

Link Layer - Error Detection/Correction and MAC

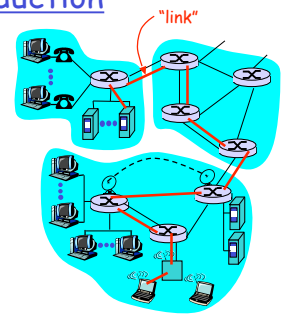
5: DataLink Layer 5-1

Link Layer: Introduction

Some terminology:

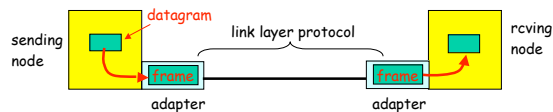
- hosts and routers are **nodes**
- communication channels that connect adjacent nodes along communication path are **links**
 - wired links
 - wireless links
 - LANs
- layer-2 packet is a **frame**, encapsulates datagram

data-link layer has responsibility of transferring datagram from one node to adjacent node over a link



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Adaptors Communicating



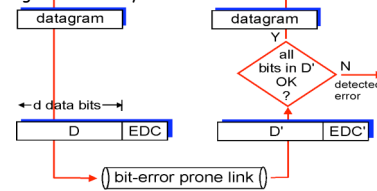
- link layer implemented in "adaptor" (aka NIC)
 - Ethernet card, PCMCIA card, 802.11 card
- sending side:
 - encapsulates datagram in a frame
 - adds error checking bits, rdt, flow control, etc.
- receiving side
 - looks for errors, rdt, flow control, etc
 - extracts datagram, passes to rcvng node
- adapter is semi-autonomous
- link & physical layers

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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

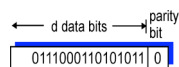


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Parity Checking

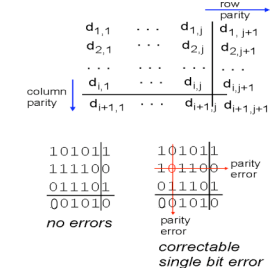
Single Bit Parity:

Detect single bit errors



Two Dimensional Bit Parity:

Detect and correct single bit errors



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Internet checksum

Goal: detect "errors" (e.g., flipped bits) in transmitted segment (note: used at transport layer only)

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

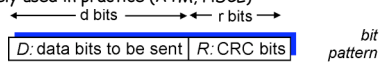
Receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
 - NO - error detected
 - YES - no error detected. But maybe errors nonetheless? More later

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Checksumming: Cyclic Redundancy Check

- view data bits, D , as a binary number
- choose $r+1$ bit pattern (generator), G
- goal: choose r CRC bits, R , such that
 - $\langle D, R \rangle$ 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)



$$D \cdot 2^r \text{ XOR } R \quad \text{mathematical formula}$$

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CRC Example

Want:

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

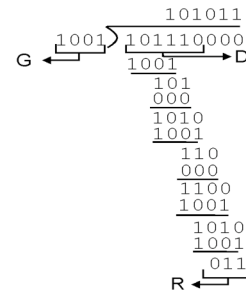
equivalently:

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

equivalently:

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

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

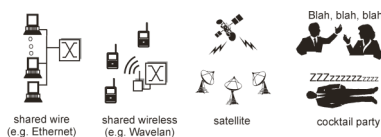


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Multiple Access Links and Protocols

Two types of "links":

- point-to-point
 - PPP for dial-up access
 - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
 - traditional Ethernet
 - upstream HFC
 - 802.11 wireless LAN



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Multiple Access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
 - collision if node receives two or more signals at the same time
- multiple access protocol
- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
 - no out-of-band channel for coordination

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Ideal Multiple Access Protocol

Broadcast channel of rate R bps

1. When one node wants to transmit, it can send at rate R .
2. When M nodes want to transmit, each can send at average rate R/M
3. Fully decentralized:
 - no special node to coordinate transmissions
 - no synchronization of clocks, slots
4. Simple

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MAC Protocols: a taxonomy

Three broad classes:

- Channel Partitioning
 - divide channel into smaller "pieces" (time slots, frequency, code)
 - allocate piece to node for exclusive use
- Random Access
 - channel not divided, allow collisions
 - "recover" from collisions
- "Taking turns"
 - Nodes take turns, but nodes with more to send can take longer turns

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Channel Partitioning MAC protocols: 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

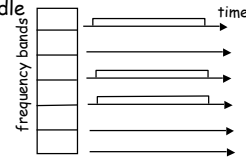


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Channel Partitioning MAC protocols: FDMA

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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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, CSMA/CD, CSMA/CA

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Slotted ALOHA

Assumptions

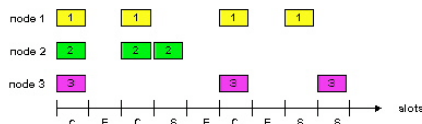
- all frames same size
- time is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation

- when node obtains fresh frame, it transmits in next slot
- no collision, node can send new frame in next slot
- if collision, node retransmits frame in each subsequent slot with prob. p until success

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Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

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Slotted Aloha efficiency

Efficiency is the long-run fraction of successful slots when there are many nodes, each with many frames to send

- Suppose N nodes with many frames to send, each transmits in slot with probability p
- prob that node 1 has success in a slot = $p(1-p)^{N-1}$
- prob that any node has a success = $Np(1-p)^{N-1}$

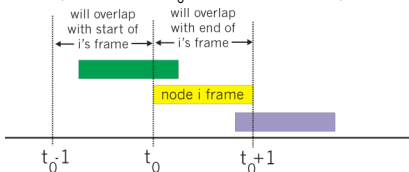
- For max efficiency with N nodes, find p^* that maximizes $Np(1-p)^{N-1}$
- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives $1/e \approx .37$

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

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Pure (unslotted) ALOHA

- ❑ unslotted Aloha: simpler, no synchronization
- ❑ when frame first arrives
 - transmit immediately
- ❑ collision probability increases:
 - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



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CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:

If channel sensed idle: transmit entire frame

- ❑ If channel sensed busy, defer transmission

- ❑ Human analogy: don't interrupt others!

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CSMA collisions

collisions *can* still occur:

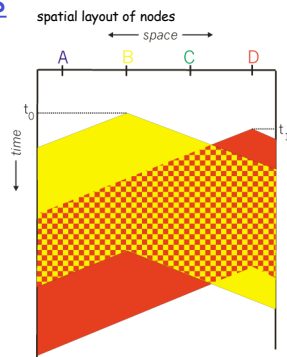
propagation delay means
two nodes may not hear
each other's transmission

collision:

entire packet transmission
time wasted

note:

role of distance & propagation
delay in determining collision
probability



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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

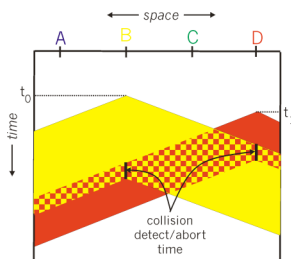
- ❑ collision detection:

- easy in wired LANs: measure signal strengths, compare transmitted, received signals
- difficult in wireless LANs: receiver shut off while transmitting

- ❑ human analogy: the polite conversationalist

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CSMA/CD collision detection



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"Taking Turns" MAC protocols

channel partitioning MAC protocols:

- share channel efficiently and fairly 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

"taking turns" protocols

look for best of both worlds!

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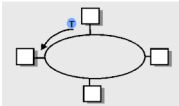
"Taking Turns" MAC protocols

Polling:

- ❑ master node
"invites" slave
nodes to transmit
in turn
- ❑ 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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Summary of MAC protocols

- ❑ What do you do with a shared media?
 - Channel Partitioning, by time, frequency or code
 - Time Division, Frequency Division
 - Random partitioning (dynamic),
 - ALOHA, S-ALOHA, CSMA, CSMA/CD
 - carrier sensing: easy in some technologies (wire),
hard in others (wireless)
 - CSMA/CD used in Ethernet
 - CSMA/CA used in 802.11
 - Taking Turns
 - polling from a central site, token passing

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