13: Link Layer, Multiple Access Protocols

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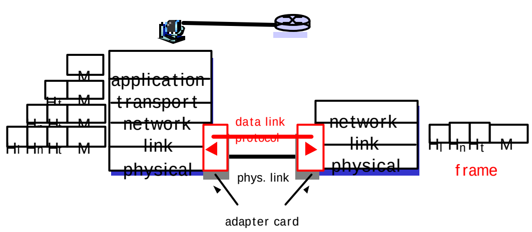
Data Link Layer

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

Link Layer: setting the context

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



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)

Communication Technologies

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

Data Model?

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

Basics of Link Layer

- Multiple Access Protocols
- Error Detection/Correction

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

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

MAC Protocols: a taxonomy

Three broad classes:

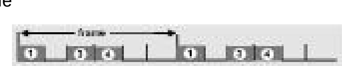
- Channel Partitioning
  - divide channel into smaller “pieces” (time slots, frequency)
  - allocate piece to node for exclusive use
- Random Access
  - allow collisions
  - “recover” from collisions
- Polling Style
  - tightly coordinate shared access to avoid collisions

Goal: efficient, fair, simple, decentralized

Channel Partitioning : TDMA

TDMA: time division multiple access

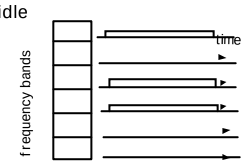
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



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



Channel Partitioning: CDMA

CDMA (Code Division Multiple Access)

- unique "code" assigned to each user; ie, code set partitioning
- used mostly in wireless broadcast channels (cellular, satellite,etc)
- all users share same frequency, but each user has own "chipping" sequence (ie, 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")

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?

Random Access protocols

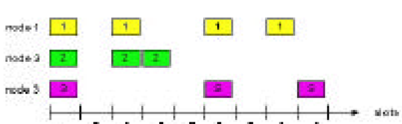
- Random access protocols are alternative to tight coordination
  - When want to transmit, transmit and hope for the best
  - If bad things happen, protocol says how to recover

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?

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.



Success (S), Collision (C), Empty (E) slots

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:

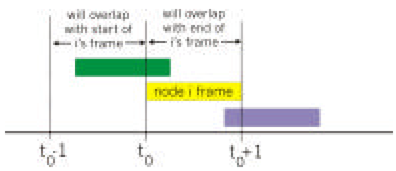
by single node: S= (prob it sends) * (prob all others do not)
 $= p\,(1-p)^{(N-1)}$

by any of N nodes
 S = Prob (only one transmits)
 $= N\,p\,(1-p)^{(N-1)}$
 … choosing optimum p as n -> infty …
 = *1/e = .37 as N -> infty*

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

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 $[t_0-1, t_0+1]$



Pure Aloha (cont.)

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[p_0-1, p_0]$) ·

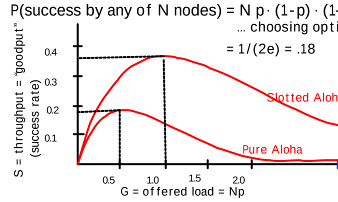
P(no other node transmits in $[p_0-1, p_0]$)

= p · (1-p) · (1-p)

P(success by any of N nodes) = N p · (1-p) · (1-p)

... choosing optimum p as n -> infty ...

= 1/(2e) = .18



protocol constrains effective channel throughput!

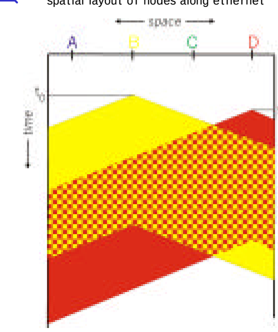
CSMA: Carrier Sense Multiple Access

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!

CSMA collisions

spatial layout of nodes along ethernet



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

collision:
entire packet transmission time wasted

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

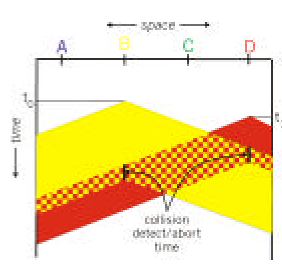
CSMA/CD (Collision Detection)

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

CSMA/CD collision detection



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

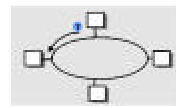
Polling style protocols ("taking turns")

look for best of both worlds!

Polling style MAC protocols

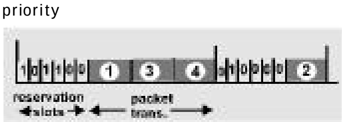
Polling:
- master node "invites" slave nodes to transmit in turn
- Request to Send, Clear to Send msgs
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

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



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



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

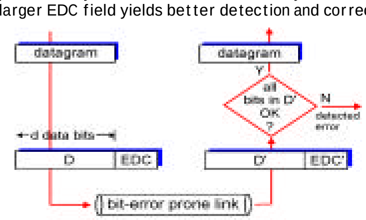
Basics of Link Layer

- Multiple Access Protocols
- Error Detection/Correction

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



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?

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

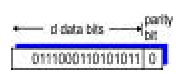
Intelligent choice for link layer?

- 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??

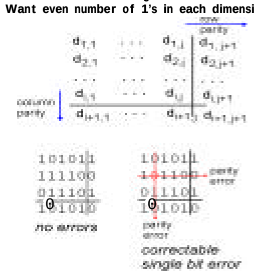
Example: Parity

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

Single Bit Parity:
Detect single bit errors



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

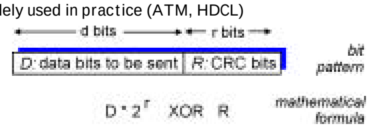


Beyond parity?

- 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

Checksumming: Cyclic Redundancy Check

- view data bits, D, as a binary number or binary polynomial
  - 101011= X^5+X^3+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
  - <D, R> = D* 2^r XOR R (shift D over place R in the end)
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits
- widely used in practice (ATM, HDCL)



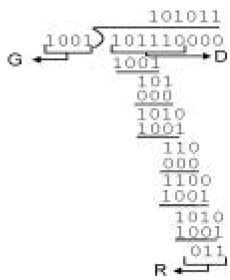
CRC Example

Want:

$D \cdot 2^r$ XOR R = nG

equivalently:

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



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

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-CCITT 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-CCITT: 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