Signaling, TDM Hierarchies/SONET and Switching #11

Overview

- Signaling & VoIP
- TDM Hierarchies and SONET
- Switching
  - “Crossbar”
  - Time division switching
  - Packet switching
  - Optical switching
Signaling

- Exchange of messages related to call setup, monitoring, teardown, and network management information.
- Provides command and control infrastructure for communications networks.
- End device (e.g., Telephone)-to-Switch and Between Switches
- Signaling enables the advanced features of modern communications (e.g., telephone) systems

Signaling

- In-band
- Out-of-band
- Common channel signaling
  - Reduces connect time
  - Increases signaling capacity
  - Increases flexibility
  - Enhanced customer services
  - Common Channel Interoffice Signaling (CCIS)
  - Common Signaling protocols
    - SS #7,
    - RSVP,
    - SIP,
    - H.323
Requirements for signaling

- **STRICT** performance and reliability requirements
  - Fast call set up
  - Always available
- To grow and provide more services signaling code must be:
  - Extensible
  - Maintainable
- Interoperability

SS7

- Signaling System 7
  - Predominant control signaling network for PSTN.
  - Signaling Point: use signaling to transmit and receive control information.
  - Signaling Link: interconnect signaling points.
  - Signaling Transfer Point (STP): transfer signaling messages from one link to another.
  - Signaling Control Point (SCP): database for SS7 network.
## SS7 Network

![SS7 Network Diagram](image)

SSP = SS7 Signaling Points  
SCP = Service Control Point  
STP = Signal Transfer Point

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## Signaling System 7 (SS7) Protocols

<table>
<thead>
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<th>SS7 layer name</th>
<th>Functionality</th>
<th>Internet example</th>
</tr>
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<td>Transport</td>
<td>Signaling Connection Control Part</td>
<td>Connections, sequence numbers, segmentation and reassembly, flow control</td>
<td>TCP</td>
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<td>Network</td>
<td>Message Transfer Part 3 (MTP-3)</td>
<td>Routing</td>
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<td>Datalink</td>
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</tr>
<tr>
<td>Physical</td>
<td>MTP-1</td>
<td>Physical bit transfer</td>
<td>Ethernet</td>
</tr>
</tbody>
</table>

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From: An Engineering Approach to Computer Networks, S. Keshav
Resource ReSerVation Protocol (RSVP)

- Designed to provide integrated services across the Internet.
- Host requests service with very specific connection parameters from the network.
- Each network element along the specified path will receive a requested for dedicated resources (e.g., bandwidth).
- If all nodes along the path dedicate the resources, the reservation is complete and the host may begin use.
Voice over IP (VoIP)

- A network that transmits voice packets over IP.
- Specialized signaling protocols are used to set up and tear down calls, carry information required to locate users and negotiate capabilities.
- Voice signal is digitized, compressed and converted to IP packets.

Voice over the Internet: Benefits

- Can place a phone call to any other internet telephony user anywhere in the world and only pay for call to local ISP
- Simplifies voice/data conferencing
- Enhanced helpdesks
- Enhanced on-line order placement
- Integration offers potential to reduce administrative cost
Voice over the Internet: Problems

- Quality of Service
  - The internet is currently "best effort"
  - The internet is unreliable
- Lack of standards
  - plethora of proprietary solutions
  - Lack of Interoperatability
- Lack of high volume call processing capability
- 911

Session Initiation Protocol (SIP)

- Session Initiation Protocol
- Comes from IETF
- All telephone calls and video conference calls take place over the Internet
- People are identified by names or e-mail addresses, rather than by phone numbers.
- You can reach the callee, no matter where the callee roams, no matter what IP device the callee is currently using.
Session Initiation Protocol (SIP)

- Begins, changes and terminates network sessions.
- Provides advanced signaling and control to an IP network.
- User Agent: end users of the SIP network that initiate requests and are the destination of services offered across the SIP network.
- Registrar: manage user agents assigned to their network domain.
- Proxy Server: forward SIP requests and responses.
- Redirect Server: take SIP requests and return location information of another user agent or server.
- Location Server: locates the next-hop for an incoming session request.
- Also, media GW and signaling GW for interworking with PSTN.
SIP Services

- **Setting up a call**
  - Provides mechanisms for caller to let callee know she wants to establish a call
  - Provides mechanisms so that caller and callee can agree on media type and encoding.
  - Provides mechanisms to end call.

- **Determine current IP address of callee.**
  - Maps mnemonic identifier to current IP address

- **Call management**
  - Add new media streams during call
  - Change encoding during call
  - Invite others
  - Transfer and hold calls

---

Setting up a call to a known IP address

- Alice’s SIP invite message indicates her port number & IP address. Indicates encoding that Alice prefers to receive (PCM ulaw)
- Bob’s 200 OK message indicates his port number, IP address & preferred encoding (GSM)
- SIP messages can be sent over TCP or UDP; here sent over RTP/UDP.
- Default SIP port number is 5060.
Setting up a call (more)

- Codec negotiation:
  - Suppose Bob doesn’t have PCM ulaw encoder.
  - Bob will instead reply with 606 Not Acceptable Reply and list encoders he can use.
  - Alice can then send a new INVITE message, advertising an appropriate encoder.
- Rejecting the call
  - Bob can reject with replies “busy,” “gone,” “payment required,” “forbidden”.
- Media can be sent over RTP or some other protocol.
- Signaling and media can go over different paths.

Example of SIP message

```
INVITE sip:bob@domain.com SIP/2.0
Via: SIP/2.0/UDP 167.180.112.24
From: sip:alice@hereway.com
To: sip:bob@domain.com
Call-ID: a2e3a@pigeon.hereway.com
Content-Type: application/sdp
Content-Length: 885

c=IN IP4 167.180.112.24
m=audio 38060 RTP/AVP 0
```

Notes:
- HTTP message syntax
- sdp = session description protocol
- Call-ID is unique for every call.

- Here we don’t know Bob’s IP address. Intermediate SIP servers will be necessary.
- Alice sends and receives SIP messages using the SIP default port number 506.
- Alice specifies in Via: header that SIP client sends and receives SIP messages over UDP.
Name translation and user location

- Caller wants to call callee, but only has callee’s name or e-mail address.
- Need to get IP address of callee’s current host:
  - user moves around
  - DHCP protocol
  - user has different IP devices (PC, PDA, car device)
- Result can be based on:
  - time of day (work, home)
  - caller (don’t want boss to call you at home)
  - status of callee (calls sent to voicemail when callee is already talking to someone)

Service provided by SIP servers:
- SIP registrar server
- SIP proxy server

SIP Registrar

- When Bob starts SIP client, client sends SIP REGISTER message to Bob’s registrar server
  (similar function needed by Instant Messaging)

Register Message:

```
REGISTER sip:domain.com SIP/2.0
Via: SIP/2.0/UDP 193.64.210.89
From: sip:bob@domain.com
To: sip:bob@domain.com
Expires: 3600
```
SIP Proxy

- Alice sends invite message to her proxy server
  - contains address sip:bob@domain.com
- Proxy responsible for routing SIP messages to callee
  - possibly through multiple proxies.
- Callee sends response back through the same set of proxies.
- Proxy returns SIP response message to Alice
  - contains Bob’s IP address
- Note: proxy is analogous to local DNS server

Example: Caller jim@umass.edu with places a call to keith@upenn.edu

(1) Jim sends INVITE message to umass SIP proxy. (2) Proxy forwards request to upenn registrar server. (3) upenn server returns redirect response, indicating that it should try keith@eurecom.fr

(4) umass proxy sends INVITE to eurecom registrar. (5) eurecom registrar forwards INVITE to 197.87.54.21, which is running keith’s SIP client. (6-8) SIP response sent back (9) media sent directly between clients.

Note: also a SIP ack message, which is not shown.
Signal Transport (SigTran)

- Developed to allow VoIP networks to utilize the extensive functionality and superior performance of SS7.
- Interworks VoIP network with SS7/PSTN
- SS7 packets are encapsulated in IP packets by Signaling GW and sent to Media GW Controller which makes routing decisions.
- Media stream (voice) is encapsulated in IP packets by Media GW.

Comparison with H.323

- H.323 is another signaling protocol for real-time, interactive
- H.323 is a complete, vertically integrated suite of protocols for multimedia conferencing: signaling, registration, admission control, transport and codecs.
- SIP is a single component. Works with RTP, but does not mandate it. Can be combined with other protocols and services.
- H.323 comes from the ITU (telephony).
- SIP comes from IETF: Borrows much of its concepts from HTTP. SIP has a Web flavor, whereas H.323 has a telephony flavor.
- SIP uses the KISS principle: Keep it simple stupid.
Components of H.323 System

H.323 is a set of standards to support real-time multimedia communications on Packet Networks, call control, management, and interfacing issues.

From: Leon-Garcia & Widjaja: Communication Networks

TDM Frame Structures

Continued on next slide...
TDM Frame Structures

Continued from previous slide

Channel

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

"s" Bit

Bit #2 Used for Alarm Signal for Loss of PCM Stream; if Bit #2 is "0" for Every Channel Word of 1 Frame, Causes Remote Alarm

If Channel Word is all "0"s", Bit #7 is stuffed with a "1" to Maintain at Least 1 Pulse in Every 8 Slots for Timing - Known as Zero Code Suppression

Channel A Signalling - Bit 8 of Frame 6
Channel B Signalling - Bit 8 of Frame 12
i.e. "0" On-Hook, "1" Off-Hook

---

T-1 Frame Structures

- Bit Rate = 8000 frames/sec. x (1 + 8 x 24) bits/frame = 1.544 Mbps
- Framing bit used to synchronize, look for 101010
- In Band Signalling (Bit Robbing for Off and On hook, Alarms, Busy)
- Super Frames (12 consecutive frames, Only Every 6\textsuperscript{th} Frame do we steal a bit from the least significant bit of each channel.
- Extended Super Frame (24 frames, 6 bits for sync, rest for diagnostics - can test without taking link down)
- Dedicated circuits don’t rob bits. (Clear Channel)

Figure 4.4 Leon-Garcia, Widjaja
T-Carrier Framing Cont.

- **Timing**
  - Bit Sync – recover the clock from received bit stream
  - Requires minimum one’s density – can’t flatline.
  - Voice coding schemes never encode a sample as all zeros
  - But data could so ..
    - AMI - Alternate Mark Inversion - Steal a bit per byte and set it to 1 – Zero Code Suppression (ZCS) – 56K per DS0. AMI alternates the polarity of a “1” being transmitted.
    - Or use B8ZS – substitution, along with line encoding trick. Perform a deliberate AMI violation, i.e. don’t alternate on 4th and 7th bit of the substitution pattern. The pattern is 0011011. - Can transmit full 64K data – Clear Channel

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North America T- System

- **DS0**, 64 Kbps channel
- **DS1**, 1.544 Mbps channel
- **DS2**, 6.312 Mbps channel
- **DS3**, 44.736 Mbps channel
- **DS4**, 274.176 Mbps channel

Figure 4.5 Leon-Garcia, Widjaja
TDM Frame Structures

- E1 System
- 32 time slots
- 8 bits/slot
- 2.048 Mb/s
- 2 time slots (128 kb/s) used for signaling

SONET

(Synchronous Optical Network)

- Open standard for optical transmission and interfaces
- It defines standard optical signals, a synchronous frame structure for multiplexed digital traffic, and operations procedures
- SONET (Synchronous Optical Network) is an specification developed by Bellcore in 1985 for optical transmission networks
SONET

(Synchronous Optical Network)

- ITU-T (CCITT) also adopted a set of SONET interface standards
- By the end of the 1980s, ITU-T (CCITT) adopted SONET as one of the physical layer standards for BISDN
- Framing overhead not in the cell structure
- Transport overhead distributed throughout the frame
- **Frame time = 125\text{us}**

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**SONET**

- Extensive management, performance monitoring, and fault detection
  - Operations, Administration, and Maintenance (OAM) functions
- Synchronous multiplexing
- Compatible with DS0, DS1, and DS3 transport mechanism as well as ATM
- Software control and access to DS0, DS1, and DS3, Add/Drop multiplexers
- Transport of advanced services
SONET Multiplexing

- **Low-speed mapping function**: DS1, DS2, E1
- **Medium speed mapping function**: DS3, E4
- **High-speed mapping function**: ATM or POS

- **STS-1**: 51.84 Mbps
- **STS-n**: Concatenated

- **PTS ==> Synchronous Transport Signal (Electrical)**
- **POS ==> Packet over SONET**

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SONET
Layered Architecture

- **Photonic Layer --> Light transfer**
- **Section Layer -----> Frame transport**
- **Line Layer +---------+ Multiplexing**
- **Path Layer +--------+ Map services into synchronous payload**
SONET: Physical Hierarchy

- **Section**: Basic building block, a single run of optical cable between transmitter/receiver
- **Line**: Sequence of sections connected by repeaters; line end points are muxers or switches
- **Path**: Sequence of lines connecting the end terminals

SONET Layered Architecture

- **By Signaling between elements**
  - Section Terminating Equipment (STE): span of fiber between adjacent devices, e.g. regenerators – Frame Transport
  - Line Terminating Equipment (LTE): span between adjacent multiplexers, encompasses multiple sections - Multiplexing
  - Path Terminating Equipment (PTE): span between SONET terminals at end of network, encompasses multiple lines – Map services into payload
- **By Functionality**
  - ADMs: dropping & inserting tributaries
  - Regenerators: digital signal regeneration
  - Cross-Connects: interconnecting SONET streams
SONET

- SONET Rates

<table>
<thead>
<tr>
<th>Line Rate (Mbps)</th>
<th>CCITT Designation</th>
<th>ANSI Designation</th>
<th>Optical Level</th>
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<tbody>
<tr>
<td>51.84</td>
<td>STS-1</td>
<td>STS-1</td>
<td>OC-1</td>
</tr>
<tr>
<td>155.52</td>
<td>STM-1</td>
<td>STS-3</td>
<td>OC-3</td>
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<td>466.56</td>
<td>STM-3</td>
<td>STS-9</td>
<td>OC-9</td>
</tr>
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<td>622.08</td>
<td>STM-4</td>
<td>STS-12</td>
<td>OC-12</td>
</tr>
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<td>933.12</td>
<td>STM-6</td>
<td>STS-18</td>
<td>OC-18</td>
</tr>
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<td>1244.16</td>
<td>STM-8</td>
<td>STS-24</td>
<td>OC-24</td>
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<td>1866.24</td>
<td>STM-12</td>
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<td>OC-36</td>
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<td>2488.32</td>
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<td>STS-48</td>
<td>OC-48</td>
</tr>
<tr>
<td>9953.28</td>
<td></td>
<td>Available for IP router interfaces</td>
<td>OC-192</td>
</tr>
<tr>
<td>99,313</td>
<td></td>
<td></td>
<td>OC-768</td>
</tr>
</tbody>
</table>

Starting to appear in MANs

SONET: Frame Structure (STS-1/OC-1)

- 9 Bytes Section
- 18 Bytes Line
- 9 Bytes Path
- 774 Bytes Payload

810 Bytes*(8bits/Byte)/125us= 51.84 Mb/s
SONET: Frame Structure (STS-1/OC-1)

STS-1 Envelope Capacity

\[
\frac{(90 \text{ bytes} \times 9 \text{ rows} \times 8 \text{ bits/byte})}{125 \text{us}} = 51.84 \text{Mb/s}
\]

SONET: Frame Structure (STS-N/OC-N)
SONET Overhead

<table>
<thead>
<tr>
<th>Section Overhead</th>
<th>Path Overhead</th>
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<tbody>
<tr>
<td>Framing A1</td>
<td>Trace J1</td>
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<tr>
<td>Framing A2</td>
<td>BIP-8</td>
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<tr>
<td>Framing C1</td>
<td>B3</td>
</tr>
<tr>
<td>B1 Orderwire</td>
<td>Data Comm D1</td>
</tr>
<tr>
<td>User F1</td>
<td>Data Comm D2</td>
</tr>
<tr>
<td>User E1</td>
<td>Data Comm D3</td>
</tr>
<tr>
<td>Data Comm D1</td>
<td>Point Act H3</td>
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<tr>
<td>Data Comm D2</td>
<td>Status G1</td>
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<td>User Chan F2</td>
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<td>Point Act H3</td>
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<tr>
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<td>Orderwire E2</td>
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<tr>
<td>Growth Z1</td>
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</tbody>
</table>

SONET Operation, Administration, and Maintenance (OAM)

ATE: ATM Terminating Equipment
PTE: SONET Path Terminating Equipment
LTE: SONET Line Terminating Equipment
STE: SONET Section Terminating Equipment
Wavelength-division Multiplexing (WDM)

Today each wavelength carries a SONET signal

Beyond SONET: Future transport over WDM Using Digital Wrapper
Beyond SONET: Optical Burst Switching

Switching

- Fully connected

Number Nodes = N
Number of Lines = N(N-1)/2

Disadvantages: N is large
Long distances between nodes
Each node does switching

\( N^2 \) Problem
Switching

- Centralized switching

![Diagram showing a central switching node with connections to and from other switches, and control to operate connections.]

Switch Architectures

- Crossbar
- Time division multiplex
Crossbar Switch
Switch Architectures

Cross point:
Electromagnetic
Electronic
Optical

Input

Distribution
Switch-to-Switch

Output

Crossbar Switch

Concentration
K > L
Switch-to-Trunk

Input

Output
Crossbar Switch

Expansion
Trunk-to-Switch
P < K

Nonblocking Networks

- N ports need \( \sim N^2 \) switch connections or cross-points
- Using multistage switch architectures, fewer cross points are needed
- Multistage switch architectures provide the model for the current generation of digital switches
- Optical crossbar switches are appearing in optical networks
Three Stage Spatial Switch Architectures

- Every stage 1 switch has one connection to each center stage switch
- Every stage 3 switch has one connection to each center stage switch
- Stage 1 switches are expansion stages
- Center stage switches are distribution stages
- Stage 3 switches are concentration stages
Three Stage Spatial Switch Architectures

- N input ports
- N output ports
- k center stage switches
- n input ports/first stage switch
- n output ports/last stage switch
- N/n first(last) stage switches

N = 512, n = 32, k = 16
Three Stage Spatial Switch

Architectures: Nonblocking Analysis

- \( n-1 \) (15) center stage switches busy serving output from stage 1 element
- \( n-1 \) (15) center stage switches busy serving input to stage 3 element
- Need one more center stage switch to serve the 16\(^{th}\) input port on the stage one element
- \( k = (n-1) + (n-1) + 1 = 2n - 1 \) needed for nonblocking

<table>
<thead>
<tr>
<th>Number of cross points</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_c = (N/n)(k \cdot n) + k(N/n)^2 + (N/n)(k \cdot n) )</td>
</tr>
<tr>
<td>= ( 2Nk + \frac{kN^2}{n^2} )</td>
</tr>
</tbody>
</table>

To prevent blocking

- \( k = 2n - 1 \), so

- \( N_c = 2N(2n - 1) + (2n - 1) \left( \frac{N}{n} \right)^2 \)

Minimum \( N_c = 4N(\sqrt{2N} - 1) \)

Optimum \( n = \sqrt{\frac{N}{2}} \)

Example: \( N = 8,192 \) --> Single Stage Switch \( N_c = 67 \text{ Million} \)

Three Stage Switch \( N_c = 4.2 \text{ Million} \)
Optical Switch fabric 512 ports

From: ALCATEL

Enabling Technology
Agilent Technologies’ Photonic Switch

♦ Innovative use of reliable inkjet
♦ Light switched based on the principle of Total Internal Reflection

From: ALCATEL
Agilent Optical Switch Concept

Top-Down View

Diagonal Cross Section

 Transmitting when “bubble” is absent

Index-matching fluid

Reflecting when “bubble” is present

Silica planar lightwave chip

Silica planar lightwave chip

Silicon matrix controller chip

Optical fibers

Index-matching fluid

Actuator off (Transmitting)

Principle (cont’d)

From: ALCATEL

Signaling .... 66
Principle (cont’d)

![Principle Diagram]

Actuator on (Reflecting)

From: [ALCATEL]

Characteristics

- # of ports: 32 x 32
- Insertion loss: 5.0 dB average
- Channel isolation: > 50 dB
- Return loss: < -38 dB
- PDL: < 0.3 dB
- Switching time: < 7 ms
- Optical bandwidth: 1260 to 1650 nm

From: [ALCATEL]
Assembly

Switch Module

• 32x32 switch
• Waveguide chip, Matrix Controller Chip, Fibers
• Strictly non-blocking + add/drop ports
• Integrated test and monitoring

• Full control electronics
• Well defined interfaces
• Full diagnostics

Digital Switching

- All voice signals are digital
- TDM is used
- Sample rate is 8000 samples/sec.
- Time between samples is 125us
- 8 bits/sample

1 24

125us
Digital Switching: Time Slot Interchanger (T)

Let $N_s =$ Number of time slots/frame

Rate = $(N_s*8)/125\text{us b/s}$

Memory requirement = $(N_s*8)\text{bits}$
Digital Switching

Examples:

- \( N_s = 128 \)
  - Rate = \( \frac{(128\times8)}{125\text{us}} = 8.192\text{Mb/s} \)
  - Memory = 128 bytes

- \( N_s = 131,072 \) (ESS #4)
  - Rate = 8.389 Gb/s
  - Memory 131,072 bytes

Digital Switching

- Time shared space division switch (S)
  - Fast electronic crossbar switch
  - Switch configuration changes every time slot
  - Each input(output) is a TDM bus
  - Slot X on TDM input bus i can be switched to Slot X on TDM output bus j
## Time Shared Space Division Switch

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$S_{11}$</td>
<td>$S_{12}$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$S_{21}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>$S_{m1}$</td>
<td>$S_{m2}$</td>
<td>$S_{mn}$</td>
</tr>
</tbody>
</table>

### Time Slot $i$

### Time Slot $i+1$
Time shared space division switch

Digital Switch Architectures

- One stage: TSI only (T)
  - Can build a switch with T stage
- One stage: Time shared space division only (S)
  - Usually one component of larger switching system
Digital Switch Architectures: T-S

User A on input TDM slot 3, bus 1 ==>
User B on output TDM slot 6, bus 5

T stage does TSI
Input to S stage is slot 6 on bus 1
S stage does space switching
Output is slot 6 on bus 5

Digital Switch Architectures T-S-T
Digital Switch Architectures

- Slot 2 on bus 1 --> Slot 5 on Bus 10
  - Slot 2 on bus 1 (TSI) Slot 5 on bus 1 (input to S-stage)
  - Slot 5 on bus 1 (S) Slot 5 on bus 10
- Slot 3 on bus 1 --> Slot 5 on Bus 20
  - Slot 3 on bus 1 (TSI) Slot 4 on bus 1 (input to S-stage)
  - Slot 4 on bus 1 (S) Slot 4 on bus 20 (output from S-stage)
  - Slot 4 on bus 20 (TSI) Slot 5 on bus 20

Time-Space-Time Switch
Digital Switch Architectures
Non-blocking Analysis

Let $T_{in} = \text{Total number on input time slots} = m(\text{busses})T \text{ (slots/bus)}$

Let $N_{in} = \text{Total number of space stage time slots} = m \text{ (busses)} N(\text{slots/bus})$

Using same analysis applied to the three stage switch,
if $N_{in} = 2T_{in} - 1$ then the system is nonblocking.

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**Example:**

Number of users = 2048, $T = 128$, $m = 16$

A 16 - by - 16 switch at 8.192 Mb/s per bus.

$N_{in} = 2T_{in} - 1 = 2(128)16 - 1 \sim 4096$

$N = N_{in} / m = 4096/16 = 256$

A speed up of a factor of two in the space stage switch will make the TST switch nonblocking.
The Structure of the Telephone Network

Fig. 2-15. Typical circuit route for a medium-distance call.

From: Computer Networks, A. S. Tanenbaum

The Structure of the Telephone Network

Fig. 2-16. The relationship of LATAs, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is in it.

From: Computer Networks, A. S. Tanenbaum
The “port count” problem

Typical Drawing of a switch

Switch

The “port count” problem

Hardware implementation

Interfaces

Interfaces