

Chapter 5: The Data Link Layer

Our goals:

- understand principles behind data link layer services:
 - error detection, correction
 - sharing a broadcast channel: multiple access
 - link layer addressing
 - reliable data transfer, flow control: *done!*
- instantiation and implementation of various link layer technologies

5: DataLink Layer 5-1

Link Layer

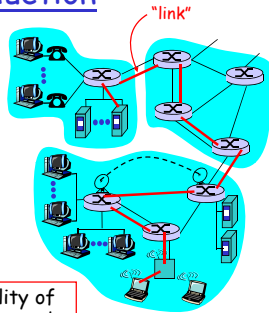
- 5.1 Introduction and services
- 5.2 Error detection and correction
- 5.3 Multiple access protocols
- 5.4 Link-Layer Addressing
- 5.5 Ethernet
- 5.6 Hubs and switches
- 5.7 PPP
- 5.8 Link Virtualization: ATM and MPLS

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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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Link layer: context

- Datagram transferred by different link protocols over different links:
 - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
 - Each link protocol provides different services
 - e.g., may or may not provide rdt over link
- transportation analogy**
- trip from Princeton to Lausanne
 - limo: Princeton to JFK
 - plane: JFK to Geneva
 - train: Geneva to Lausanne
 - tourist = **datagram**
 - transport segment = **communication link**
 - transportation mode = **link layer protocol**
 - travel agent = **routing algorithm**

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Link Layer Services

- **Framing, link access:**
 - encapsulate datagram into frame, adding header, trailer
 - channel access if shared medium
 - "MAC" addresses used in frame headers to identify source, dest
 - different from IP address!
- **Reliable delivery between adjacent nodes**
 - we learned how to do this already (chapter 3)!
 - seldom used on low bit error link (fiber, some twisted pair)
 - wireless links: high error rates
 - Q: why both link-level and end-end reliability?

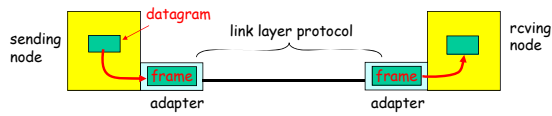
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Link Layer Services (more)

- **Flow Control:**
 - pacing between adjacent sending and receiving nodes
- **Error Detection:**
 - errors caused by signal attenuation, noise.
 - receiver detects presence of errors:
 - signals sender for retransmission or drops frame
- **Error Correction:**
 - receiver identifies **and corrects** bit error(s) without resorting to retransmission
- **Half-duplex and full-duplex**
 - with half duplex, nodes at both ends of link can transmit, but not at same time

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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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Link Layer

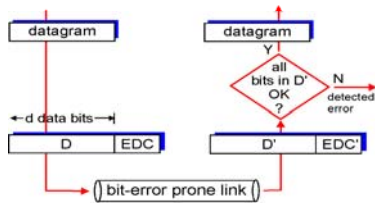
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Error Detection

EDC= Error Detection and Correction bits (redundancy)
 D = Data protected by error checking, may include header fields

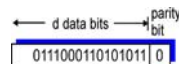
- Error detection not 100% reliable!
 - protocol may miss some errors, but rarely
 - larger EDC field yields better detection and correction



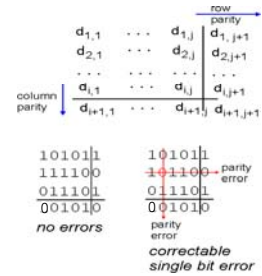
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Parity Checking

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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Link Layer

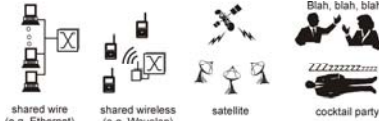
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Multiple Access Links and Protocols

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:

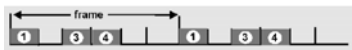
- Channel Partitioning
 - divide channel into smaller "pieces" (time slots, frequency, code)
 - allocate piece to node for exclusive use
- Random Access
 - channel not divided, allow collisions
 - "recover" from collisions
- "Taking turns"
 - Nodes take turns, but nodes with more to send can take longer 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 2,5,6 idle



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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

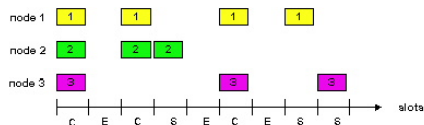
- all frames same size
- time is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

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

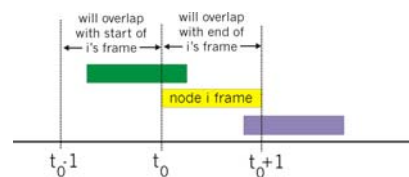
Cons

- 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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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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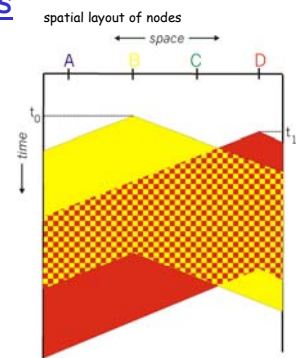
CSMA collisions

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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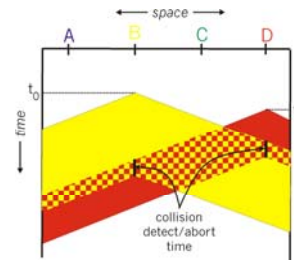
CSMA/CD (Collision Detection)

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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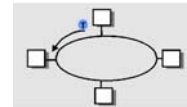
"Taking Turns" MAC protocols

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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