Signaling, TDM Hierarchies/SONET and Switching #13

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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

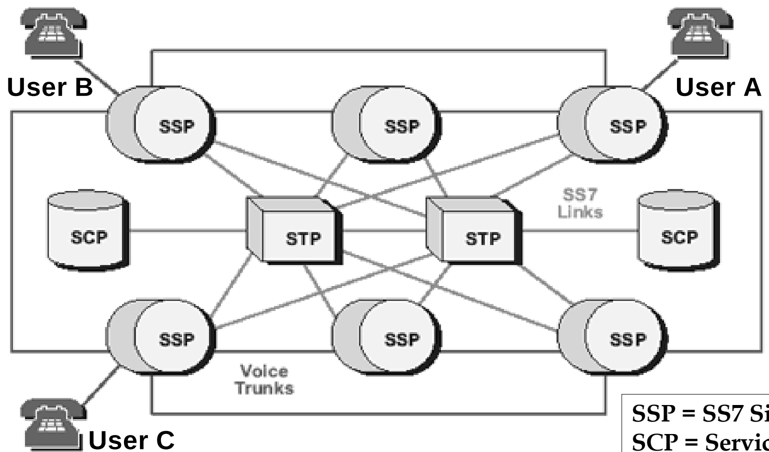
Requirements for signaling

- **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



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

From: International Engineering Consortium,
http://www.iec.org/online/tutorials/ip_in/topic01.html, 2002

Signaling System 7 (SS7) Protocols

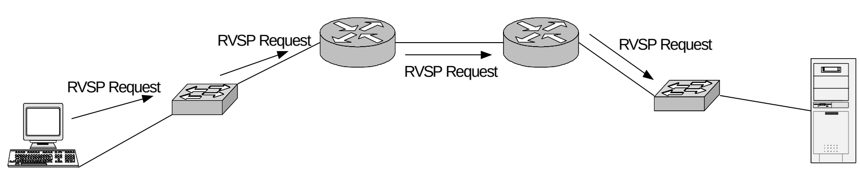
OSI layer name	SS7 layer name	Functionality	Internet example
Application	Application Service Element	Application	FTP
	Transaction Capabilities Application part	RPC	RPC
Transport	Signaling Connection Control Part	Connections, sequence numbers, segmentation and reassembly, flow control	TCP
Network	Message Transfer Part 3 (MTP-3)	Routing	IP
Datalink	MTP-2	Framing , link-level error detection and retransmission	Ethernet
Physical	MTP-1	Physical bit transfer	Ethernet

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.

Resource ReSerVation Protocol (RSVP)



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:
Common Operational Modes

- PC-to-PC
  - Requires connection to "Internet"
  - Requires PC sound card
  - Requires internet voice software
- PC-to-Phone
  - Requires connection to "Internet"
  - Requires PC sound card
  - Requires internet voice software
  - Requires an internet-to-telephone gateway (switch-to-router)
- Phone-to-Phone
  - Requires connection to "Internet"
  - Requires PC sound card
  - Requires internet voice software
  - Requires an internet-to-telephone gateway (switch-to-router)

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

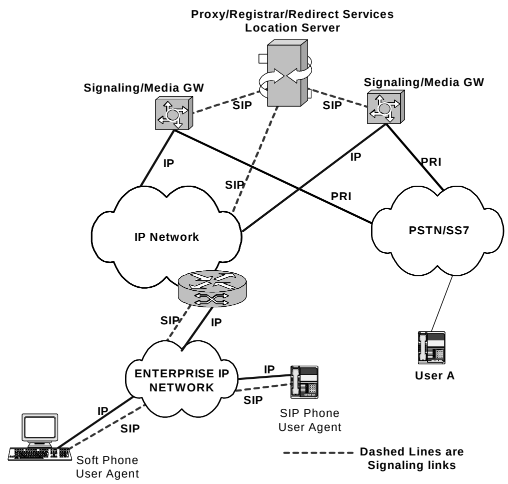
<u>SIP long-term vision</u>

- 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.

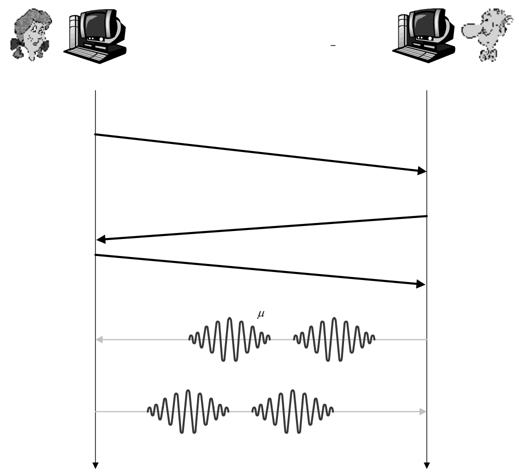
Session Initiation Protocol (SIP) Network Elements



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

180.112.24

INVITE bob(
c=IN IP4 167
m=audio 380

port 5060

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)

<u>Service provided by SIP servers:</u>
- 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:

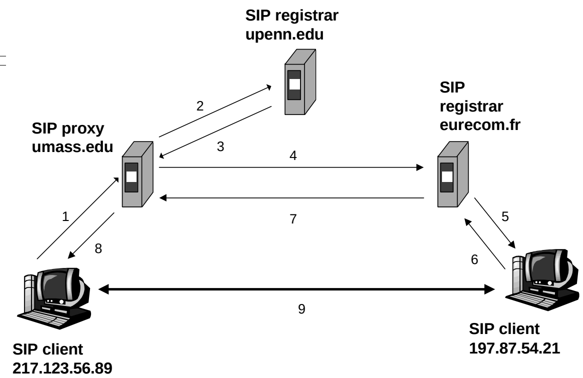
```
REGISTER sip:domain.com SIP/2.0
Via: SIP/2.0/UDP 193.64.210.89
From: sip:bob@domain.com
To: sip:bob@domain.com
Expires: 3600
```


SIP Proxy

- Alice send's 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 regristrar 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)

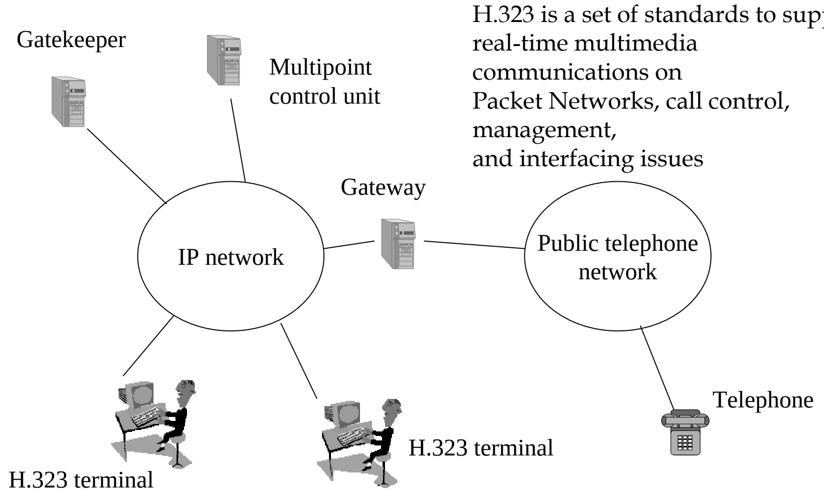
- Developed to allow VoIP networks to utilize the extensive functionality and superior performance of SS7.
- Interworks VoIP network with SS7/PSTN
- SS7 packets are encapsulated in IP packets by Signaling GW and sent to Media GW Controller which makes routing decisions.
- Media stream (voice) is encapsulated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

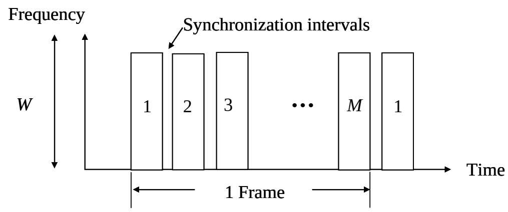
H.323 is a set of standards to support real-time multimedia communications on
Packet Networks, call control, management,
and interfacing issues



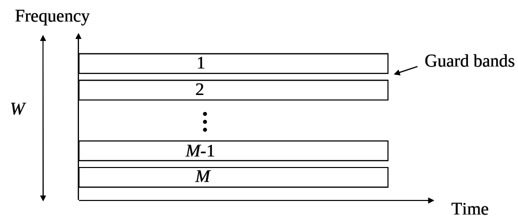
From: Leon-Garcia & Widjaja: *Communication Networks*

TDM & FDM

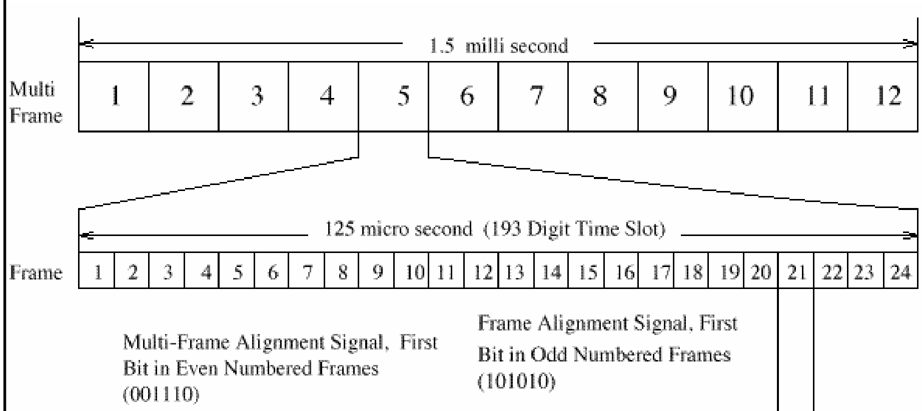
Time Division Multiplexing



Frequency Division Multiplexing



TDM Frame Structures



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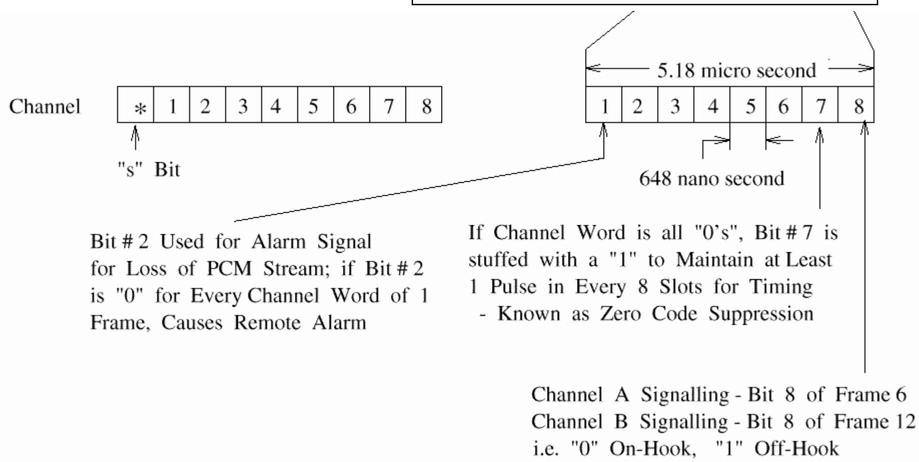
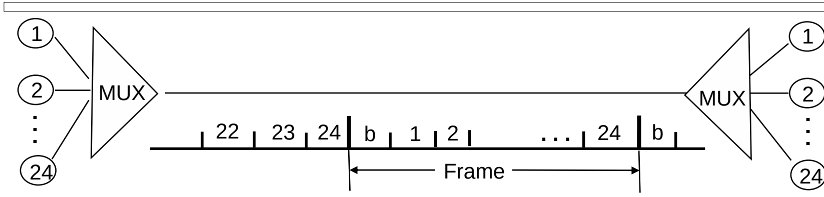
TDM Frame Structures

Continued from previous slide



T-1 Frame Structures



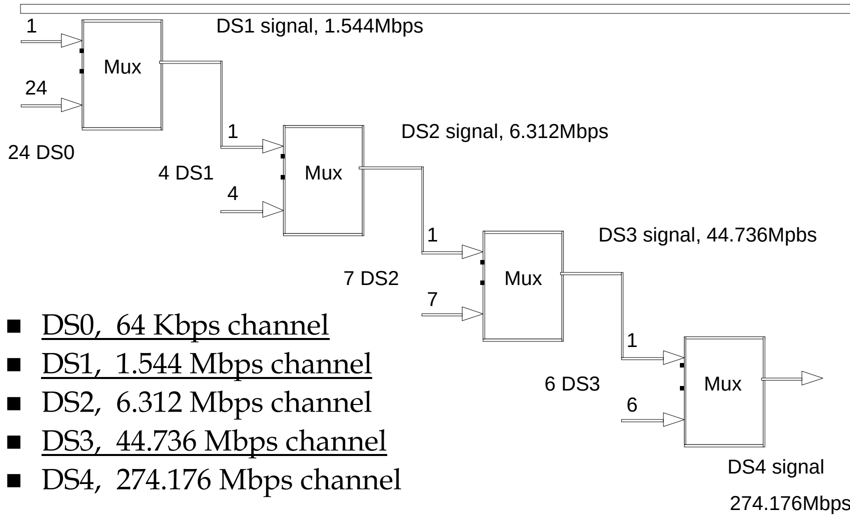
- Bit Rate = 8000 frames/sec. x (1 + 8 x 24) bits/frame = 1.544 Mbps
- Framing bit used to synchronize, look for 101010
- In Band Signalling (Bit Robbing for Off and On hook, Alarms, Busy)
- Super Frames (12 consecutive frames, Only Every 6th Frame do we steal a bit from the least significant bit of 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 00011011. - Can transmit full 64K data – Clear Channel

North America T- System



- <u>DS0, 64 Kbps channel</u>
- <u>DS1, 1.544 Mbps channel</u>
- DS2, 6.312 Mbps channel
- <u>DS3, 44.736 Mbps channel</u>
- 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

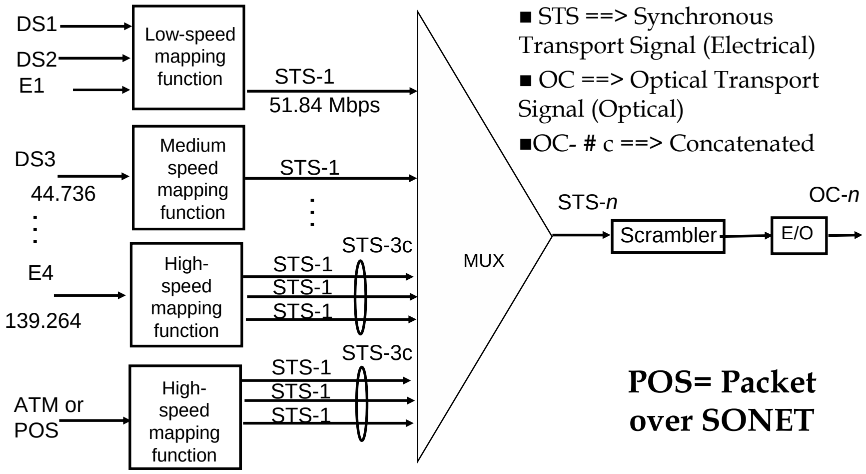
SONET
(Synchronous Optical Network)

- 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 = 125us**

SONET

- Extensive management, performance monitoring, and fault detection
- 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



- STS ==> Synchronous Transport Signal (Electrical)
- OC ==> Optical Transport Signal (Optical)
- OC- # c ==> Concatenated

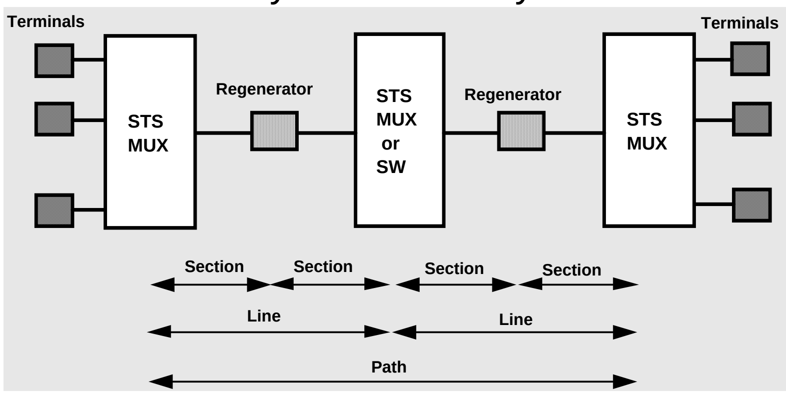
POS= Packet over SONET

Figure 4.10 Leon-Garcia, Widjaja

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

Line Rate (Mbps)	CCITT Designation	ANSI Designation	Optical Level
51.84		STS-1	OC-1
155.52	STM-1	STS-3	OC-3
466.56	STM-3	STS-9	OC-9
622.08	STM-4	STS-12	OC-12
933.12	STM-6	STS-18	OC-18
1244.16	STM-8	STS-24	OC-24
1866.24	STM-12	STS-36	OC-36
2488.32	STM-16	STS-48	OC-48
9953.28			OC-192
39,813			OC-768

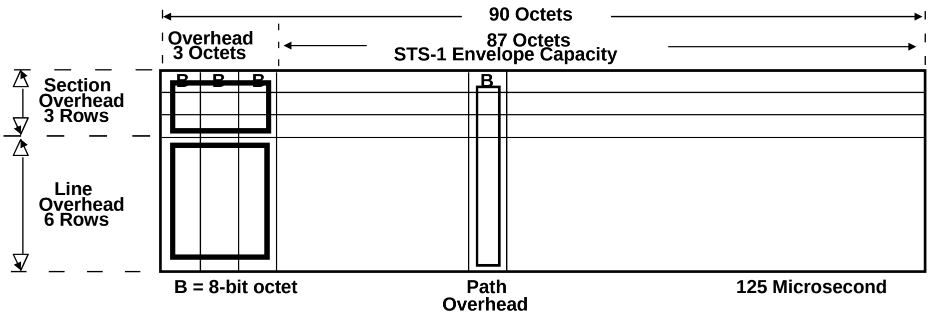
Available for IP router interfaces

Starting to appear in MANs

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

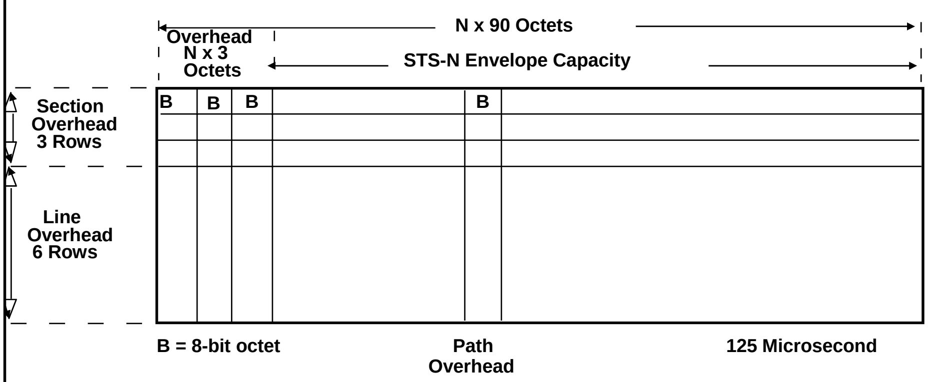
- 9 Bytes Section
- 18 Bytes Line
- 9 Bytes Path
- 774 Bytes Payload
- 810 Bytes*(8bits/Byte)/125us= 51.84 Mb/s

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



(90 bytes*9 rows*8 bits/byte)/125us = 51.84Mb/s

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

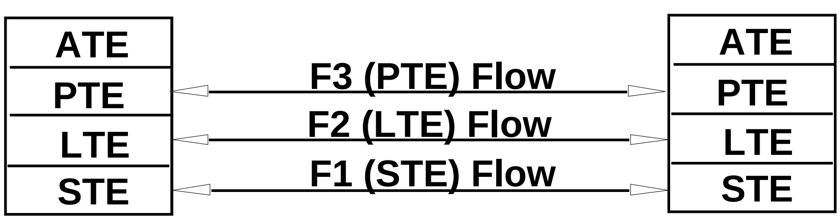


SONET Overhead

Section Overhead	Framing A1	Framing A2	STS-1 ID C1	Trace J1	Path Overhead
	BIP-8 B1	Orderwire E1	User F1	BIP-8 B3	
	Data Comm D1	Data Comm D2	Data Comm D3	Sig Label C2	
Line Overhead	Pointer H1	Pointer H2	Point Act H3	Status G1	
	BIP-8 B2	APS K1	APS K2	User Chan F2	
	Data Comm D4	Data Comm D5	Data Comm D6	Indicator H4	
	Data Comm D7	Data Comm D8	Data Comm D9	Growth Z3	
	Data Comm D10	Data Comm D11	Data Comm D12	Growth Z4	
	Growth Z1	Growth Z2	Orderwire E2	Growth Z5	

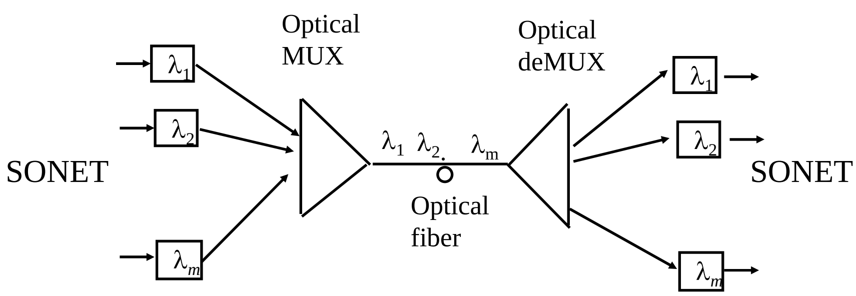
SONET

Operation, Administration, and Maintenance (OAM)

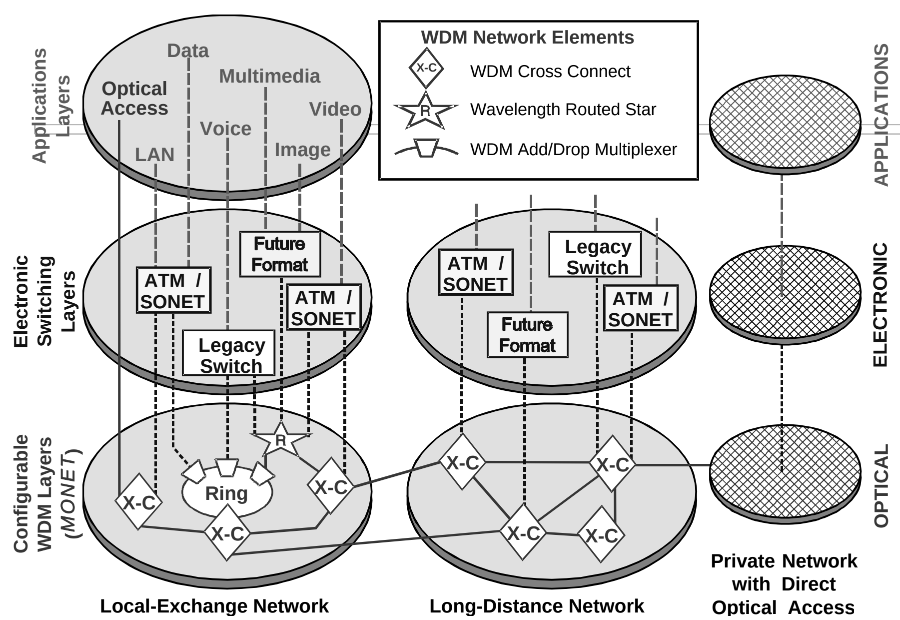


ATE: ATM Terminating Equipment
PTE: SONET Path Terminating Equipment
LTE: SONET Line Terminating Equipment
STE: SONET Section Terminating Equipment

Wavelength-division Multiplexing (WDM)

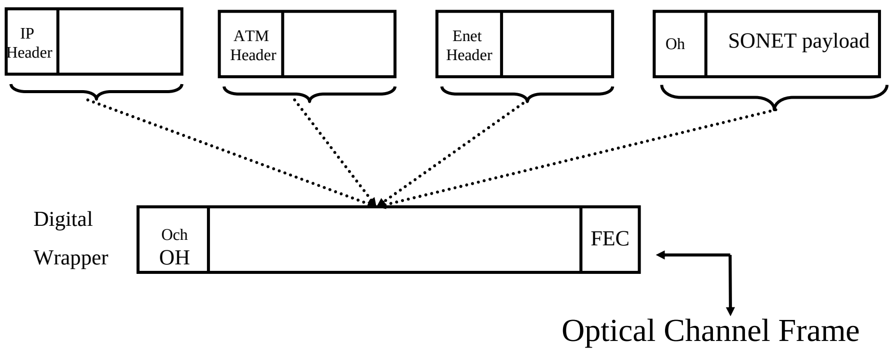


Today each wavelength carries a SONET signal

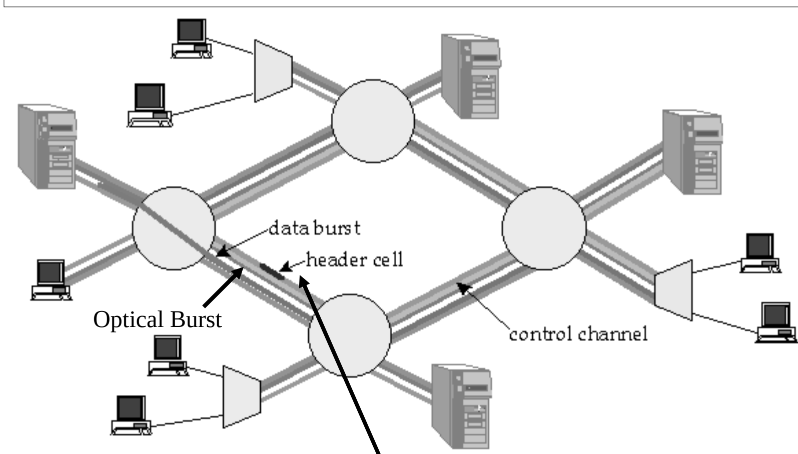


From R. E.Wagner, MONET Overview
DARPA NETS PI Meeting 3-7-97

Beyond SONET:
Future transport over WDM Using Digital Wrapper



Beyond SONET:
Optical Burst Switching

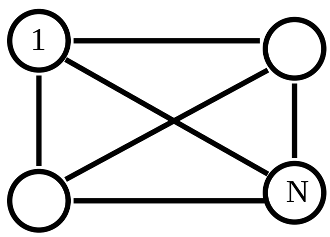


Switch configuration using optical control Burst

From: WDM Burst Switching Jonathan S. TURNER <jst@cs.wustl.edu>
Washington University in St. Louis, USA http://www.isoc.org/inet99/4j/4j_3.htm

Switching

- Fully connected

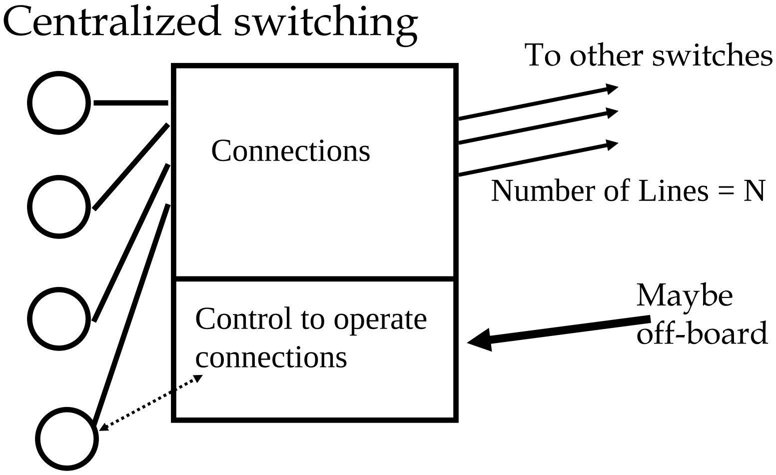


Number Nodes = N
Number of Lines = N(N-1)/2

Disadvantages: N is large
Long distances between nodes
Each node does switching
N^2 Problem

Switching

- Centralized switching

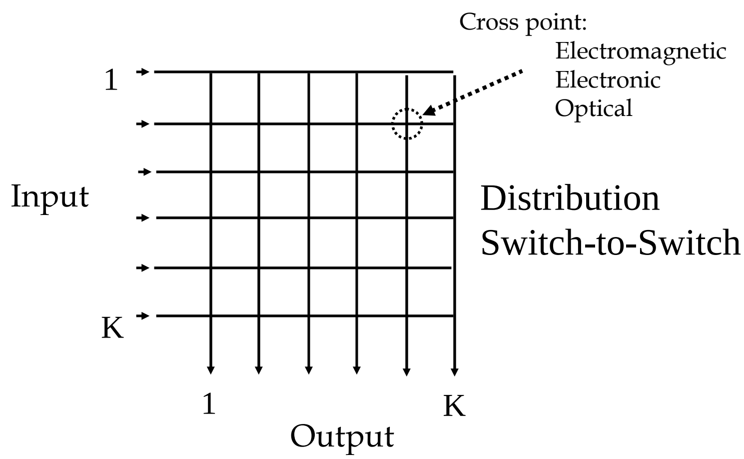


Switch Architectures

- Crossbar
- Time division multiplex

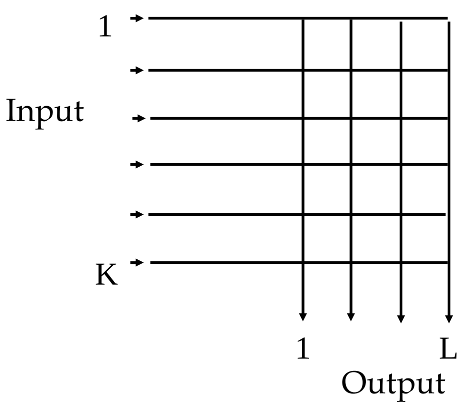
Crossbar Switch

Switch Architectures



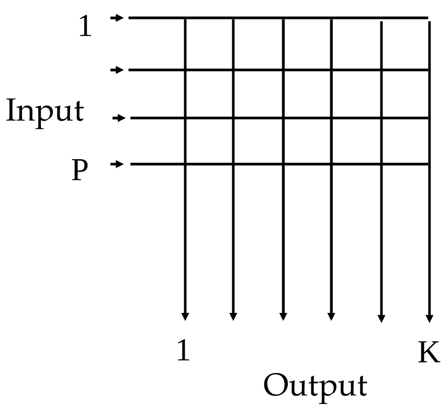
Distribution
Switch-to-Switch

Crossbar Switch



Concentration
K > L
Switch-to-Trunk

Crossbar Switch

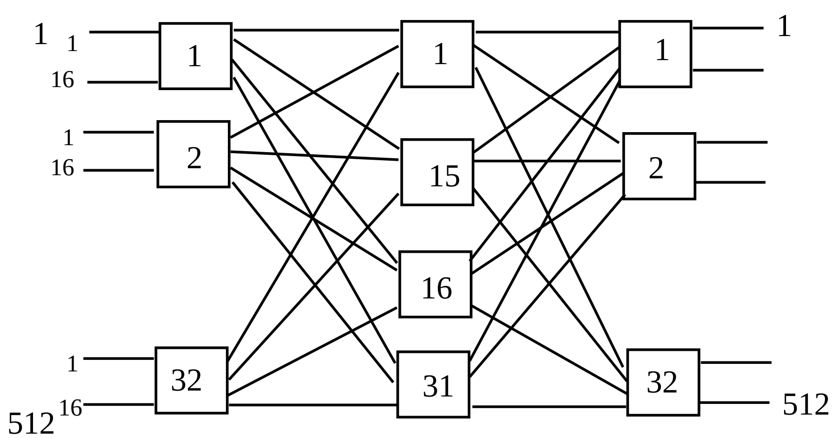


Expansion
Trunk-to-Switch
P < K

Nonblocking Networks

- N ports need ~N*N 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



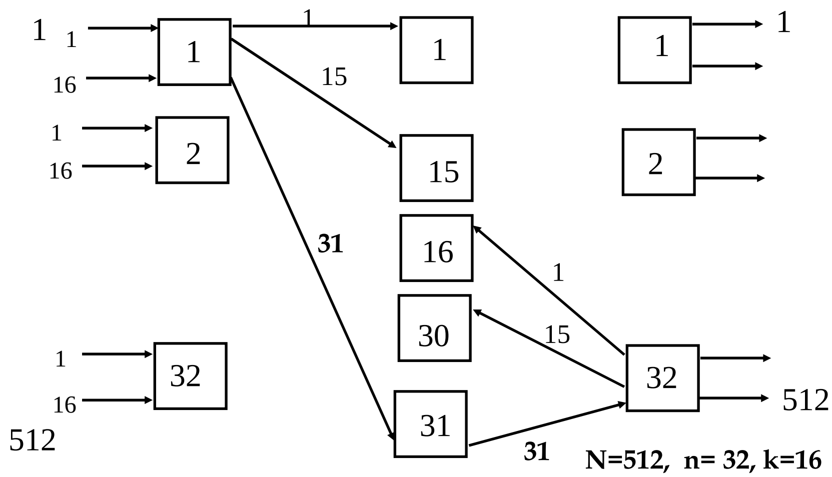
Three Stage Spatial Switch Architectures

- 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

Three Stage Spatial Switch Architectures
Nonblocking Analysis



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 16th input port on the stage one element
- k = (n-1) + (n-1) + 1 = 2n - 1 needed for nonblocking

Three Stage Spatial Switch Architectures

Non-blocking Analysis

Number of cross points

$$N_c = (N/n)(k \bullet n) + k(N/n)^2 + (N/n)(k \bullet n)$$

$$= 2Nk + \frac{kN^2}{n^2}$$

To prevent blocking

$k = 2n - 1$, so

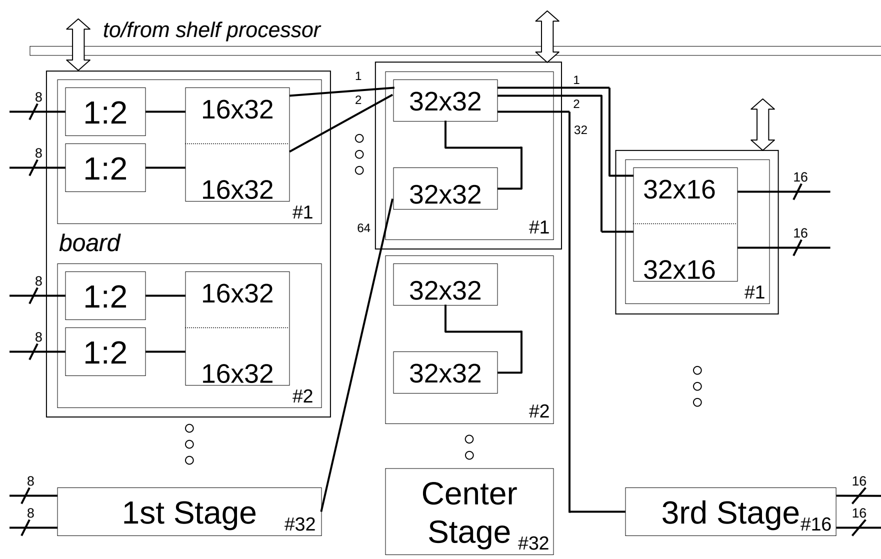
$$N_c = 2N(2n - 1) + (2n - 1)\left(\frac{N}{n}\right)^2$$

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

Optimum $n = \sqrt{\frac{N}{2}}$

Example: N = 8,192--> Single Stage Switch N_c = 67 Million
Three Stage Switch N_c = 4.2 Million

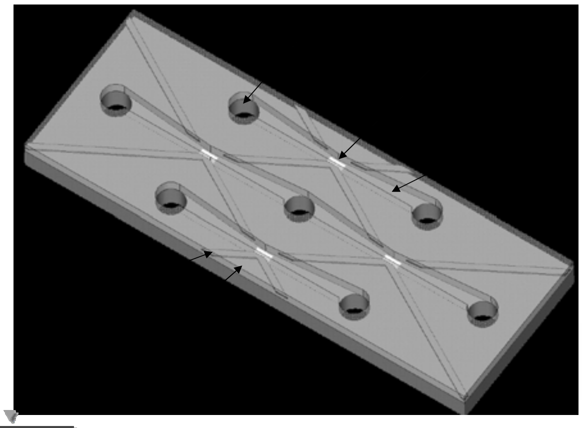
Optical Switch fabric 512 ports



From: ALCATEL

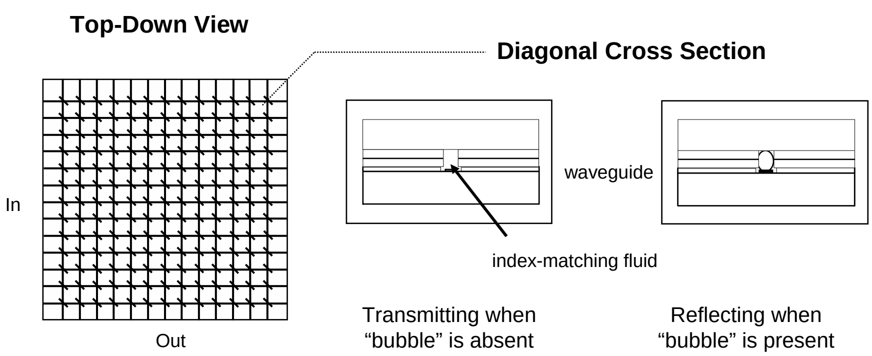
Enabling Technology
Agilent Technologies' Photonic Switch

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



Agilent Technologies
Innovating the HP Way

Agilent Optical Switch Concept



Agilent Technologies
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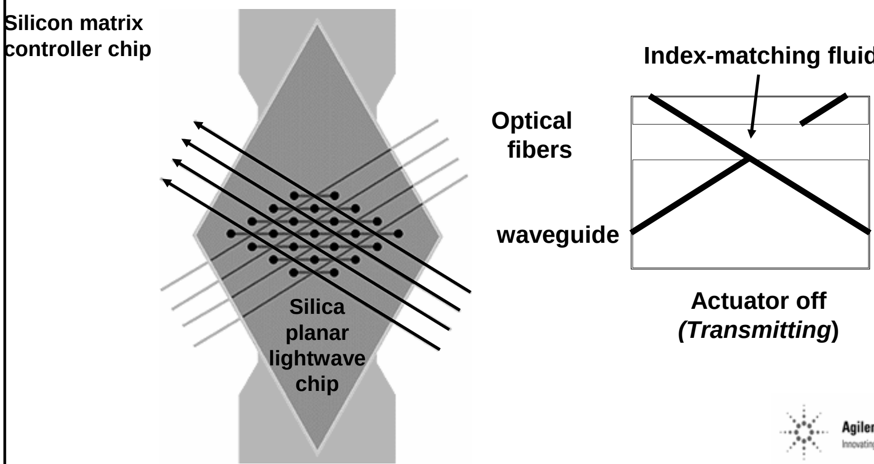
Principle (cont'd)



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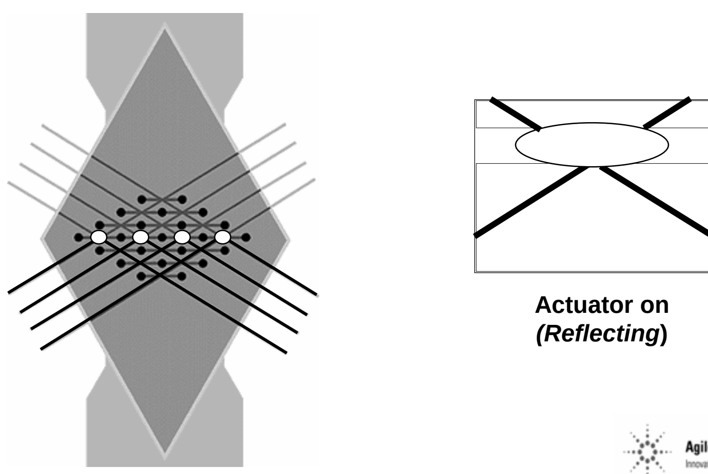
Principle (cont'd)



From: ALCATEL

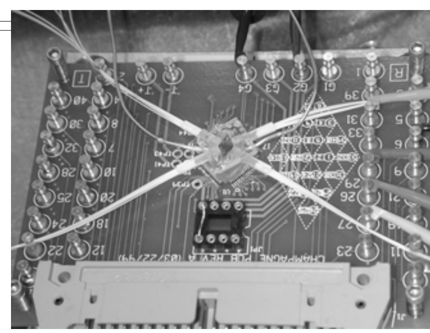
Characteristics

- # 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

Agilent Technologies
Innovating the HP Way

From: ALCATEL

Assembly



Switch Module

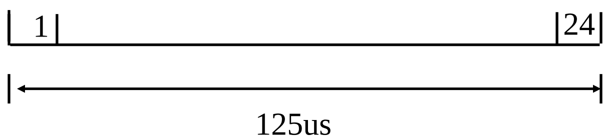
- 32x32 switch
- Waveguide chip, Matrix Controller Chip, Fibers
- Strictly non-blocking + add/drop ports
- Integrated test and monitoring

- Full control electronics
- Well defined interfaces
- Full diagnostics

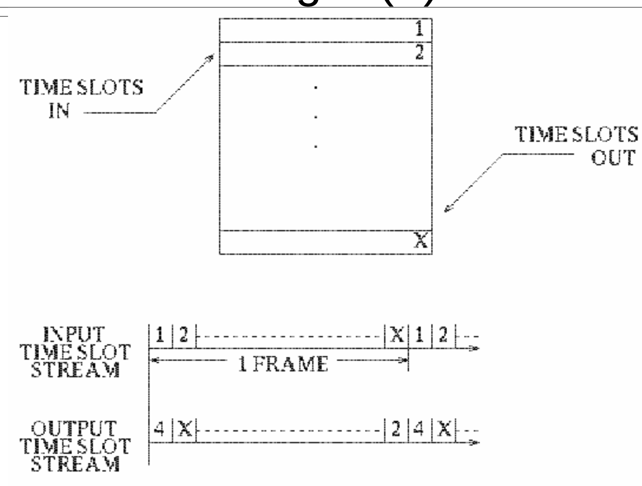
Agilent Technologies
Innovating the HP Way

Digital Switching

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



Digital Switching:
Time Slot Interchanger (**T**)



Schematic illustration of time–slot interchanging process

Digital Switching: Time Slot Interchanger (**T**)-Speed & Memory

- Let N_s=Number of time slots/frame
- Rate = (N_s*8)/125us b/s
- Memory requirement = (N_s*8)bits

Digital Switching

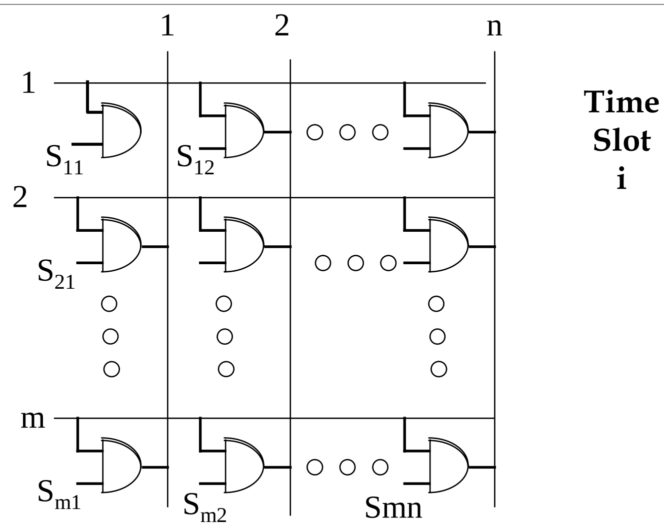
Examples:

- N_s=128
  - Rate = (128*8)/125us=8.192Mb/s
  - Memory = 128 bytes
- N_s=131,072 (ESS #4)
  - Rate = 8.389 Gb/s
  - Memory 131,072 bytes

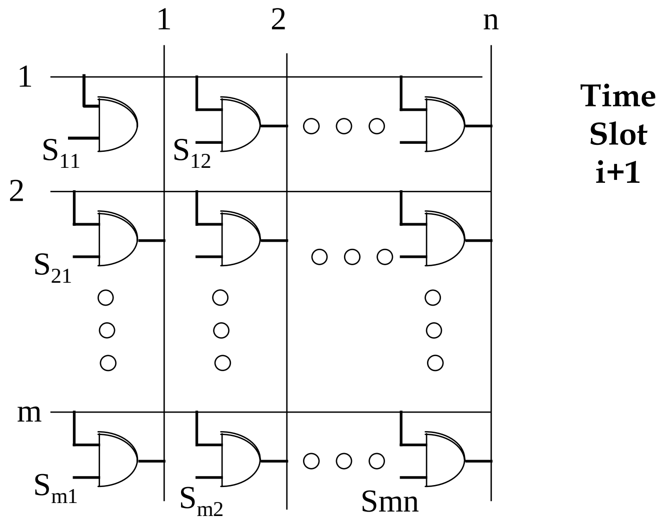
Digital Switching

- 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

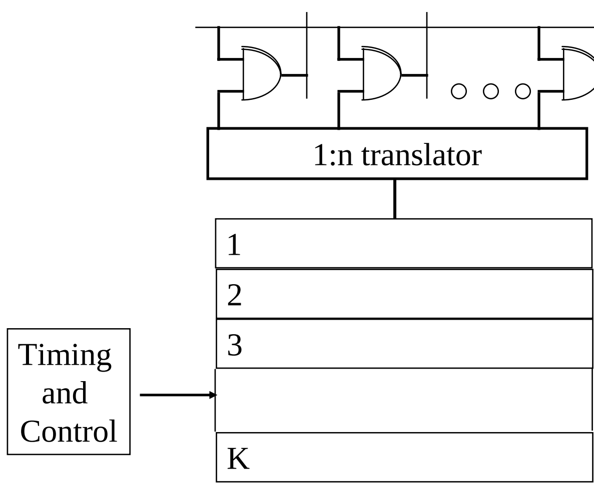
Time shared space division switch



Time shared space division switch



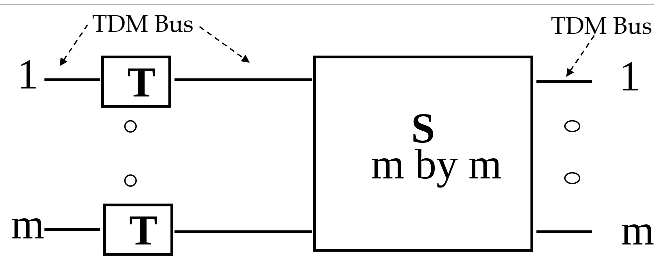
Time shared space division switch



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

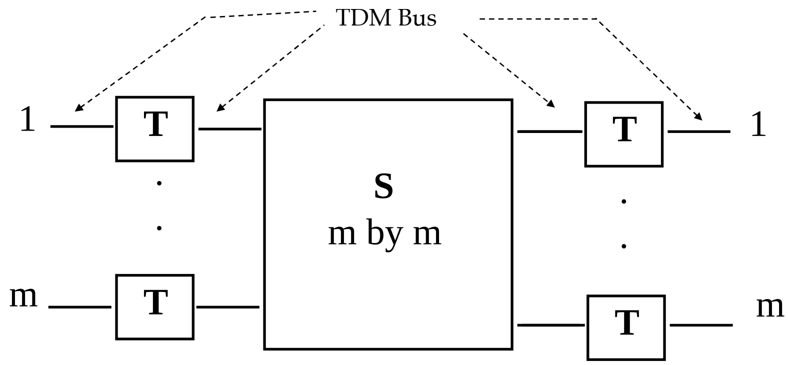
T stage does TSI

Input to S stage is slot 6 on bus 1

S stage does space switching

Output is slot 6 on bus 5

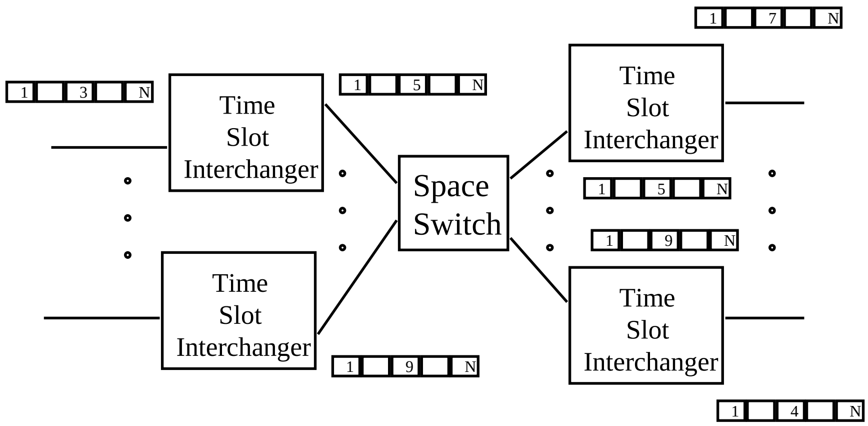
Digital Switch Architectures T-S-T



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} = Total number on input time slots

= m(busses)T (slots/bus)

Let N_{in} = Total number of space stage time slots

= m (busses) N(slots/bus)

Using same analysis applied to the three stage switch,

if $N_{in} = 2T_{in} - 1$ then the system is nonblocking.

Digital Switch Architectures
Non-blocking Analysis

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

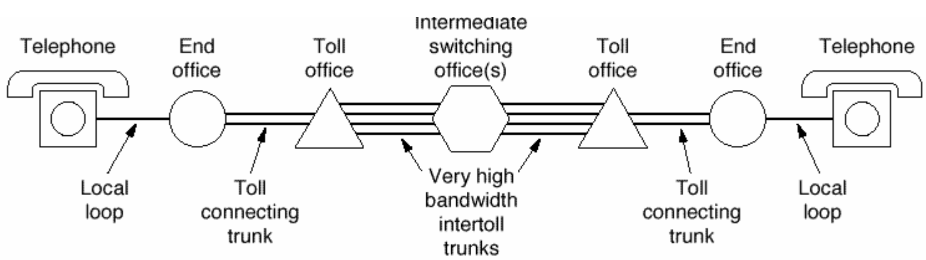


Fig. 2-15. Typical circuit route for a medium-distance call.

From: Computer Networks, A. S. Tanenbaum
3rd Edition, Prentice Hall, 1996

The Structure of the Telephone Network

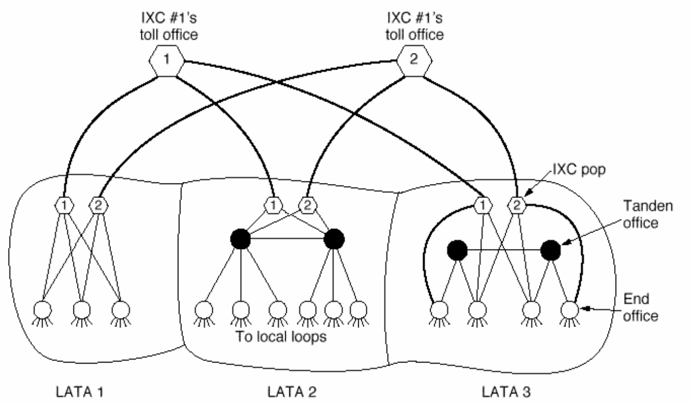


Fig. 2-16. The relationship of LATAs, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is in it.

IXC: Interexchange Carrier

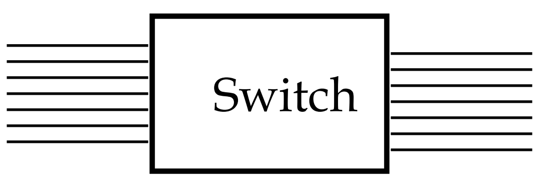
LEC: Local Exchange Carrier

LATA: Local Access and Transport Area

From: Computer Networks, A. S. Tanenbaum
3rd Edition, Prentice Hall, 1996

The "port count" problem

Typical Drawing of a switch



The “port count” problem

Hardware implementation