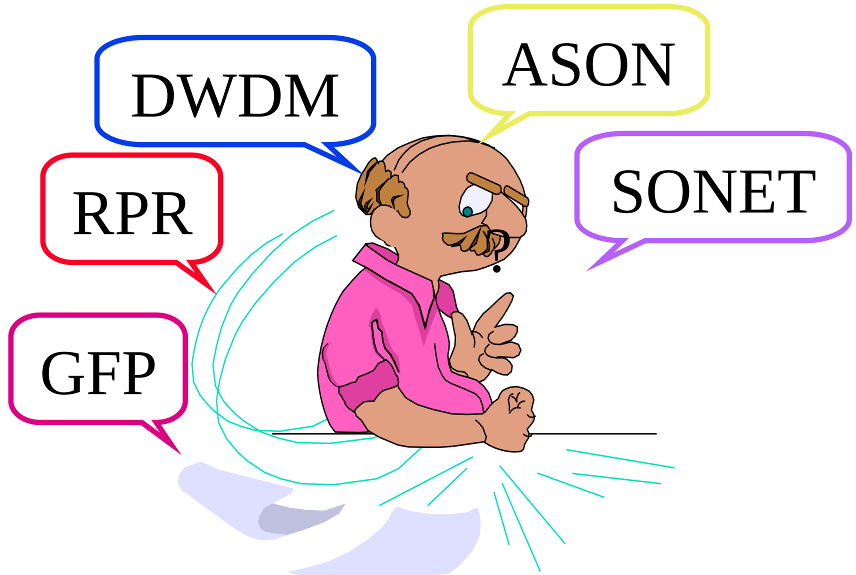
Introduction to Optical Networking



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Modules

1. Fundamentals of Networking:
   OSI Reference Model, Physical and Datalink layers
2. Introduction to TCP/IP: Addressing, DNS, OSPF, BGP
3. Fundamentals of Optical Communication:
   Types of Fibers, Optical components
4. Carrier Networking Technologies:
   SONET/SDH, OTN, GFP, LCAS
5. Next Generation Data Networking Technologies:
   Gigabit and 10 Gbps Ethernet
6. Recent Developments in Optical Networking:
   IP over DWDM, UNI, ASON, GMPLS

Fundamentals of Networking

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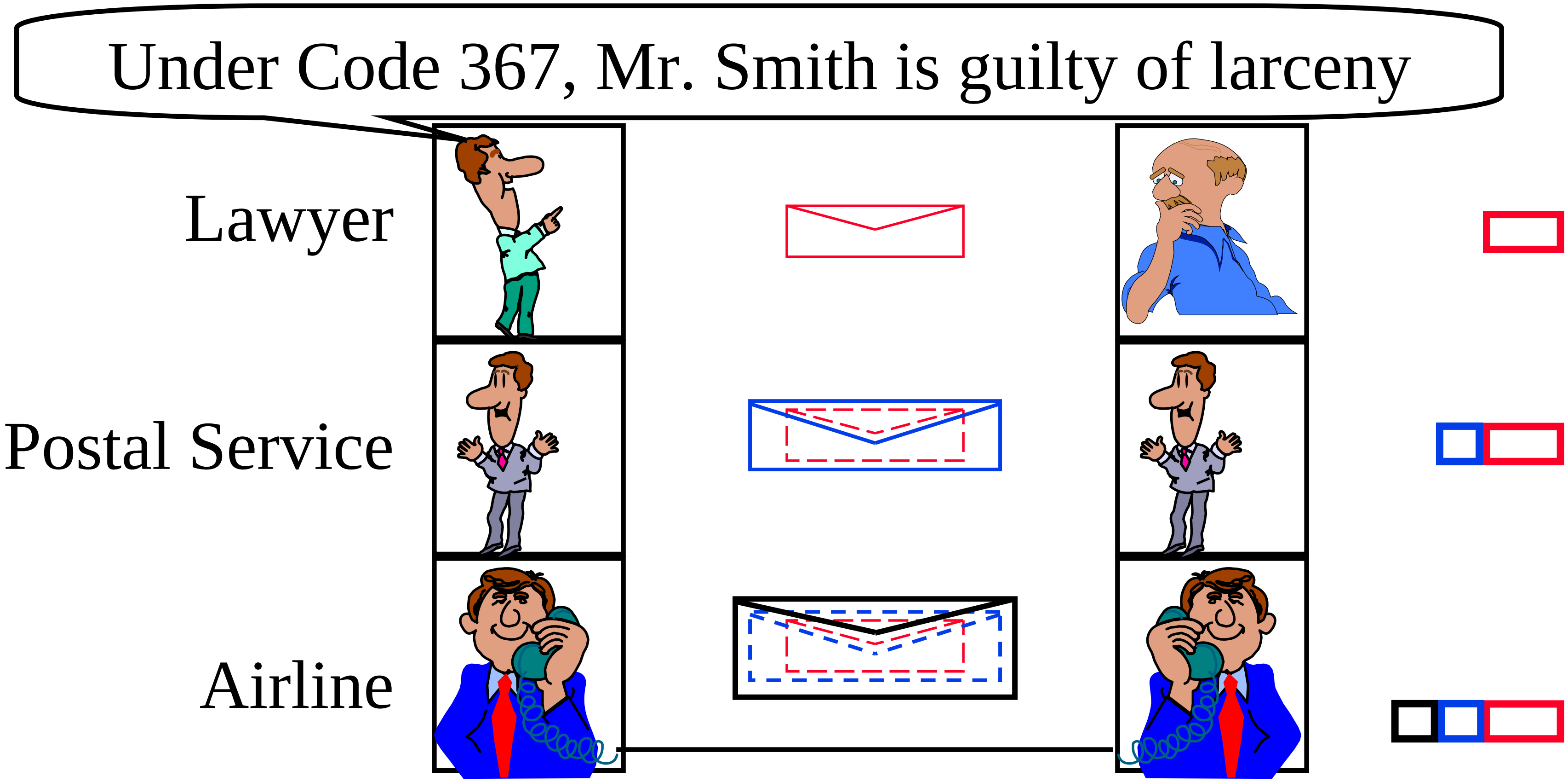
- ISO/OSI Reference Model
- Transmission Media
- Fundamentals of Light
- Physical Layer: Coding, Bit, Baud, Hertz
- HDLC, PPP, Ethernet
- Interconnection Devices
- Spanning Tree

Protocol Layers

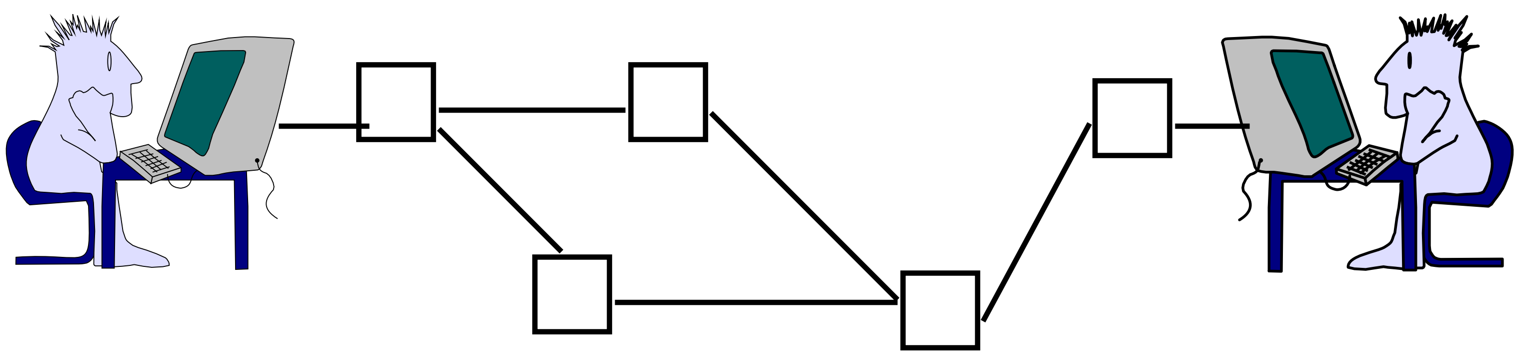
- Problem: Lawyers in different cities.



- Layer specific functions, Headers

ISO/OSI Reference Model

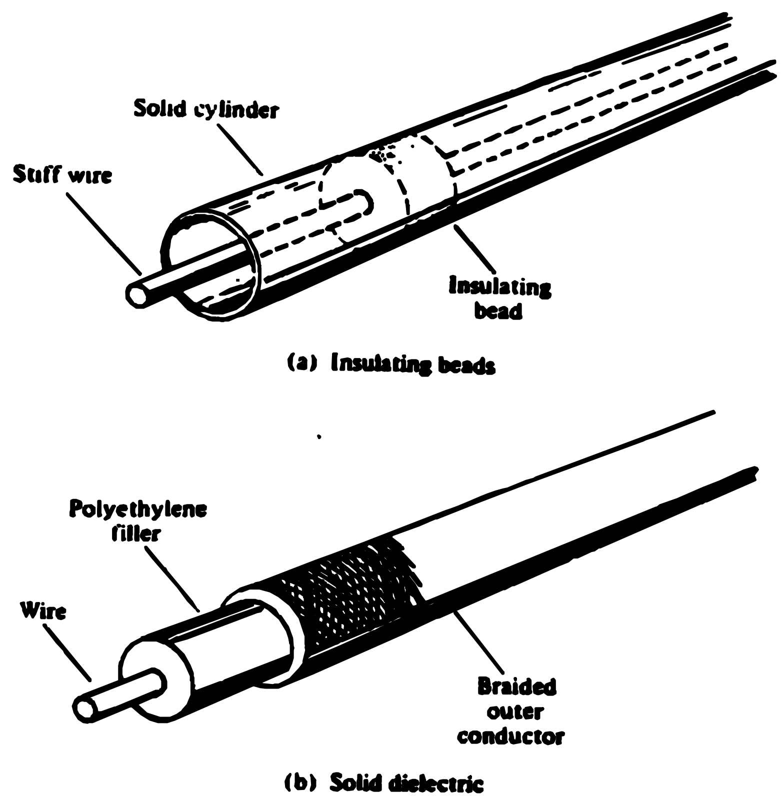
	Layer	Function
4	Application	File transfer, Email, Remote Login
	Presentation	ASCII Text, Sound
3	Session	Establish/manage connection
	Transport	End-to-end communication: TCP
2	Network	Routing, Addressing: IP
1	Datalink	Two party communication: Ethernet
	Physical	How to transmit signal: Coding



Transmission Media

- Coaxial cable
- Twisted Pair
- Optical Fiber

Coaxial Cable



- Used in original Ethernet (~ 1983)

Fig 2.20

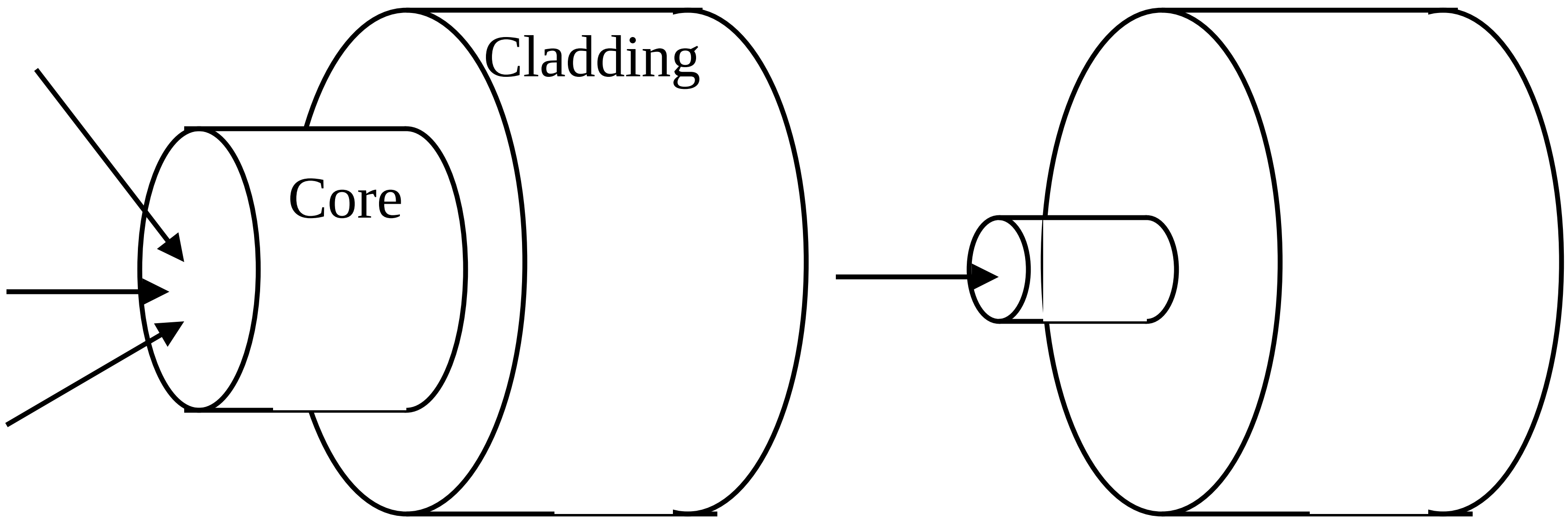
Twisted Pair

- Shielded Twisted Pair (STP)
  Used in original token ring

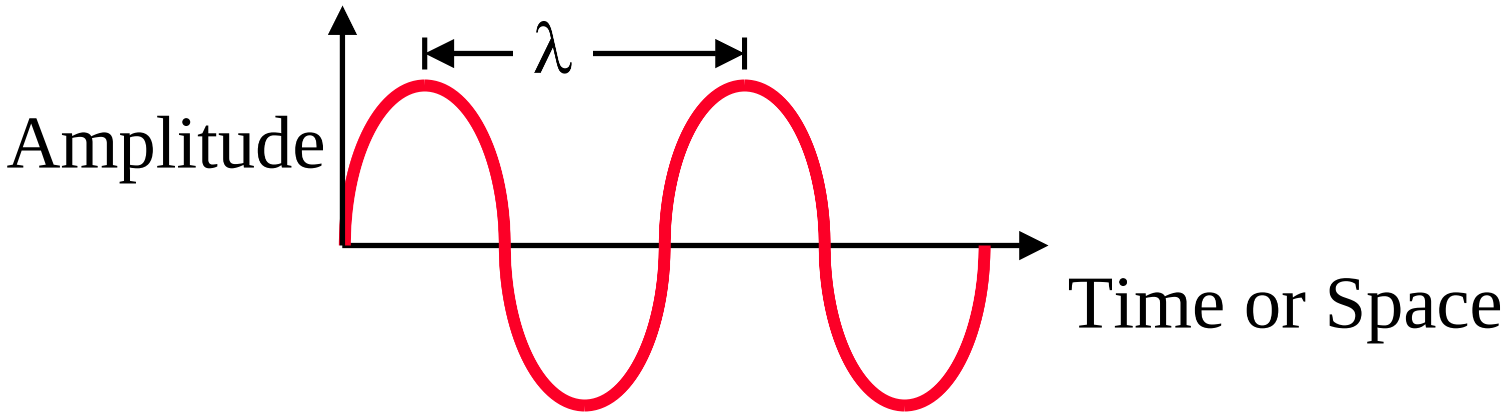
- Unshielded Twisted Pair (UTP)
  - Category 1, 2, 3, …, 5, 6
  - UTP-3: Voice Grade: Telephone wire
  - UTP-5: Data Grade: Better quality
    1 Mbps over 100 m in 1984
    1000 Mbps over 100 m in 2002

Optical Fibers

- Multimode Fiber: Core Diameter 50 or 62.5 µm
  Wide core ⇒ Several rays (mode) enter the fiber
  Each mode travels a different distance
- Single Mode Fiber: 10-µm core. Lower dispersion.



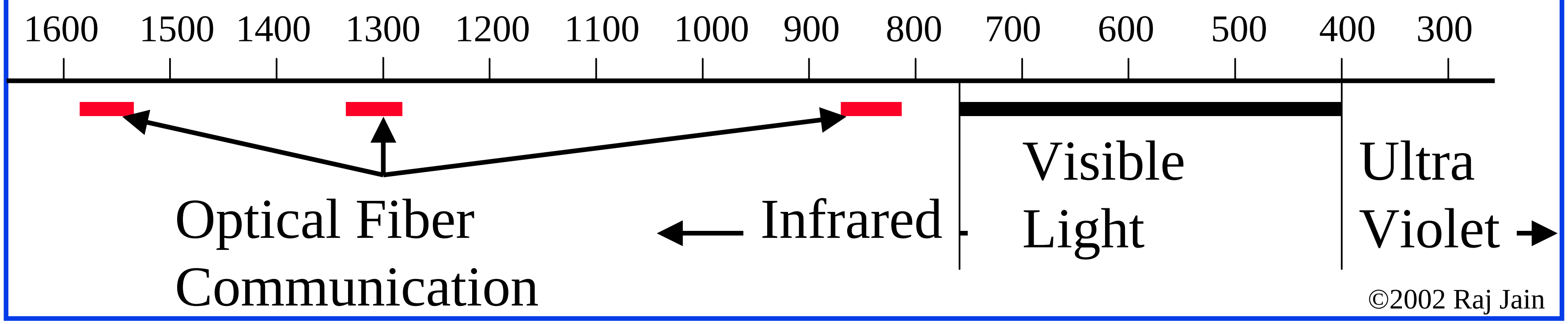
Fundamentals of Light



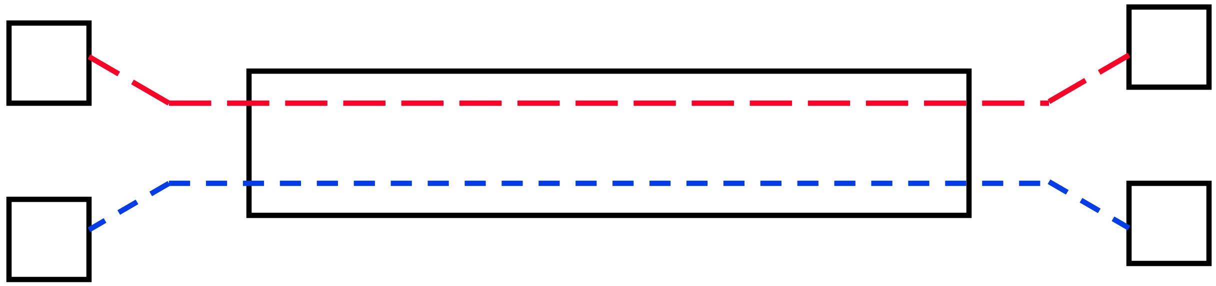
- Similar to waves produced by a stone throw in a pond
- Frequency = Cycles per second at a point in space
- Wavelength = Distance between peaks at time t
- Speed = Frequency ×Wavelength
- Speed in Vacuum = 300 m/μs
- Speed in Fiber = 200 m/μs
- Speed in Vacuum/Speed in Fiber ≈ 1.5
  = Index of Refraction

Fundamentals of Light (Cont)

- Frequency of visible light ≈ 500 THz
- Wavelength of visible light ≈ 600 nm
  (Violet = 400 nm, Red = 700 nm)
- Visible light has a high loss
  ⇒ OK for short distance communication only
- Infrared light (700-1600 nm) has a lower loss

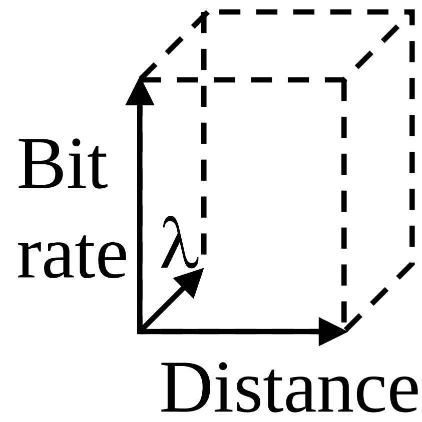


Wavelength Division Multiplexing



- 10 Mbps Ethernet (10Base-F) uses 850 nm
- 100 Mbps Ethernet (100Base-FX) + FDDI use 1310 nm
- Some telecommunication lines use 1550 nm
- WDM: 850nm + 1310nm or 1310nm + 1550nm
- Dense ⇒ Closely spaced ≈ 0.1 - 2 nm separation
- Coarse = 2 to 25 nm = 4 to 12 λ's
- Wide = Different Wavebands

Recent DWDM Records



- 32λ× 5 Gbps to 9300 km (1998)
- 16λ× 10 Gbps to 6000 km (NTT'96)
- 160λ× 20 Gbps (NEC'00)
- 128λ× 40 Gbps to 300 km (Alcatel'00)
- 64λ× 40 Gbps to 4000 km (Lucent'02)
- 19λ× 160 Gbps (NTT'99)
- 7λ× 200 Gbps (NTT'97)
- 1λ×1200 Gbps to 70 km using TDM (NTT'00)
- 1022 Wavelengths on one fiber (Lucent'99)

Potential: 58 THz = 50 Tbps on 10,000 λ's

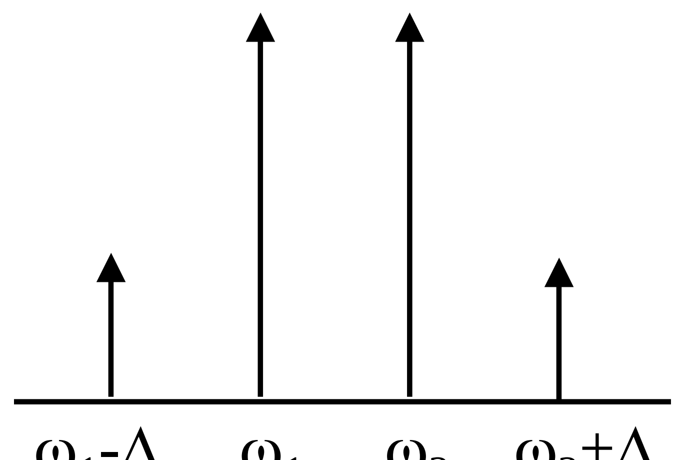
Ref: IEEE J. on Selected Topics in Quantum Electronics, 11/2000.
Optical Fiber Communications (OFC) Conference

DeciBels

Wire or Fiber

- Power reduces exponentially with distance
- Input = 10 mW, At 1 km: 5 mW, At 2 km: 2.5 mW, ..
- Attenuation = $\text{Log}_{10}(P_{in}/P_{out})$ **Bel**
  = $10\ \text{Log}_{10}(P_{in}/P_{out})$ deci**Bel**
- Example: P_{in} = 10 mW, P_{out}= 5 mW
  Attenuation = $10 \log_{10}(10/5) = 10 \log_{10}2 = 3$ dB
- Power is measured in dBm
  0 dBm = 1 mW
  n dBm = $10^{n/10}$ mW, $10\log_{10}x$ dBm = x mW
- Example: P_{in} = 10 dBm, P_{out} = 7 dBm, Atten.= 3 dB

Four-Wave Mixing



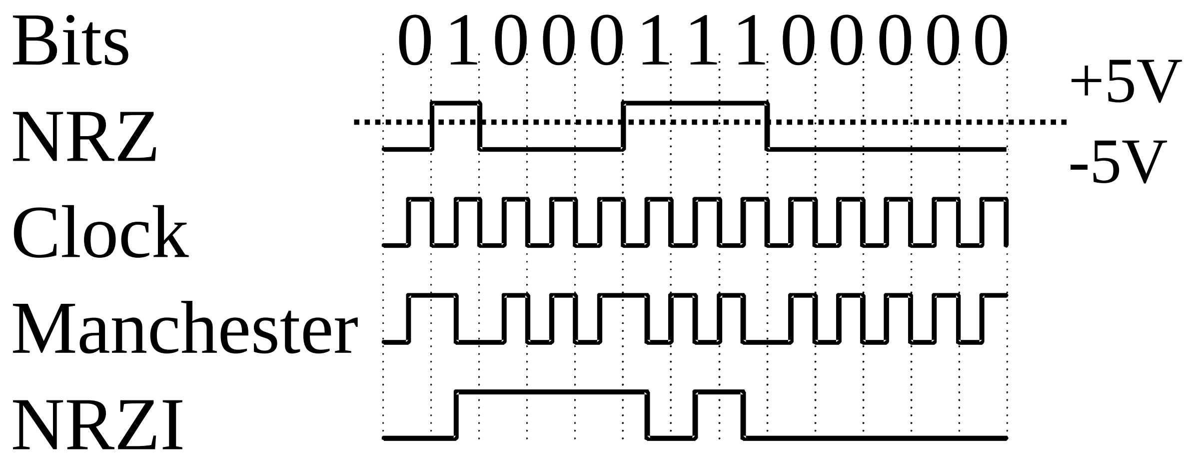
- If two signals travel in the same phase for a long time, new signals are generated.

Recent Products Announcements

Product	λ's	Gb/s	km	Avail-ability
Siemens/Optisphere TransXpress	80	40	250	2001
	160	10	250	2001
Alcatel 1640 OADM	160	2.5	2300	2001
	80	10	330	2001
Corvis Optical Network Gateway	160	2.5	3200	2000
	40	10	3200	2000
Ciena Multiwave CoreStream	160	10	1600	2001
Nortel Optera LH4000	56	10	4000	2000
Optera LH 5000	104	40	1200	2002
Sycamore SN10000	160	10	800	2001
	40	10	4000	2001
Cisco ONS 15800	160	10	2000	2002

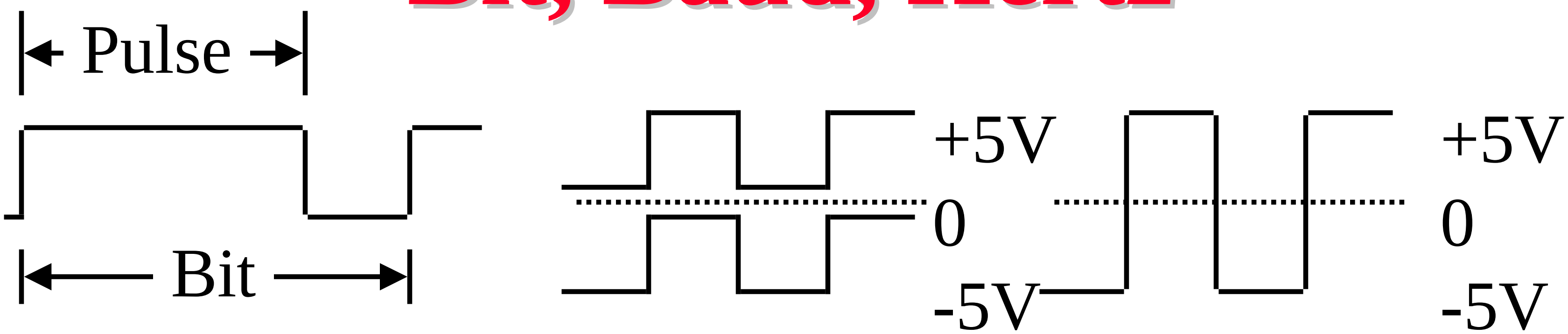
- Ref: "Ultra everything," Telephony, October 16, 2000

Physical Layer: Coding



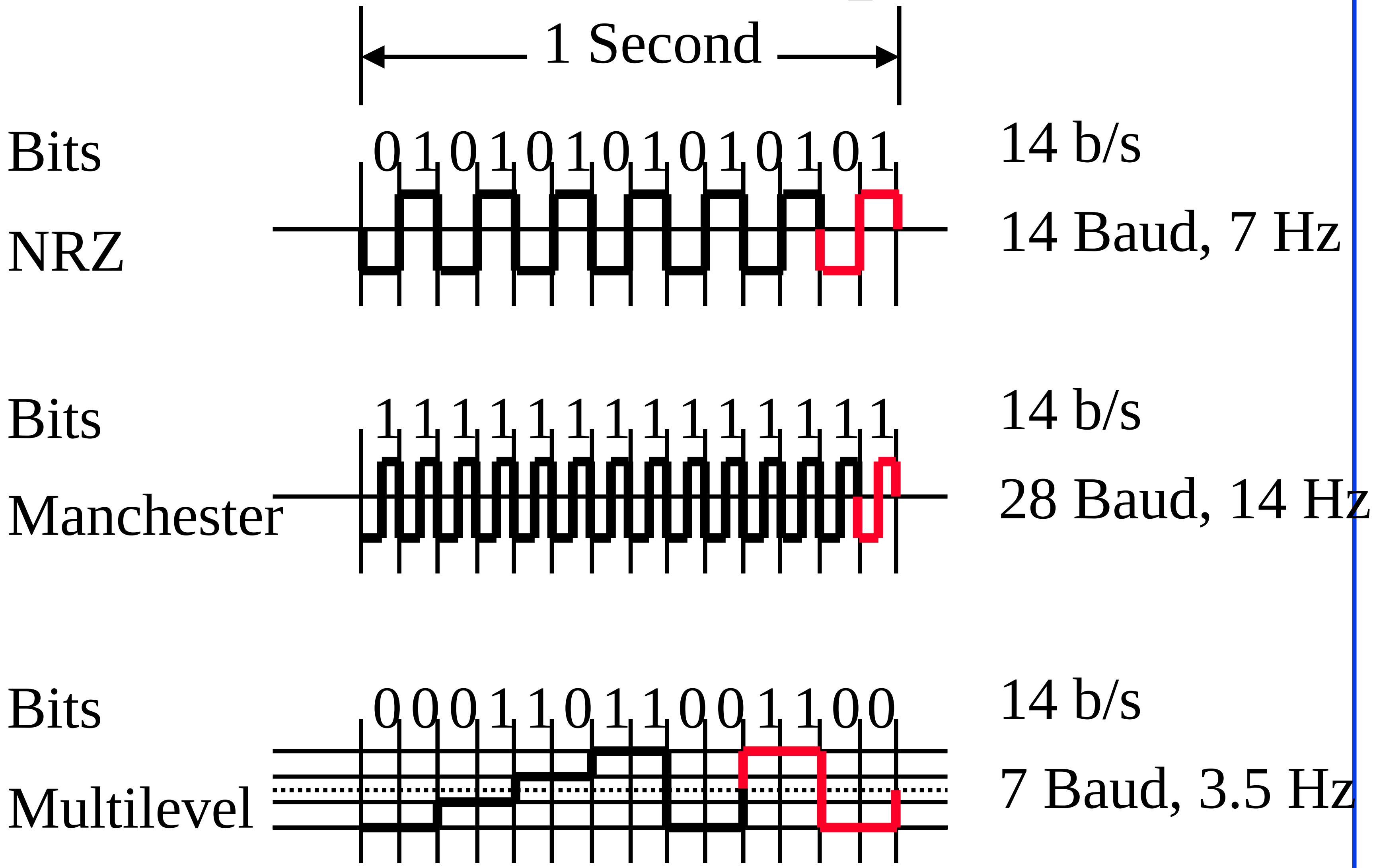
- Simplest Coding: 0 = Light Off, 1 = Light On
  Non-return to zero (NRZ)
- Problems with NRZ:
  - Pulse width indeterminate: Clocking
  - DC, Baseline wander
  - No line state/error detection/Control signals

Bit, Baud, Hertz

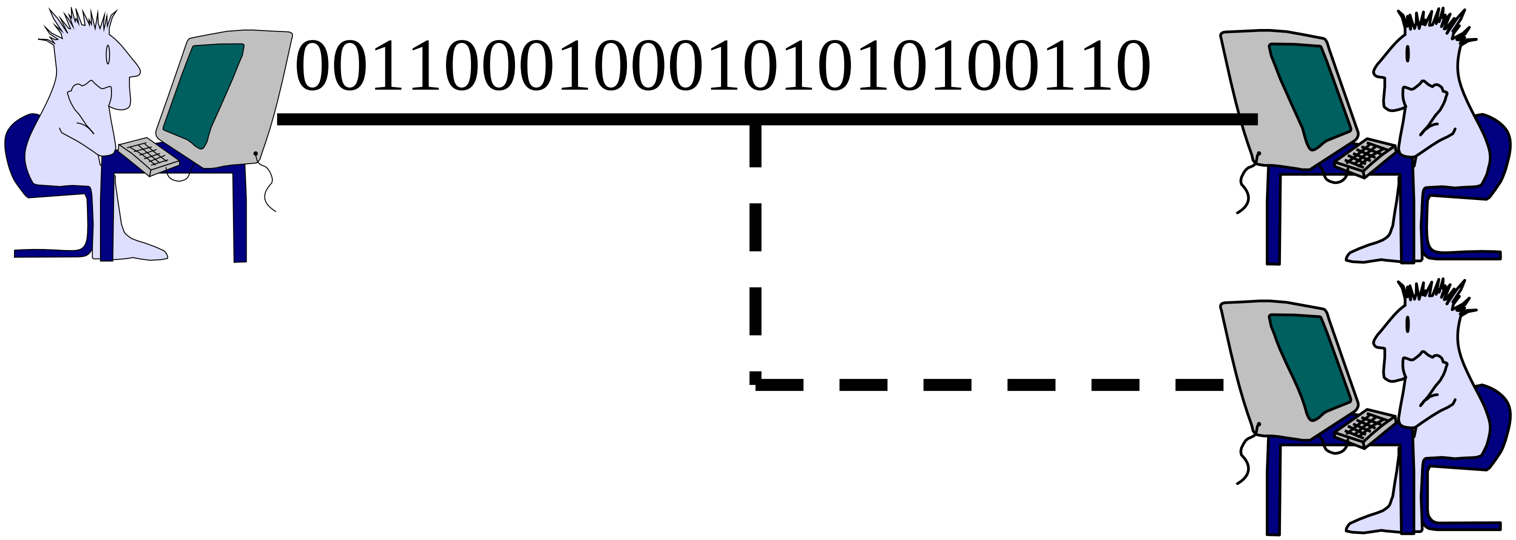


- Signal element: Pulse
- Modulation Rate: 1/Duration of the smallest element
  =Baud rate
- Data Rate: Bits per second
- Frequency: Cycles per second = Hertz
- Bit, Baud, Hertz: User, Receiver, Medium
- Data Rate = Fn(Bandwidth, signal/noise ratio, encoding)

Coding Examples



Layer 2: Datalink



- **Framing**: Beginning and end of each message
- **Addressing**: To whom if multiple receivers
- **Flow Control**: To avoid buffer overflow at receiver
- **Error Control**: Detect Errors, Ack each message, Retransmit if not acked

High-Level Data Link Control

- ISO Standard
- Derived from Synchronous Data Link Control (SDLC): IBM
- Mother of all datalinks
  - Link Access Procedure-Balanced (LAPB): X.25
  - Link Access Procedure for the D channel (LAPD): ISDN
  - Link Access Procedure for modems (LAPM): V.42
  - Point-to-Point Protocol (PPP): Internet

HDLC Framing

Flag	Address	Control	Information	CRC	Flag	
1B	1B	1B		2B	1B	← Size

- **Flag**: Indicates beginning and end of a frame
  = 01111110
- **Address**: Destination of the frame
  Ignored if point to point
- **Control**: Type of frame (Data, Ack)
  Sequence number
- **Information**: Message
- **Cyclic Redundancy Check (CRC)**: Detect errors

Bit Stuffing

- Problem: What if user messages contain flag 01111110?
- Patented Solution:
  Replace 11111 by 111110 at transmitter
  Replace all 111110 by 11111 at receiver

Original Pattern

111111111111011111101111110

After bit-stuffing

11111*0*11111*0*11011111*0*1011111*0*10

Point-to-point Protocol (PPP)

- Originally for User-network connection
  Now being used for router-router connection
- Typical connection setup:
  - Home PC Modem calls Internet
    Provider's router: sets up physical link
  - PC sends Link Control Protocol (LCP) packets
    - Select PPP (data link) parameters. Authenticate.
  - PC sends Network Control Protocol (NCP) packets
    - Select network parameters, E.g., Get IP address
- Transfer IP packets

PPP in HDLC-Like Framing

Flag	Address	Control	Protocol	
01111110	11111111	00000011		

Info	Padding	CRC	Flag

- Flag = 0111 1110 = 7E
- Byte Stuffing: 7E ⇒ 7D 5E
  7D ⇒ 7D 5D
- Address=FF ⇒ All stations. Control=03 ⇒ Unnumbered
- 16-bit FCS default. 32-bit FCS can be negotiated using LCP

CSMA/CD

- Aloha at Univ of Hawaii:
  Transmit whenever you like
  Worst case utilization = 1/(2e) =18%
- Slotted Aloha: Fixed size transmission slots
  Worst case utilization = 1/e = 37%
- CSMA: Carrier Sense Multiple Access
  Listen *before* you transmit
- CSMA/CD: CSMA with Collision Detection
  Listen *while* transmitting. Stop if you hear someone else

IEEE 802.3 CSMA/CD

- If the medium is idle, transmit
- If the medium is busy, wait until idle and then transmit immediately.
- If a collision is detected while transmitting,
  - Transmit a jam signal for one *slot* (Slot = 51.2 μs = 64 byte times)
  - Wait for a random time and reattempt (up to 16 times)
    Random time = Uniform[0,$2^{\min(k,10)}$-1] slots
- Collision detected by monitoring the voltage
  High voltage ⇒ two or more transmitters
  Collision
  ⇒ Length of the cable is limited to 2 km

Ethernet Standards

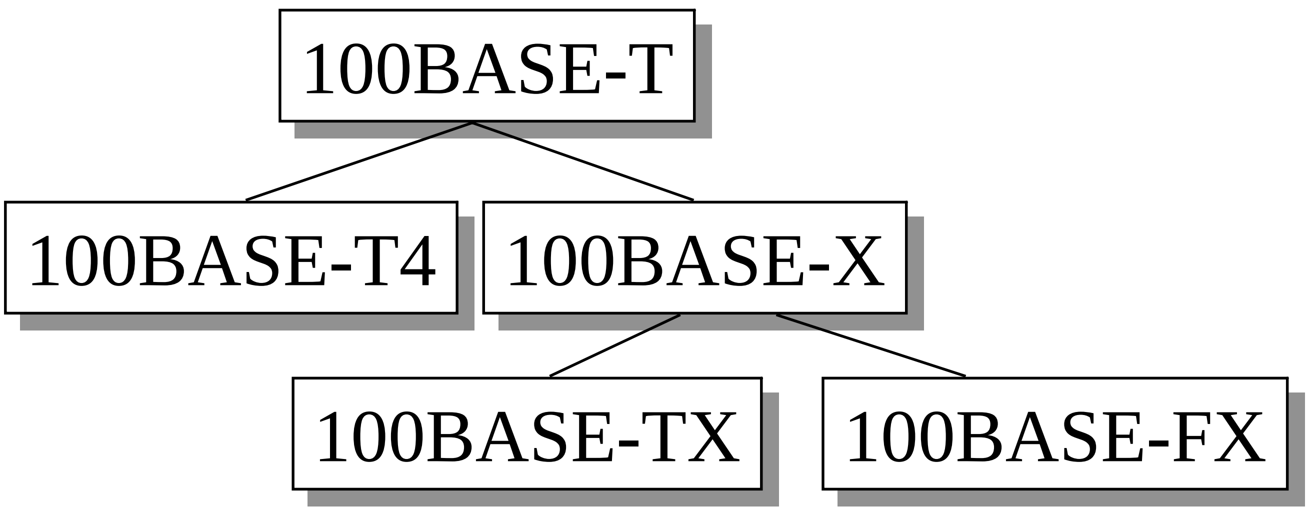
- 10BASE5: 10 Mb/s over coaxial cable (ThickWire)
- 10BROAD36: 10 Mb/s over broadband cable, 3600 m max segments
- 1BASE5: 1 Mb/s over 2 pairs of UTP
- 10BASE2: 10 Mb/s over thin RG58 coaxial cable (ThinWire), 185 m max segments
- 10BASE-T: 10 Mb/s over 2 pairs of UTP
- 10BASE-FL: 10 Mb/s fiber optic point-to-point link
- 10BASE-FB: 10 Mb/s fiber optic backbone (between repeaters). Also, known as synchronous Ethernet.

Ethernet Standards (Cont)

- 10BASE-FP: 10 Mb/s fiber optic passive star + segments
- 10BASE-F: 10BASE-FL, 10BASE-FB, or 10BASE-FP
- 100BASE-T4: 100 Mb/s over 4 pairs of CAT-3, 4, 5 UTP
- 100BASE-TX: 100 Mb/s over 2 pairs of CAT-5 UTP or STP
- 100BASE-FX: 100 Mbps CSMA/CD over 2 optical fiber

Ethernet Standards (Cont)

- 100BASE-X: 100BASE-TX or 100BASE-FX
- 100BASE-T: 100BASE-T4, 100BASE-TX, or 100BASE-FX
- 1000BASE-T: 1 Gbps (Gigabit Ethernet)



IEEE 802 Address Format

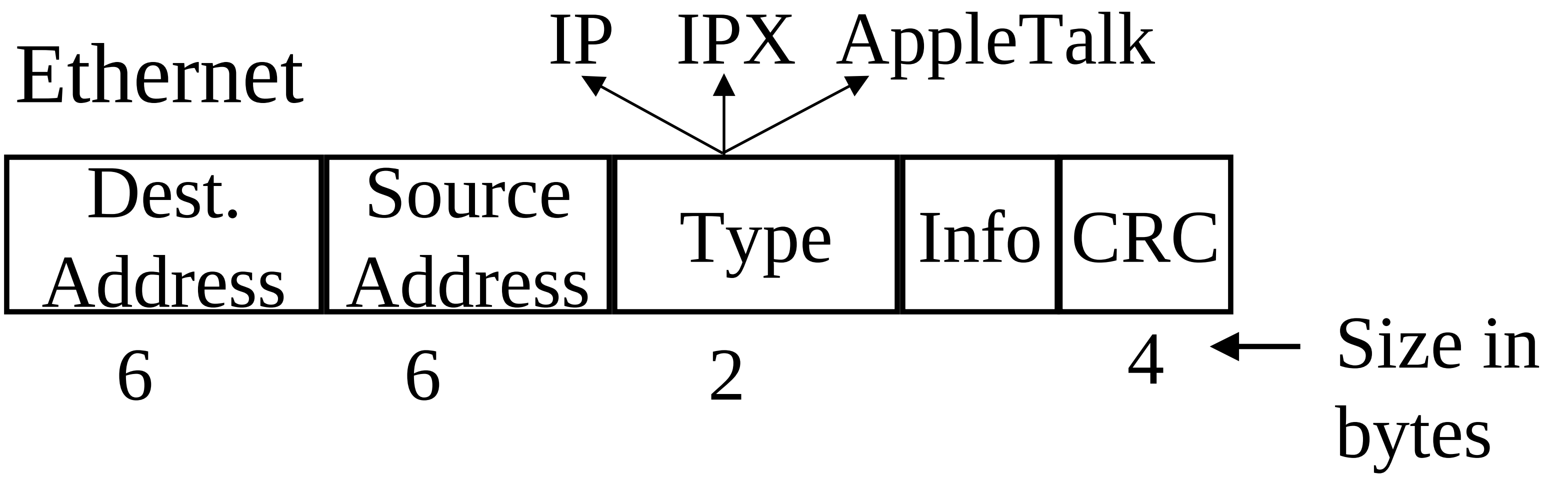
- 48-bit:1000 0000 : 0000 0001 : 0100 0011 : 0000 0000 : 1000 0000 : 0000 1100 = 80:01:43:00:80:0C

Organizationally Unique Identifier (OUI)			24 bits assigned by OUI Owner
Individual/ Group	Universal/ Local		
1	1	22	24

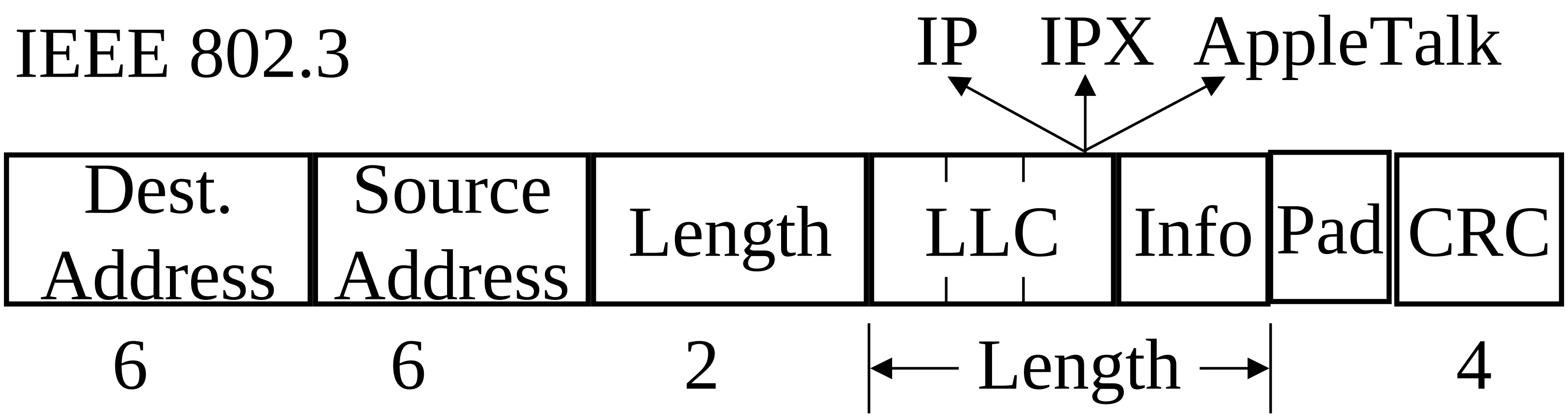
- Multicast = "To all bridges on this LAN"
- Broadcast = "To all stations" = 111111....111 = FF:FF:FF:FF:FF:FF

Ethernet vs IEEE 802.3

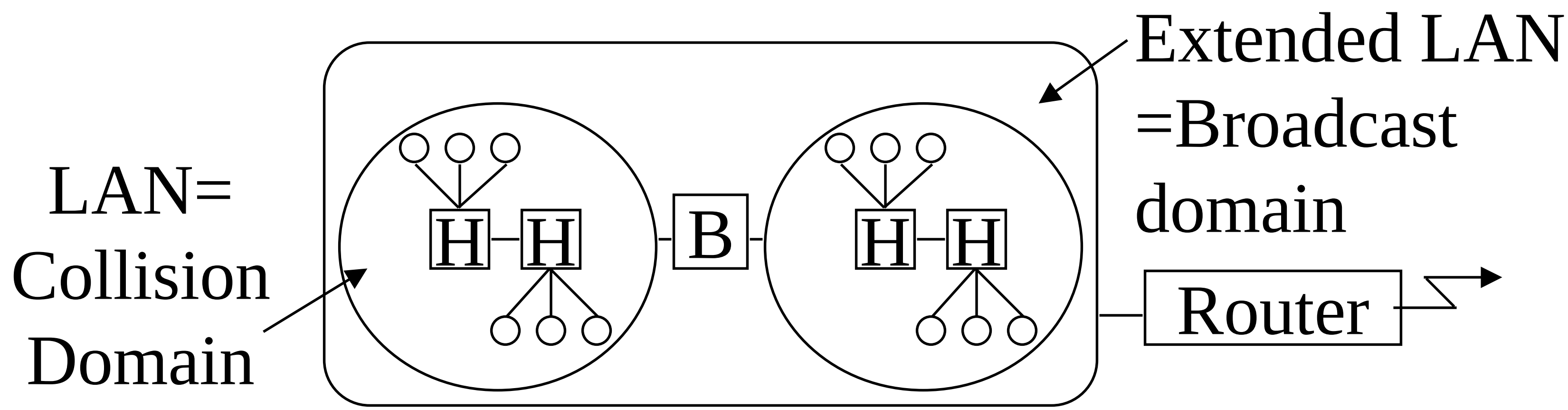
- Ethernet

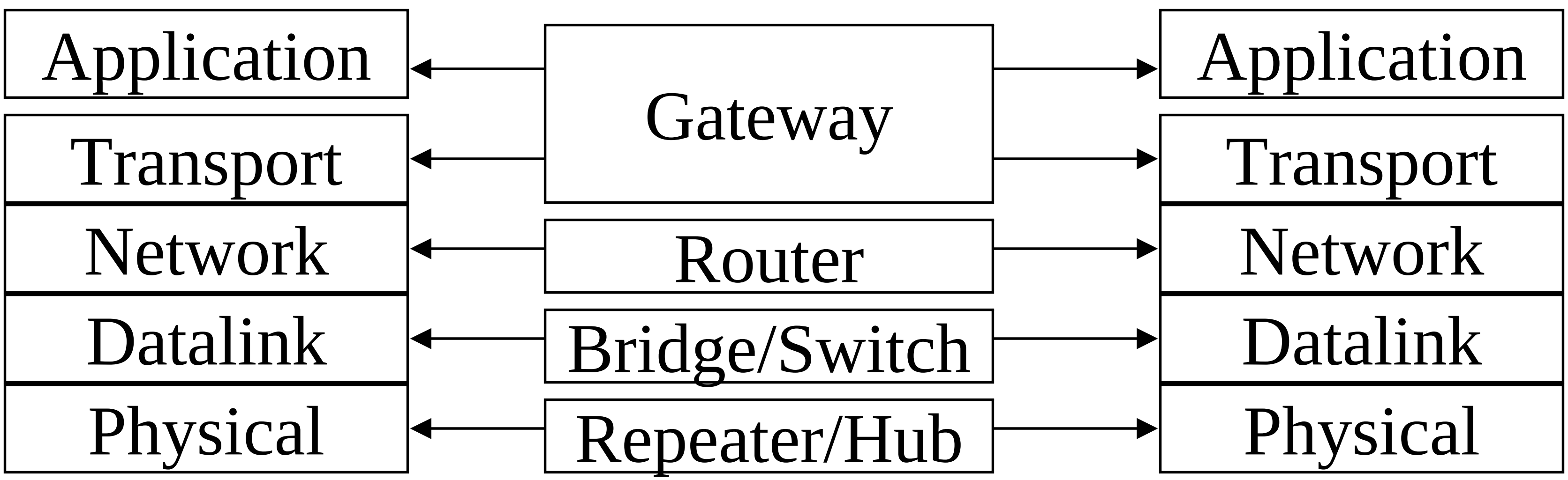


- IEEE 802.3



Interconnection Devices





Interconnection Devices

- **Repeater**: PHY device that restores data and collision signals
- **Hub**: Multiport repeater + fault detection and recovery
- **Bridge**: Datalink layer device connecting two or more collision domains. MAC multicasts are propagated throughout "extended LAN."
- **Router**: Network layer device. IP, IPX, AppleTalk. Does not propagate MAC multicasts.
- **Switch**: Multiport bridge with parallel paths
- These are functions. Packaging varies.

Spanning Tree

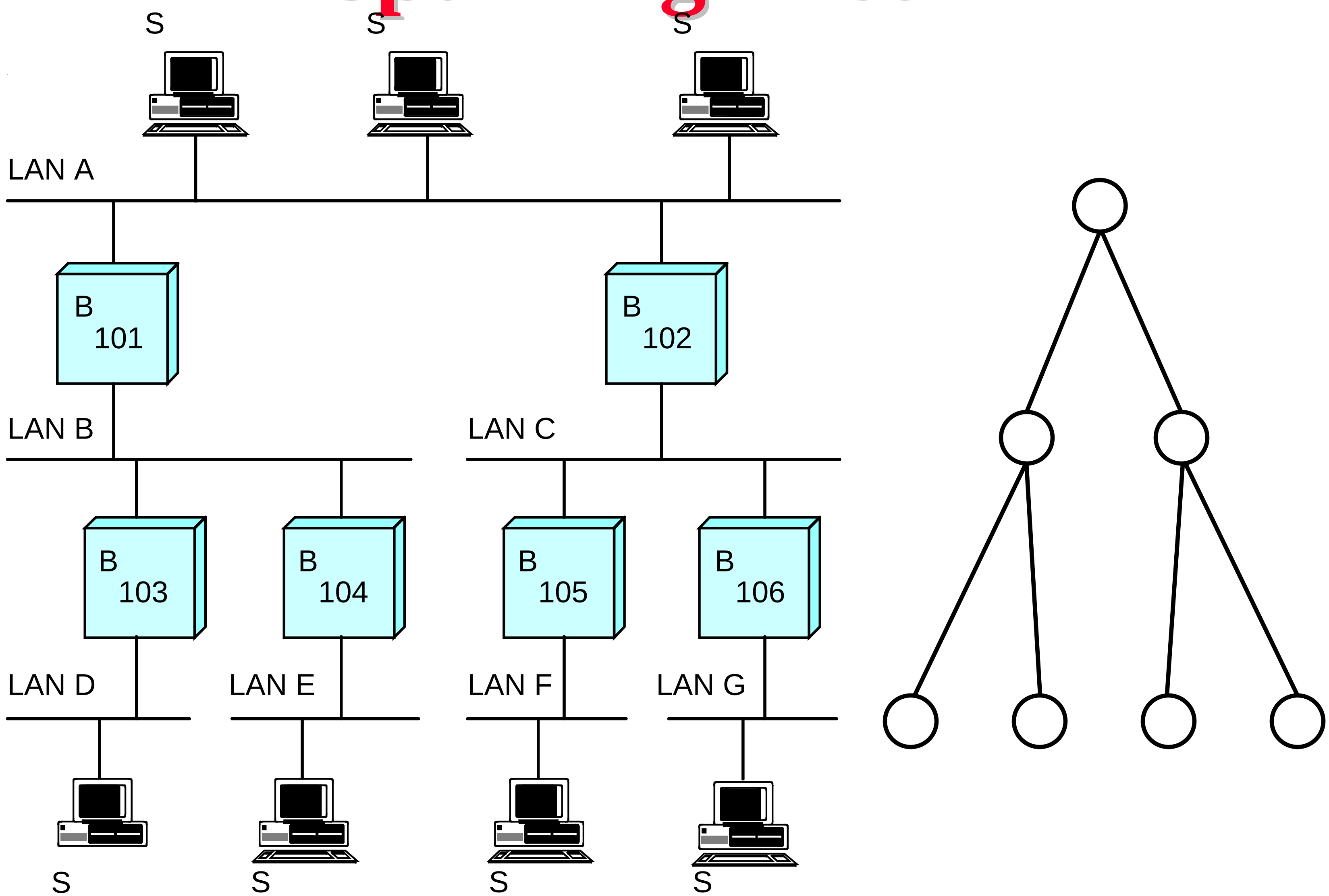


Fig 14.5

Spanning Tree (Cont)

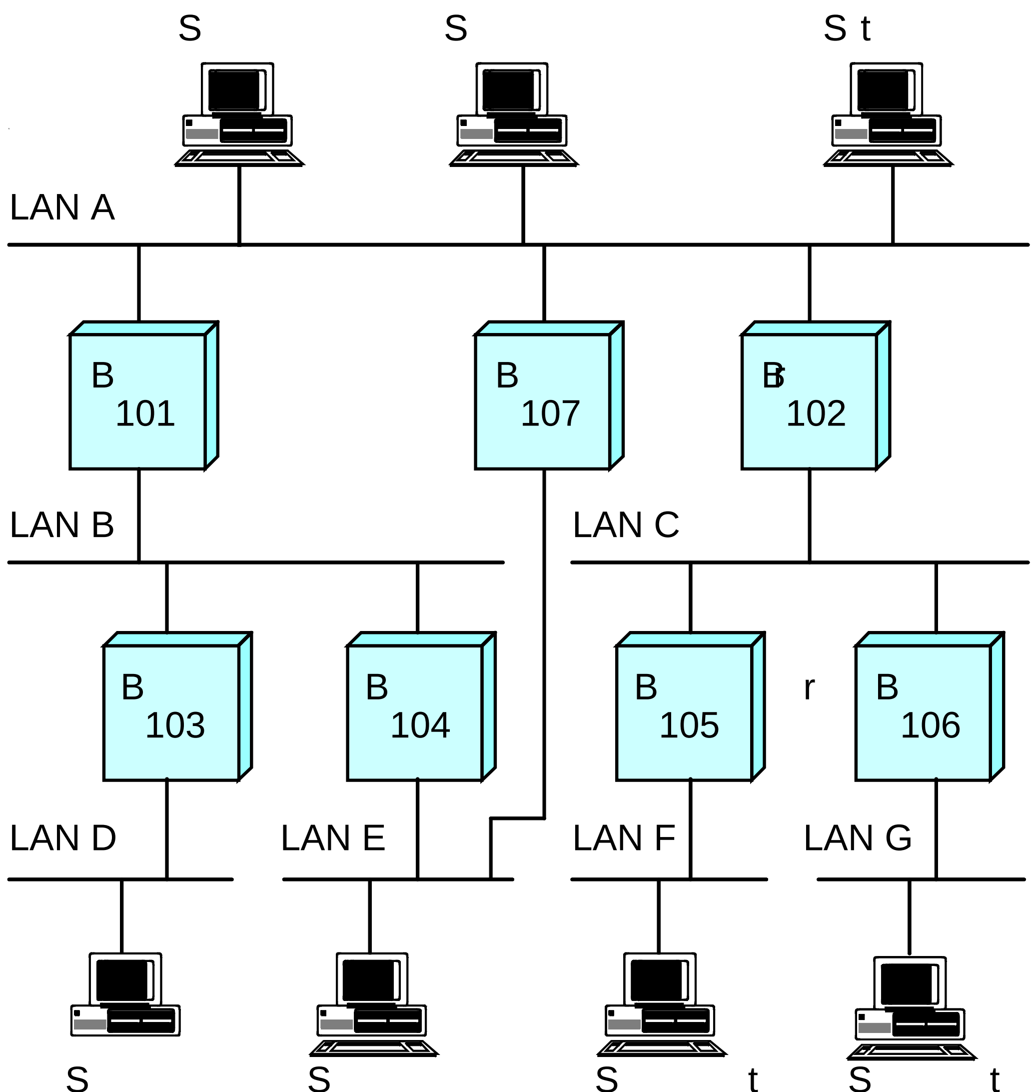
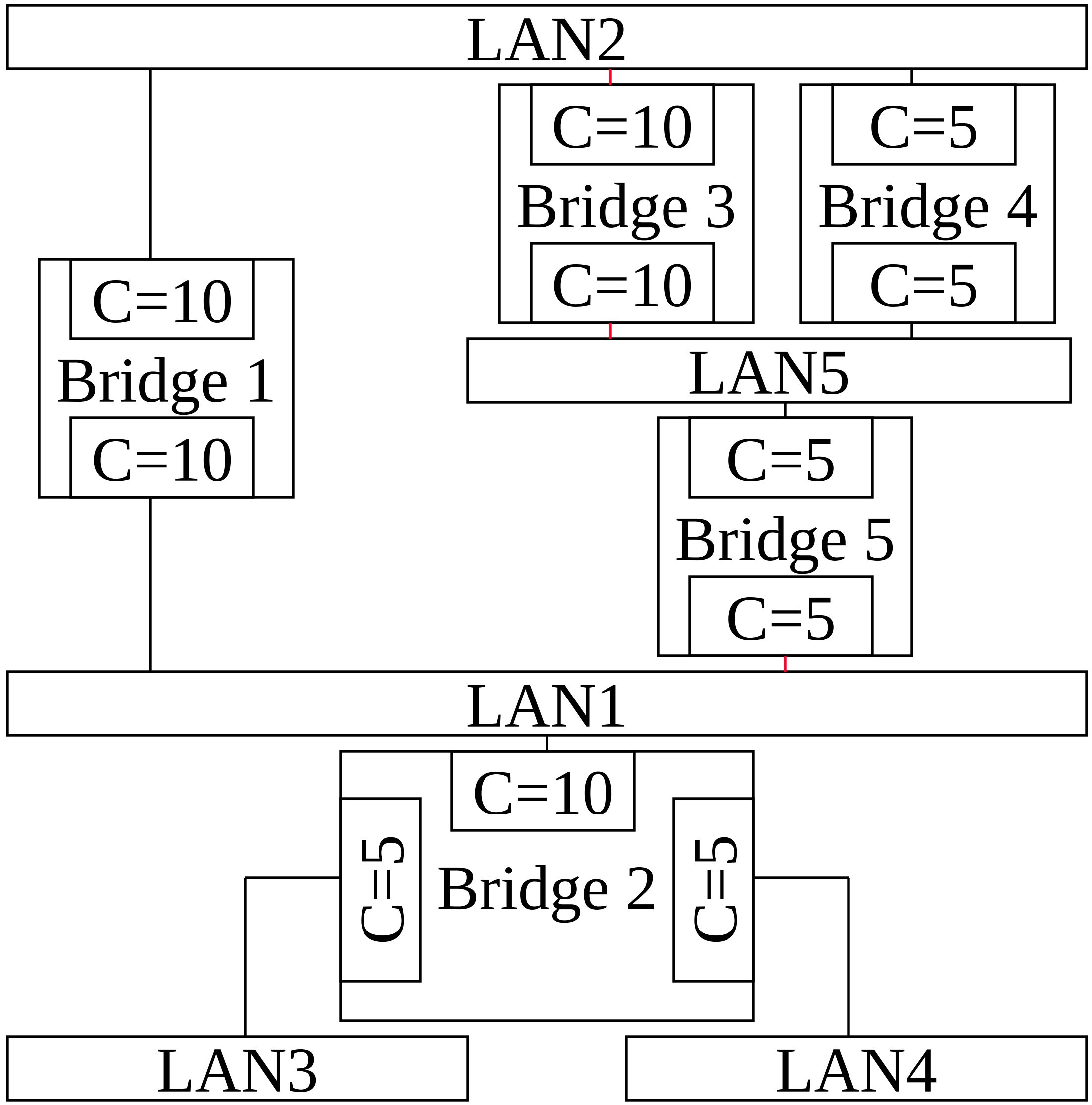


Fig 14.6

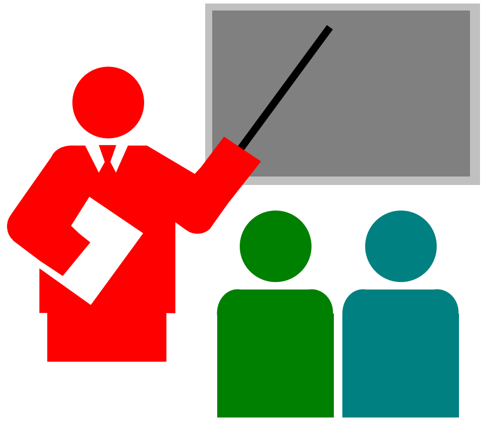
Spanning Tree Algorithm

- All bridges multicast to "All bridges"
  - My ID
  - Root ID
  - My cost to root
- The bridges update their info using Dijkstra's algorithm and rebroadcast
- Initially all bridges are roots but eventually converge to one root as they find out the lowest Bridge ID.
- On each LAN, the bridge with minimum cost to the root becomes the Designated bridge
- All ports of all non-designated bridges are blocked.

Spanning Tree Example



Summary



- ISO/OSI reference model has seven layers.
- Physical layer deals with bit transmission across a single wire/fiber
- Ethernet/IEEE 802.3 uses CSMA/CD.
- Addresses: Local vs Global, Unicast vs Broadcast.
- Spanning tree ⇒ simple packet forwarding

Homework

True or False?

T F

❑ ❑ Datalink refers to the 2nd layer in the ISO/OSI reference model

❑ ❑ If you change UTP-5 with fiber based Ethernet, you have changed the physical layer

❑ ❑ UTP-3 is better than UTP-5

❑ ❑ Multimode fiber has a thicker core than a single mode fiber and hence it is used for higher data rate transmission.

❑ ❑ A signal of 100 mW power is transmitted. 1 mW is received after 50km $\Rightarrow$ attenuation is 2 dB/km

❑ ❑ It is impossible to send 3000 bits/second through a wire which has a bandwidth of 1000 Hz.

❑ ❑ Bit stuffing is used so that characters used for framing do not occur in the data part of the frame.

❑ ❑ Ethernet uses a CSMA/CD access method.

❑ ❑ 10Base2 runs at 2 Mbps.

❑ ❑ Spanning tree algorithm is used to find a loop free path in a network.

Marks = Correct Answers _____ - Incorrect Answers_____ = ______