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

SDM

User a
00110011001101000111100010010000101001010010101110100010011001

User b
10011100010101010101010101010101110010100110101101110010101011

User c
11000111000111000000000000000000000000000000000000000000000000

User d
1011100111 1011100111 1011100111 1011100111 1011100111

User A

User B

User C

User D

Framed Mode

Save wires

TDM

User a
101010010111

User b
0011100001101

User c
1011100100100

User d
1000011101101

TDM

User A

User B

User C

User D
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 …
Agenda

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

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

Flag  8 bit A1 - A2  8 bit B1 - B2  8 bit C1 - C2  8 bit D1 - D2  Flag  8 bit A1 - A2

constant time interval
Synchronous (Deterministic) TDM

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

Framing

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

4 × 64 kbit/s + F ≅ 256 kbit/s
Idle Timeslots with Synchronous TDM

- If a communication channel has nothing to transmit
- \(\text{-> Idle timeslots} \rightarrow \text{Waste of bandwidth}\)
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
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

Each channel experiences constant delay and no delay variation (jitter)
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

Lead to development of asynchronous/statistical multiplexing
Agenda

• Introduction
• Synchronous (Deterministic) TDM
• Asynchronous (Statistical) TDM
• Telco Backbones
  – Digital Voice Transmission
  – PDH
  – SDH
Asynchronous (Statistical) TDM

Method 1: Terminal Session

Method 2: Computer Session

Px = Port identifier – Address information !!!
Asynchronous (Statistical) TDM

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

 Explicit addressing by usage of address fields in the frame

Average data rates $\simeq 16$ kbit/s

© 2016, D.I. Lindner / D.I. Haas

TDM Techniques, v6.0
• If other users are silent, one user can fully utilize his/her access rate
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 channel 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

Trunk rate is dimensioned for average usage in statistical manner
Each user channel 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
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
Agenda

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

\[
R = 2 \cdot B \cdot \log_2 V
\]

---

**Telephone channel: 300-3400 Hz**

8000 Hz x 8 bit resolution = 64 kbit/s

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

[Diagram showing linear quantization with amplitude and time axes, highlighting quantization error]
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: $\mu$-law (Bell)
  - Europe: A-law (CCITT)

Conversion is task of the $\mu$-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

8 bit PCM sample

Segment 0
Segment 1
Segment 2
Segment 3

Amplitude

Polarity

Segment
Step

Time
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
Agenda

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

\[ E_1 = 30 \times 64 \text{ kbit/s} + \text{Overhead} \]

\[ E_2 = 4 \times 30 \times 64 \text{ kbit/s} + O \]

\[ E_3 = 4 \times 4 \times 30 \times 64 \text{ kbit/s} + O \]

\[ E_4 = 4 \times 4 \times 4 \times 30 \times 64 \text{ kbit/s} + O \]
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

<table>
<thead>
<tr>
<th>Signal</th>
<th>Carrier</th>
<th>Channels</th>
<th>Mbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td></td>
<td>1</td>
<td>0.064</td>
</tr>
<tr>
<td>DS1</td>
<td>T1</td>
<td>24</td>
<td>1.544</td>
</tr>
<tr>
<td>DS1C</td>
<td>T1C</td>
<td>48</td>
<td>3.152</td>
</tr>
<tr>
<td>DS2</td>
<td>T2</td>
<td>96</td>
<td>6.312</td>
</tr>
<tr>
<td>DS3</td>
<td>T3</td>
<td>672</td>
<td>44.736</td>
</tr>
<tr>
<td>DS4</td>
<td>T4</td>
<td>4032</td>
<td>274.176</td>
</tr>
</tbody>
</table>

## Europe

<table>
<thead>
<tr>
<th>Signal</th>
<th>Carrier</th>
<th>Channels</th>
<th>Mbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>&quot;E0&quot;</td>
<td>1</td>
<td>0.064</td>
</tr>
<tr>
<td>CEPT-1</td>
<td>E1</td>
<td>32</td>
<td>2.048</td>
</tr>
<tr>
<td>CEPT-2</td>
<td>E2</td>
<td>128</td>
<td>8.448</td>
</tr>
<tr>
<td>CEPT-3</td>
<td>E3</td>
<td>512</td>
<td>34.368</td>
</tr>
<tr>
<td>CEPT-4</td>
<td>E4</td>
<td>2048</td>
<td>139.264</td>
</tr>
<tr>
<td>CEPT-5</td>
<td>E5</td>
<td>8192</td>
<td>565.148</td>
</tr>
</tbody>
</table>

- 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

1 digital voice channel

DS0: 1 Byte

1 digital voice channel

31 digital voice channels

E1: 32 Byte

64 kbit/s

131 digital voice channel

E2: 132 Byte

2.048 kbit/s

125 μs

8.448 kbit/s

– 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

End-to-End Synchronization

Synchronous MUX

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

Asynchronous transport network

Network Clock (Stratum 1)

M14 + LT

DS0 Switch

M14 + LT

M14 + LT

M14 + LT

Synchronous MUX

E1

E1

E1

E1

E4

E4

E4

E4
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 (34 Mbit/s)
  - E4 (139 Mbit/s)

- Relevant standards
  - G.703: Interfacing and encoding
  - G.704: Framing
  - G.732: Multiplex issues
E1 Frame Structure

8000 frames per second

----- frame frame frame frame frame frame frame frame -----

8 bits per slot

<table>
<thead>
<tr>
<th>timeslot 0</th>
<th>timeslot 1</th>
<th>timeslot 2</th>
<th>timeslot 3</th>
<th>................</th>
<th>timeslot 31</th>
</tr>
</thead>
</table>

2.048 Mbit/s

Frame Alignment Signal (FAS) (every alternating frame)

<table>
<thead>
<tr>
<th>C</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
</table>

or

Not Frame Alignment Signal (NFAS) (every alternating frame)

| C | 1 | A | N | N | N | N | N | N |
CRC Multiframe Structure Timeslot 0

<table>
<thead>
<tr>
<th>timeslot 0</th>
<th>timeslot 1 ........... timeslot 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>frame 0</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 1</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 2</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 3</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 4</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 6</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 7</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 8</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 9</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 10</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 11</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 12</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 13</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>NFAS</td>
</tr>
<tr>
<td>frame 14</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>FAS</td>
</tr>
<tr>
<td>frame 15</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>NFAS</td>
</tr>
</tbody>
</table>

semi-multiframe 1

CRC Multiframe Sync - bits

0
0
1
0
1
1

semi-multiframe 2
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**

- **Semi-multiframe 1**
  - Channels 1-15
    - CAS Multiframe Alignment Pattern
    - Synchronization Pattern indicate start of multiframe structure

- **Semi-multiframe 2**
  - Channels 17-31
  - Yellow Alarm

### CAS Multiframe Alignment Pattern

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>X</th>
<th>Y</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C2</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C3</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C4</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C1</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C2</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C3</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C4</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>

© 2016, D.I. Lindner / D.I. Haas
TDM Techniques, v6.0
**T1 Basics**

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

![Diagram showing T1 frame structure]

- 8000 frames per second
- 8 bits per slot
- Extra bit for framing

---

© 2016, D.I. Lindner / D.I. Haas  
TDM Techniques, v6.0
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

one superframe SF / D4 Format

..... F frame 1 F frame 2 F frame 3 F frame 4 ..... F Frame 12 .....  

1 0 0 0 1101110 0 sync pattern

one (extended) superframe ESF
12 basic frames

..... F frame 1 F frame 2 F frame 3 F frame 4 ..... F Frame 24 .....  

24 basic frames

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

<table>
<thead>
<tr>
<th>Frame</th>
<th>Timeslot 1</th>
<th>...............</th>
<th>Timeslot 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame 1</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 2</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 3</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 4</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 5</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 6</td>
<td>Data</td>
<td>A</td>
<td>Data</td>
</tr>
<tr>
<td>Frame 7</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 8</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 9</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 10</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 11</td>
<td>Data</td>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Frame 12</td>
<td>Data</td>
<td>B</td>
<td>Data</td>
</tr>
</tbody>
</table>
Robbed Bit Signaling ESF

<table>
<thead>
<tr>
<th>Timeslot 1</th>
<th>............</th>
<th>Timeslot 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame 1</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>Frame 2</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>Frame 6</td>
<td>Data A</td>
<td>Data A</td>
</tr>
<tr>
<td>Frame 12</td>
<td>Data B</td>
<td>Data B</td>
</tr>
<tr>
<td>Frame 18</td>
<td>Data C</td>
<td>Data C</td>
</tr>
<tr>
<td>Frame 22</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>Frame 23</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>Frame 24</td>
<td>Data D</td>
<td>Data D</td>
</tr>
</tbody>
</table>
PDH Limitations

- PDH overhead increases dramatically with high bitrates
Agenda

• Introduction
• Synchronous (Deterministic) TDM
• Asynchronous (Statistical) TDM
• Telco Backbones
  – Digital Voice Transmission
  – PDH
  – SDH
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

- PTE: Path Termination Equipment
- REG: Regenerator Section
- ADM or DCS: Add-Drop Multiplexer or Digital Cross-Connect System
- Line: Line termination (MUX section termination)
- Service (DSn or En) mapping and demapping

SONET (SDH) Terms include:
- Path Termination
- Line Termination (MUX section termination)
- Section Termination
- Regenerator Section
- ADM or DCS (Add-Drop Multiplexer or Digital Cross-Connect System)
## SONET/SDH Line Rates

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

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

(Coming soon)
Uni- and Bi-directional Routing

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

Uni-directional Ring
(1 fiber)

Bi-directional Ring
(2 fibers)
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