Telco Scalable Backbones

PDH, SONET/SDH

“Everything that can be invented has been invented”

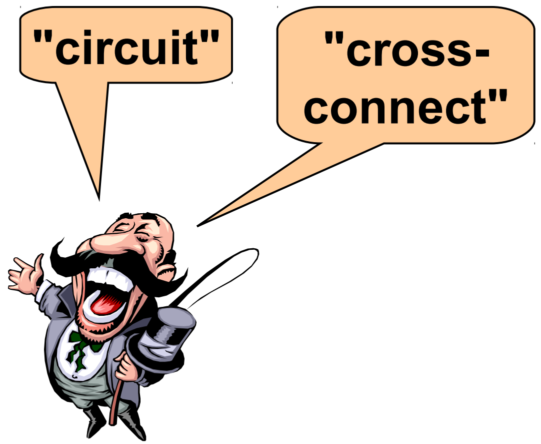
Charles H. Duell, commissioner of the US Office of Patents 1899

Agenda

- Basics
  - Shannon
  - Jitter
  - Compounding laws
  - Digital Hierarchies
- PDH
- SONET/SDH

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

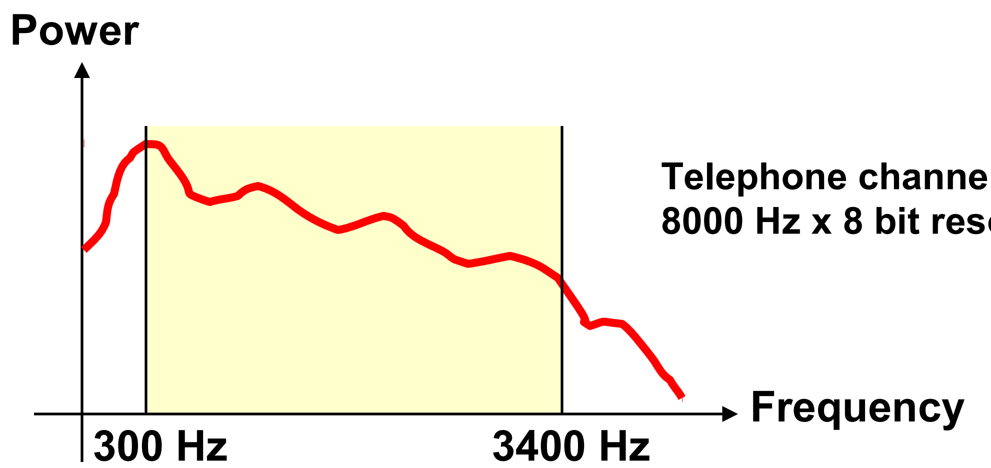


General Goals

- **Interoperability**
  - **Over decades**
  - **Over different vendors**
  - **World-wide!**
- **Availability**
  - **Protection lines in case of failures**
  - **High non-blocking probability**

Sampling of Voice

- **Shannon's Theorem**
  - **Any analogue signal with limited bandwidth f_B can be sampled and reconstructed properly when the sampling frequency is $2f_B$**
  - **Speech signal has most of its power and information between 0 and 4000 Hz**



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

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

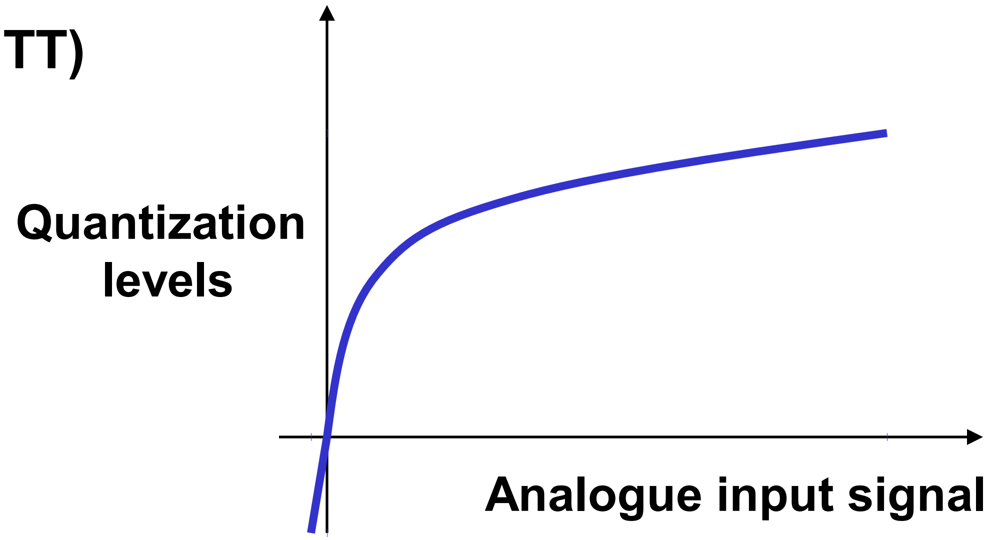
Solutions

- 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

Improving SNR

- SNR improvement of speech signals
  - Quantize loud signals much coarser than quiet signals
- Expansion and compression specified by nonlinear function
  - USA: μ-law (Bell)
  - Europe: A-law (CCITT)

Conversion is task of the μ-law world



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?

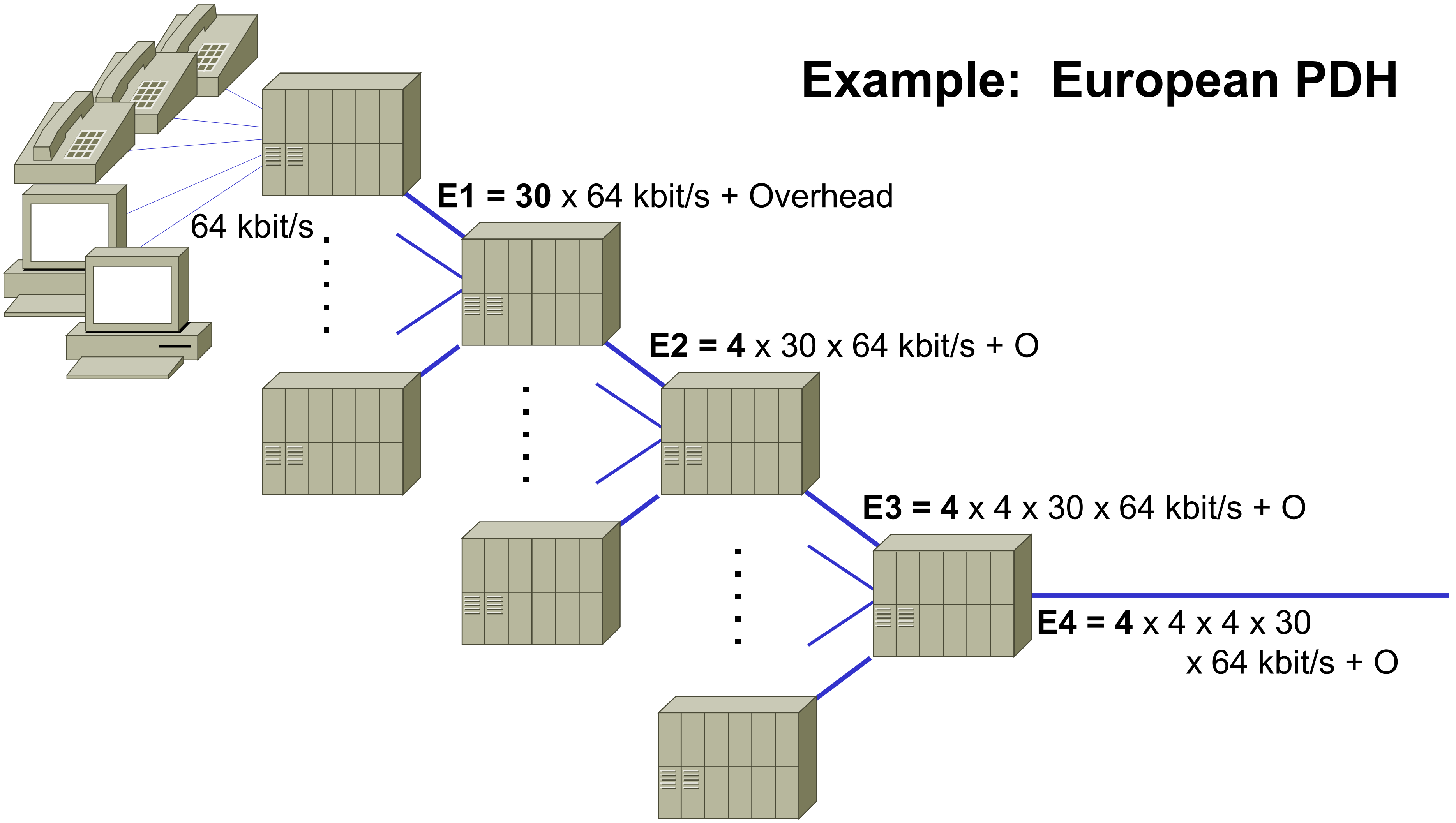
- 1960s technology: No buffering of frames at high speeds possible
- Goal: Fast delivery, very short delays (voice!)
  - Immediate forwarding of bits
  - Pulse stuffing instead of buffering
- Plesiochronous = "nearly synchronous"
  - Network is not synchronized but fast
  - Sufficient to synchronize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

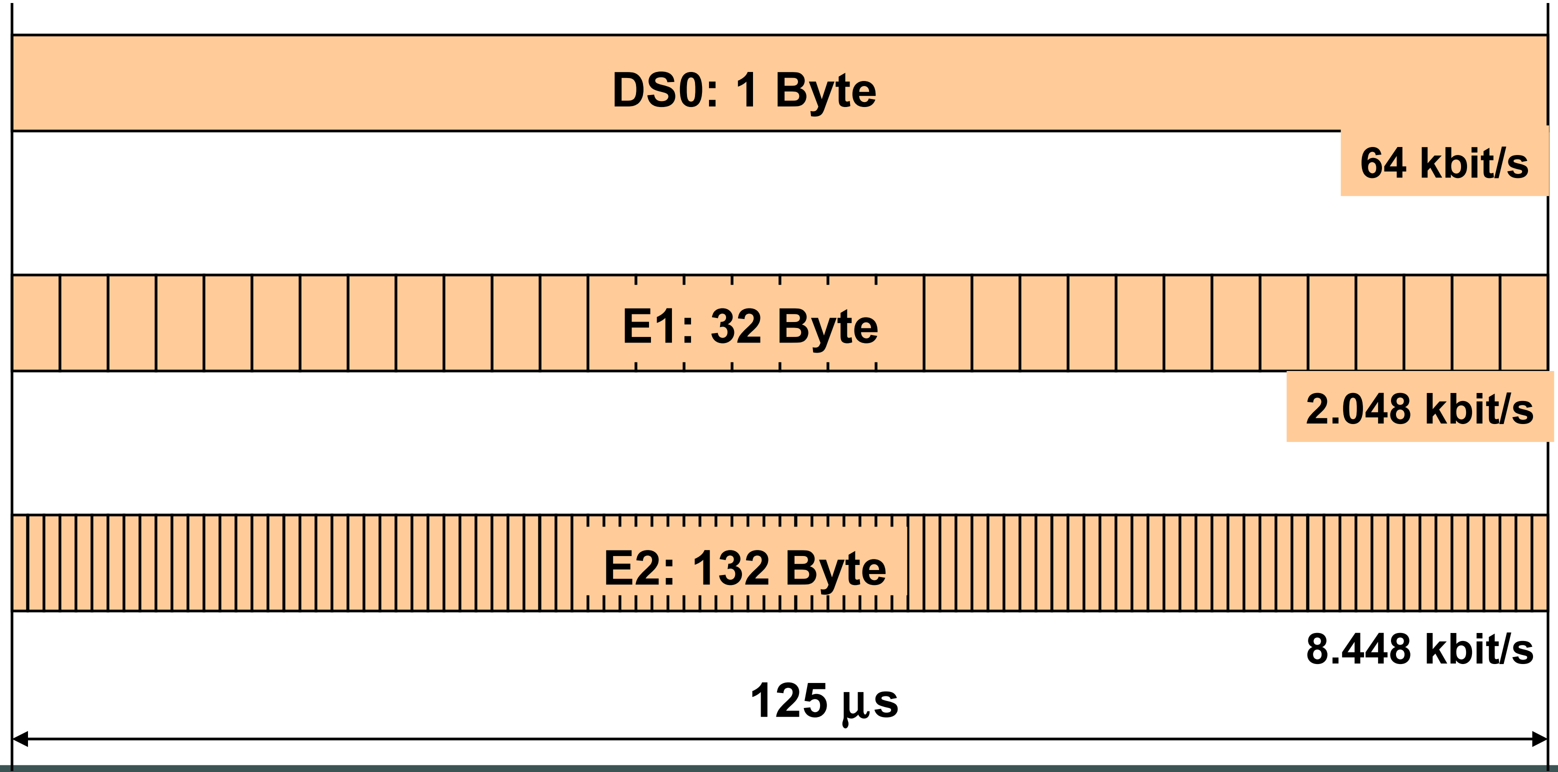
Europe

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 signalling schemes
- Different overhead
- μ-law versus A-law

Frame Duration

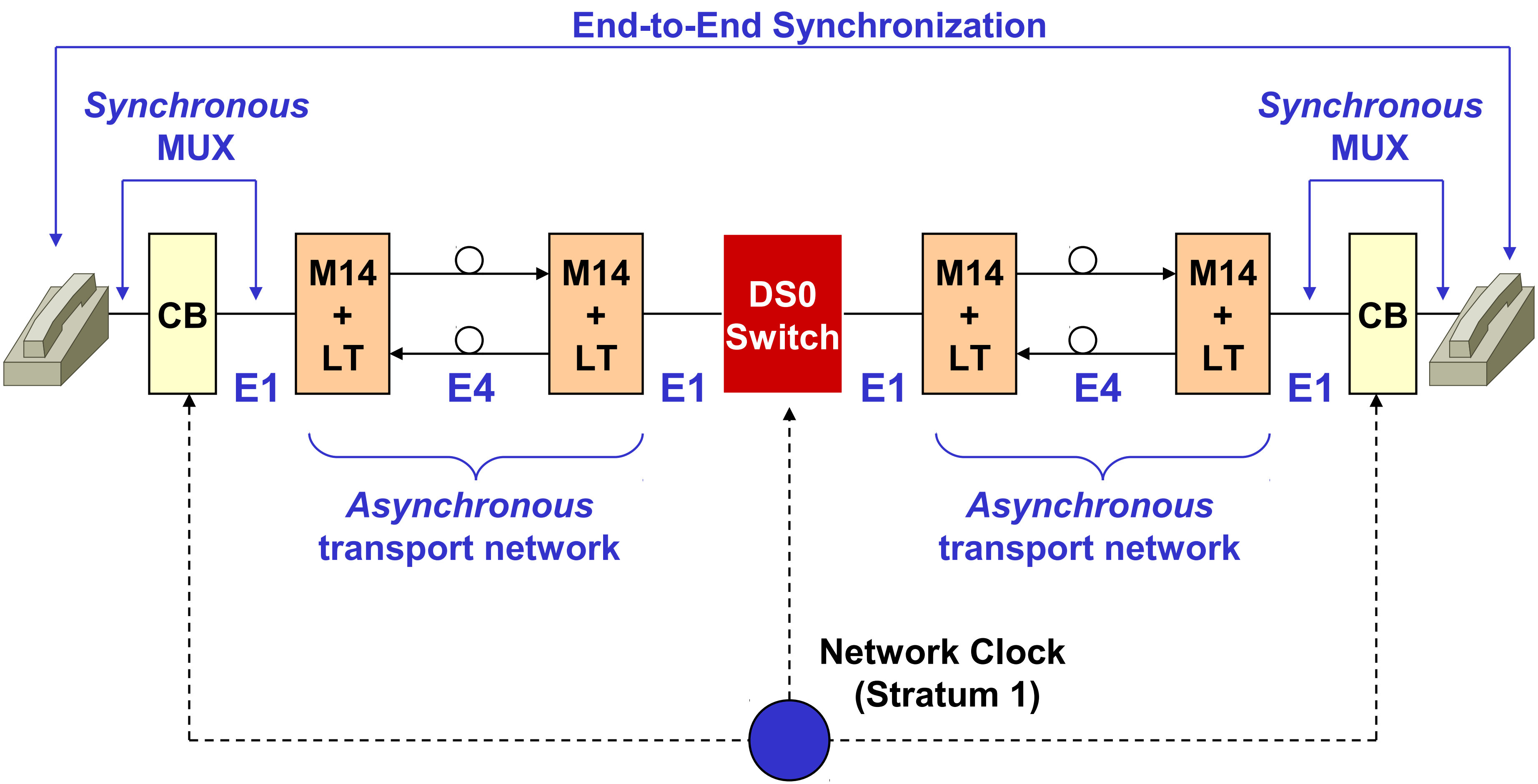
- Each samples (byte) must arrive within 125 μs
  - To receive 8000 samples (bytes) per second
  - Higher order frames must ensure the same byte-rate per user(!)



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



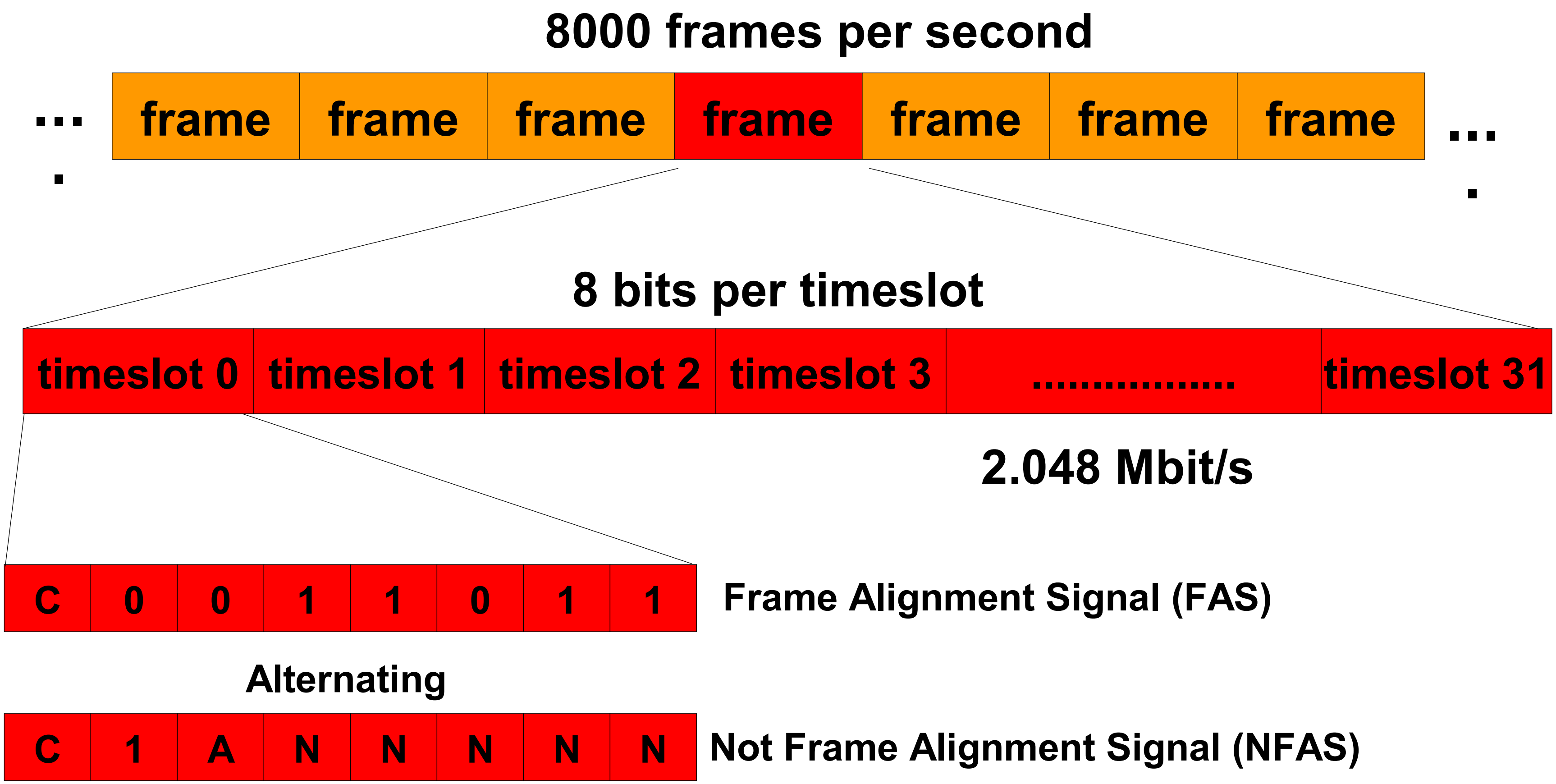
CB .... Channel Bank
M14+LT ... MUX and Line Termination

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

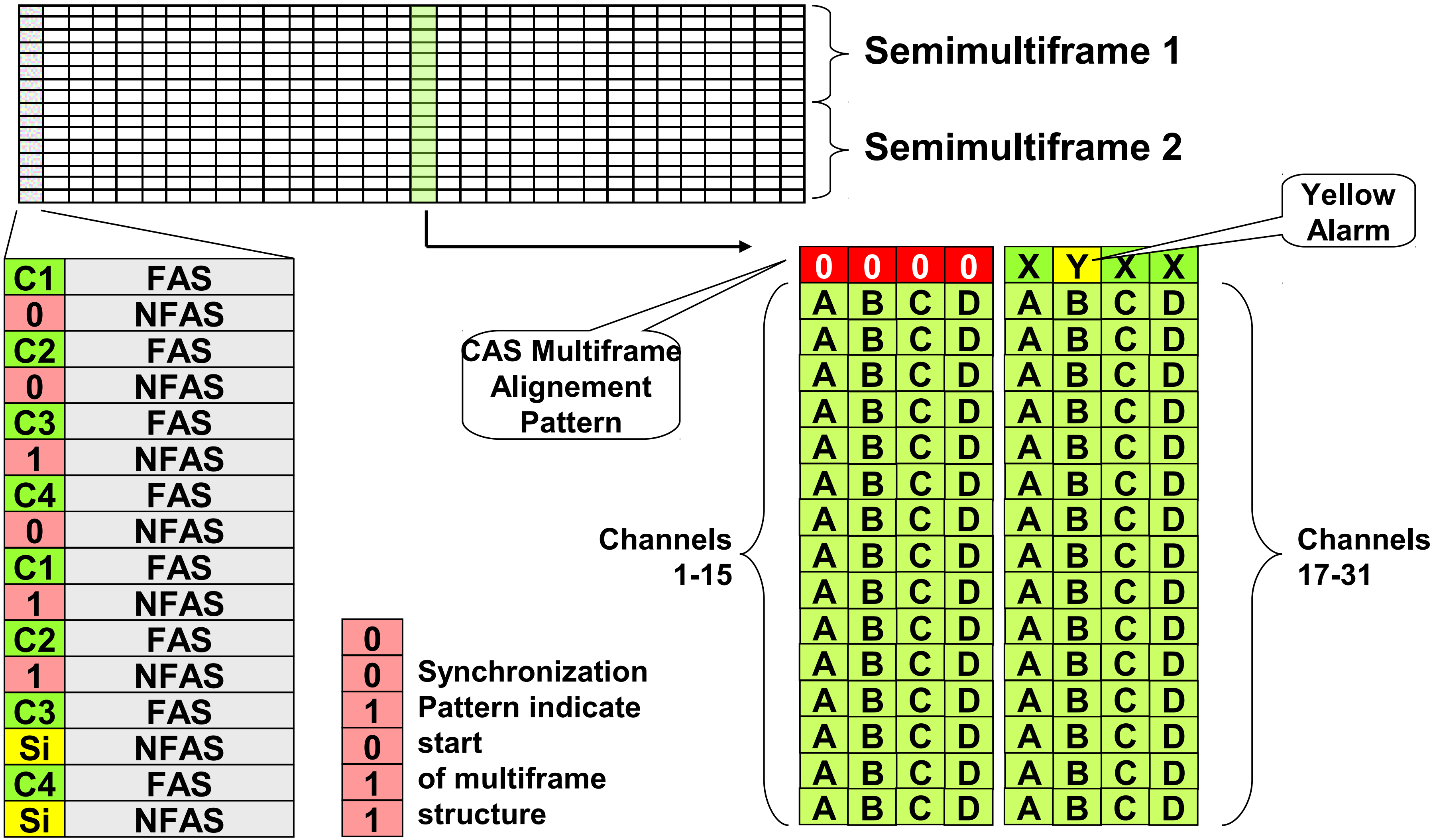
E1 Frame Structure



E1 Signaling: Timeslot 16

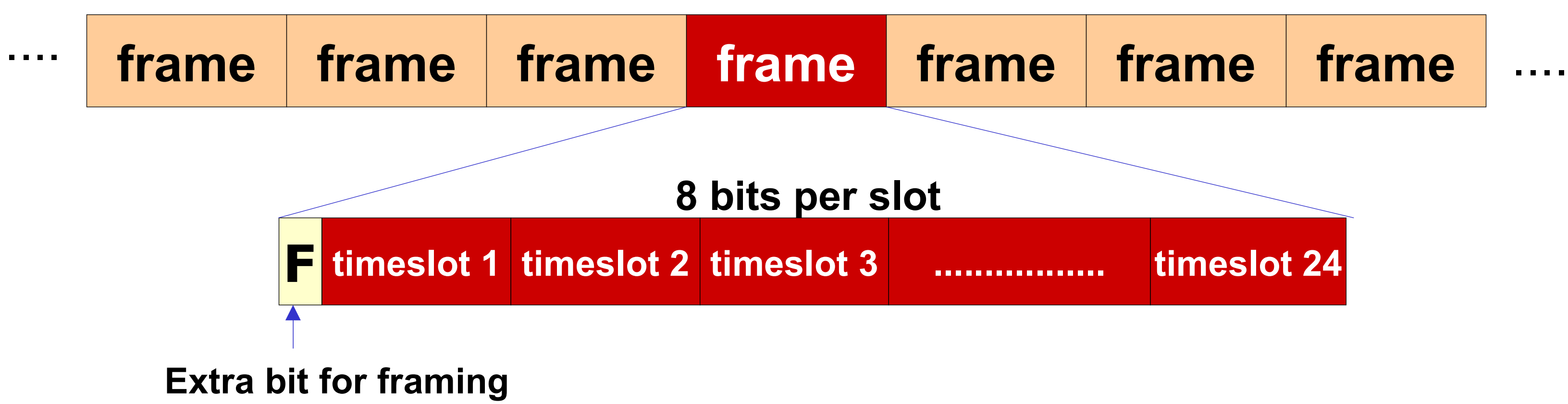
- To connect PBXs via E1
  - Timeslot 16 can be used as standard out-band signaling method
- Common Channel Signaling (CCS)
  - Dedicated 64 kbit/s channel for signaling protocols such as DPNSS, CorNet, QSIG, or SS7
- Channel Associated Signaling (CAS)
  - 4 bit signaling information per timeslot (=user)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

Multiframe Structure



T1 Basics

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

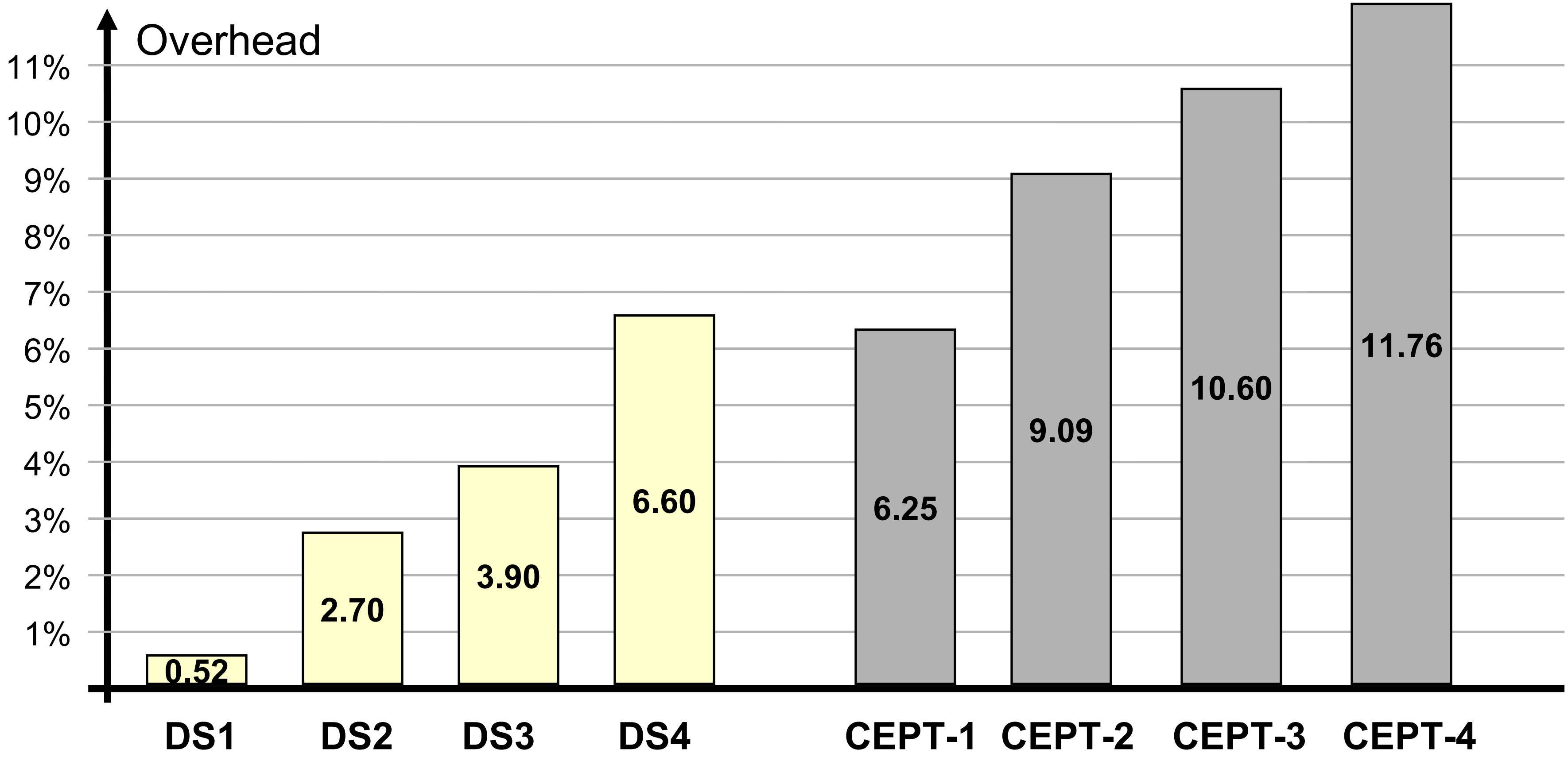


T1 Basics

- No reserved timeslot for signaling → Robbed Bit Signaling
- Combinations of frames to superframes
  - 12 T1 frames (DS4)
  - 24 T1 frames (Extended Super Frame, ESF)
- Modern alternative: Common Channel Signaling

PDH Limitations

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



Why SONET/SDH?

- Many incompatible PDH implementations
- PDH does not scale to very high bitrates
  - Increasing overhead
  - Complex multiplexing procedures
- Demand for a true synchronous network
  - No pulse stuffing between higher MUX levels
  - Better compensate phase shifts by floating playload and pointer technique
- Demand for add-drop MUXes and ring topologies

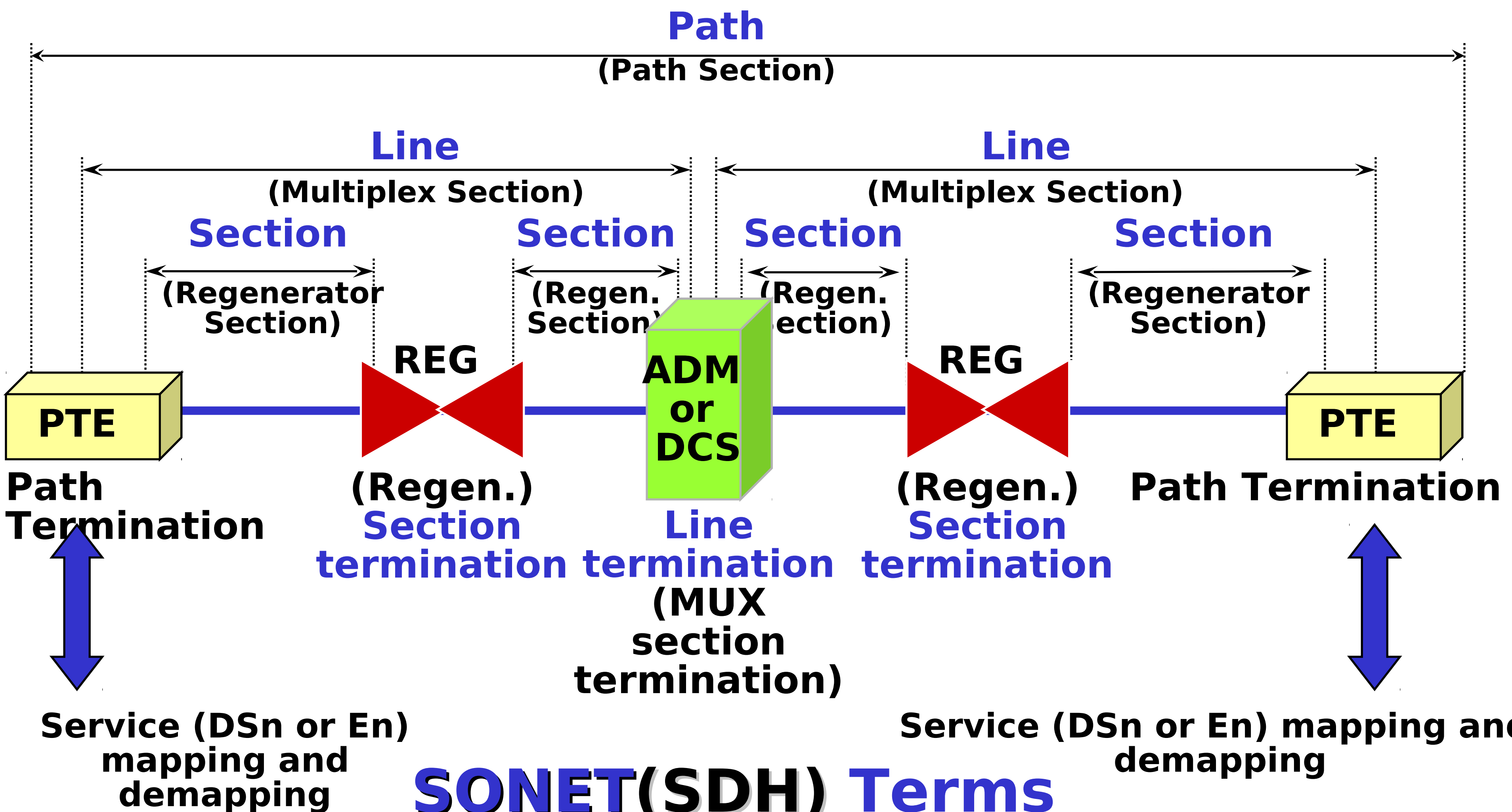
History Take 1: USA

- Many companies after divestiture of AT&T
  - Many proprietary solutions for PDH successor technology
- In 1984 ECSA (Exchange Carriers Standards Association) started on SONET
  - Goal: one common standard
  - A standard that almost wasn't: over 400 proposals!
- SONET became an ANSI standard
  - Designed to carry US PDH payloads

History Take 2: World

- In 1986 CCITT became interested in SONET
  - Created SDH as a superset
  - Designed to carry European PDH payloads including E4 (140 Mbit/s)
- Originally designed for fiber optics

Network Structure



Layers and Overhead

- SONET (SDH) consists of 4 layers
  - Physical Layer
  - Section (Regenerator Section) Layer
  - Line (Multiplex Section) Layer
  - Path Layer
- All layers (except the physical) insert information into the so-called overhead of each frame
- Note:
  - SONET and SDH are technically consistent, only the terms might be different
  - In this chapter, each SONET term is named first, followed by the associated SDH term written in brackets

SONET Signals

- Electrical signal: STS-n
  - Synchronous Transport Signal level n
- Optical signal: OC-n
  - Optical Carrier level n
  - OC-nc means concatenated
    - No multiplexed signal
    - Administrative overhead optimized compared to multiplexed signal
- Frame format is independent from electrical or optical signals

SDH Signals

- Electrical signal: STM-n
  - Synchronous Transport Module level n
  - STM-nc means concatenated
    - No multiplexed signal
    - Administrative overhead optimized compared to real multiplexed signal
  - Optical signal: STM-nO
- Frame format is independent from electrical or optical signals
    - Typically only the term STM-n is used

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

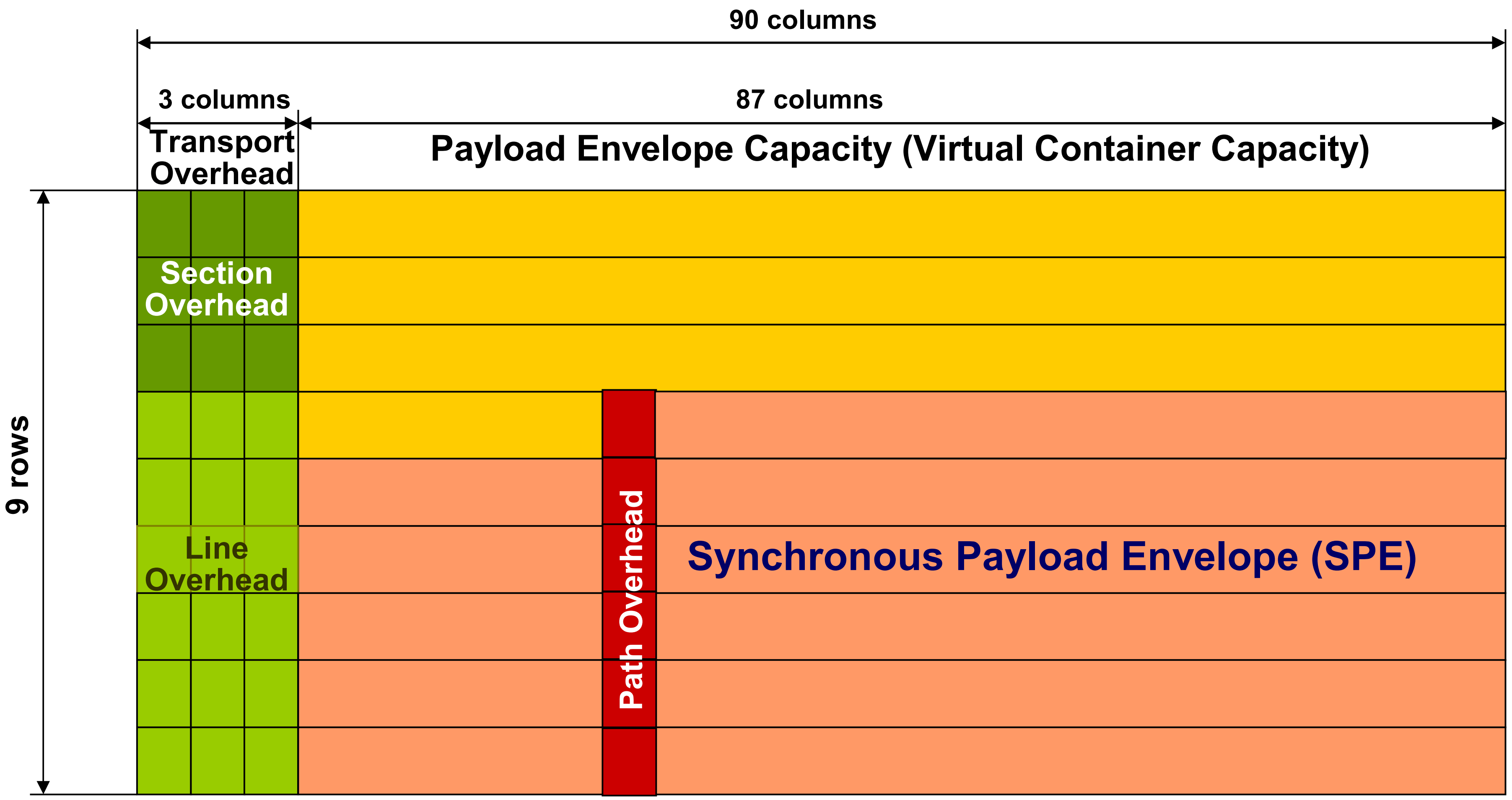
Defined but later removed, and only the multiples by four were left!

(Coming soon)

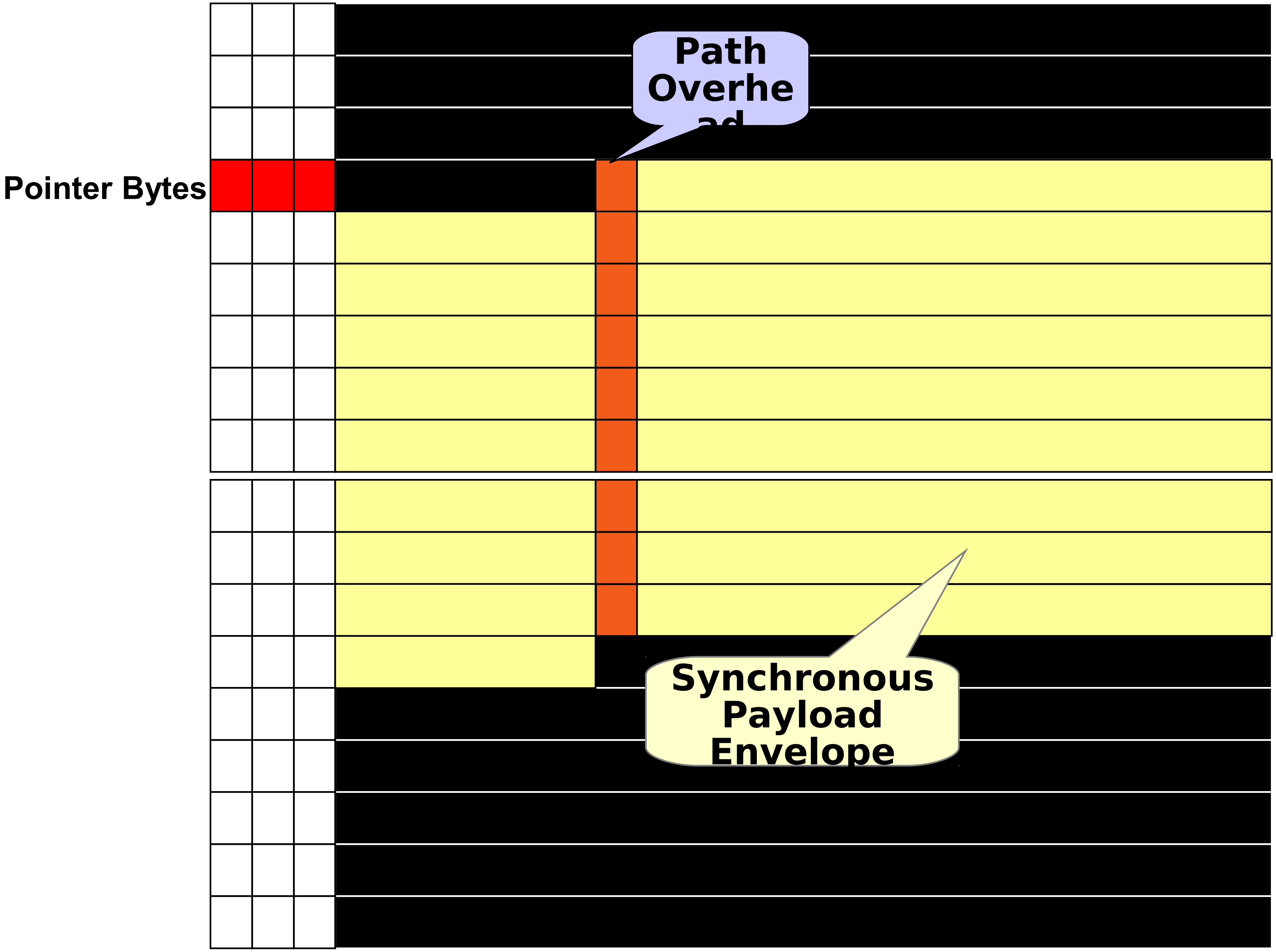
Two-dimensional Frame Model

- Similar to PDH every frame has 125 μs time length
  - To support 8 kHz sampled voice applications
- Bytes organized into rows and columns
  - Administrative channels are rate decoupled for easier processing
- Basic SONET frame is STS-1
  - 9 rows and 90 columns = 810 bytes total
  - 810 bytes $\times$ 8 bits $\times$ 8000/s = 51.8 Mbit/s
- Basic SDH frame is STM-1
  - 9 rows and 270 (3$\times$90) columns = 2430 bytes total
  - 2430 bytes $\times$ 8 bits $\times$ 8000/s = 155.52 Mbit/s

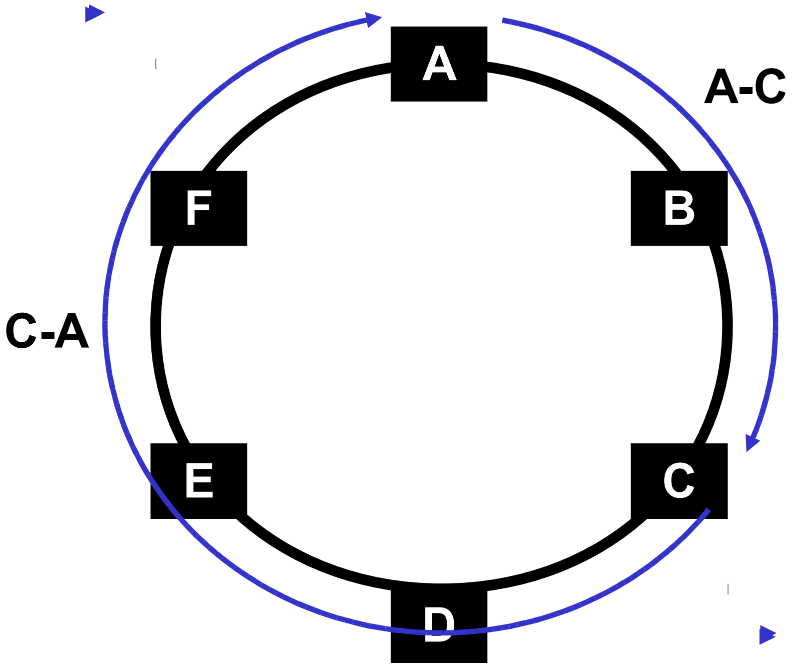
STS-1 (STM-0) Frame Structure



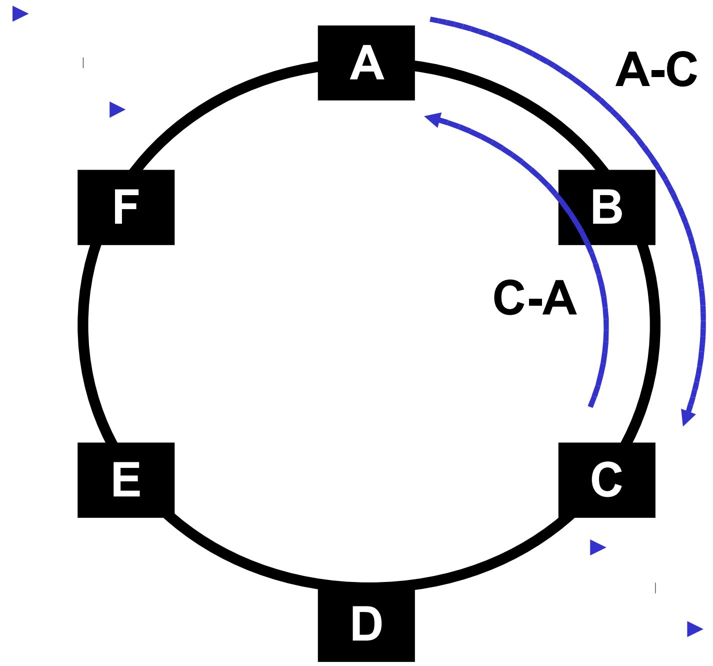
Floating Payload



Uni- and Bi-directional Routing



Uni-directional Ring
(1 fiber)



Bi-directional Ring
(2 fibers)

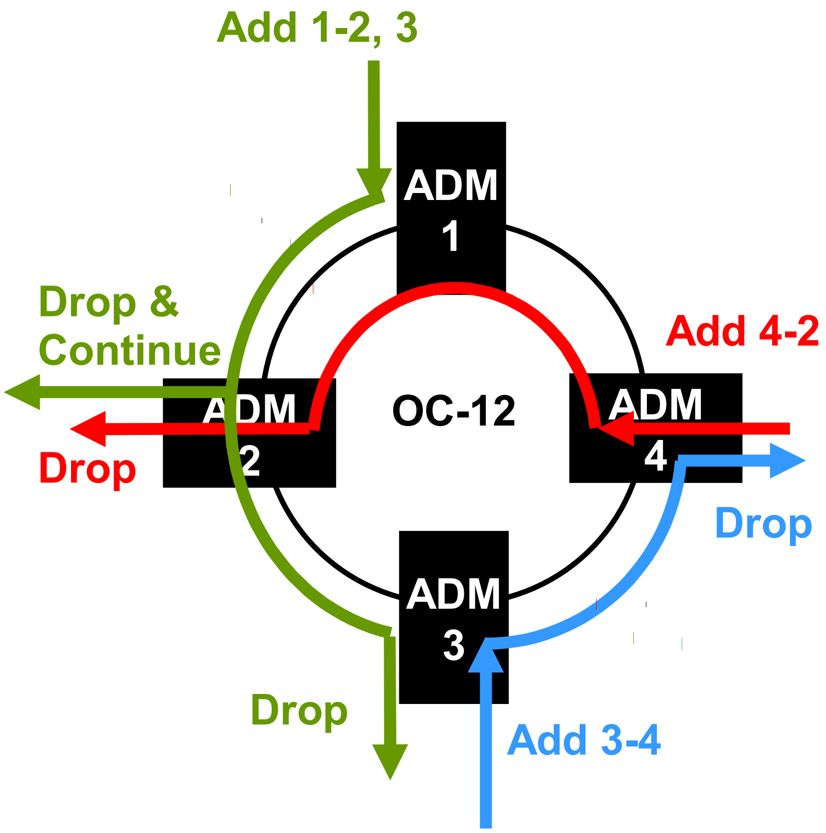
- Only working traffic is shown
- Path or line switching for protection

Add-drop Provisioning

- Transport connections over a SONET infrastructure are created by add-drop provisioning
  - A path is built up hop-by-hop by specifying which channels should be added to a ring and which channels should be dropped from the ring
- Add-drop provisioning is typically done by the network management system
  - There is no signaling protocol !!!

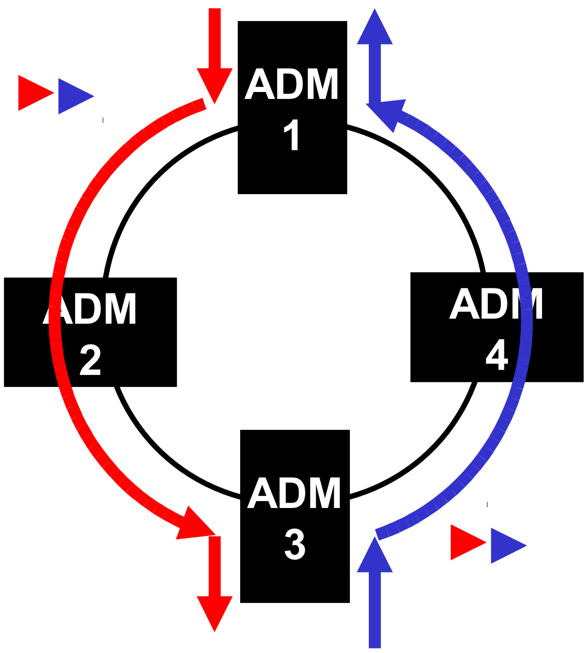
Add and Drop Example

- Example: OC-12 ring
  - Consists of 4 x OC-3c channels
  - Uni-directional routing
- 2 channels occupied

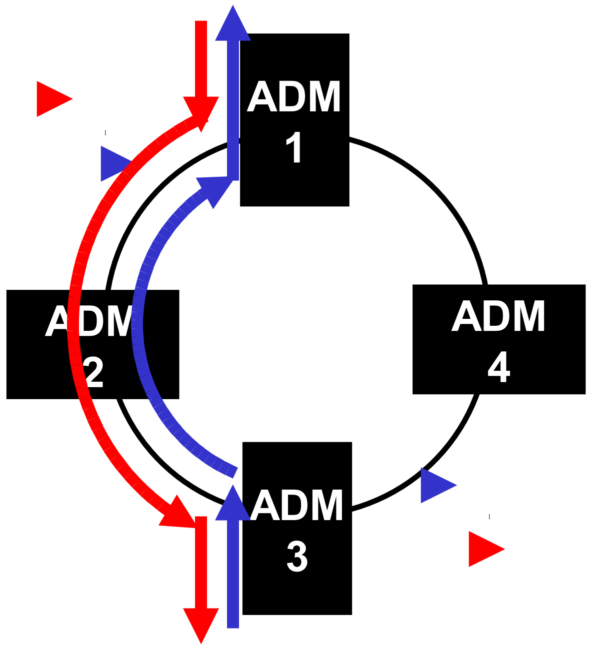


Uni- and Bi-directional Routing

Uni-directional routing



Bi-directional routing



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
  - Worst case: IP over LANE over ATM over SONET

Summary

- Telecommunication backbones must be very reliable and backward compatible
- PDH is still an important backbone technology
- Recently moving to optical backbones using SONET/SDH
- Traffic volume of voice services will decrease relative to general IP traffic