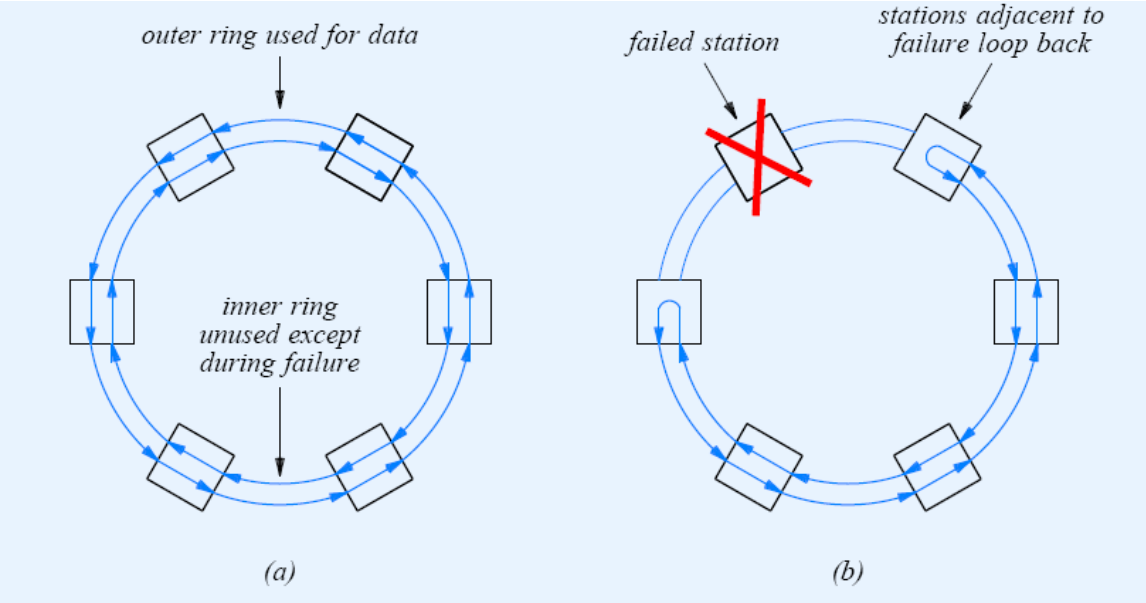
Illustration Of Failure Recovery



- Normal operation uses one of two rings
- Second ring used for loopback during failure

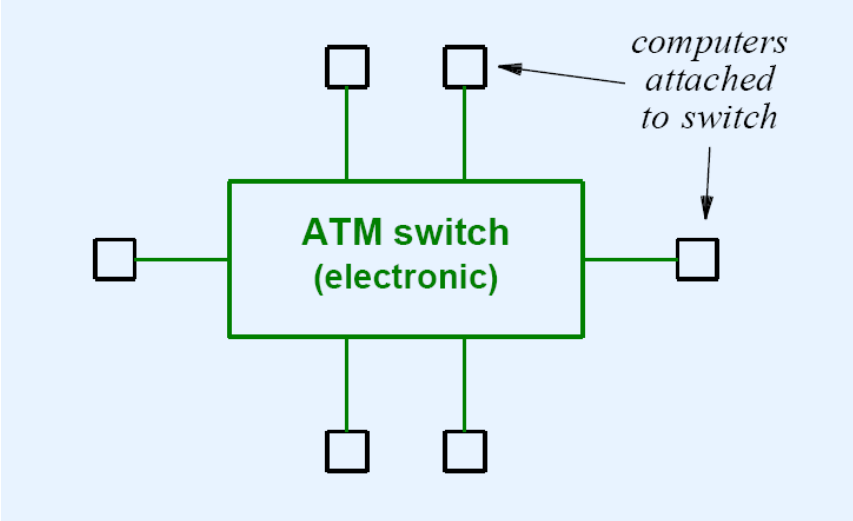
Token Passing Ring Technologies

- *ProNet-10*
  - Operated at 10 Mbps
- *IBM Token Ring*
  - Originally operated at 4 Mbps
  - Later version operated at 16 Mbps
- *Fiber Distributed Data Interconnect (FDDI)*
  - Operates at 100 Mbps
- All are now virtually obsolete

Example Of A Physical Star Topology

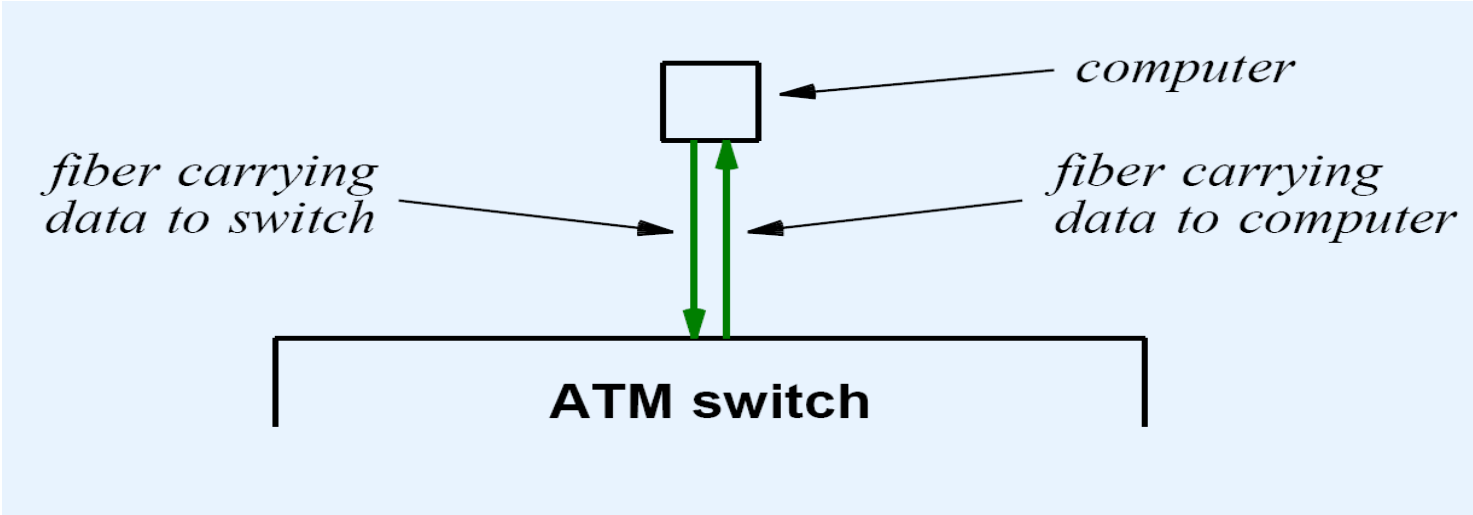
- *Asynchronous Transfer Mode (ATM)*
- Designed by telephone companies
- Intended to accommodate
  - Voice
  - Video
  - Data

ATM



- Building block known as *ATM switch*
- Each station connects to switch
- Switches can be interconnected

Details Of ATM Connection



- Full–duplex connections
- Two fibers used

ATM Characteristics

- High data rates (e.g. 155 Mbps)
- Fixed size packets
  - Called *cells*
  - Important for voice
- Cell size is 53 octets
  - 48 octets of data
  - 5 octets of header

Summary

- Local Area Networks
  - Designed for short distance
  - Use shared media
  - Many technologies exist
- Topology refers to general shape
  - Bus
  - Ring
  - Star

Summary (continued)

- Address
  - Unique number assigned to station
  - Put in frame header
  - Recognized by hardware
- Address forms
  - Unicast
  - Broadcast
  - Multicast

Summary (continued)

- Type information
  - Describes data in frame
  - Set by sender
  - Examined by receiver
- Frame format
  - Header contains address and type information
  - Payload contains data being sent

Summary (continued)

- Currently popular LAN technology
  - Ethernet (bus)
- Older LAN technologies
  - IBM Token Ring
  - FDDI (ring)
  - ATM (star)

Summary (continued)

- Wiring and topology
  - Can distinguish
    - Logical topology
    - Physical topology (wiring)
  - Hub allows
    - Star-shaped bus
    - Star-shaped ring

PART V

Extending Networks
(Repeaters, Bridges, Switches)

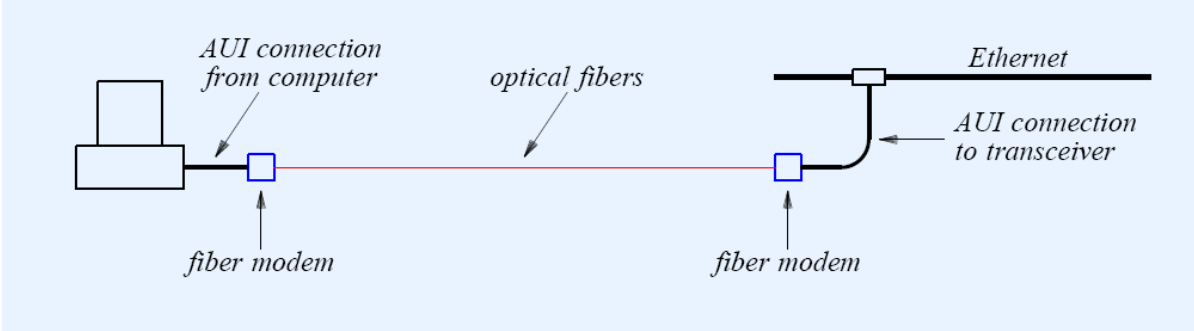
Motivation

- Recall
  - Each LAN technology has a distance limitation
  - Example: CSMA/CD cannot work across arbitrary distance
- However
  - Users desire arbitrary distance connections
  - Example: two computers across a corporate campus are part of one workgroup

Extension Techniques

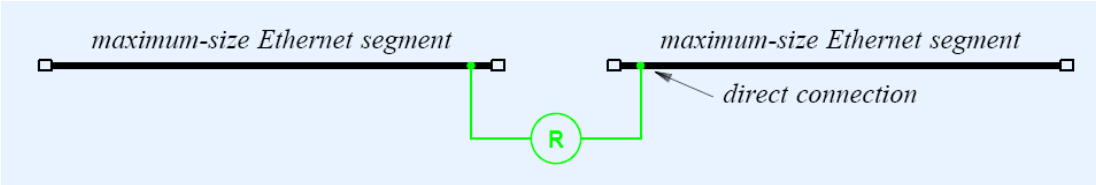
- Must not violate design assumptions
- Often part of original design
- Example technique
  - Use connection with lower delay than copper

Illustration Of Extension For One Computer



- Optical fiber
  - Has low delay
  - Has high bandwidth
  - Can pass signals within specified bounds

Repeater

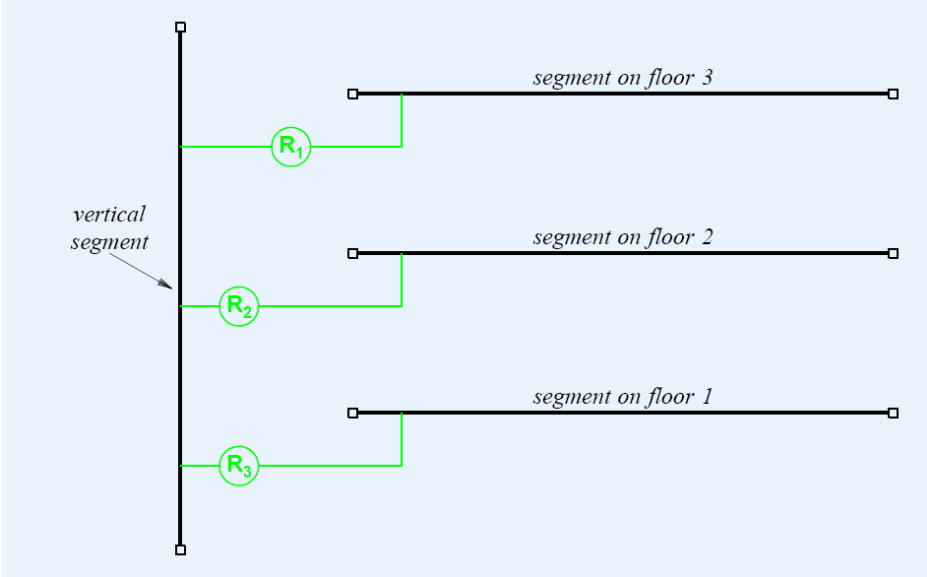


- Hardware device
- Connects two LAN segments
- Copies signal from one segment to the other
- Connection can be extended with Fiber Optic Intra-Repeater Link

Repeater (continued)

- Amplifies signals from one segment and sends to the other
- Operates in two directions simultaneously
- Propagates noise and collisions

Repeaters And The Original Ethernet Wiring Scheme



- Designed for office
- Only two repeaters between any pair of stations

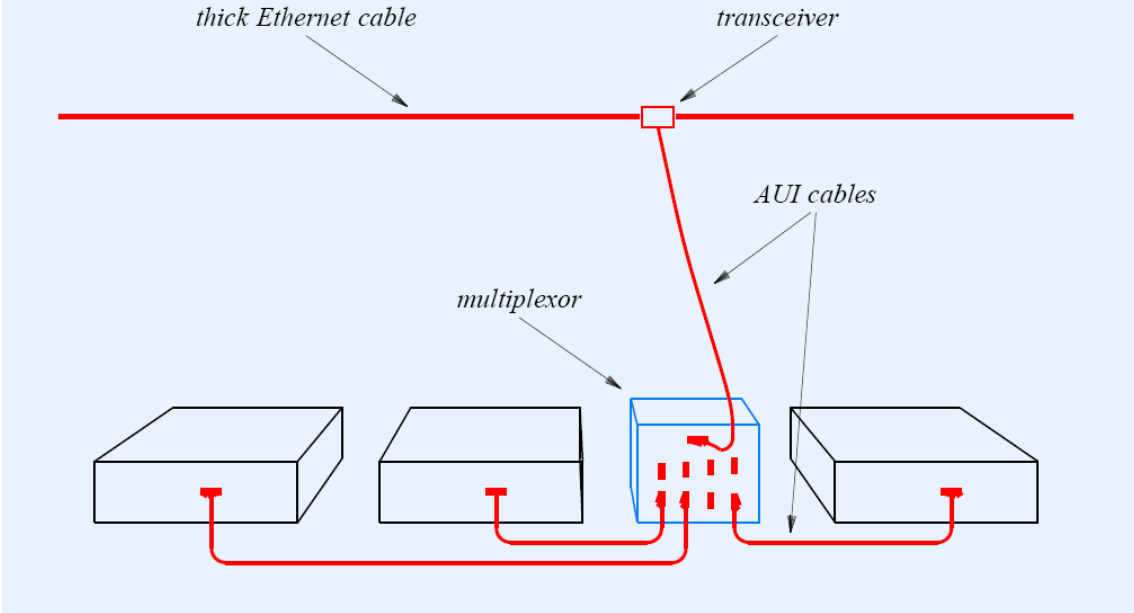
Hub

- Physically
  - Small electronic device
  - Has connections for several computers (e.g., 4 or 20)
- Logically
  - Operates on signals
  - Propagates each incoming signal to all connections
  - Similar to connecting segments with repeaters
  - Does not understand packets
- Extremely low cost

Connection Multiplexing

- Concept
  - Multiple stations share one network connection
- Motivation
  - Cost
  - Convenience of wiring
- Hardware device required

Illustration Of Connection Multiplexing



- Multiplexing device attached to network
- Stations attach to device
- Predates hubs

Modern Equivalent Of Connection Multiplexing

- Hubs used now
- Connections on a hub
  - One for each attached computer
  - One for another hub
- Multiple hubs
  - Can be interconnected in a *daisy chain*
  - Operate as one giant hub
  - Called *stacking*

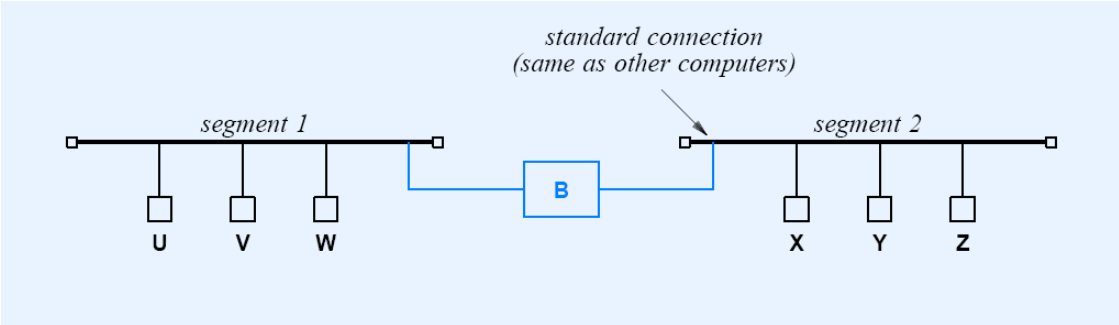
Bridge

- Hardware device
- Connects two LAN segments
- Forwards frames
- Does not forward noise or collisions
- Learns addresses and filters
- Allows independent transmission

Bridge Algorithm

- Listen in promiscuous mode
- Watch source address in incoming frames
- Make list of computers on each segment
- Only forward if necessary
- Always forward broadcast/multicast

Illustration Of A Bridge

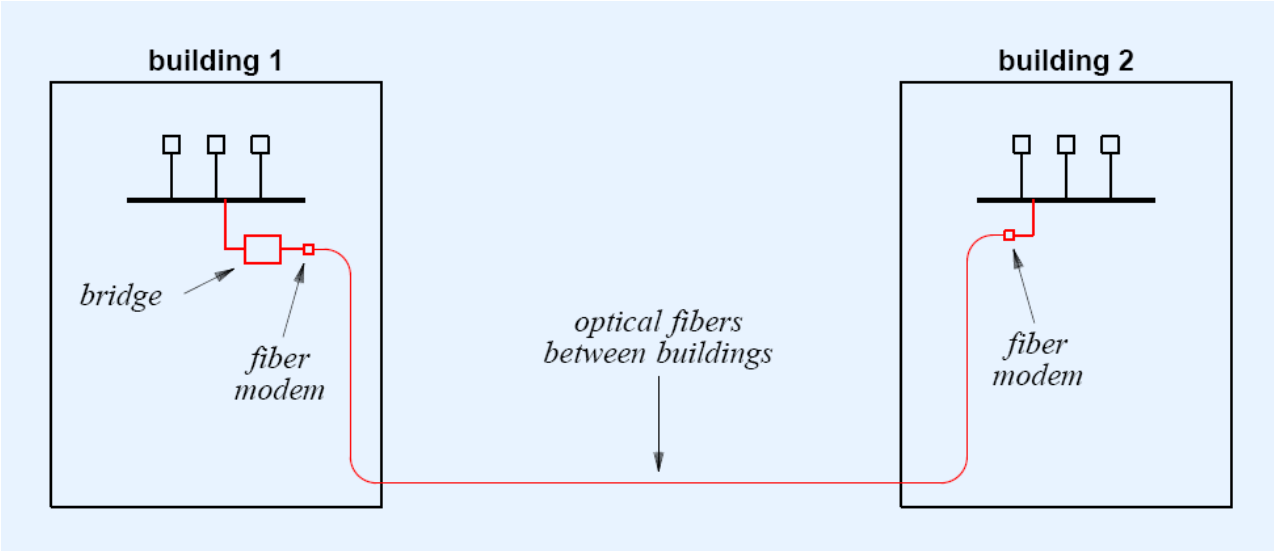


Event List	Segment 1 List	Segment 2
Bridge boots	–	–
U sends to V	U	–
V sends to U	U, V	–
Z broadcasts	U, V	Z
Y sends to V	U, V	Z, Y
Y sends to X	U, V	Z, Y
X sends to W	U, V	Z, Y, X
W sends to Z	U, V, W	Z, Y, X

Bridge uses source address to learn location of computers

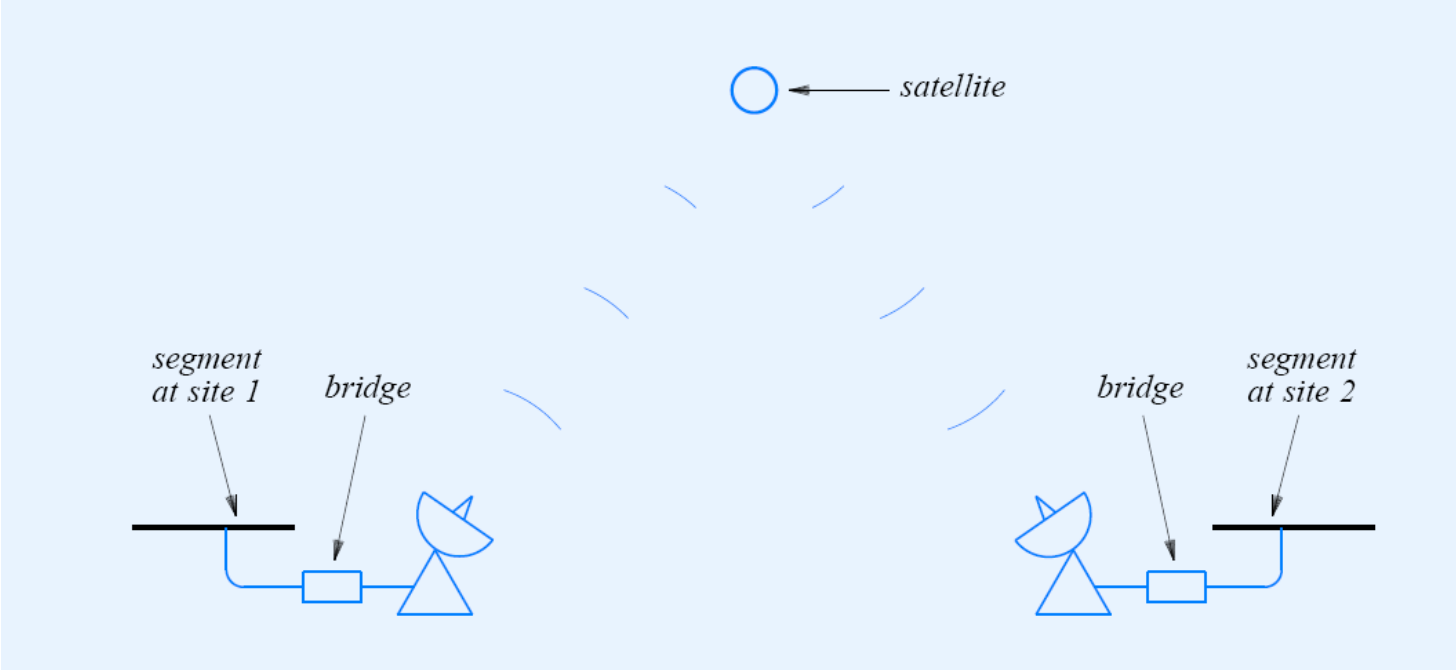
Learning is completely automated

Extending A Bridge



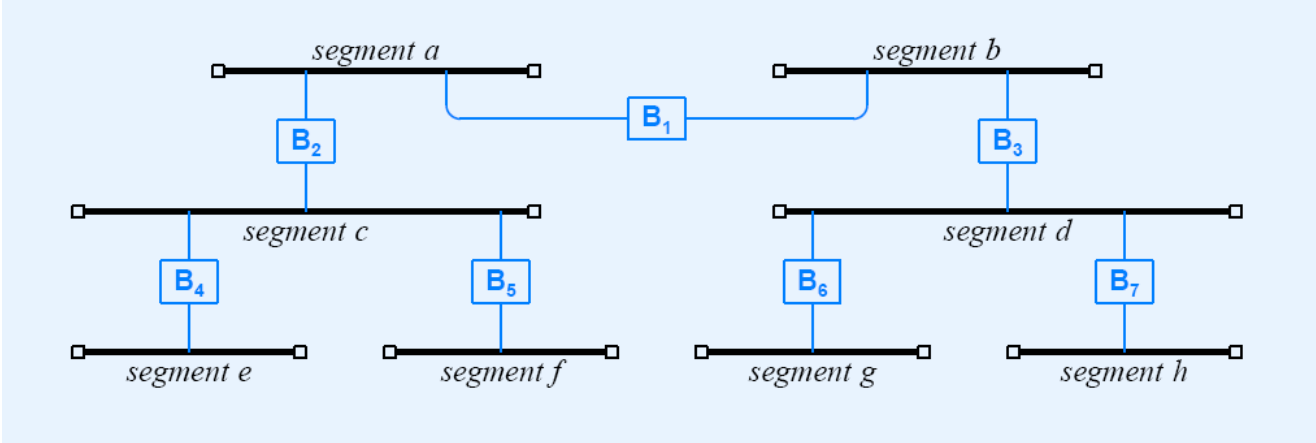
- Typically optical fiber
- Can span buildings

Satellite Bridging



- Can span arbitrary distance

Apparent Problem



- Complex bridge connections may not be apparent
- Adding one more bridge inadvertently introduces a cycle
- Consider a broadcast frame

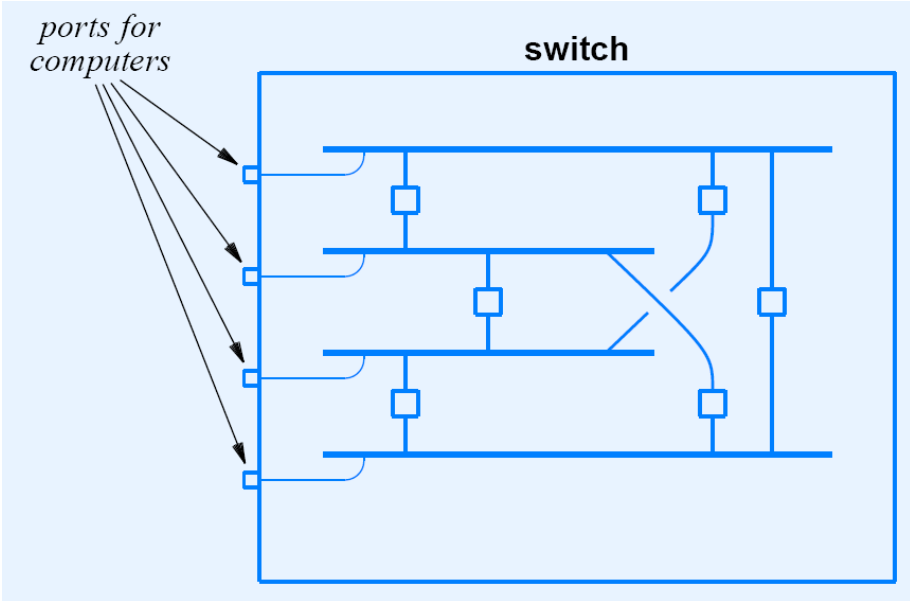
Spanning Tree Algorithm

- Allows cycles
- Used by all bridges to
  - Discover one another
  - Break cycle(s)
- Known as *Distributed Spanning Tree (DST)*

Switch

- Electronic device
- Physically similar to a hub
- Logically similar to a bridge
  - Operates on packets
  - Understands addresses
  - Only forwards when necessary
- Permits separate pairs of computers to communicate at the same time
- Higher cost than hub

Conceptual Switch Function



- Conceptual operation
  - One LAN segment per host
  - Bridge interconnects each pair of segments
- NOT an actual implementation

Summary

- LANs
  - Have distance limitations
  - Can be extended
- Fiber can be used between computer and LAN
- Repeater
  - Connects two LAN segments
  - Repeats and amplifies all signals
  - Forwards noise and collisions

Summary (continued)

- Bridge
  - Connects two LAN segments
  - Understands frames
  - Uses addresses
  - Does not forward noise or collisions
  - Allows simultaneous transmission on segments

Summary (continued)

- Hub
  - Central facility in star-shaped network
  - Operates like a repeater
- Switch
  - Central facility in star-shaped network
  - Operates like a set of bridged segments

PART VI

Long-Distance and Local Loop Digital Connection Technologies

Motivation

- Connect computers across
  - Large geographic distance
  - Public right-of-way
    - Streets
    - Buildings
    - Railroads

Long-Distance Transmission Technologies

- General solution: lease transmission facilities from telephone company
  - Point-to-point topology
  - NOT part of conventional telephone system
  - Copper, fiber, microwave, or satellite channels available
  - Customer chooses analog or digital

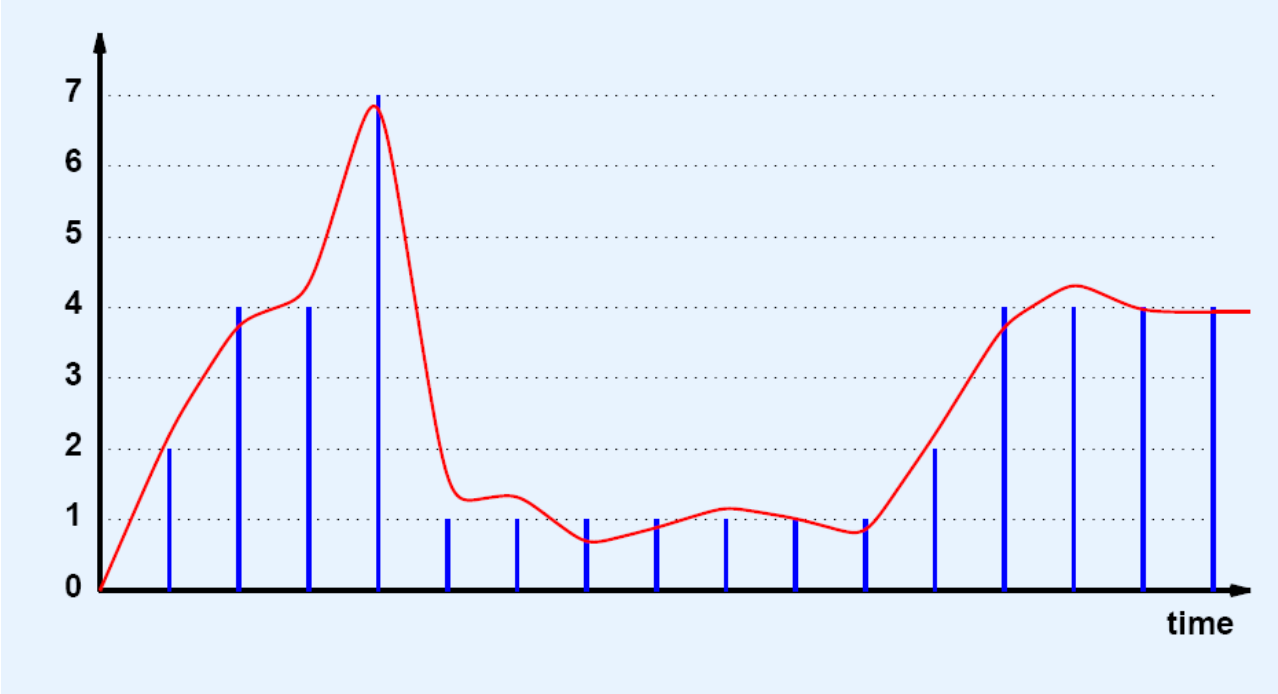
Equipment For Leased Connections

- Analog circuit
  - Modem required at each end
- Digital circuit
  - DSU/CSU required at each end

Digital Circuit Technology

- Developed by telephone companies
- Designed for use in voice system
  - Analog audio from user's telephone converted to digital format
  - Digital format sent across network
  - Digital format converted back to analog audio

Illustration Of Digitized Signal

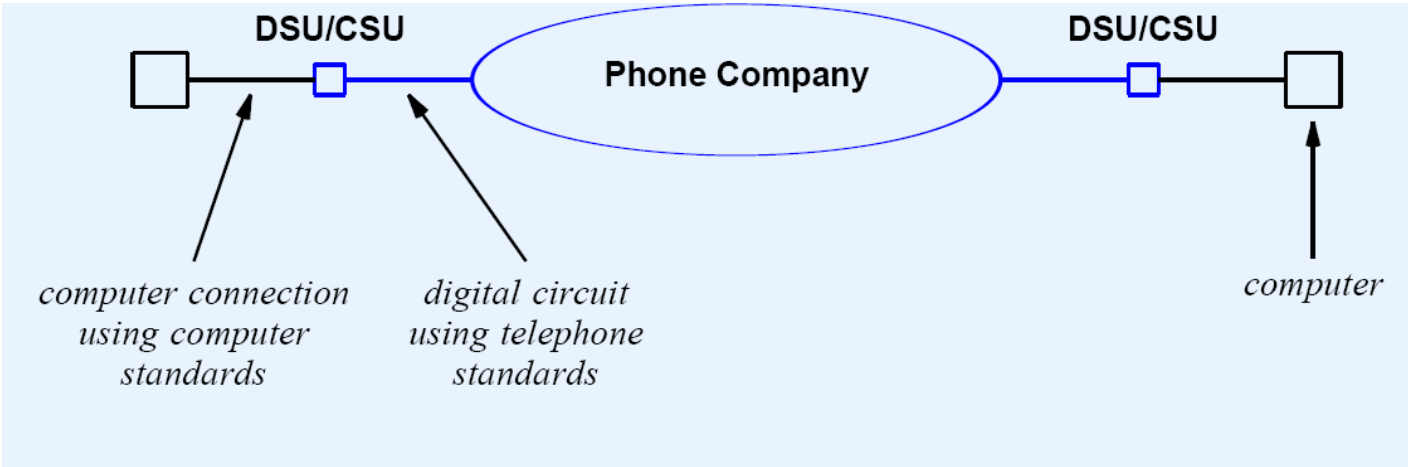


- Pick nearest digital value for each sample
- Telephone standard known as *Pulse Code Modulation(PCM)*

DSU/CSU

- Performs two functions; usually a single “box”
- Needed because telephone industry digital encoding differs from computer industry digital encoding
- DSU portion
  - Translates between two encodings
- CSU portion
  - Terminates line
  - Allows for maintenance

Illustration Of DSU/CSU



- Cost of digital circuit depends on
  - Distance
  - Capacity

Telephone Standards For Digital Circuits

- Specified by the telephone industry in each country
- Differ around the world
- Are known by two-character standard name
- Note: engineers refer to circuit capacity as “speed”

Example Circuit Capacities

Name	Bit Rate	Voice calls	Location
–	0.064 Mbps	1	
T1	1.544 Mbps	24	North America
T2	6.312 Mbps	96	North America
T3	44.736 Mbps	672	North America
E1	2.048 Mbps	30	Europe
E2	8.448 Mbps	120	Europe
E3	34.368 Mbps	480	Europe

Note: T2 not popular

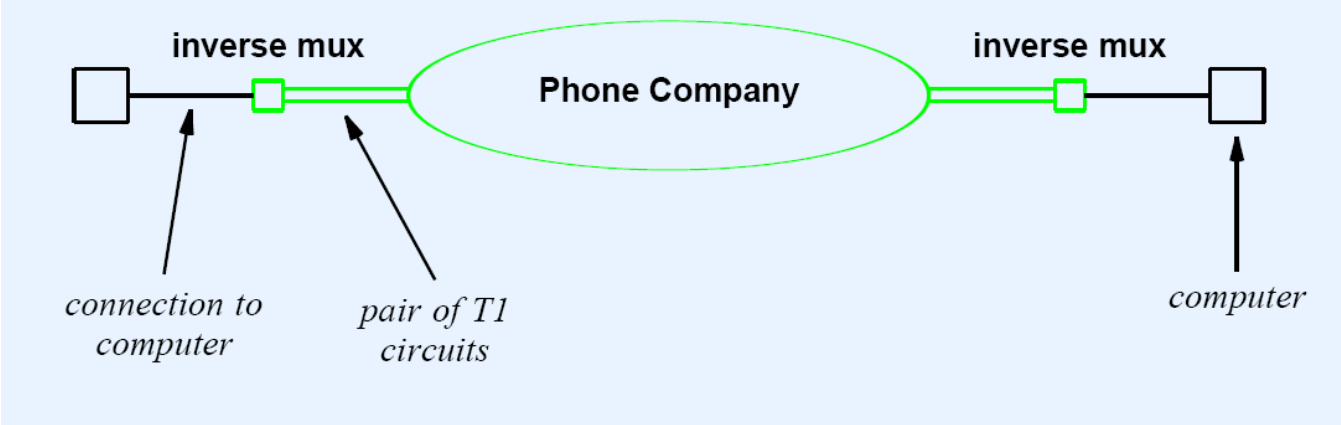
Common Digital Circuit Terminology

- Most common in North America
  - T1 circuit
  - T3 circuit (28 times T1)
- Also available
  - Fractional T1 (e.g., 64 Kbps circuit)

Inverse Multiplexing

- Combines two or more circuits
- Produces intermediate capacity circuit
- Special hardware required
  - Needed at each end
  - Called *inverse multiplexor*

Example Of Inverse Multiplexing



- Can alternate between circuits for
  - Every other bit
  - Every other byte

High-Capacity Digital Circuits

- Also available from phone company
- Use optical fiber
- Electrical standards called *Synchronous Transport Signal (STS)*
- Optical standards called *Optical Carrier (OC)*

High-Capacity Circuits

Standard Name	Optical Name	Bit Rate	Voice Calls
STS-1	OC-1	51.840 Mbps	810
STS-3	OC-3	155.520 Mbps	2430
STS-12	OC-12	622.080 Mbps	9720
STS-24	OC-24	1,244.160 Mbps	19440
STS-48	OC-48	2,488.320 Mbps	38880

- *STS-* is standard for electrical signals
- *OC-* is standard for optical signals
- Engineers usually use *OC-* terminology for everything
- *OC-3* popular

Local Loop

- Telephone terminology
- Refers to connection between residence/business and central office
- Crosses public right-of-way
- Originally for analog POTS (Plain Old Telephone Service)