

Chapter 2 Direct Link Networks

Outline

- Point-to-Point Links
- Shared Media

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Point-to-Point Links

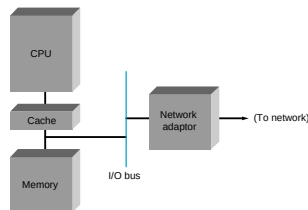
Outline

- Hardware Building Blocks
- Encoding
- Framing
- Error Detection
- Sliding Window Algorithm

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2.1 Hardware Building Blocks Fig. 2-1 Example workstation architecture



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2.1 Hardware Building Blocks

• 2.1.1 Nodes

- Network Adaptor
 - Sits on system's I/O bus and delivers data between the workstation's memory and the network link.
- Device Driver
 - A software module running on the workstation to manage the adaptor
- CPU and Memory
 - CPU doubles its speed every 18 months
 - Memory improves 7% of latency each year
 - Effect on network software design and development

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Network Adaptors

- Nearly all functions described in this chapter are implemented in the network adaptor: framing, error detection, MAC.
- Only exception: pt-to-pt ARQ
 - implemented in the lowest-level protocol on host.
- Serves as an interface between the host and the network:
 - Bus interface : communicate with the host
 - Link interface : speaks the (MAC) protocol on the network

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- Bus interface : communicate with the host

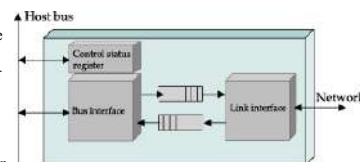
- Designed for a specific I/O bus that defines a protocol

- Used by the host's CPU to program the adaptor
- Used by the adaptor to interrupt the host's CPU and to read/write memory on the host

- I/O bus data transfer rate

- Eg. $32 \text{ bit} \times 33 \text{ MHz}$
 $\Rightarrow 1 \text{ Gbps}$
- May support
 STS-12, 622 Mbps

Network Adaptors - Components



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Network Adaptors

- Frames (network)
- Buffers (host architecture)
- Messages (OS)

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Network Adaptors

- Device Driver
 - A collection of OS routines that anchor the protocol stack to the network hardware
 - Initialize device, transmit frames, field interrupts
 - Transmit routine:
 - check buffer available
 - Disable interrupts
 - Translates message from OS format to device format
 - Set CSR (Control Status Register)
 - Enable interrupts

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2.1 Hardware Building Blocks

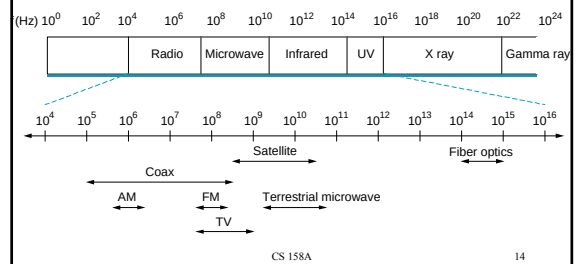
- 2.1.2 Links
 - Physical Media
 - Twisted pair, coaxial cable, optical fiber, space
 - Propagate Signals
 - Frequency, wavelength, speed (Fig. 2.4 next slide)
 - Modulation
 - Varying the frequency, amplitude, or phase of the signal to effect the transmission
 - Full-duplex, half-duplex

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2.1 Hardware Building Blocks

Fig. 2-4 Electromagnetic Spectrum



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2.1 Hardware Building Blocks

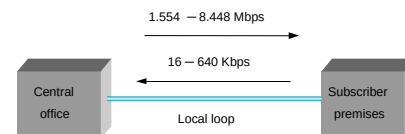
- Cables - Table 2.1 Common types of cables and fibers available for local links
- Leased Lines - Table 2.2 Common bandwidths available from the carriers
- Last-Mile Links - Table 2.3 Common services available to connect your home

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2.1 Hardware Building Blocks

Fig. 2.5 ADSL connects the subscriber to the central office via the local loop



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2.1 Hardware Building Blocks

Fig. 2.6 VDSL connects the subscriber to the optical network that reaches the neighborhood



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2.1 Hardware Building Blocks Shanon's Theorem

- Provides an upper bound to the capacity of a link, bps
- $C = B \log_2 (1 + S/N)$
 - C: Capacity, in bps
 - B: Frequency Spectrum Bandwidth, in Hz
 - S/N : Signal to Noise Ratio
- S/N (dB):
 - $\text{dB} = 10 \times \log_{10} (S/N)$

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2.1 Hardware Building Blocks Example for Shanon's Theorem

- Data rate - How fast binary data can be transmitted over a voice-grade phone line?
- B: 300 Hz to 3,300 Hz; B = ??
- S/N: 30 dB; S/N = ??
- C = ??

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2.1 Hardware Building Blocks Wireless Links

- Wireless links transmit electromagnetic (em) signals – radio, microwave, infrared, and visible light.
- Attenuation makes it feasible to limit the area covered by an em signal.
- FCC determines the allocation of frequency spectrum (AM, FM, TV, cell phone, etc.)
- Several frequency bands set aside as “license-exempt” usage.

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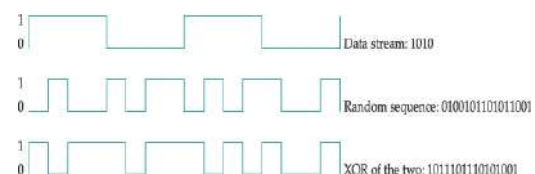
2.1 Hardware Building Blocks Wireless Links – License exempt usage

- 2 restrictions: power, spread spectrum techniques (to reduce interference)
- Frequency hopping
 - Transmitting over a random sequence of frequencies (by pseudorandom number generator)
 - Sender and receive both know the sequence
- Direct sequence
 - Adds redundancy for greater interference tolerance
 - Each bit is represented by multiple bits
 - Data bit XOR with n random bits (n-bit chipping code) – see Fig. 2.7
- Used by 802.11, 802.15.1, 802.16, etc. (Sec 2.8)

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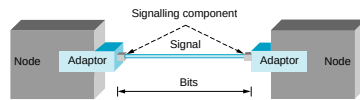
2.1 Hardware Building Blocks Wireless Links – 4-bit chipping Sequence



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2.2 Encoding (NRZ, NRZI, Manchester, 4B/5B)



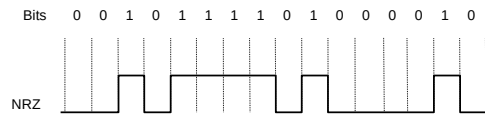
- Fig. 2.8 – Signals travel between signaling components; bits flow between adaptors
- Signals propagate over a physical medium
 - modulate electromagnetic waves
 - e.g., vary voltage

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2.2 Encoding (NRZ, NRZI, Manchester, 4B/5B)

- Encode binary data onto signals
 - e.g., 0 as low signal and 1 as high signal
 - known as Non-Return to zero (NRZ) – Fig. 2.9



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Problem: Consecutive 1s or 0s

- Low signal (0) may be interpreted as no signal
- Too many consecutive high (or low signals) leads to baseline wander
- Unable to recover clock
 - On every clock cycle the sender transmits a bit and the receiver recovers a bit
 - Needs to be precisely synchronized

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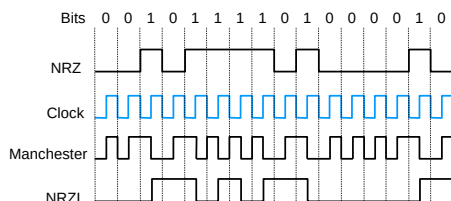
Alternative Encodings

- Non-return to Zero Inverted (NRZI) (Fig. 2.10 next slide)
 - make a transition from current signal to encode a one; stay at current signal to encode a zero
 - solves the problem of consecutive ones
 - Still has the problem of ...?
- Manchester
 - transmit XOR of the NRZ encoded data and the clock
 - only 50% efficient (bit rate = 1/2 baud rate)
- Baud rate vs. Bit rate
 - Next slide.

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2.2 Encoding Fig. 2.10



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Alternative Encodings

- Baud rate vs. Bit rate
 - Baud rate: the rate at which signals changes, Hz
 - Bit rate: the rate that bits are transmitted, bps
 - Bit rate > Baud rate (Eg. Can transmit 4 distinguished signals)
 - Baud rate > Bit rate (Manchester Encoding)

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2.2 Encodings (cont)

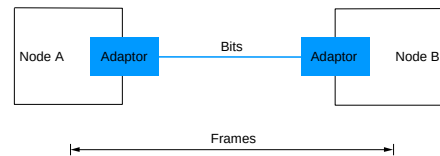
- 4B/5B (See Table 2.4)
 - every 4 bits of data encoded in a 5-bit code
 - 5-bit codes selected to have no more than one leading 0 and no more than two trailing 0s
 - thus, never get more than three consecutive 0s
 - resulting 5-bit codes are transmitted using NRZI (taken care of consecutive 1s)
 - achieves 80% efficiency (bit rate = 80% baud rate)
 - 8B/10B?

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2.3 Framing

- Break sequence of bits into a frame
- Typically implemented by network adaptor



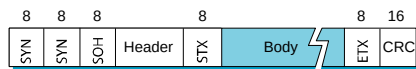
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Approaches

2.3.1 Byte-Oriented protocols

- Sentinel-based
 - delineate frame with special pattern, eg. 01111110
 - e.g., BISYNC (Binary Synchronous Communication) developed by IBM in 1960's (Fig. 2.12)
 - SYN: synchronization. STX: Start of Text. SOH: Start of header. ETX: End of Text.
 - If ETX appears in the data, preceding it with a DLE (Data Link Escape) – character stuffing.



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Approaches

2.3.2 Bit-Oriented protocols (HDLC)

- Fig. 2.15
- View the frame as a collection of bits.
- Beginning and end: 01111110



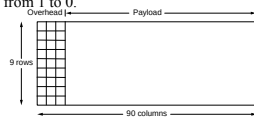
- problem: special pattern appears in the payload
- solution: *bit stuffing*
 - sender: insert 0 after five consecutive 1s
 - receiver: delete 0 that follows five consecutive 1s

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2.3.3 Clock-based framing (SONET) Synchronous Optical Network

- Dealt with framing, encoding, and multiplexing
 - STS-1: 51.84 Mbps (Fig. 2.13)
 - First 2 bytes of 90 bytes are special bit pattern
 - Overhead bytes:
 - NRZ
 - Scrambled with a well-known 127 bits that has plenty of transitions from 1 to 0.

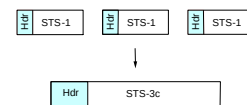


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2.3.3 Clock-based framing (SONET) Synchronous Optical Network – Cont'd

- Supports multiplexing of multiple low-speed links.
- Rates ranging from STS-1 = 51.84 Mbps to STS-48 of 2.488 Gbps
 - each frame is 125us long
 - # of bytes for STS-1 and for STS-3?
 - STS-N consists of N STS-1 frames: bytes from these frame interleaved for a smooth rate
 - STS-Nc (concatenation)



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2.4 Error Detection (Correction)

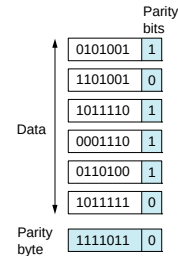
- Add k bits of redundant data to an n -bit message
 - want $k \ll n$
 - e.g., Ethernet: $k = 32$ and $n = 12,000$ (1500 bytes)
- Chechsum: Code created based on addition, used in IP, UDP, and TCP
- CRC: 32 bit used in Ethernet, 8 bits used in ATM (for both correcting 1 bit error and detection multiple bit error).

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2.4.1 Two-Dimensional parity

- Fig. 2.19



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2.4.2 Internet Checksum Algorithm

- Code: The sum of all the words transmitted
- IP: Consider data as a sequence of 16-bit integers
- Add them using 16-bit ones complement arithmetic
- Eg. $-5 + -3 = -8$ (0111)
- Strength: small redundancy
- Weakness:
- Why still use?

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2.4.3 Cyclic Redundancy Check

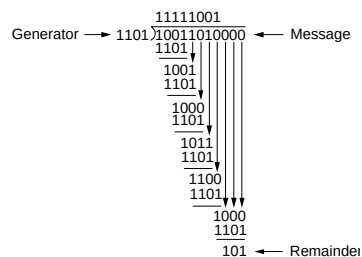
- Add k bits of redundant data to an n -bit message
 - want $k \ll n$
 - e.g., $k = 32$ and $n = 12,000$ (1500 bytes)
- Represent n -bit message as $n-1$ degree polynomial
 - e.g., MSG=10011010 as $M(x) = x^7 + x^4 + x^3 + x^1$
- Let k be the degree of some divisor polynomial
 - e.g., $C(x) = x^3 + x^2 + 1$

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CRC (cont)

CRC Calculation using polynomial long division (Fig. 2.20)



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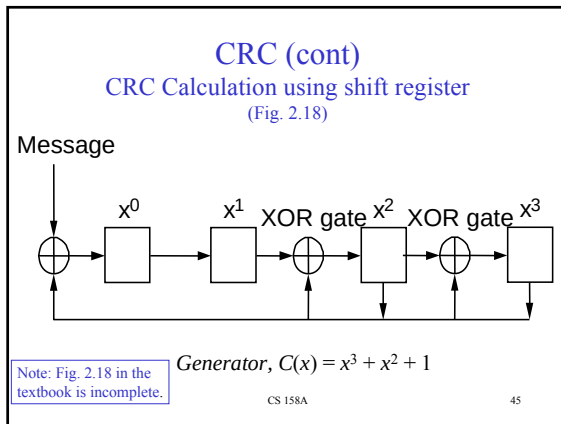
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CRC (cont)

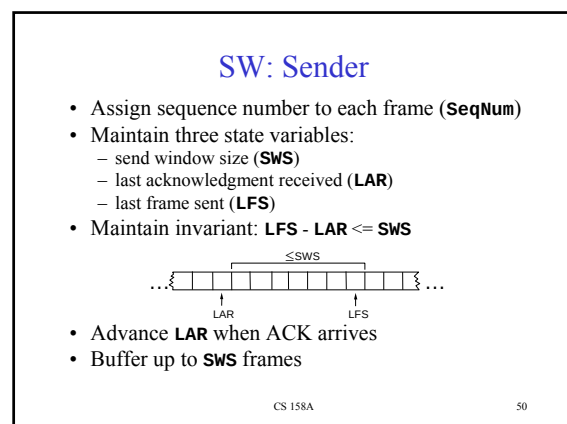
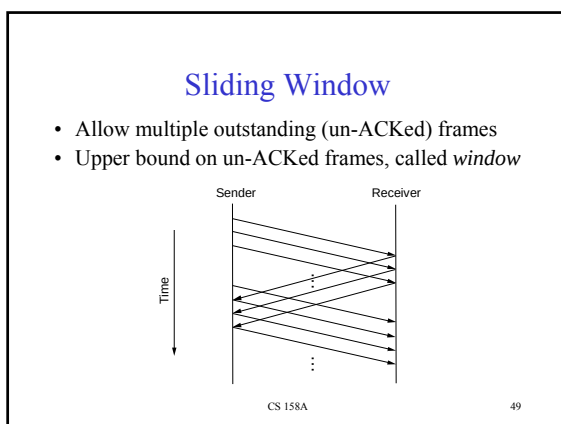
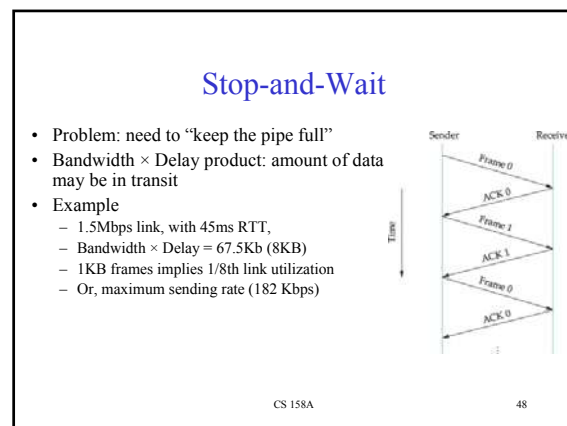
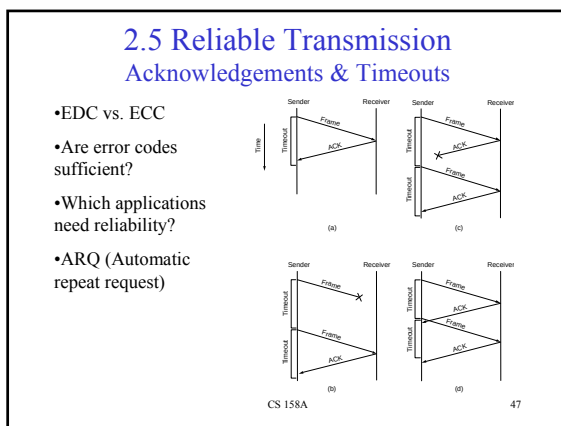
- Transmit polynomial $P(x)$ that is evenly divisible by $C(x)$
 - shift left k bits, i.e., $M(x)x^k$
 - subtract remainder of $M(x)x^k / C(x)$ from $M(x)x^k$
- Receiver polynomial $P(x) + E(x)$
 - $E(x) = 0$ implies no errors
- Divide $(P(x) + E(x))$ by $C(x)$; remainder zero if:
 - $E(x)$ was zero (no error), or
 - $E(x)$ is exactly divisible by $C(x)$

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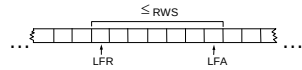


- ### CRC (cont)
- #### Selecting $C(x)$
- All single-bit errors, as long as the x^k and x^0 terms have non-zero coefficients.
 - All double-bit errors, as long as $C(x)$ contains a factor with at least three terms
 - Any odd number of errors, as long as $C(x)$ contains the factor $(x + 1)$
 - Any 'burst' error (i.e., sequence of consecutive error bits) for which the length of the burst is less than k bits.
 - Most burst errors of larger than k bits can also be detected
 - See Table 2.5 on page 96 for common $C(x)$
- CS 158A 46



SW: Receiver

- Maintain three state variables
 - receive window size (**RWS**)
 - largest frame acceptable (**LFA** or **LAF**)
 - last frame received (**LFR**)
- Maintain invariant: $LFA - LFR \leq RWS$



- Frame **SeqNum** arrives:
 - if $LFR < SeqNum \leq LFA$ accept
 - if $SeqNum < LFR$ or $SeqNum > LFA$ discarded
- Send cumulative ACKs

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Shared Access Networks

Outline

- Bus (Ethernet)
- Token ring (FDDI)
- Wireless (802.11)

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Gedanken experiment

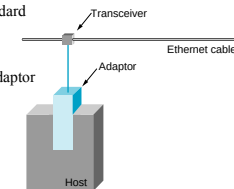
- How does communication work in real life?
- If there are lots of speakers/speaking?
- If there is little speaking?
- If there are “important” people?
- Can we map this to computer networks?

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Ethernet Overview

- History
 - developed by Xerox PARC in mid-1970s
 - roots in Aloha packet-radio network
 - standardized by Xerox, DEC, and Intel in 1978
 - similar to IEEE 802.3 standard
- Physical Properties
 - Fig. 2.24
 - Ethernet transceiver and adaptor

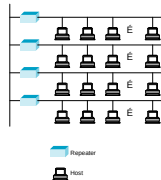


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Ethernet Overview

- Physical Properties (Cont)
 - Fig. 2.25 - Ethernet repeaters
 - Traditionally, 50 ohms coaxial cable (like cable TV)
 - Repeater: a device that forwards digital signals, like an amplifier forwards analog signals.
 - Ethernet segment $< 500m$
 - ≤ 4 repeaters; thus $\leq 2500m$
 - 10Base2 (thin-net cable)
 - 10Base5 (thicknet cable)
 - 10BaseT (twisted pair, $\leq 100m$)
 - 100BaseT, 1000BaseT

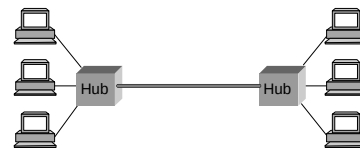


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Ethernet Overview

- Ethernet Hub (Fig. 2.26)
- Broadcasting
- Collision Domain

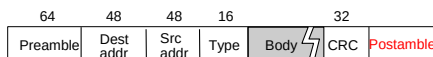


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Ethernet Overview

- CSMA/CD
 - carrier sense
 - multiple access
 - collision detection
- Frame Format



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Ethernet (cont)

- Addresses
 - unique, 48-bit unicast address assigned to each adapter
 - example: **8:0:e4:b1:2**
 - broadcast: all **1s**
 - multicast: first bit is **1**
- Bandwidth: 10Mbps, 100Mbps, 1Gbps, 10Gbps
- Length: 2500m (500m segments with 4 repeaters)
- Problem: Distributed algorithm that provides fair access

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Transmit Algorithm

- If line is idle...
 - send immediately
 - upper bound message size of 1500 bytes
 - must wait 9.6us between back-to-back frames
- If line is busy...
 - wait until idle and transmit immediately
 - called *1-persistent* (special case of *p-persistent*)

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Algorithm (cont)

- If collision...
 - jam for 32 bits, then stop transmitting frame
 - minimum frame is **64 bytes** (why?)
 - 64 bytes = (header + 46 bytes of data)
 - delay and try again
 - 1st time: 0 or 51.2us
 - 2nd time: 0, 51.2, 102.4, or 153.6us
 - *n*th time: $k \times 51.2$ us, for randomly selected $k=0..2^n - 1$
 - give up after several tries (usually 16)
 - **exponential backoff** – why the name?

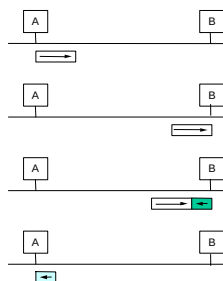
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Collisions

Worst-case Scenario - Fig. 2.28

- d = link latency = end-to-end prop time
- Max. collision detection time = $2d$
- Max length of 2,500 m, Transmission rate of 10 Mbps, thus, how many bits may be transmitted before a collision is detected? (51.2 μ sec, 512 bits)
- That is the **minimum frame length**
- What happen when link rate increases to 100 Mbps (Fast Ethernet)? 1Gbps?



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2.6.3 Experience with Ethernet

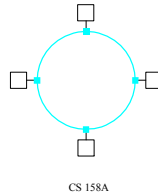
- Why Ethernet so successful?
 - Simple, easy to manage, cheap
 - Utilization $\leq 30\%$
 - Usually ≤ 200 hosts (1024),
 - Usually RTT $\sim 5 \mu$ sec (51.2 μ sec)
 - Switching technology
 - Faster link rate: 8B/10B encoding, optical fiber technology, DWDM (Dense Wavelength Division Multiplexing)

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Token Ring Overview

- Examples
 - 16Mbps IEEE 802.5 (based on earlier IBM ring)
 - 100Mbps Fiber Distributed Data Interface (FDDI)

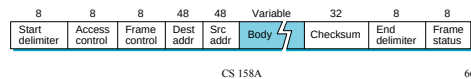


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Token Ring (cont)

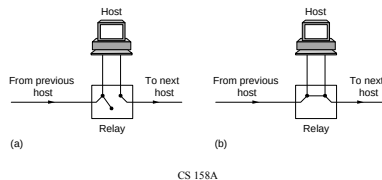
- Idea
 - Frames flow in one direction: upstream to downstream
 - special bit pattern (token) rotates around ring
 - must capture token before transmitting
 - release token after done transmitting
 - immediate release
 - delayed release
 - remove your frame when it comes back around
 - stations get round-robin service

Frame Format



Physical Properties

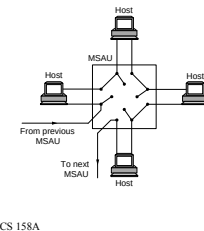
- Ring failure – if a node or a link is down the ring is down.
- Use relay (Fig. 2.30)
- (a) Relay open – host active. (b) Relay closed – host bypassed.



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Physical Properties - cont

- Multi-station access unit (MSAU – Fig 2.31)
- Like a star topology
- Easy to add/remove stations
- Robustness



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Token Ring MAC

- Adaptor consists of a receiver, a transmitter, and ≥ 1 bit storage in between. (Eg. 24-bit token, at least 24 stations, or use ring monitor to insert delay.)
- Token Holding Time (THT)
 - upper limit on how long a station can hold the token
- Token Rotation Time (TRT)
 - how long it takes the token to traverse the ring
 - $TRT \leq \text{ActiveNodes} \times THT + \text{RingLatency}$
 - RingLatency = total propagation delay of the ring

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Token Ring MAC

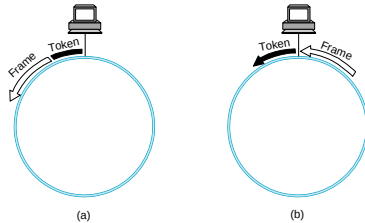
- Priority (a strict priority scheme)
 - Using a 3-bit priority field as token priority
 - Each node assigns a priority to its packet
 - A node can only seize the token to transmit a packet if the packet's priority is $\geq$ the token's priority
 - Priority of the token changes over time due to the use of three reservation bits in frame header
- Reliability
 - Using 2 bits in the packet trailer
 - A bit: destination sets it when it sees the frame
 - C bit: Destination sets it when it copies the frame into its adaptor
 - Source retransmits the frame if either A or C bit is not set

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Token Ring

- Token release: (a) early vs. (b) delayed



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Token Ring Maintenance

- Ring monitor
 - Ensure the health of the ring.
 - Periodically announces its presence with a control message.
 - Insert additional delay if needed.
 - Making sure there is always a token in the ring:
 - Max. TRT = NumStations x THT + RingLatency
 - “Beacon” frame
- Electing ring monitor
 - “claim token” frame.

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2.8 Wireless

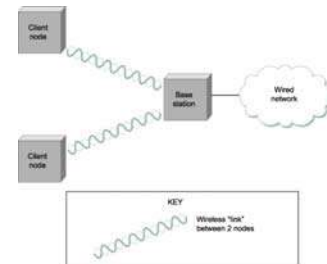
- Table 2.6 – Overview of leading wireless technologies
 - Bluetooth (IEEE 802.15.1)
 - Wi-Fi (IEEE 802.11)
 - WiMAX (IEEE 802.16)
 - 3G Cellular

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Two architectures

- Figures 2.38
- A wireless network using a base station (BS)
- 802.11 - “Infrastructure” mode
- WiMAX, Bluetooth

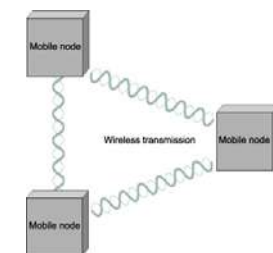


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Two architectures

- Figures 2.39
- A wireless ad-hoc or mesh network
- 802.11 “ad-hoc” mode
- 802.11s “wireless mesh” networks



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2.8.1 Bluetooth (802.15.1) PAN

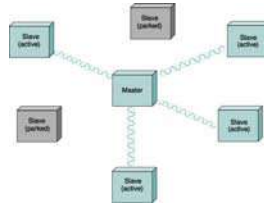
- For very short range such as mobile phones, PDA, laptops, etc.
- Operates in license-exempt band at 2.45 GHz
- Range of 10m
- Version 2.0: Speed of 2.1 Mbps
- Specified by Bluetooth SIG
- Profiles
 - Entire suite of protocols; DL to AL
 - Syn. A PDA w/ PC
 - Laptop to WLAN
 - IEEE 802.15.1 standard is based on Bluetooth; excluded AL
- Basic network configuration (next slide)
 - Piconet: 1 master, ≤ 7 slaves.
 - Slaves only comm w/ master

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2.8.1 Bluetooth (802.15.1)

- Uses frequency hopping of 79 channels; each 625 micro-m
- TDM: A frame takes up to 1, 3, or 5 consecutive timeslots
- Master can start to transmit in odd-numbered slots; slave in even-numbered slots, but only response to a request from master
 - Avoid contention
- Slave operates in 2 states
 - Parked – low-powered, inactive
 - A piconet has ≤ 255 parked devices
- ZigBee/IEEE 802.15.4
 - Competes with Bluetooth
 - Lower bandwidth, power consumption
 - Simpler and cheaper than Bluetooth



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2.8.2 Wi-Fi (802.11)

- Wi-Fi (Wireless Fidelity)
- LAN (like 802.3 and 802.5)
- Primary challenge: shared medium (space)
- Additional functions
 - Time-bounded services
 - Power management
 - Security mechanisms

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Physical Properties Spread Spectrum

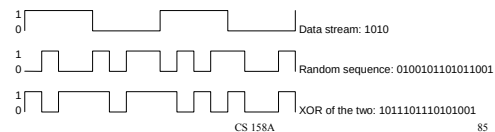
- Physical layer
 - Five are based on spread spectrum radio
 - One is based on diffused infrared
 - Max rate of 54 Mbps
- Spread Spectrum
 - spread signal over wider frequency band than required
 - originally designed to thwart jamming
- Frequency Hopping
 - transmit over random sequence of frequencies
 - sender and receiver share
 - pseudorandom number generator
 - seed
 - 802.11 uses 79 x 1MHz-wide frequency bands

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Spread Spectrum (cont)

- Direct Sequence
 - for each bit, send XOR of that bit and n random bits
 - random sequence known to both sender and receiver
 - Spread the signal across a frequency band that is n times wider
 - called n -bit *chipping code*
 - 802.11 defines an 11-bit chipping code
 - Fig. below shows a 4-bit chipping code



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802.11 Variations

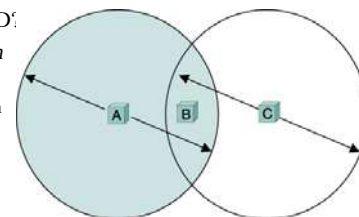
- Original 802.11 – 2 Mbps (using both frequency hopping and direct sequence)
- 802.11b – 11 Mbps (using license-exempt 2.4 GHz)
- 802.11a – 54 Mbps (using OFDM, license-exempt 5 GHz)
 - Less interference
 - More signal absorption, almost need line of sight
- 802.11g
 - 54 Mbps (using OFDM, license-exempt 2.4 GHz)
 - Backward compatible
- Most commercial products support all three
- New high-speed standard: 802.11n

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Collisions Avoidance

- MAC - Similar to Ethernet
- Why not CSMA/CD?
- Problem #1: *hidden nodes*
 - A and C are hidden from each other

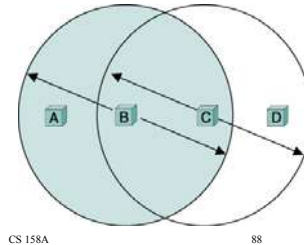


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Collisions Avoidance

- Problem #2:
exposed nodes
- B and C are
exposed to each
other's signals
- OK if B → A and C
→ D
 - A and D do not
interfere



MACAW (MACA for WLAN)

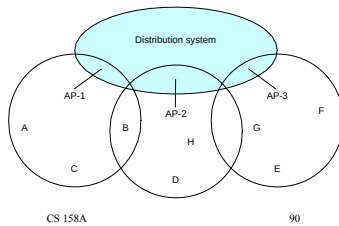
- Sender transmits **RequestToSend** (RTS) frame
- Receiver replies with **CleartoSend** (CTS) frame
- Neighbors...
 - see CTS: keep quiet
 - see RTS but not CTS: ok to transmit
- Receiver sends ACK when has frame
 - neighbors silent until see ACK
- Collisions
 - no collisions detection
 - known when don't receive CTS
 - exponential backoff

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Distributed System

- Case 1: *ad hoc*
networking
- Case 2: *access points*
(AP)
 - Access points connected
to a distributed network
 - The distributed network
can be tethered (current)
or wireless (future)
 - each mobile node
associates with an AP
 - Eg: A → AP1 → AP3 →
E



Mobility (cont)

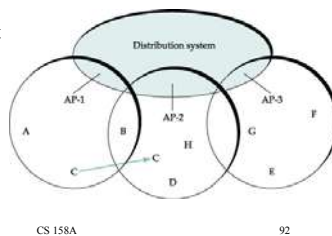
- Scanning (selecting an AP)
 1. node sends **Probe** frame
 2. all AP's w/in reach reply with **ProbeResponse** frame
 3. node selects one AP; sends it **AssociateRequest** frame
 4. AP replies with **AssociationResponse** frame
 5. new AP informs old AP via tethered network
- When
 - active: when join or move
 - passive: AP periodically sends **Beacon** frame

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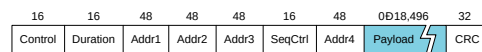
Supporting Mobility

- Node C is moving
from AP-1 to AP-2
- Following steps of last
slide
- Frame format in the
next slide



Frame Format

- DS = 0
 - Addr1 – target node
 - Addr2 – source node
- DS = 1
 - Addr1 –ultimate destination
 - Addr2 – intermediate source node
 - Addr3 – intermediate destination
 - Addr4 – original source



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2.8.3 WiMAX (802.16)

- MAN technology (up to 30 miles; 70 Mbps)
- Mobility: IEEE 802.16e
- BS (Base station) and SS (Subscriber station)
- PHY:
 - 10-60GHz; need LOS
 - 11GHz (no need for LOS)
 - Upstream (SS to BS) and down stream
 - # of up/down streams adjust adaptively by BS
 - FDD and TDD
 - Connection-oriented, QoS

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2.8.4 Cell Phone Technologies

- An extension for mobile computer communications – providing data services
- Major problems: incompatible standards
 - Europe (and most of Asia): 900 MHz and 1800 MHz
 - N. America: 850 MHz and 1900 MHz
 - Many other examples
- Base station, cell, handoff

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Cell Phone Technology Standards

- Collection of competing standards
- 1G: Analog (limited interest from data communications)
- 2G
 - Digital
 - GSM (Global System for Mobile communications); used in more than 200 countries.
 - Either Combination of FDM and (then) TDM
 - Or CDMA – uses different chipping codes to distinguish the transmissions of different cell phone users
 - Using compression algorithm tailored to human speech: 8 Kbps
 - Not enough bandwidth for data

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Cell Phone Technology Standards

- GSM (2.5G)
 - First cellular data standards: GPRS (General Packet Radio Service); also referred to as 2.5G. It is part of GSM
 - GSM uses TDMA – Like TDM, but timeslots can be dynamically allocated/deallocated to/from users or devices
 - Data rates tend to be lower in busy cells; 30-70 Kbps
- 3G
 - Concept established before any implementation
 - Aim of shaping a single international standard that would provide much higher data bandwidth
 - Several competing technologies, all based on CDMA

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Cell Phone Technology Standards

- 3G
 - UMTS (Universal Mobile Telecommunication Systems)
 - Based on W-CDMA
 - Poised as successor to GSM, also called 3GSM
 - Intended to support up to 1.92 Mbps
 - Commercial networks in operation
- 3.5G and 4G standards also in the works
- Satellite phones (satphones); not cellular
 - Using satellites as BS
 - Much higher bandwidth, but much higher prices
 - Use only when no alternative

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