15-441/641: Datalink

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https://computer-networks.github.io/sp19/

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Outline

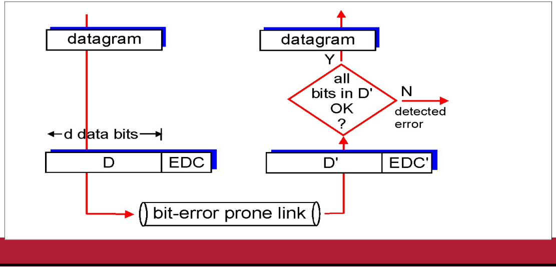
- Encoding
  - Bits to digital signal
- Framing
  - Bit stream to packets
- Packet loss & corruption
  - Error detection
  - Flow control
  - Loss recovery

Error Coding

- Transmission may introduce errors into a message.
  - Received “digital signal” is different from that transmitted
  - Single bit errors versus burst errors
- Detection:
  - Requires a convention that some messages are invalid
  - Hence requires extra bits
  - An (n,k) code has codewords of n bits with k data bits and r = (n-k) redundant check bits
- Correction
  - Forward error correction: many related code words map to the same data word
  - Detect errors and retry transmission

Error Detection

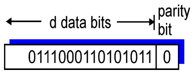
- EDC= Error Detection and Correction bits (redundancy)
- D = Data protected by error checking, may include header fields
- Error detection not 100% reliable!
  - Protocol may miss some errors, but this is rare (more on this later)
  - Larger EDC field yields better detection and correction



Parity Checking

Single Bit Parity:

Detect single bit errors



Internet Checksum

- Goal: detect “errors” (e.g., flipped bits) in transmitted segment
- Must be easy to computer in software

Sender

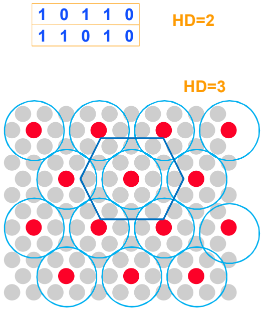
- Treat segment contents as sequence of 16-bit integers
- Checksum: addition (1’s complement sum) of segment contents
- Sender puts checksum value into checksum field in header

Receiver

- Compute checksum of received segment
- Check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. But maybe errors nonethless?

Basic Concept: Hamming Distance

- Hamming distance of two bit strings = number of bit positions in which they differ.
- If the valid words of a code have minimum Hamming distance D, then D-1 bit errors can be detected.
- If the valid words of a code have minimum Hamming distance D, then [(D-1)/2] bit errors can be corrected.



Cyclic Redundancy Codes (CRC)

- Widely used codes that have good error detection properties.
  - Can catch many error combinations with a small number of redundant bits
- Based on division of polynomials.
  - Errors can be viewed as adding terms to the polynomial
  - Should be unlikely that the division will still work
- Can be implemented very efficiently in hardware
- Examples:
  - CRC-32: Ethernet
  - CRC-8, CRC-10, CRC-32: ATM

Take-away: Encoding and Modulation

- Encoding and modulation work together
  - Must generate a signal that works well for the receiver – has good electrical properties
  - Must be efficient with respect to spectrum use
  - Can shift some of the burden between the two layers
  - Tradeoff is figured out by electrical engineers
- Maintaining good electrical properties
  - Spectrum efficient modulation requires more encoding
  - For example: 4B/5B encoding
- Error recovery
  - Aggressive modulation needs stronger coding

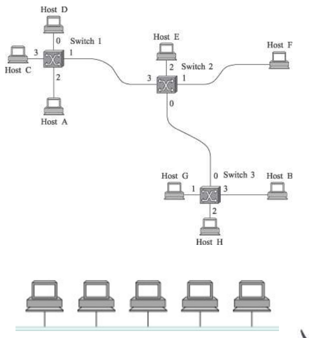
What is Used in Practice?

- No flow or error control.
  - E.g. regular Ethernet, just uses CRC for error detection
- Flow control only
  - E.g. Gigabit Ethernet
- Flow and error control.
  - E.g. X.25 (older connection-based service at 64 Kbs that guarantees reliable in order delivery of data)
- Flow and error control solutions also used in higher layer protocols
  - E.g., TCP for end-to-end flow and error control

Outline

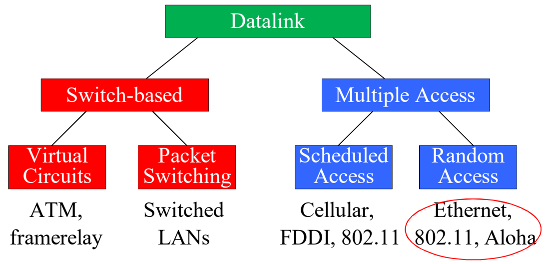
- Datalink architectures
- Ethernet
- Wireless networking
  - Wireless Ethernet
  - Aloha
  - 802.11 family
  - Cellular

Datalink MAC Architectures

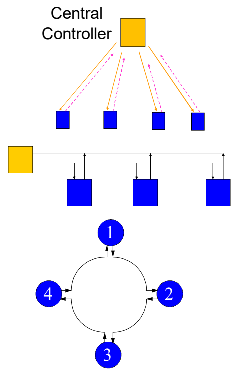


- Media Access control (MAC): who gets to send packet next?
- Switches connected by point-to-point links -- store-and-forward.
  - Used in WAN, LAN, and for home connections
  - Conceptually similar to “routing”
    - But at the datalink instead of network layer
- Multiple access networks.
  - Multiple hosts are sharing the same transmission medium
  - Used in LANs and wireless
  - Access control is distributed and much more complex

Datalink Classification



Scheduled Access MACs

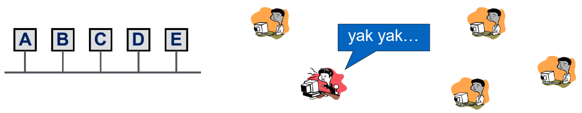


- Reservation systems
  - Central controller
  - Distributed algorithm, e.g. using reservation bits in frame
- Polling: controller polls each nodes
- Token ring: token travels around ring and allows nodes to send one packet
  - Distributer version of polling
  - FDDI, …

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:
  - CSMA and CSMA/CD
  - Wireless protocols

Problem: Sharing a Wire



- Just send a packet when you are ready
  - Does not work well: collisions! More on this later
- Natural scheme – listen before you talk …
  - Works well in practice
  - A cheap form of coordination
- But sometimes this breaks down
  - Why? How do we fix/prevent this?

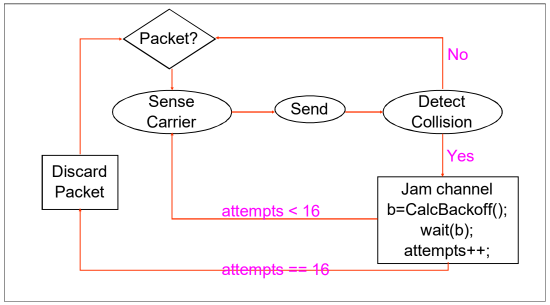
Ethernet MAC Features

- Carrier Sense: listen before you talk
  - Avoid collision with active transmission
  - Assumes all nodes can hear each other

- Collision Detection during transmission
  - Listen while transmitting
  - If you notice interference → assume collision
  - Abort transmission immediately – saves time
  - Assumes a sender can identify competing transmissions while transmitting

Ethernet MAC – CSMA/CD

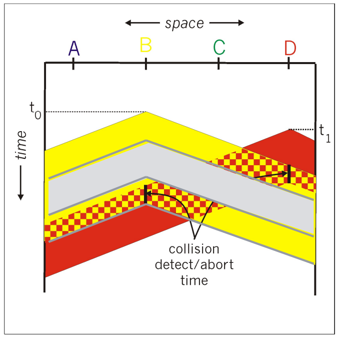
- Carrier Sense Multiple Access/Collision Detection



Packet?
No
Sense Carrier
Send
Detect Collision
Yes
Discard Packet
attempts < 16
Jam channel
b=CalcBackoff();
wait(b);
attempts++;
attempts == 16

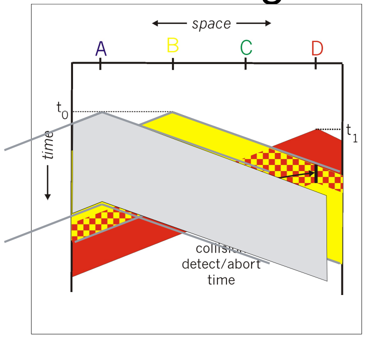
Collision Detection: Depends on Packet Length

- Packets must be long enough to guarantee all nodes observe collision
- In this example:
  - A can decode packets
  - C observes collision
  - B and D cannot sense collision
- Min packet length > 2x max prop delay



Collision Detection: Depends on the Wire Length

- Wires must be short enough to guarantee all nodes observe collision
- In this example
  - B and C will see collision
  - A and D cannot see collision
- Min packet length > 2x max prop delay



Scaling Ethernet

- What about scaling? 10Mbps, 100Mbps, 1Gbps, ...
  - Use a combination of reducing network diameter and increasing minimum minimum packet size
- Reality check: 40 Gbps is 4000 times 10 Mbps
  - 10 Mbps: 2.5 km and 64 bytes -> silly
  - Solution: switched Ethernet – see lecture 3
- What about a maximum packet size?
  - Needed to prevent node from hogging the network
  - 1500 bytes in Ethernet = 1.2 msec on original Ethernet
  - For 40 Gps -> 0.3 microsec -> silly and inefficient

Things to Remember

- Trends from CSMA networks to switched networks
  - Need for more capacity
  - Low cost and higher line rate
- Emphasis on low configuration and management complexity and cost
  - Fully distributed path selection
- Trends are towards “Software Defined Networks”
  - Network is managed by a centralized controller
  - Allows for the implementation of richer policies
    - Easier to manage centrally
  - Already common in data centers