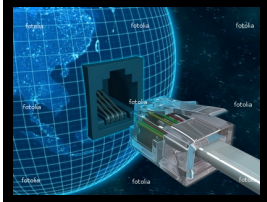
Direct Link Networks

COS 460/540

1



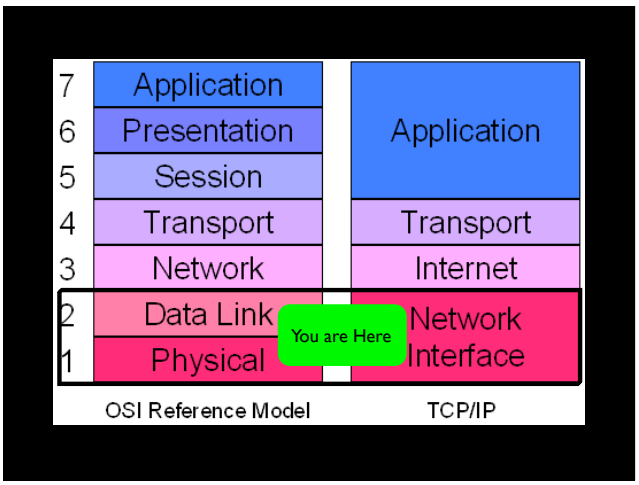
How to physically **connect** hosts

2

Direct Link Networks

- Hardware
- Encoding
- Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)

3



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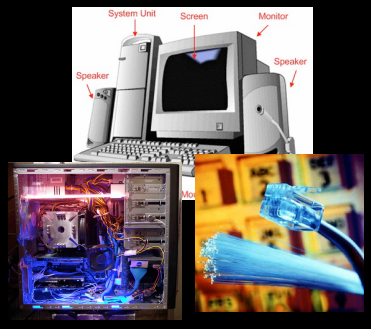
Hardware

- Nodes
- Links



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Nodes

- General Purpose Computer
  - Runs Application Software
  - Connects via Network Adapter
  - Limited Memory
  - Internal Bus = Internal Data Network

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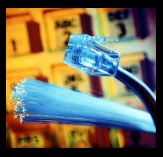
Links

- Physical Media
  - Copper
  - Coaxial Cable
  - Optical Fiber
  - Space



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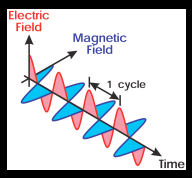
Physical Media



Carries
Electromagnetic Waves

- Frequency (Hz)
- Data is *encoded* in the signal - *modulation*
- One way or two way (half v full duplex)
- Signal degrades over distance

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Cables

Cat-5	100Mbps	100m
Coax	100Mbps	200m
Multimode fiber	100Mbps	2km
Single-mode fiber	10Gbps	40km

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Last Mile Links

POTS	28.8Kbps - 56Kbps
xDSL	128Kbps - 100Mbps
4G/LTE	5 - 12Mbps
Cable	1 - 40Mbps (single channel)
FiOS	5 - 100Mbps*
WiMAX	10Mbps*

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Direct Link Networks

- ✓ Hardware
- Encoding
- Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)

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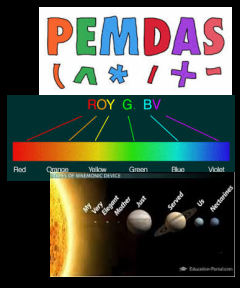
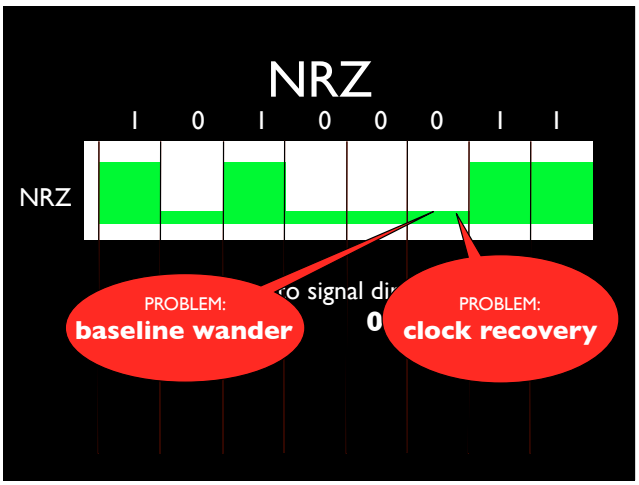
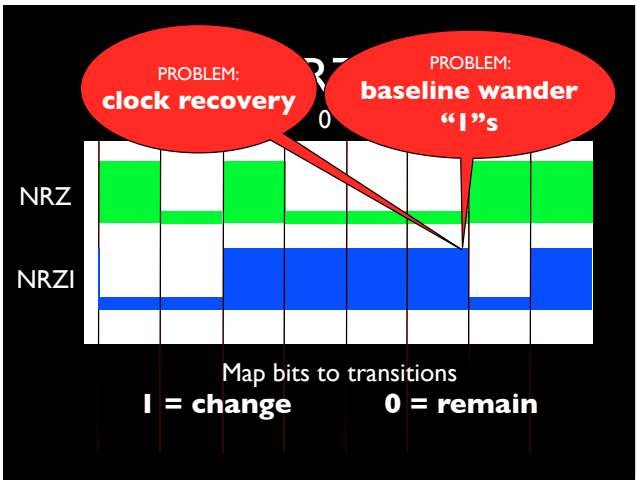
Encoding

- NRZ
- NRZI
- Manchester
- 4B/5B

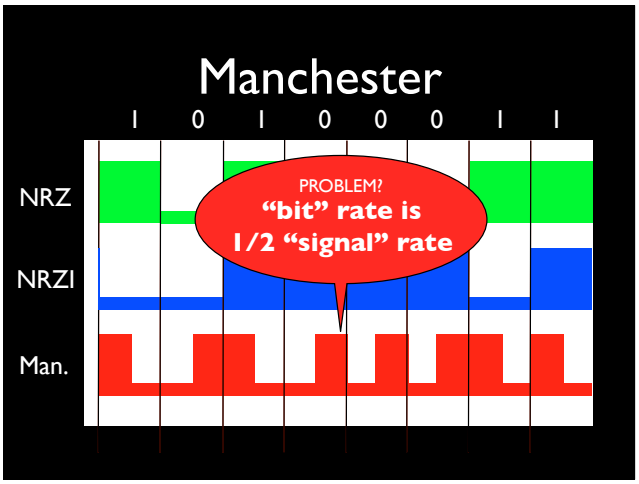



NRZ
1 0 1 0 0 0 1 1
NRZ
PROBLEM:
baseline wander
PROBLEM:
clock recovery

13


PROBLEM:
clock recovery
PROBLEM:
baseline wander
"1"s
NRZ
NRZI
Map bits to transitions
1 = change
0 = remain

14


Manchester
1 0 1 0 0 0 1 1
NRZ
NRZI
Man.
PROBLEM?
"bit" rate is
1/2 "signal" rate

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4B/5B Encoding

- Solve NRZI problems
  - encode 5 bits for every 4
  - avoid repeated 0's
  - ensure regular signal transitions

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4B/5B Encoding

4B	5B
0000	11110
0001	01001
0010	
0011	
0100	
0101	
0110	
0111	01111

4B	5B
1000	10010
1001	10011
	10110
	10111
	11010
	11011
	11100
1111	11101

PROBLEM:
"bit" rate is 7/8 "signal" rate

172 = 0xAC = 1010 1100 → 10110 11010

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Direct Link Networks

- ✓ Hardware
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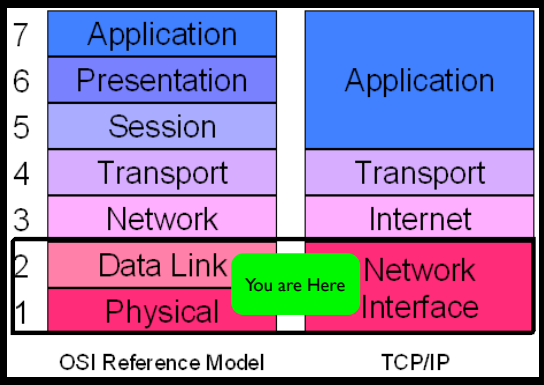
- Reliable Transmission
- Examples (Ethernet & Wireless)

19



20

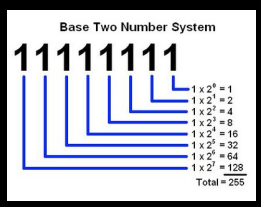
Framing

We can **transmit** and **receive** bits; but how do we recognize individual **messages**?

21

Framing

- **Byte-Oriented**
- Bit-Oriented
- Clock-Based



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Sentinel Based

Use **special** characters, wrap message

- SYN, SOH, STX, ETX, DLE, ...
- Indicate where things begin… and end
- Problems: corrupt ETX

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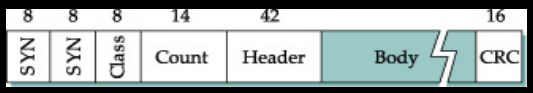
Byte Counting



Include **count** of bytes in message

Problems: corrupt count field

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Bit-Oriented

- Frame is a collection of bits
- STX is distinguished bit sequence
  - 01111110 (six 1's)
  - used when link is idle as well
  - bit-stuffing
    (after 5 1's stuff in a 0 & ignore)

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Clock Based

- Works well on optical networks
- fixed frame sizes; 9 rows x 90 bytes
- rigid (and large) definition
- "special" bit pattern
  - at start of frame
  - every 810 bytes

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Error **DETECTION**

- Parity
- 2D Parity
- Checksum
- Cyclic Redundancy Check (CRC)

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Parity

1010101p Even = 0
Odd = 1

- Simple method to detect bit errors
- 1 bit parity for each 7 bits of data
- 7/8 of data rate (87%)
- only odd # of errors (bad)

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2D Parity

- Compute across 7 rows as well as 7 columns
- 7/8 of 7/8 data rate (76%)
- catches multi-bit errors (good)

1010101p
1110001p
1011010p
....
pppppppp

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Internet CheckSUM

- Add up all the words and transmit the sum
- Truncate to 16 bit word
- Much better on "bandwidth"
- Misses 1/65k errors

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CRC

- message = 10101010
- M(x) = $1x^7 + 0x^6 + 1x^5 + 0x^4 \ldots = x^7 + x^5 \ldots$
- P(x) = message bits + CRC bits such that

  P(x)/C(x) = 0
- C(x) chosen based on common errors

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Direct Link Networks

- ✓ Hardware
- ✓ Encoding
- ✓ Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)

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Reliable Transmission

- Stop and Wait
- Sliding Window
- Concurrent Logical Channels

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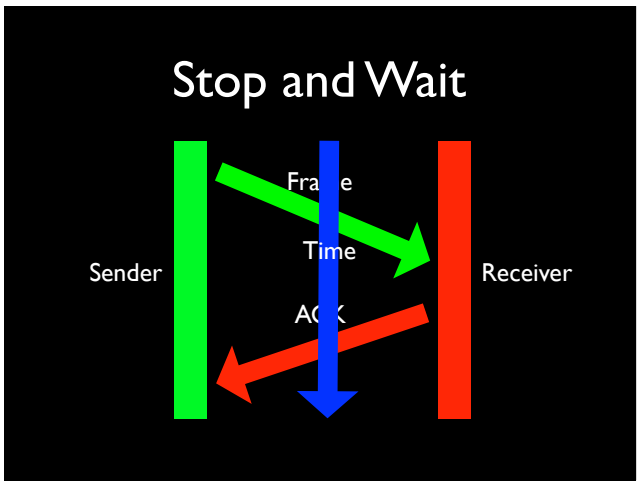
ARQ

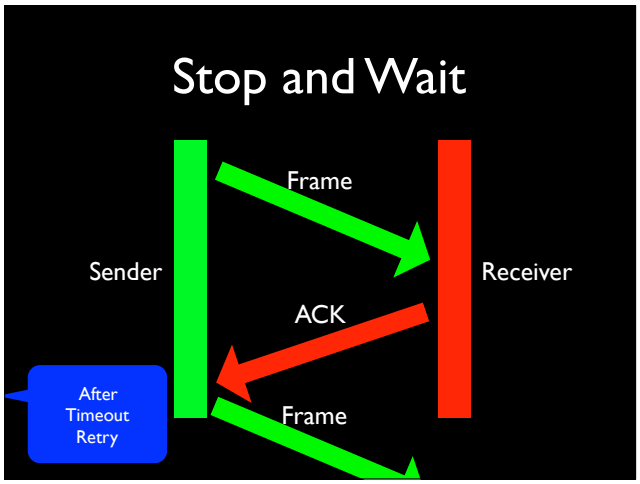
Automatic Repeat Request

Tools:

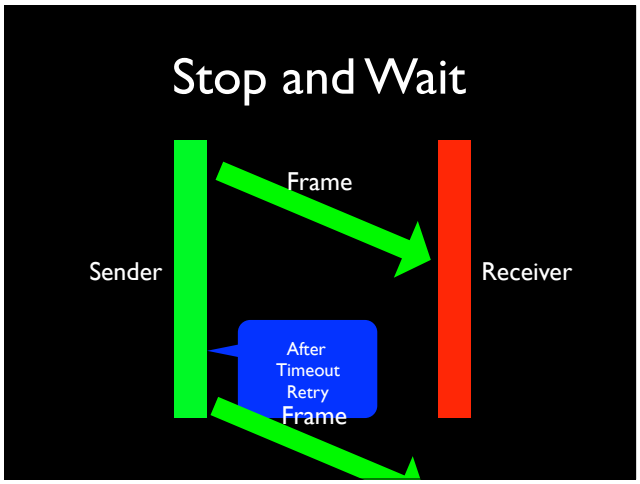
- acknowledgement (ACK)
- timeout


Stop and Wait
Sender
Receiver
Time

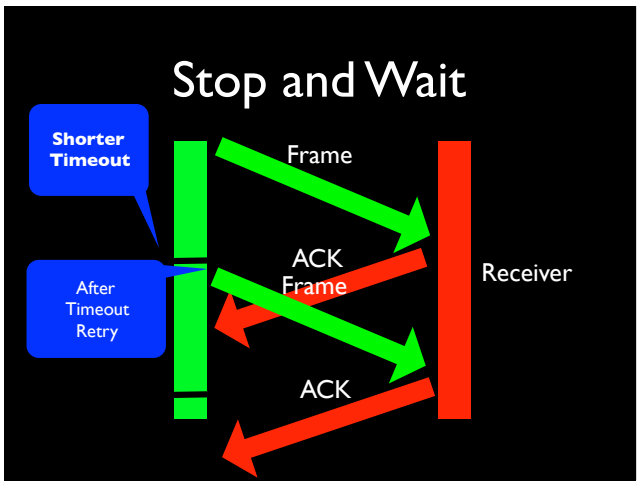
34


Stop and Wait
Frame
Sender
Receiver
ACK
After
Timeout
Retry
Frame

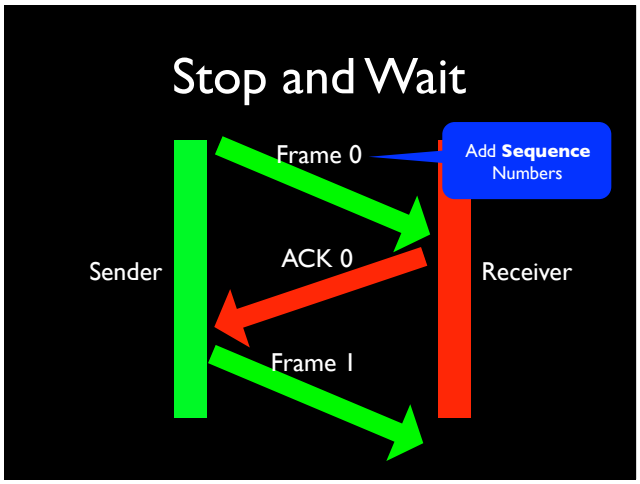
35


Stop and Wait
Frame
Sender
Receiver
After
Timeout
Retry
Frame

36


Stop and Wait
Shorter Timeout
After Timeout Retry
Frame
ACK
Frame
Receiver
ACK

37


Stop and Wait
Frame 0
Add Sequence Numbers
Sender
ACK 0
Receiver
Frame 1

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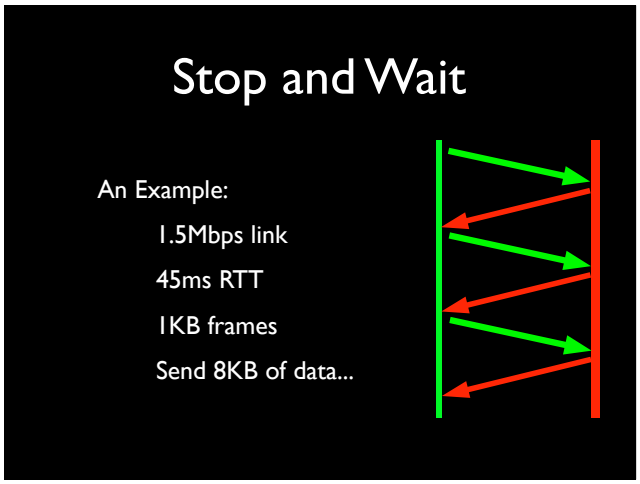
Stop and Wait
An Example:
1.5Mbps link
45ms RTT
1KB frames
Send 8KB of data...

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Stop and Wait

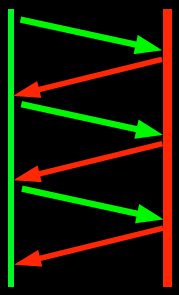
Sending Rate

1KB every 45ms

(1024 x 8) / 0.045

182 Kbps

on a 1.5Mbps link!



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Stop and Wait

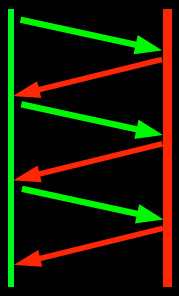
The "pipe" is not full

we could have…

delay x bandwidth

67.5Kb

on the wire



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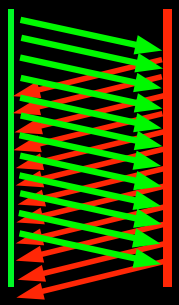
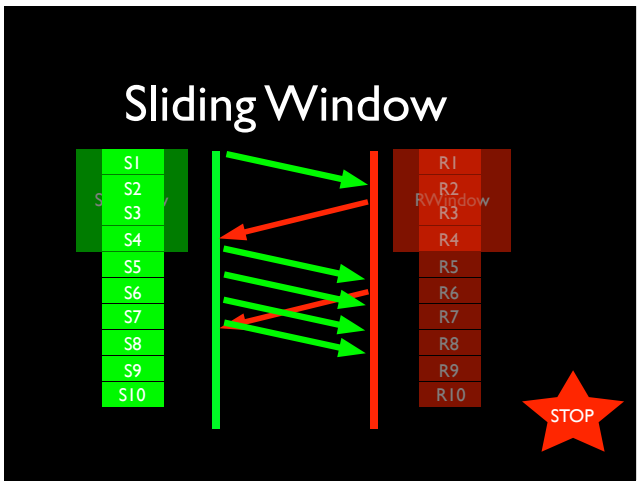
Sliding Window

Keep the "pipe" full

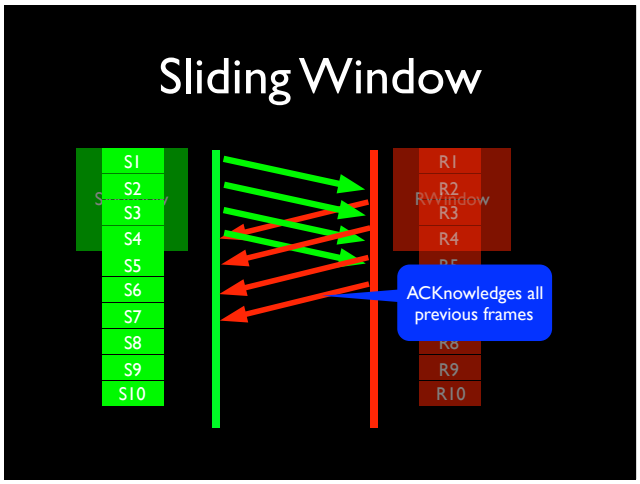
Overlap **sending** data and **acknowledgements**

with "buffers" on each end




Sliding Window
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
STOP

43


Sliding Window
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
R1
R2
R3
R4
R9
R10
ACKnowledges all previous frames

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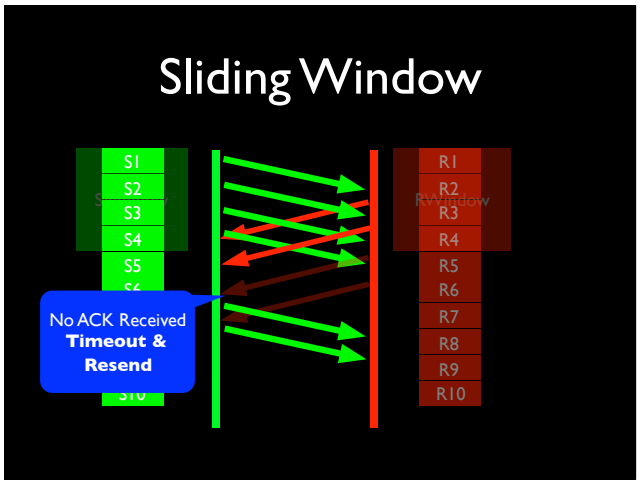
Sliding Window
S1
S2
S3
S4
S5
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
No ACK Received
Timeout &
Resend

45

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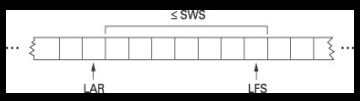
Sliding Window



LFS - LAR <= SWS

LAF - LFR <= RWS

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Reliable Transmission

- Using;
  - Error Detection
  - Timeout & Acknowledgements
- Stop and Wait
- Sliding Window

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Direct Link Networks

- ✓ Hardware
- ✓ Encoding
- ✓ Framing & Error-Detection
- ✓ Reliable Transmission
- Examples (Ethernet, Token Ring, & Wireless)

Ethernet (802.3)

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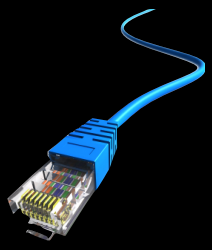

- Physical Properties
- Access Protocol
- Experience

Ethernet

50

- Most popular & successful Local Area Network (LAN)
- Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
- Updated with larger bandwidth

Physical Properties

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- Coaxial Cable <= 500m
- Same cable shared among all nodes
- Literally "tap" into cable to get on Ethernet
- ~255 hosts per "link"

Joining Ethernets

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- Multiple segments joined by "repeaters"
- Much like an amplifier
- <= 4 repeaters between nodes (total 2500m reach)
- terminators at ends
- broadcast over entire network

Typical Ethernet

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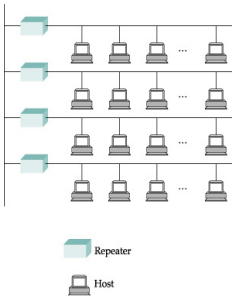

Ethernet Encoding

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- Manchester encoding

Alternate Media

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- Coax - 10Base2 (thin - 10Mbps, 200m)
- Coax - 10Base5 (thick - 10Mbps, 500m)
- Twisted Pair - 10BaseT (10Mbps, 100m)
  - 100BaseT... etc..

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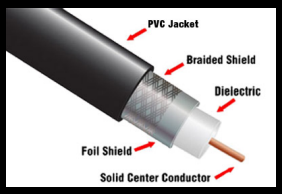

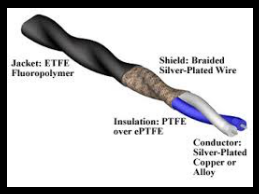

Ethernet Switches

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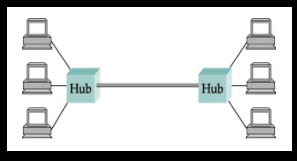

- Ethernet Switches emulate the shared access to the same media
- Optimizations are made to make better use of bandwidth and buffers

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Physical Properties

- Shared link between all nodes
  - Good: easy to transmit/rcv. traffic
  - Bad: same "collision domain"
- Connected by repeaters
- ~2,500m max length

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Access Protocol

- Frame Format
  - Addresses
- Receiver Algorithm
- Transmitter Algorithm

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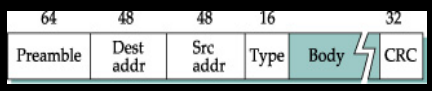
Frame Format



- Preamble = 01010101010....
- Addresses (MAC Address)
- Type (or length) <= 1,500
- Body = Data >= 46 bytes
- CRC = Cyclic Redundancy Check

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Addresses

- MAC = Media Access Control
- Every host has unique address (on LAN)
- 48 bits
  - 24 bits assigned to manufacturer
  - 24 bits assigned by manufacturer

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Receiver Algorithm

- Pass to host if destination address...
  - is *my* address?
  - is the *broadcast* address?
  - is a subscribed *multicast* address
- Or if adapter is in *promiscuous* mode

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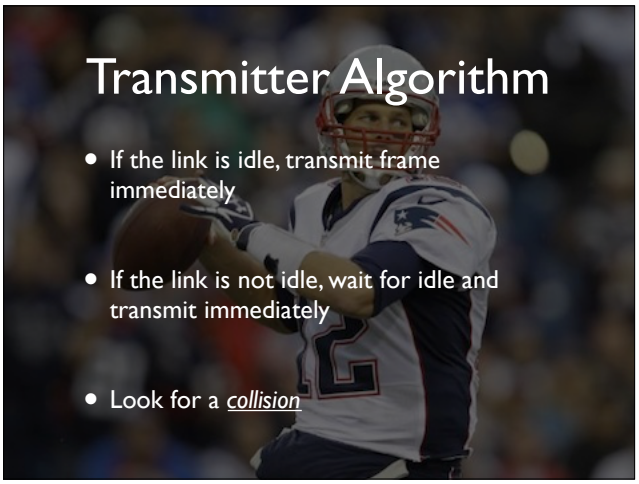

Transmitter Algorithm

- If the link is idle, transmit frame immediately
- If the link is not idle, wait for idle and transmit immediately
- Look for a *collision*

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Collision

When two or more nodes begin transmitting at (or near) the same time the frames are said to **collide**.

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Collision Detection

- Adapter "listens" to wire when transmitting
- If what it "hears" is not what was sent... we have a collision

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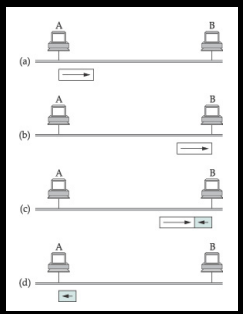
Collision Detection

- A sends to B.
- B starts to send just before A's frame arrives.
- B senses and sends jam
- If the link is "too long" A will not "hear" the collision.



Collision Detection

67

- Max length = 2,500m
- 10 Mbps
- RTT = 51.2 µs
- 512 bits, hence minimum frame size

Exponential Backoff

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When a host recognizes a collision it does not immediately retry

- Wait either 0 or 51.2 µs
- If collide again, wait either 0, 51.2, 102.4, or 153.6 µs
- if we collide again, double the max....

Ethernet Experience

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- Simple to deploy and administer
- Works best under light load; <30%
- Most are conservative deployments
- Inexpensive to implement

Token Ring

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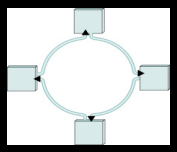
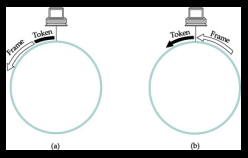
- Multiple access
- Receive and forward
- "token" circulates around the ring
- Deterministic access





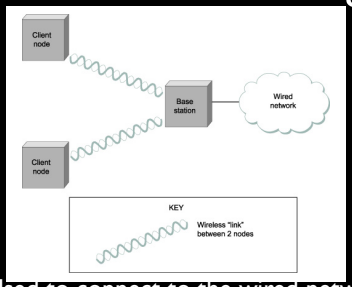
Wireless

71

- Bluetooth (802.15.1)
- Wi-Fi (802.11)
- WiMax (802.16)
- Cell Phones

Wireless Technology

72



Used to connect to the wired network

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Wireless Technology

- Bandwidth capabilities
- Frequency range - license required?
- Power requirements
- Symmetric vs Asymmetric (base vs host)

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Wireless Technology

	Bluetooth	Wi-Fi	WiMAX	3G
Length	10m	100m	10km	10's km
Bandwidth	2.1Mbps	54Mbps	70Mbps	384Kbps
Use	Devices	Notebook	Building	Phone
Compare	USB	Ethernet	Coaxial	DSL

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Bluetooth (802.15.1)

- Short range
- Replace (augment) device connections
- License exempt 2.45GHz frequency band
- Range of 10m
- Personal Area Network (PAN)

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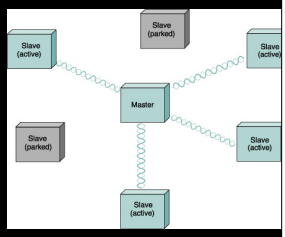
Bluetooth

- Master-Slave Network
- Devices only talk to master
- Spread spectrum technique (see physical layer)



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Wi-Fi (802.11)

- Physical Properties
- Collision Avoidance
- Distribution System
- Frame Format

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Wi-Fi Physical

- 6 different physical layers (a, b, g, n...)
- various spread spectrum techniques
- 2.4GHz & 5GHz license free bands
- Range 10+m
- Chooses highest bandwidth available

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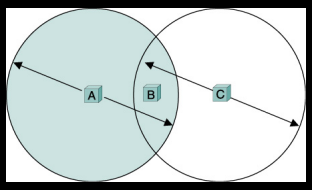
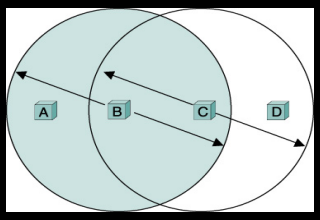
Collision Avoidance



Cannot be same as Ethernet because there are "hidden nodes"

80

Collision Avoidance



... also the "exposed node" problem

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Collision Avoidance

Multiple Access with Collision Avoidance

- Send Request to Send (RTS) w/length
  - Reply with Clear to Send (CTS) w/ length

Now all nodes in range know the length

Collision Avoidance

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- If a node sees RTS but not CTS?
  - free to communicate (hidden)
- Receiver also sends ACK after frame
  - everyone waits for ACK
- Simultaneous RTS?
  - Corruption at receivers and no CTS

Distribution & Association

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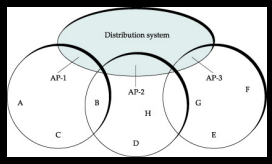

Goal is to connect to wired network

Probe and Response -- Associate with best

Frame Format

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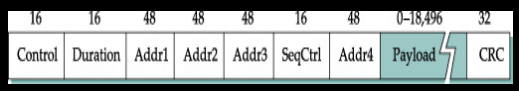

- Similar to Ethernet?
- Control = CTS, RTS, etc.
- 4 addresses; used for proxy frames through distribution system

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WiMAX (802.16)

- "Last Mile" Technology
- Range 6 - 30 miles
- No "mobility"
- 10 - 60GHz frequency bands
- Asynchronous upstream & downstream using time division multiplexing

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Cellular (1&2G)

- Licensed spectrum, wired base stations
- 1G = analog
- 2G = digital optimized for voice
  - TDM, FDM, and CDMA (code division)
- 2.5G = "data oriented" 2G
  - TDM with dynamic time slots

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Cellular 3G

- Planned to be international standard
- Higher data bandwidth
- Incompatible implementations
- CDMA based (UTMS)
- 1.92 Mbps
- Satellite Phones

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Wireless

- ✓ Bluetooth (802.15.1)
- ✓ Wi-Fi (802.11)
- ✓ WiMax (802.16)
- ✓ Cell Phones

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Direct Link Networks

- ✓ Hardware
- ✓ Encoding
- ✓ Framing & Error-Detection
- ✓ Reliable Transmission
- ✓ Examples (Ethernet, Token Ring, & Wireless)

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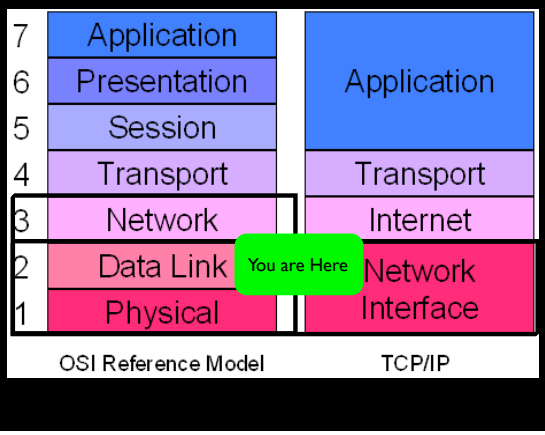


fin
Direct Link Networks