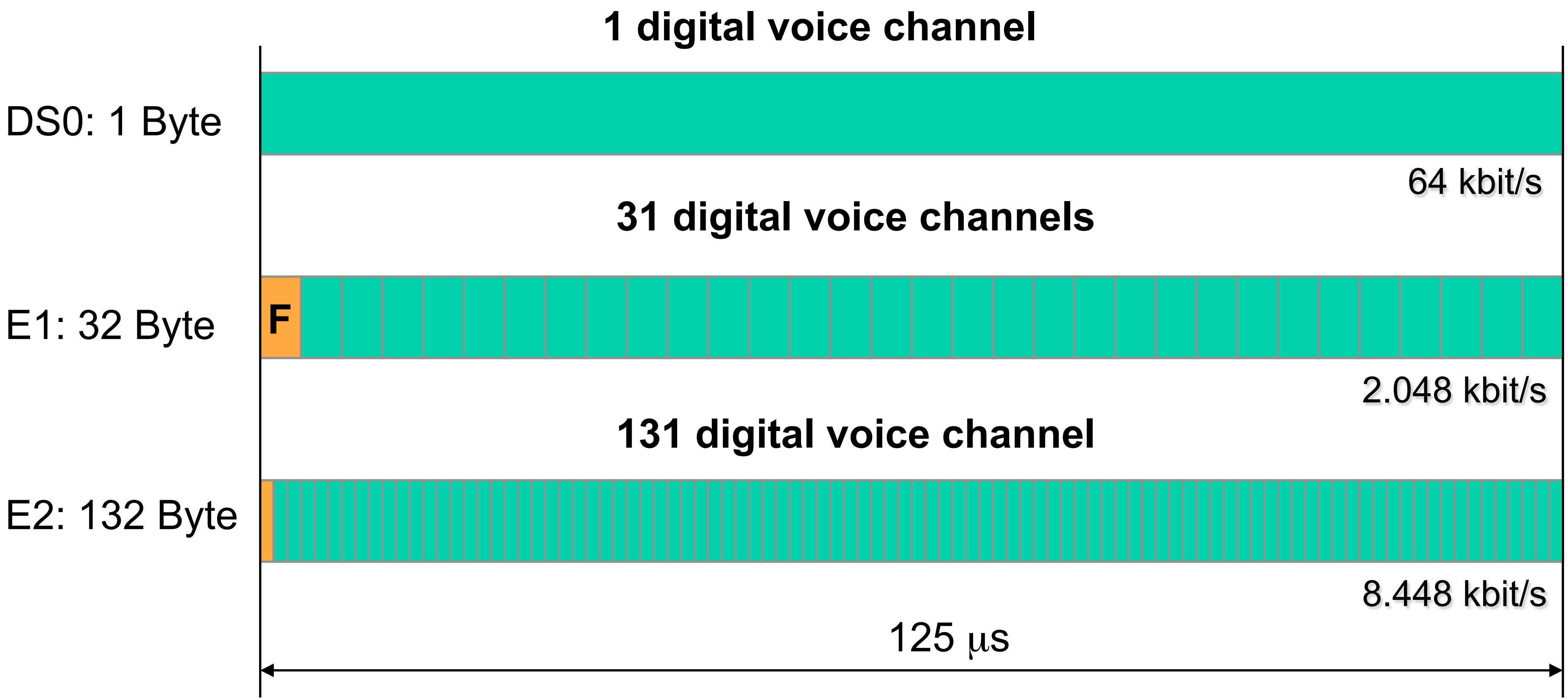
- **Incompatible MUX rates**
- **Different signaling schemes**
- **Different overhead**
- **μ-law versus A-law**

Multiplexing Basics



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

Multiplexing Basics

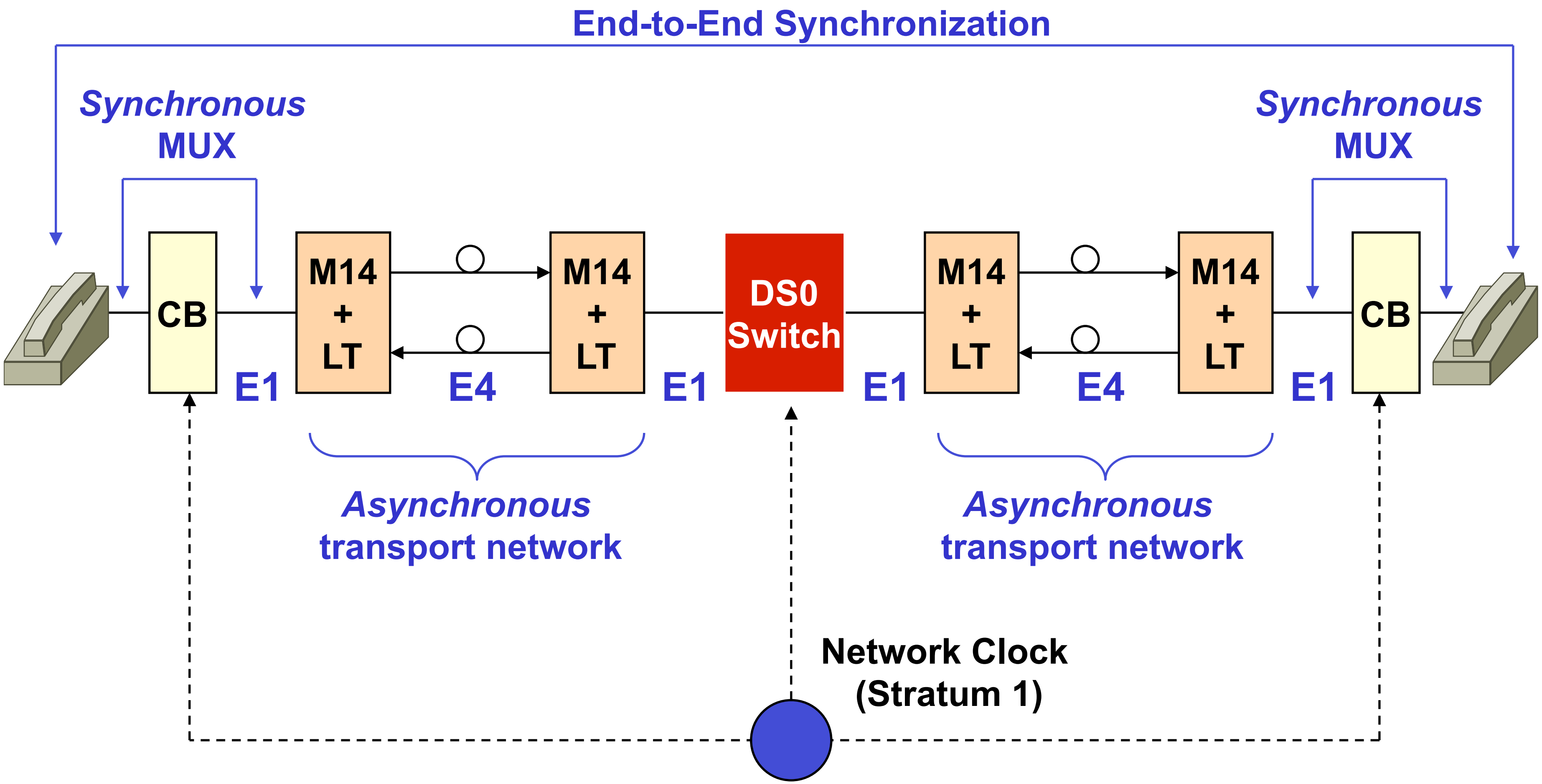


– note: DS0 and higher rates can be used for any transport digital information -> data transmission

Plesiochronous Multiplexing

- **Bit interleaving at higher MUX levels**
  - Simpler with slow circuits (Bit stuffing!)
  - Complex frame structures and multiplexers (e.g. M12, M13, M14)
- **DS1/E1 signals can only be accessed by demultiplexing**
- **Add-drop multiplexing not possible**
  - All channels must be demultiplexed and then recombined
  - No ring structures, only point-to-point

Synchronization



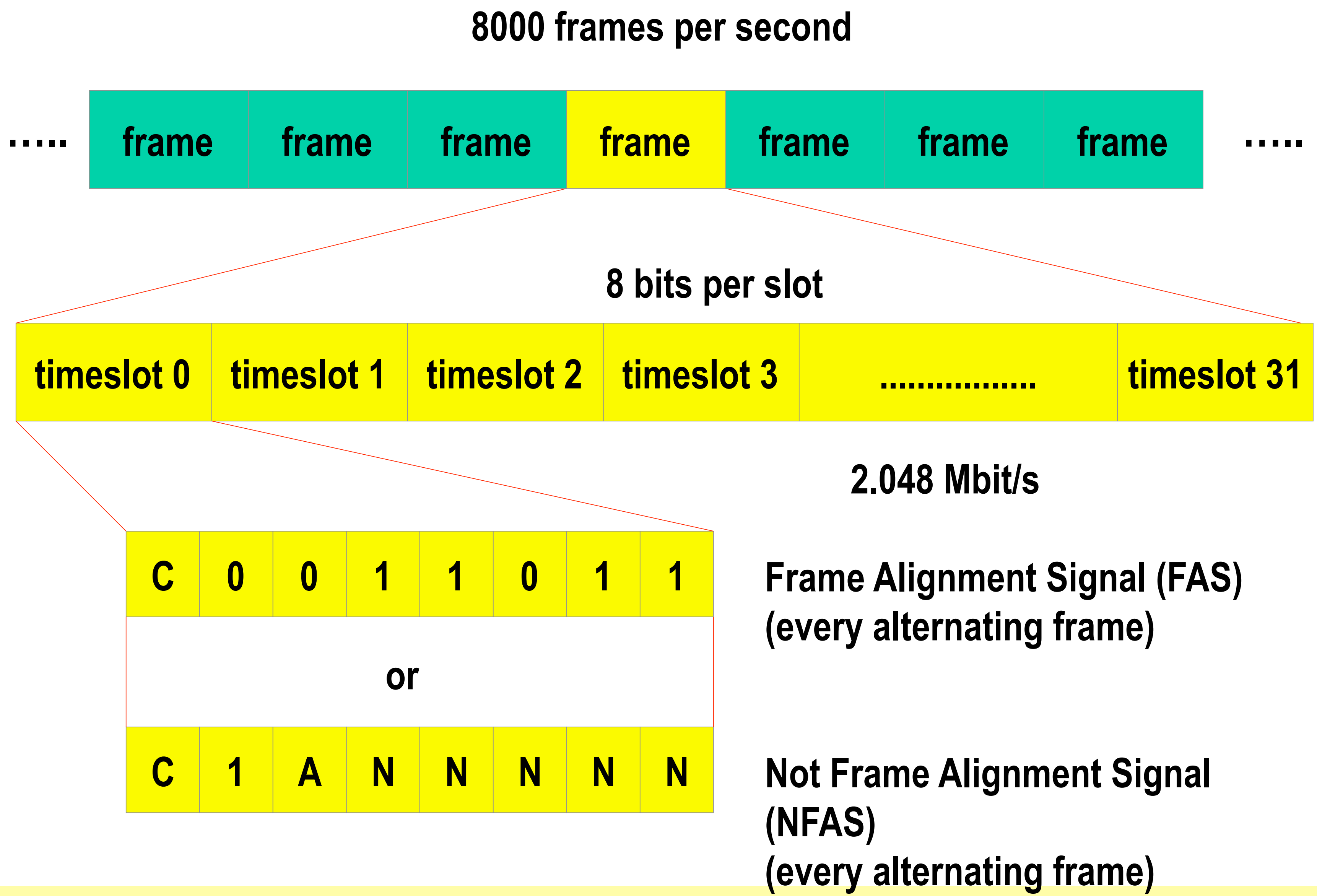
CB .... Channel Bank
M14+LT ... MUX and Line Termination

E1 Basics

- **CEPT standardized E1 as part of European channelized framing structure for PCM transmission (PDH)**
  - E1 (2 Mbit/s)
  - E2 (8 Mbit/s)
  - E3 (34Mbit/s)
  - E4 (139Mbit/s)

- **Relevant standards**
  - G.703: Interfacing and encoding
  - G.704: Framing
  - G.732: Multiplex issues

E1 Frame Structure



CRC Multiframe Structure Timeslot 0

	timeslot 0		timeslot 1 .... timeslot 31
frame 0	C1	FAS	
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	
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	

semi-multiframe 1 (frames 0–7)

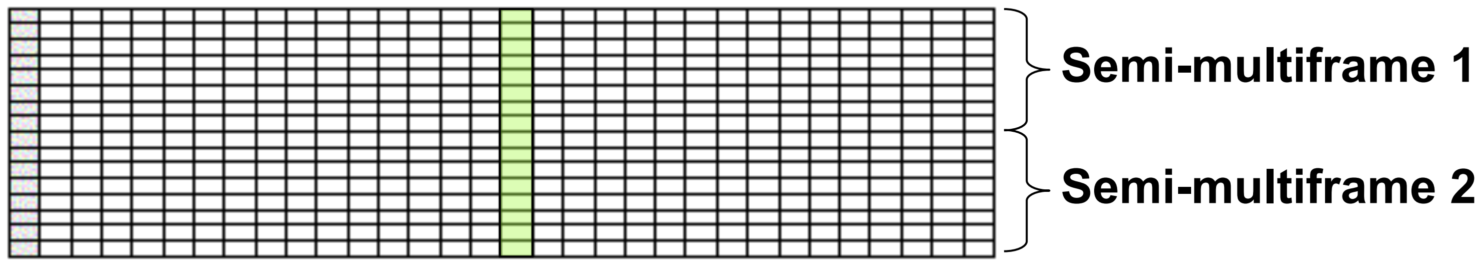
semi-multiframe 2 (frames 8–15)

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

E1 Signaling: Timeslot 16

- **To connect PBXs via E1**
  - Timeslot 16 can be used as standard out-band signaling method
- **Common Channel Signaling (CCS)**
  - Dedicated 64 kbit/s channel for signaling protocols such as DPNSS, CorNet, QSIG, or SS7
- **Channel Associated Signaling (CAS)**
  - 4 bit signaling information per timeslot (=user) every 16th frame
  - 30 independent signaling channels
    (2kbit/s per channel)

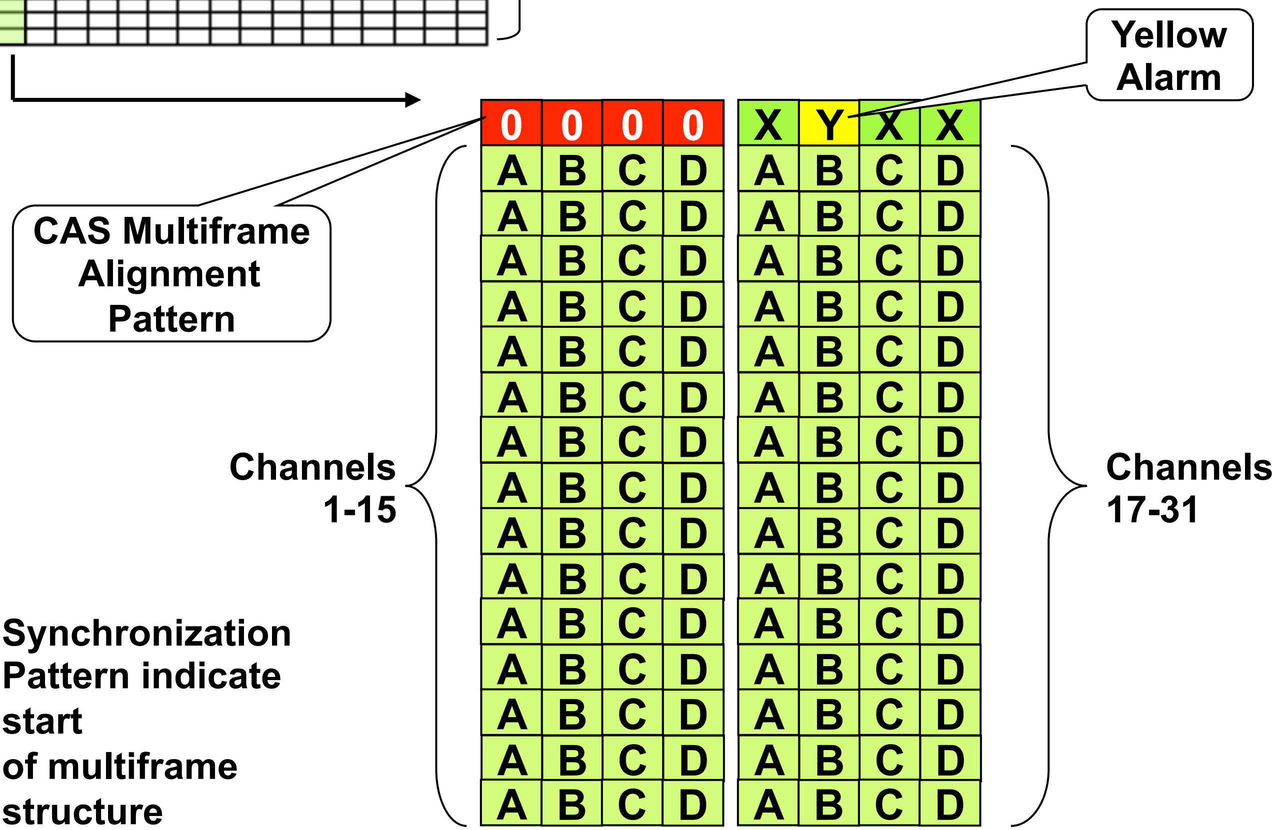
Multiframe Structure



C1	FAS
0	NFAS
C2	FAS
0	NFAS
C3	FAS
1	NFAS
C4	FAS
0	NFAS
C1	FAS
1	NFAS
C2	FAS
1	NFAS
C3	FAS
Si	NFAS
C4	FAS
Si	NFAS

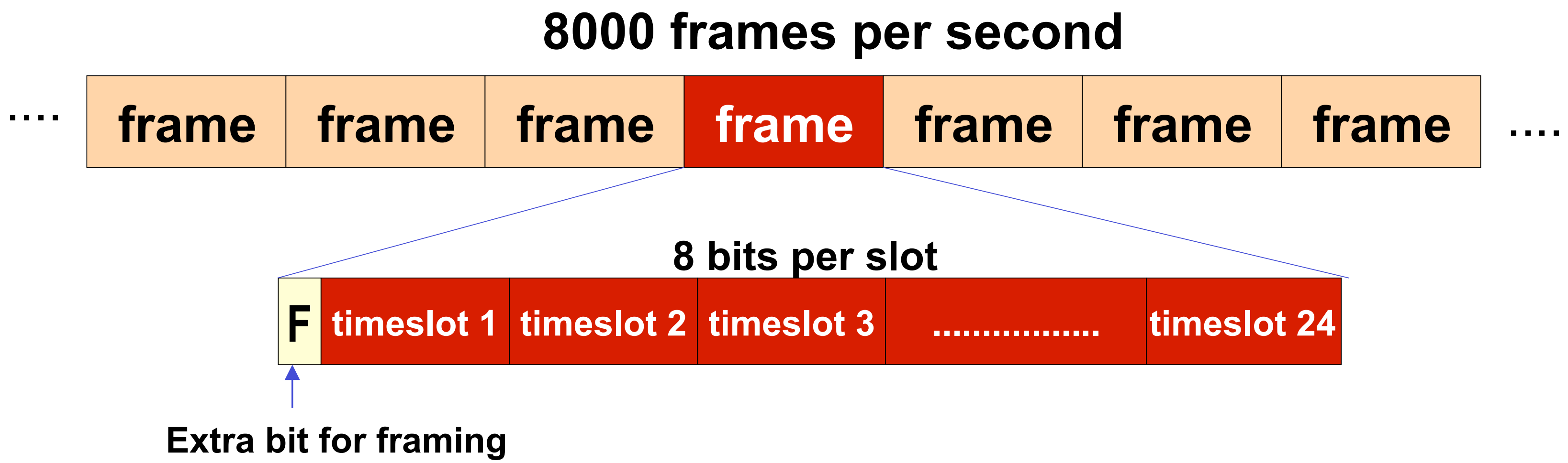
0
0
1
0
1
1

Synchronization Pattern indicate start of multiframe structure



T1 Basics

- **T1 is the North American PDH variant**
  - DS0 is basic element
- **24 timeslots per T1 frame = 1.544 Mbit/s**



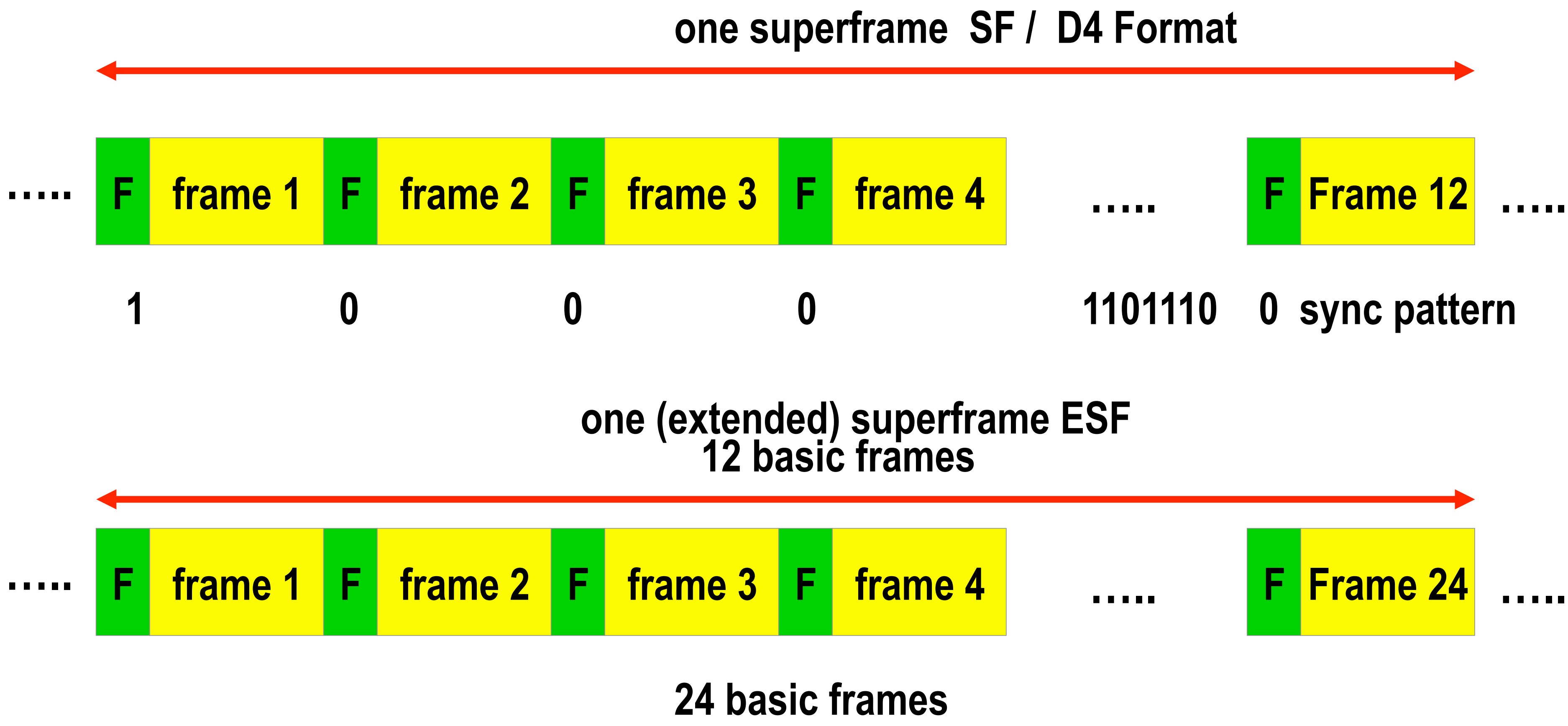
T1 Basics

- **Combinations of frames to superframes**
  - 12 T1 frames (DS4)
  - 24 T1 frames (Extended Super Frame, ESF)

- **No reserved timeslot for signaling ➔ Robbed Bit Signaling**
  - No Problem for PCM
  - Problem for data -> only 56kbit/s usable

- **Modern alternative: Common Channel Signaling**

D4 Format / ESF Format



sync pattern 001011 in frames 4, 8, 12, 16, 20, 24
six CRC bits in frames 2, 6, 10, 14, 18, 22
diagnostic bits in frame 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23

Robbed Bit Signaling D4

	timeslot 1		....	timeslot 24	
frame 1	Data			Data	
frame 2	Data			Data	
frame 3	Data			Data	
frame 4	Data			Data	
frame 5	Data			Data	
frame 6	Data	A		Data	A
frame 7	Data			Data	
frame 8	Data			Data	
frame 9	Data			Data	
frame 10	Data			Data	
frame 11	Data			Data	
frame 12	Data	B		Data	B

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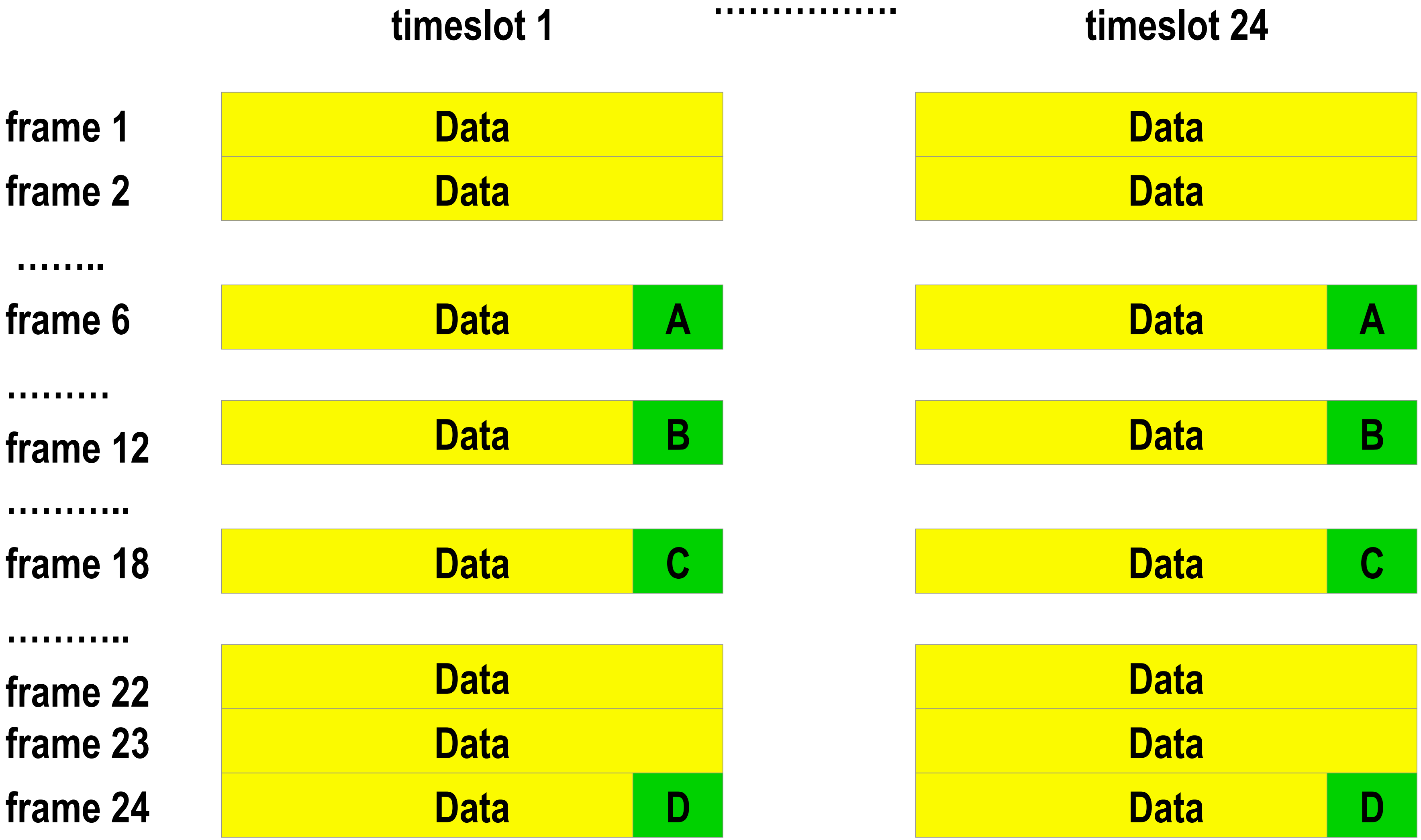
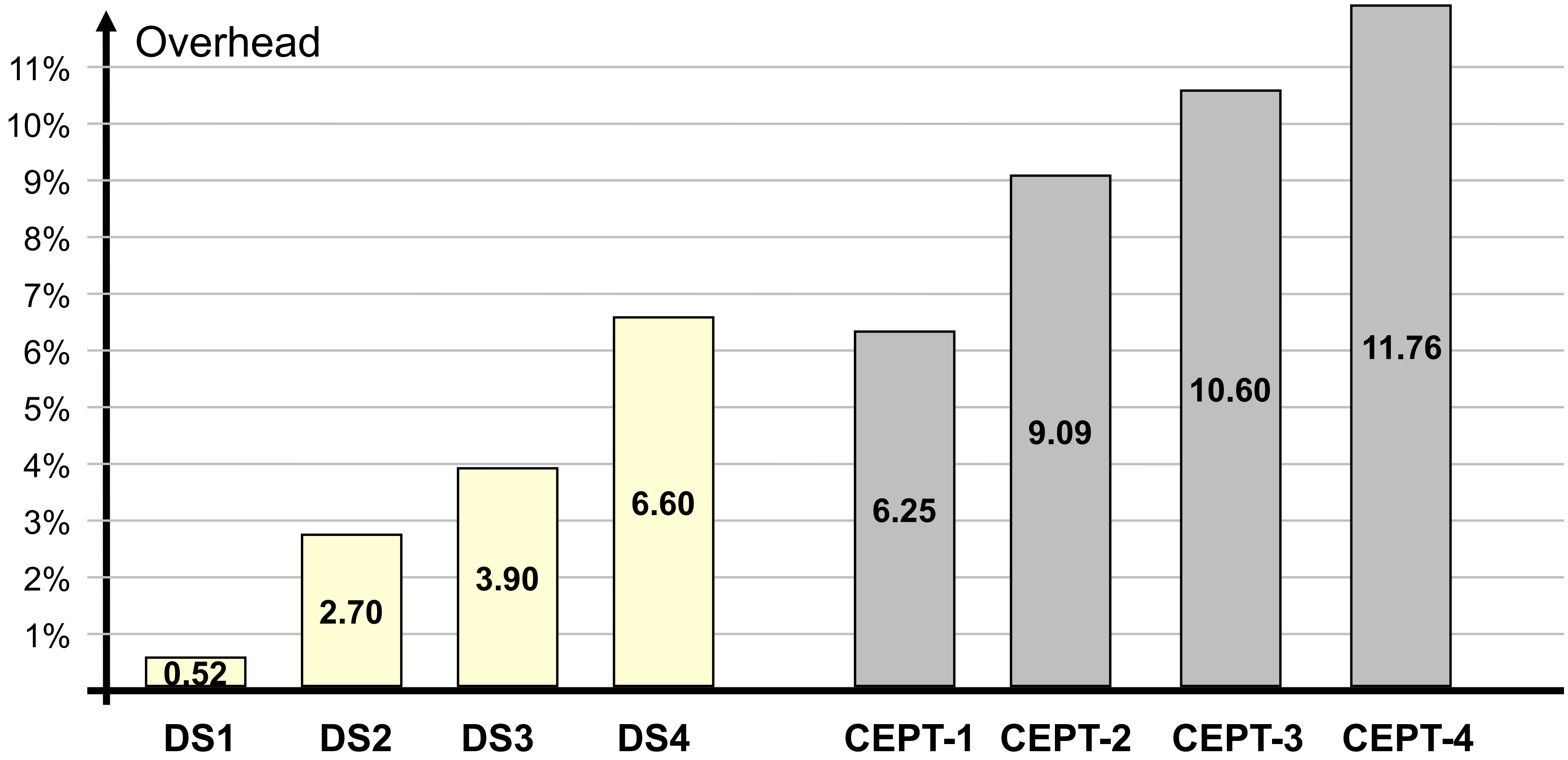
Robbed Bit Signaling ESF



PDH Limitations

- **PDH overhead increases dramatically with high bitrates**



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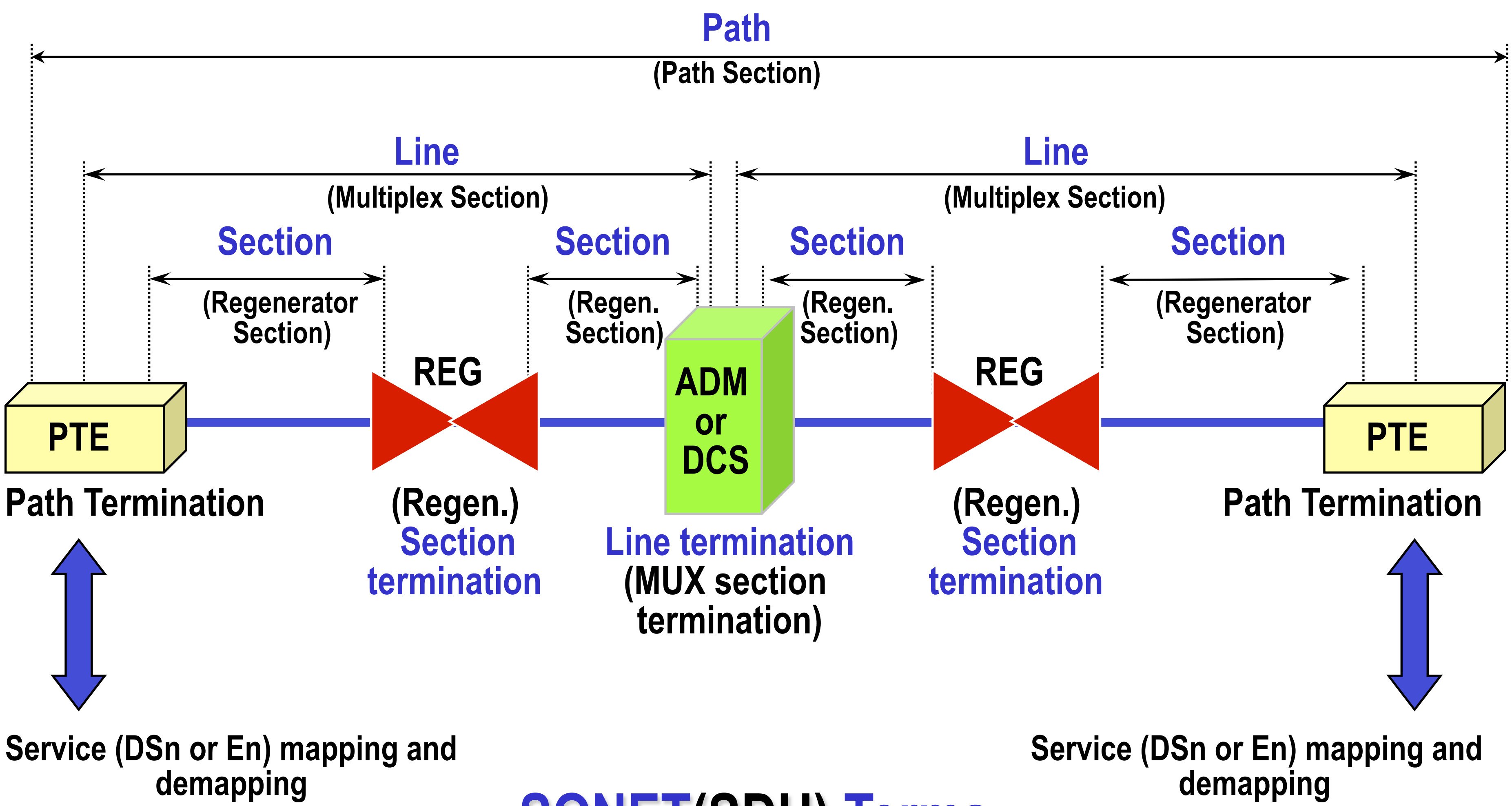
Reasons for SONET/SDH Development

- **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) Terms

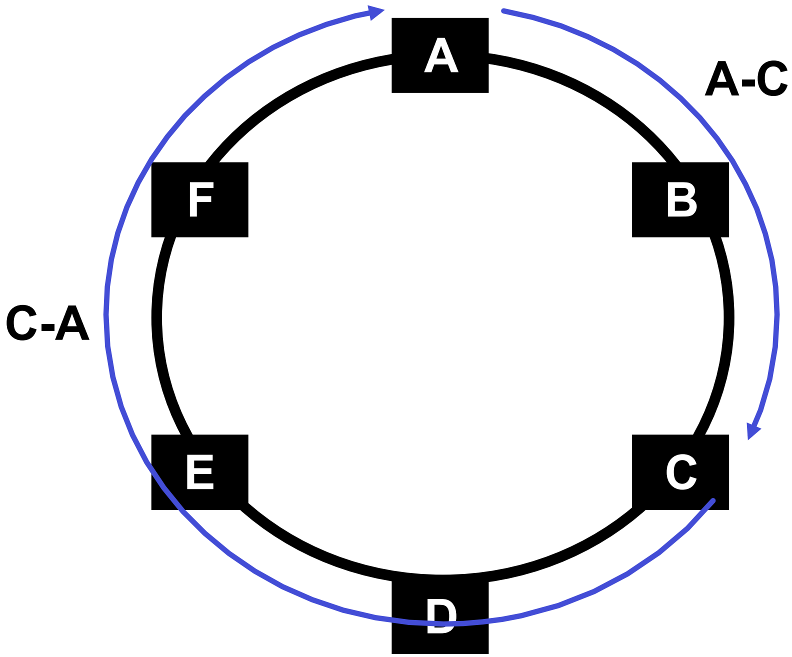
SONET/SDH Line Rates

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

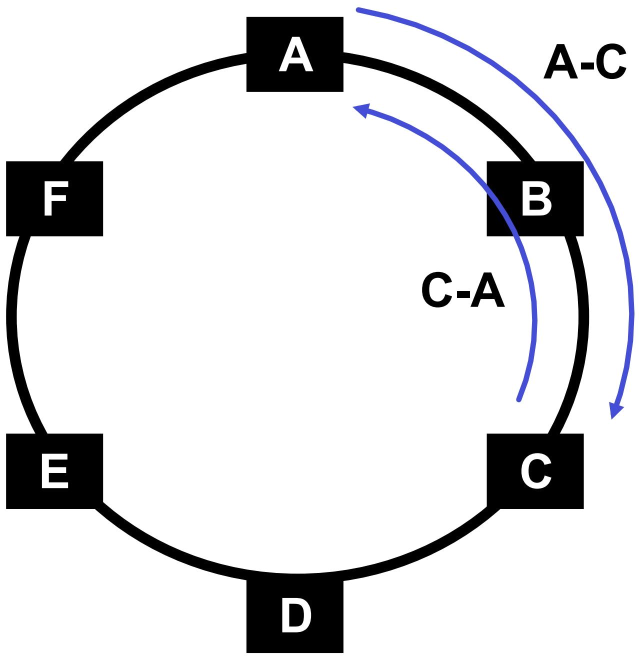
Defined but later removed, and only the multiples by four were left!

(Coming soon)

Uni- and Bi-directional Routing



Uni-directional Ring (1 fiber)



Bi-directional Ring (2 fibers)

– Only working traffic is shown
– Path or line switching for protection

SDH Operations

- **Protection**
  - Circuit recovery in milliseconds
- **Restoration**
  - Circuit recovery in seconds or minutes
- **Provisioning**
  - Allocation of capacity to preferred routes
- **Consolidation**
  - Moving traffic from unfilled bearers onto fewer bearers to reduce waste trunk capacity
- **Grooming**
  - Sorting of different traffic types from mixed payloads into separate destinations for each type of traffic

SONET/SDH and the OSI Model

- **SONET/SDH covers**
  - Physical, Data Link, and Network layers
- **However, in data networking it is used mostly as a transparent bit stream pipe**
- **Therefore SONET/SDH is regarded as a Physical layer, although it is more**
- **Functions might be repeated many times in the overall protocol stack**