15-441/641: Datalink

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https://computer-networks.github.io/fa19/

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Outline

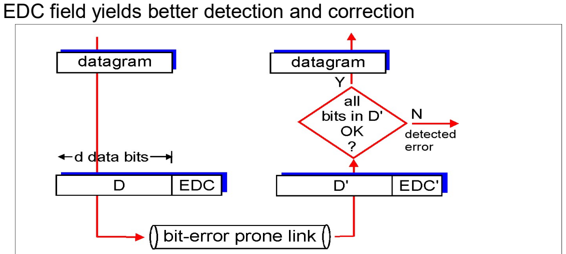
- Encoding
  - Bits to digital signal
- Framing
  - Bit stream to packets
- Packet loss & corruption
  - Error detection and recovery
  - Flow control
  - Loss recovery

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

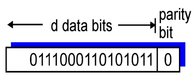
Error Detection

- 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

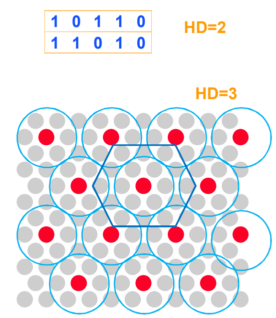
- Compute checksum of received segment
- Check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. But maybe errors nonethless?

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

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.



Error Correcting Codes

- More aggressive coding can allow the receiver to (locally) recover from errors – Forward Error Correction (FEC)
  - Details outside of scope
- Informally: if a received code is close to one “red” dot, and far away from all other “red” dots, it is very likely the nearby red dot
  - With very high probability
- FEC is very widely used in wireless networks
  - Bit errors are much more common
- Example: Hybrid ARQ (HARQ) combines ARQ and FEC used in LTE
  - ARQ – automatic repeat request

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?

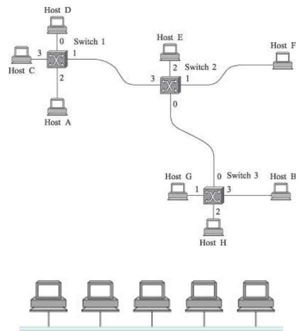
- No flow or error control.
  - E.g. regular Ethernet, just uses CRC for error detection
- Flow control only
  - E.g. Gigabit Ethernet
- Flow and error control.
  - E.g. X.25 (older connection-based service at 64 Kbs that guarantees reliable in order delivery of data)
- Flow and error control solutions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

Outline

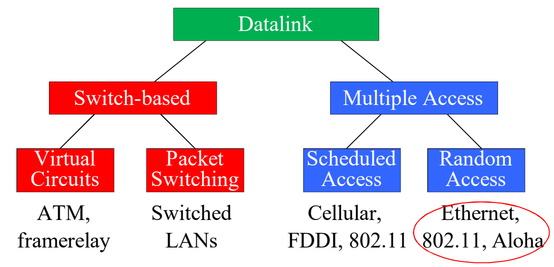
- Datalink architectures
- Ethernet
- Wireless networking
  - Wireless Ethernet
  - Aloha
  - 802.11 family
  - Cellular

Datalink MAC Architectures

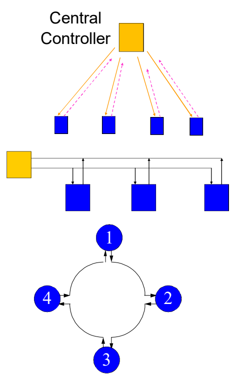
- Media Access control (MAC): who gets to send packet next?
- Switches connected by point-to-point links -- store-and-forward.
  - Used in WAN, LAN, and for home connections
  - Conceptually similar to "routing"
    - But at the datalink instead of network layer
- Multiple access networks.
  - Multiple 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

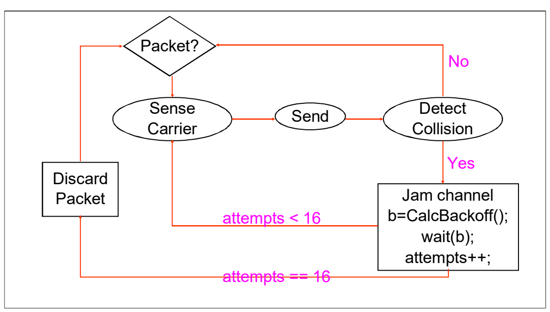
- Just send a packet when you are ready
  - Does not work well: many collisions! More on this later
- Natural scheme – listen before you talk …
  - Works well in practice
  - A cheap form of coordination
- But sometimes this breaks down
  - Why? How do we fix/prevent this?

Ethernet MAC Features – CSMA/CD

- Carrier Sense: listen before you talk
  - Cheap way avoiding 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, reduces penalty of a collision
  - Means a sender can identify competing transmissions while transmitting

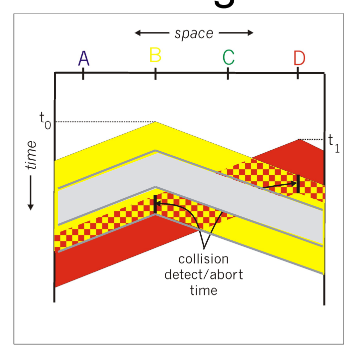
Ethernet MAC – CSMA/CD

- Carrier Sense Multiple Access/Collision Detection



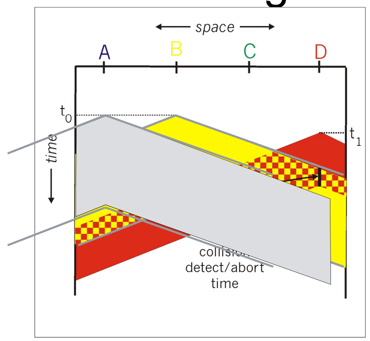
Collision Detection: Depends on Packet Length

- 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
- Rule: 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, ...
  - Oops: packets get shorter (in time – msec)
  - 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 early lecture
- 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

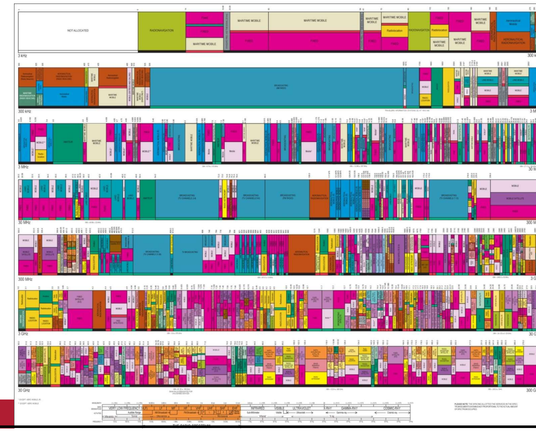
Outline

- Ethernet
- Wireless networking intro
  - Spectrum discussion
  - Wireless Ethernet
  - Aloha

History

- Aloha wireless data network
- Car phones
  - Big and heavy “portable” phones
  - Limited battery life time
  - But introduced people to “mobile networking”
  - Later turned into truly portable cell phones
- Wireless LANs
  - Originally in the 900 MHz band
  - Later evolved into the 802.11 standard
  - Later joined by the 802.15 and 802.16 standards
- Cellular data networking
  - Data networking over the cell phone
  - Many standards – throughput is the challenge

Spectrum Allocation in US



Spectrum Use Comments

- Each country is in charge of spectrum allocation and use internally
  - Federal Communication Commission (FCC) and National Telecommunication and Information Administration in the US
  - Spectrum allocation differs quite a bit – implications for mobile users?
- Broadly speaking two types of spectrum
  - Licensed spectrum: allocated to licensed user(s)
  - Unlicensed spectrum: no license needed but device must respect rules

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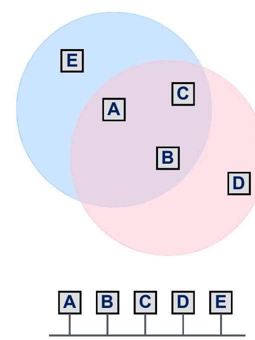
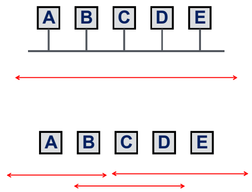
Wireless Communication

- Wireless communication is based on broadcast
  - A, B, and C can all hear each other’s signal
- Looks like Ethernet!
- Why not use CSMA/CD?
  - Carrier-sense Multiple Access / Collision Detection
- Well, it is not that easy



What is the Problem? There are no Wires!

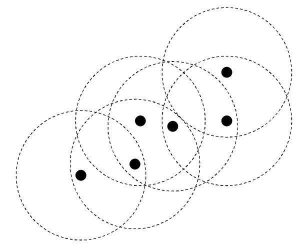
- Attenuation is very high!
  - Signal is not contained in a wire
  - Attenuation is $1/D^2$ for distance D
- There is significant noise and interference
  - No wire to protect the signal
  - Much higher error rates



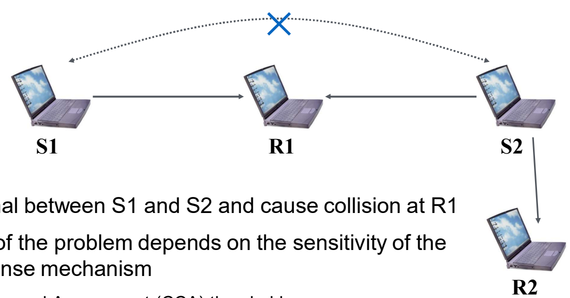
- Not all nodes in the wireless network can hear each other
  - Wireless communication range is shorter
  - Standard cannot limit the length of the wires

Implications for Wireless Ethernet

- Collision detection is not practical
  - Ratio of transmitted signal power to received power is very high high at the transmitter
  - Transmitter cannot detect competing transmitters (deaf while transmitting)
  - So how do you detect collisions?
- Not all nodes can hear each other
  - “Listen before you talk” often fails
  - Hidden terminals
  - Exposed terminals,
- Made worse by fading
  - Changes over time!

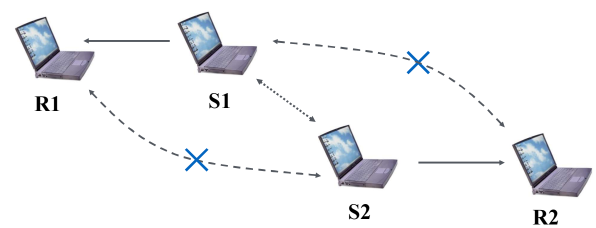


Hidden Terminal Problem



- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - Clear Channel Assessment (CCA) threshold

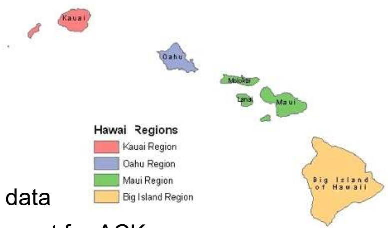
Exposed Terminal Problem



- Carrier sense prevents two senders from sending simultaneously although they do not reach each other’s receiver
- Severity again depends on CCA threshold
  - Higher CCA reduces occurrence of exposed terminals, but can create hidden terminal scenarios

Aloha – Basic Technique

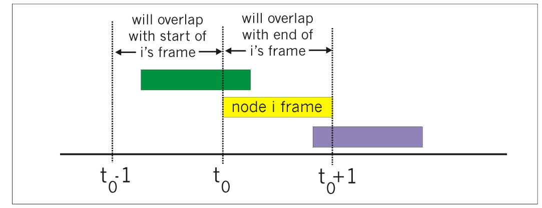
- First random MAC developed
  - For radio-based communication in Hawaii (1970)



- Basic idea:
  - When ready, transmit
  - Receivers send ACK for data
  - Detect collisions by timing out for ACK
  - Recover from collision by trying after random delay

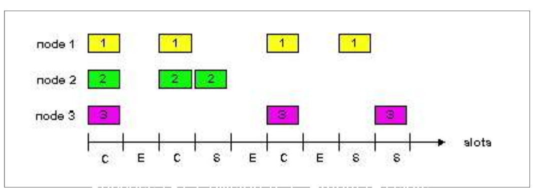
Collisions in ALOHA

- Original ALOHA had no synchronization
- Pkt needs transmission:
  - Send without awaiting for beginning of slot
- Many chances for collision
  - Pkt sent at t_0 collide with other pkts sent in $[t_0\text{-}1, t_0\text{+}1]$



Slotted Aloha

- Time is divided into equal size slots
  - Equal to packet transmission time
- Node (w/ packet) transmits at beginning of next slot
- If collision: retransmit pkt in future slots with probability p, until successful



Aloha Throughput Comparison

- It is possible to calculate throughput for Aloha
  - Many assumptions: exponential arrival, transmitters independent, …
- Bad news: maximum throughput is low
  - Slotted Aloha can achieve higher throughput
- Still useful for some networks, e.g., low power, low load, ..

protocol constrains effective channel throughput!