

13: Link Layer, Multiple Access Protocols

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5: DataLink Layer 5a-1

Data Link Layer

Goals:

- understand principles behind data link layer services:
 - sharing a broadcast channel: multiple access
 - link layer addressing
 - error detection, correction
- instantiation and implementation of various link layer technologies

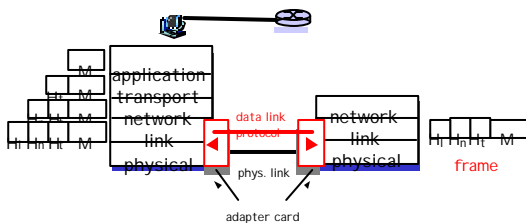
Overview:

- link layer services
- error detection, correction
- multiple access protocols and LANs
- link layer addressing, ARP
- specific link layer technologies:
 - Ethernet
 - hubs, bridges, switches
 - IEEE 802.11 LANs
 - PPP
 - ATM

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Link Layer: setting the context

- two **physically connected** devices:
 - host-router, router-router, host-host
- unit of data: **frame**



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Link Layer

- Node-to-node connectivity
- Point-to-point or multiple access
 - Multiple access requires addressing
 - Both require rules for sharing the links
- Examples:
 - Point-to-point (single wire, e.g. PPP, SLIP)
 - Broadcast (shared wire or medium; e.g., Ethernet or wireless)
 - Switched (e.g., switched Ethernet, ATM etc)

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Communication Technologies



- Wired LANs, Wireless LANs (RF or light), Cellular Telephones, Satellites, Packet Radio, Wired Telephone, Voice

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Data Model?

- Packet Mode – bursty discrete transmissions
- Circuit Mode – continuous traffic

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NTT EX2009
MediaTek v. NTT
IPR2020-1404

Basics of Link Layer

- ❑ Multiple Access Protocols
- ❑ Error Detection/Correction

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Multiple Access

- ❑ Multiple Access - fundamental to communication
- ❑ Two or more communicators use a shared medium to share information
- ❑ Multiple Access Protocol - Rule for sharing medium to facilitate communication?
 - Can simultaneous transmissions cause interference?
- ❑ Claim: humans use multiple access protocols all the time

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Multiple Access protocols

- ❑ Algorithm that determines how stations share channel, i.e., determine when station can transmit
- ❑ Note: communication about channel sharing must use channel itself! (or be agreed upon ahead of time)
- ❑ what to look for in multiple access protocols:
 - synchronous or asynchronous
 - information needed about other stations
 - robustness (e.g., to channel errors)
 - performance

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MAC Protocols: a taxonomy

Three broad classes:

- ❑ **Channel Partitioning**
 - divide channel into smaller "pieces" (time slots, frequency)
 - allocate piece to node for exclusive use
- ❑ **Random Access**
 - allow collisions
 - "recover" from collisions
- ❑ **Polling Style**
 - tightly coordinate shared access to avoid collisions

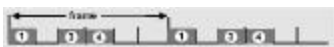
Goal: efficient, fair, simple, decentralized

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Channel Partitioning : TDMA

TDMA: time division multiple access

- ❑ access to channel in "rounds"
- ❑ each station gets fixed length slot (length = pkt trans time) in each round
- ❑ unused slots go idle
- ❑ example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle

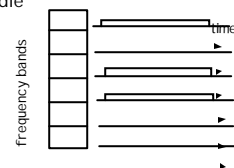


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Channel Partitioning : FDMA

FDMA: frequency division multiple access

- ❑ channel spectrum divided into frequency bands
 - each station assigned fixed frequency band
- ❑ unused transmission time in frequency bands go idle
- ❑ example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



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Channel Partitioning: CDMA

CDMA (Code Division Multiple Access)

- unique "code" assigned to each user; i.e. code set partitioning
- used mostly in wireless broadcast channels (cellular, satellite, etc)
- all users share same frequency, but each user has own "chipping" sequence (i.e. code) to encode data
- **encoded signal** = (original data) X (chipping sequence)
- **decoding**: inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

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TDMA vs FDMA

- In TDMA, each station gets the whole channel spectrum some of the time
- In FDMA, each station gets part of the channel spectrum all of the time
- In CDMA, each station is assigned a code that determines what portions of the channel spectrum they use and for how long to avoid collision with others
- All require lots of coordination about who "speaks" when and in what way!
 - What if didn't want to coordinate things so tightly?

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Random Access protocols

- Random access protocols are alternative to tight coordination
 - When want to transmit, transmit and hope for the best
 - If bad things happen, protocol says how to recover

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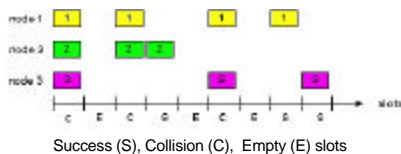
Random Access Protocols

- When node has packet to send
 - transmit at full channel data rate R.
 - no *a priori* coordination among nodes
- two or more transmitting nodes -> "collision",
- **random access MAC protocol** specifies:
 - how to detect collisions
 - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
 - slotted ALOHA
 - ALOHA
 - CSMA and CSMA/CD (Ethernet)
 - Remember Ethernet grew out of technology for broadcast in Hawaiian Islands?

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Random Access: Slotted Aloha

- time is divided into equal size slots (= pkt trans. time)
- node with new arriving pkt: transmit at beginning of next slot
- if collision: retransmit pkt in future slots with probability p , until successful.



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Slotted Aloha efficiency

Q: what is max fraction slots successful?

A: Suppose N stations have packets to send

- each transmits in slot with probability p
- prob. successful transmission S is:

$$\text{by single node: } S = (\text{prob it sends}) * (\text{prob all others do not}) = p(1-p)^{N-1}$$

by any of N nodes

$$S = \text{Prob (only one transmits)}$$

$$= N p (1-p)^{N-1}$$

... choosing optimum p as $n \rightarrow \infty$...

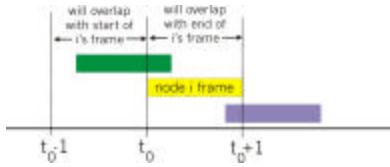
$$= 1/e = .37 \text{ as } N \rightarrow \infty$$

At best: channel use for useful transmissions 37% of time!

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Random Access: Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- pkt needs transmission:
 - send without awaiting for beginning of slot
- collision probability increases:
 - pkt sent at t_0 collide with other pkts sent in $[t_0-1, t_0+1]$



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Pure Aloha (cont.)

$$P(\text{success by given node}) = P(\text{node transmits}) \cdot$$

$$P(\text{no other node transmits in } [p_0-1, p_0]) \cdot$$

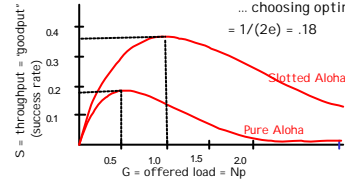
$$P(\text{no other node transmits in } [p_0-1, p_0])$$

$$= p \cdot (1-p) \cdot (1-p)$$

$$P(\text{success by any of } N \text{ nodes}) = N p \cdot (1-p) \cdot (1-p)$$

... choosing optimum p as $n \rightarrow \infty$...

$$= 1/(2e) = .18$$



protocol constrains effective channel throughput!

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CSMA: Carrier Sense Multiple Access

CSMA: listen before transmit:

- If channel sensed idle: transmit entire pkt
- If channel sensed busy, defer transmission
 - **Persistent CSMA:** retry immediately with probability p when channel becomes idle (may cause instability)
 - **Non-persistent CSMA:** retry after random interval
- human analogy: don't interrupt others!

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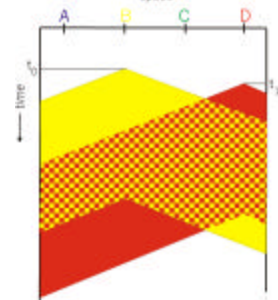
CSMA collisions

collisions *can* occur:
propagation delay means
two nodes may not yet
hear each other's
transmission

collision:
entire packet transmission
time wasted

note:
role of distance and
propagation delay in
determining collision prob.

spatial layout of nodes along ethernet



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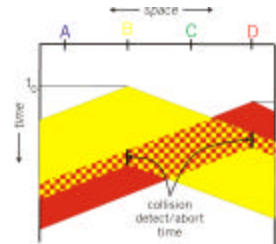
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions detected within short time
- colliding transmissions aborted, reducing channel wastage
- persistent or non-persistent retransmission
- collision detection:
 - easy in wired LANs: measure signal strengths, compare transmitted, received signals
 - difficult in wireless LANs: receiver shut off while transmitting
- human analogy: if start talking at same time some one else does don't just continue talking

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CSMA/CD collision detection



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Compromise? Polling Style MAC protocols

channel partitioning MAC protocols:

- share channel efficiently at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

Polling style protocols ("taking turns")

look for best of both worlds!

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Polling style MAC protocols

Polling:

- master node "invites" slave nodes to transmit in turn
- Request to Send, Clear to Send msgs
- concerns:
 - polling overhead
 - latency
 - single point of failure (master)

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
 - token overhead
 - latency
 - single point of failure (token)



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Reservation-based protocols

Distributed Polling:

- time divided into slots
- begins with N short **reservation slots**
 - reservation slot time equal to channel end-end propagation delay
 - station with message to send posts reservation
 - reservation seen by all stations
- after reservation slots, message transmissions ordered by known priority



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Summary of MAC protocols

- What do you do with a shared media?
 - Channel Partitioning, by time, frequency or code
 - Time Division, Code Division, Frequency Division
 - Random access
 - ALOHA, S-ALOHA, CSMA, CSMA/CD
 - carrier sensing: easy in some technologies (wire), hard in others (wireless)
 - CSMA/CD used in Ethernet
 - Polling Style
 - polling from a central cite, token passing

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Basics of Link Layer

- Multiple Access Protocols
- Error Detection/Correction

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Error Detection

EDC= Error Detection and Correction bits (redundancy)

D = Data protected by error checking, may include header fields

- Error detection not 100% reliable!
 - protocol may miss some errors, but rarely
 - larger EDC field yields better detection and correction



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Smart Redundancy

- In general, more bits of redundancy the stronger the error detection/correction abilities but smart redundancy
- What if transmitted another copy of the same thing?
 - How many bits till not detected? Ability to correct?
- Can we do better than that with less space?

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Recall: Internet checksum

We saw this a bunch of times in upper layers – is this a good choice for the link layer?

Sender:

- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

Receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value

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Intelligent choice for link layer?

- Tailored to type and frequency of errors expected in the specific technology being used
 - Some technologies (like fiber) have very low error rates
 - Some technologies (like wireless) have high error rates
- How to we tailor the number of bits to use and *how* we use them to get the desired effect??

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Example: Parity

Single Bit vs Two Dimensional Bit Parity: Example of using redundant bits intelligently for increased error detection/correction capability!

Two Dimensional Bit Parity:
Detect and correct single bit errors
Want even number of 1's in each dimension



Single Bit Parity:
Detect single bit errors



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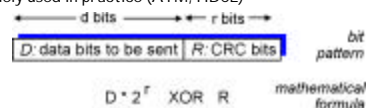
Beyond parity?

- How can we generalize this example of single vs double bit parity?
- Is there a theory of using redundant bits efficiently based on the types of errors we expect to find?
- Cyclic Redundancy Checks (CRC) views both the data and the redundant bits as binary polynomials and ensures that they satisfy a certain mathematical relationship

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Checksumming: Cyclic Redundancy Check

- view data bits, D , as a binary number or binary polynomial
 - $101011 = X^5 + X^4 + X^3 + X^2 + X^1 + X^0 = X^5 + X^3 + X + 1$
- choose $r+1$ bit pattern/polynomial (generator), G
- goal: choose r CRC bits, R , such that
 - $\langle D, R \rangle = D \cdot 2^r \text{ XOR } R$ (shift D over place R in the end)
 - $\langle D, R \rangle$ exactly divisible by G (modulo 2)
 - receiver knows G , divides $\langle D, R \rangle$ by G . If non-zero remainder: error detected!
 - can detect all burst errors less than $r+1$ bits
- widely used in practice (ATM, HDCL)



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CRC Example

Want:

$$D \cdot 2^r \text{ XOR } R = nG$$

equivalently:

if we divide $D \cdot 2^r$
by G , want
remainder R

$$R = \text{remainder} \left[\frac{D \cdot 2^r}{G} \right]$$



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Common CRC Polynomials (G)

- ❑ CRC-12 used for transmission of streams of 6-bit characters and generates 12-bit FCS
 - CRC-12: $X^{12} + X^{11} + X^3 + X^2 + X + 1$
- ❑ Both CRC-16 and CCRC-CCI TT are used for 8 bit transmission streams and both result in 16 bit FCS. Considered to give adequate protection for most applications.
 - CRC-16: $X^{16} + X^{15} + X^2 + 1$ (USA)
 - CRC-CCI TT: $X^{16} + X^{12} + X^5 + 1$ (Europe)
- ❑ CRC-32 gives extra generates 32 bit FCS. Used by the local network standards committee (IEEE-802) and in some DOD applications.
 - CRC-32: $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$

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