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

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Fundamentals of Networking

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Overview

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

Under Code 367, Mr. Smith is guilty of larceny

- Lawyer
- Postal Service
- Airline

Layer specific functions, Headers
## ISO/OSI Reference Model

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

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Transmission Media

- Coaxial cable
- Twisted Pair
- Optical Fiber
Coaxial Cable

- Used in original Ethernet (~ 1983)
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.
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 $\approx 500 \text{ THz}$
- Wavelength of visible light $\approx 600 \text{ nm}$
  (Violet = 400 nm, Red = 700 nm)
- Visible light has a high loss
  $\Rightarrow$ 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

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

Potential: $58 \text{ THz} = 50 \text{ Tbps}$ on 10,000 $\lambda$’s


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DeciBels

- Power reduces exponentially with distance
- Input = 10 mW, At 1 km: 5 mW, At 2 km: 2.5 mW, ..
- Attenuation = \( \log_{10}\left(\frac{P_{in}}{P_{out}}\right) \) Bel
  = \( 10 \log_{10}\left(\frac{P_{in}}{P_{out}}\right) \) deciBel
- Example: \( P_{in} = 10 \text{ mW} \), \( P_{out} = 5 \text{ mW} \)
  Attenuation = \( 10 \log_{10}(10/5) = 10 \log_{10}2 = 3 \text{ dB} \)
- Power is measured in dBm
  0 dBm = 1 mW
  \( n \) dBm = \( 10^{n/10} \) mW, \( 10 \log_{10}x \) dBm = \( x \) mW
- Example: \( P_{in} = 10 \text{ dBm} \), \( P_{out} = 7 \text{ dBm} \), Atten.= 3 dB
Four-Wave Mixing

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

\[ \Delta = \omega_2 - \omega_1 \]
## Recent Products Announcements

<table>
<thead>
<tr>
<th>Product</th>
<th>λ’s</th>
<th>Gb/s</th>
<th>km</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens/Optisphere TransXpress</td>
<td>80</td>
<td>40</td>
<td>250</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>10</td>
<td>250</td>
<td>2001</td>
</tr>
<tr>
<td>Alcatel 1640 OADM</td>
<td>160</td>
<td>2.5</td>
<td>2300</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>10</td>
<td>330</td>
<td>2001</td>
</tr>
<tr>
<td>Corvis Optical Network Gateway</td>
<td>160</td>
<td>2.5</td>
<td>3200</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>10</td>
<td>3200</td>
<td>2000</td>
</tr>
<tr>
<td>Ciena Multiwave CoreStream</td>
<td>160</td>
<td>10</td>
<td>1600</td>
<td>2001</td>
</tr>
<tr>
<td>Nortel Optera LH4000</td>
<td>56</td>
<td>10</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>Optera LH 5000</td>
<td>104</td>
<td>40</td>
<td>1200</td>
<td>2002</td>
</tr>
<tr>
<td>Sycamore SN10000</td>
<td>160</td>
<td>10</td>
<td>800</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>10</td>
<td>4000</td>
<td>2001</td>
</tr>
<tr>
<td>Cisco ONS 15800</td>
<td>160</td>
<td>10</td>
<td>2000</td>
<td>2002</td>
</tr>
</tbody>
</table>

- Ref: “Ultra everything,” Telephony, October 16, 2000

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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
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

1 Second

Bits 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
14 b/s
14 Baud, 7 Hz

NRZ

Bits 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
14 b/s
28 Baud, 14 Hz

Manchester

Bits 0 0 0 1 1 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0
14 b/s
7 Baud, 3.5 Hz

Multilevel
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

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# HDLC Framing

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Information</th>
<th>CRC</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B</td>
<td>1B</td>
<td>1B</td>
<td></td>
<td>2B</td>
<td>1B</td>
</tr>
</tbody>
</table>

- **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

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**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**

```
11111111111011111101111110
```

**After bit-stuffing**

```
111111011111101110111111010111111010
```

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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

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>01111110 11111111 00000011</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Info</th>
<th>Padding</th>
<th>CRC</th>
<th>Flag</th>
</tr>
</thead>
</table>

- 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 \textit{slot} (Slot = 51.2 \mu s = 64 byte times)
  - Wait for a random time and reattempt (up to 16 times)
    Random time = Uniform[0, 2^{\text{min}(k,10)}-1] slots
- Collision detected by monitoring the voltage
  High voltage $\Rightarrow$ two or more transmitters
  Collision
  $\Rightarrow$ 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
- 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

<table>
<thead>
<tr>
<th>Individual/Group</th>
<th>Universal/Local</th>
<th>Organizationally Unique Identifier (OUI)</th>
<th>24 bits assigned by OUI Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>22</td>
<td>24</td>
</tr>
</tbody>
</table>

- Multicast = “To all bridges on this LAN”
- Broadcast = “To all stations”
  = 1111111....111 = FF:FF:FF:FF:FF:FF:FF

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### Ethernet vs IEEE 802.3

#### Ethernet

<table>
<thead>
<tr>
<th>Dest. Address</th>
<th>Source Address</th>
<th>Type</th>
<th>Info</th>
<th>CRC</th>
<th>Size in bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>2</td>
<td></td>
<td>4</td>
<td></td>
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</table>

#### IEEE 802.3

<table>
<thead>
<tr>
<th>Dest. Address</th>
<th>Source Address</th>
<th>Length</th>
<th>LLC</th>
<th>Info</th>
<th>Pad</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
Interconnection Devices

LAN = Collision Domain

Extended LAN = Broadcast domain

Router

Application
Transport
Network
Datalink
Physical

Gateway
Router
Bridge/Switch
Repeater/Hub

Application
Transport
Network
Datalink
Physical

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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.”
- **Switch**: Multiport bridge with parallel paths
- These are functions. Packaging varies.
Spanning Tree

Fig 14.5
Spanning Tree (Cont)

LAN A

<table>
<thead>
<tr>
<th>101</th>
</tr>
</thead>
</table>

LAN B

<table>
<thead>
<tr>
<th>102</th>
</tr>
</thead>
</table>

LAN C

<table>
<thead>
<tr>
<th>103</th>
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</table>

LAN D

<table>
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<th>104</th>
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</thead>
</table>

LAN E

<table>
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<tr>
<th>105</th>
</tr>
</thead>
</table>

LAN F

<table>
<thead>
<tr>
<th>106</th>
</tr>
</thead>
</table>

LAN G

<table>
<thead>
<tr>
<th>107</th>
</tr>
</thead>
</table>

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

LAN2

C=10
Bridge 1
LAN3

C=10
Bridge 2
C=10

C=5
Bridge 3
C=5
Bridge 4
C=5
Bridge 5
C=5
LAN5

LAN1

C=10

C=10

LAN4
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 $\Rightarrow$ simple packet forwarding.
Homework

True or False?
T  F

ança Datalink refers to the 2nd layer in the ISO/OSI reference model
ança If you change UTP-5 with fiber based Ethernet, you have changed the physical layer
ança UTP-3 is better than UTP-5
ança Multimode fiber has a thicker core than a single mode fiber and hence it is used for higher data rate transmission.
ança A signal of 100 mW power is transmitted. 1 mW is received after 50km ⇒ attenuation is 2 dB/km
ança It is impossible to send 3000 bits/second through a wire which has a bandwidth of 1000 Hz.
ança Bit stuffing is used so that characters used for framing do not occur in the data part of the frame.
ança Ethernet uses a CSMA/CD access method.
ança 10Base2 runs at 2 Mbps.
ança Spanning tree algorithm is used to find a loop free path in a network.
Marks = Correct Answers _____ - Incorrect Answers _______ = _______