15-496 : A Hand-on Introduction to Wireless Networks
Lecture 5: MAC Layer

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http://www.cs.cmu.edu/~prs/wireless08/

Outline

- Data link fundamentals (refresher)
- Supporting bursty traffic
- Wireless-specific challenges
- Aloha

Datalink Functions

- Framing: encapsulating a network layer datagram into a bit stream.
  - Add header, mark and detect frame boundaries, …
- Media access: controlling which frame should be sent over the link next.
  - Easy for point-to-point links; half versus full duplex
  - Harder for multi-access links: who gets to send?
- Logical link control: managing the frame transfer, e.g.
  - Error detection and correction to deal with bit errors
  - Flow control: avoid that the sender outruns the receiver

Framing

- Similar design as in wired networks.
  - But must be more robust because of noise, …
- Typical structure:
  - Preamble: synchronize clocks sender and receiver
  - Header: usual information
  - Data packet
  - Trailer: padding, CRC, ..
- But may also have some differences:
  - Different transmit rates for different parts of packet
  - Control information for physical layer

Error Control: Error Detection versus Error Recovery

- Detection: only detect errors
  - Make sure corrupted packets get thrown away, e.g. Ethernet
- Recovery: also try to recover from lost/corrupted packets
- Wireless networks typically use error recovery.
  - Errors are much more common than in wired
- First step is to detect packet loss:
  - Use of error detection codes, e.g. CRC
  - Timeouts to detect packet loss
- Recovery mechanism based on:
  - Positive acknowledgements
  - Timeouts on the transmit side
  - Negative acknowledgements

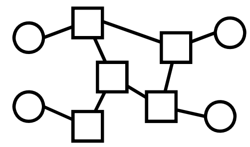
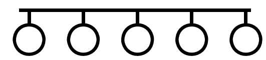
Automatic Repeat Request - ARQ

- All packets are acknowledged and missing ACK results in retransmit
  - Very common in wireless
- Many variants:
  - Stop and wait: one packet at a time
  - Go Back N: sender keeps sending and retransmits, starting with the unacknowledged packet
  - Selective Repeat: only packets that are not acknowledged are retransmitted
- When should what variant be used?

Media Access Control

- How do we transfer packets between two hosts connected to the same network?
- Using point-to-point "links" with "switches" -- store-and-forward
  - » Very common in wired networks
  - » Also in some wireless or in hybrid networks
  - » In wireless, links can interfere if they share the same spectrum
- Multiple access networks
  - » Multiple hosts are sharing the same transmission medium
  - » Used in LANs and wireless
  - » Need to control access to the medium
  - » Taking turn versus contention based protocols

Datalink Architectures

- Packet forwarding.
- Error and flow control.
- Media access control.
- Scalability.

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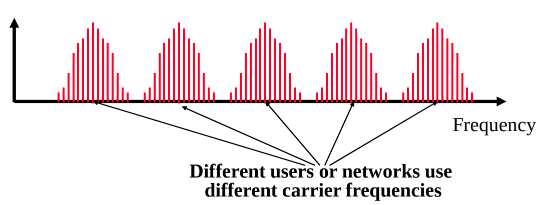
Creating Multiple Channels

- Multiple channels can coexist if they transmit at a different frequency, or at a different time, or in a different part of the space (or different code)
  - » Three dimensional space: frequency, space, time
- Space can be limited (using wires or) using transmit power of wireless transmitters
- Frequency multiplexing means that different users use a different part of the spectrum
  - » Again, similar to radio: 95.5 versus 102.5 station
- Time division multiplexing means that users send at different times
  - » Static partitioning of time
- Duplexing: splitting the time/frequencies between the up and down link

Supporting Bursty Data Traffic

- Data traffic is typically bursty but …
- Carving up bandwidth in fixed-bandwidth channels is not efficient for bursty traffic
- Frequency: static partitioning for practical reasons
  - » Partitioning is done per network, not per user
  - » Simplifies management, cheaper devices, etc.
- Space: not really a free variable
  - » People want access everywhere!
- Time: need to explore "dynamic time sharing" of a single channel, i.e. users send packets as they become available.
  - » Channel = frequency band in a certain "area"

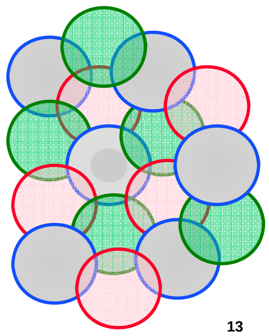
Frequency Division Multiplexing



- Effective way of creating fixed bandwidth channels
- Not useful for changing bandwidth to match bursty traffic: too complex to manage, overlapping cells, etc.

Frequency Reuse in Space

- Users want access everywhere.
- Can control capacity of cells by controlling power
  - » Users in “small” cells will have more bandwidth on average
- Not a practical way of dealing with bursty traffic: more of a load balancing tool
  - » Coarse time scale



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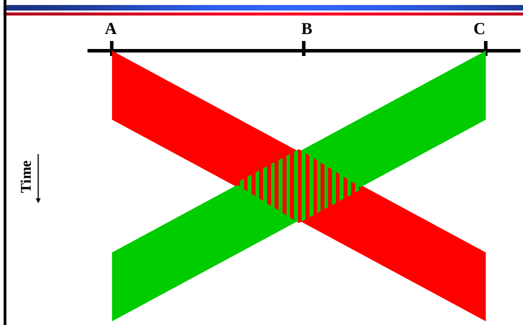
“Regular” Ethernet

- Multiple access: multiple hosts are competing for access to the channel
- Carrier-sense: make sure the channel is idle before sending
- Collision detection: collisions are detected by listening on the medium and comparing the received and transmitted signals
- Collisions results in 1) aborting the colliding transmissions and 2) retransmission of the packets
- Exponential backoff is used to reduce the chance of repeat collisions
  - » Also effectively reduces congestion

Ethernet Backoff Calculation

- Exponentially increasing random delay
  - » Infer senders from # of collisions
  - » More senders → increase wait time
- First collision: choose K from {0,1}; delay is K x 512 bit transmission times
- After second collision: choose K from {0,1,2,3}…
- After ten or more collisions, choose K from {0,1,2,3,4,…,1023}

Collisions



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- Data link fundamentals (refresher)
- Wireless Ethernet?
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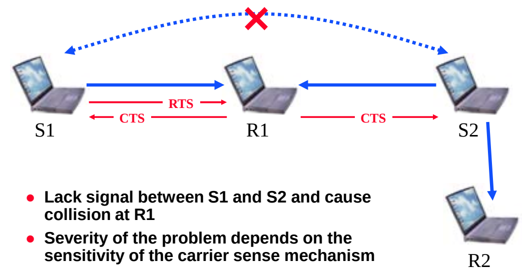
Wireless Ethernet is a Good Idea, but …

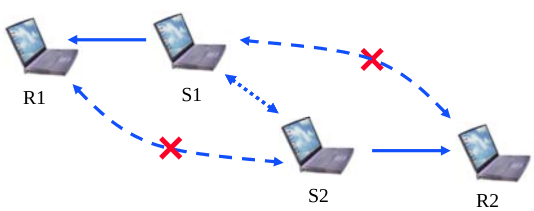
- In the ether, signals attenuate significantly with distance, so receivers need to deal with weak signals
  - » Plus strong signals from nearby transmitters
- This has many implications!
- Collision detection is not practical
  - » Signal power is too high at the transmitter
  - » So how do you detect collisions?
  - » Lack of acknowledgement for the transmitted packet
- Not all nodes can hear each other
  - » Many problems: hidden terminals, exposed terminals, capture effects, etc.

Hidden Terminal Problem



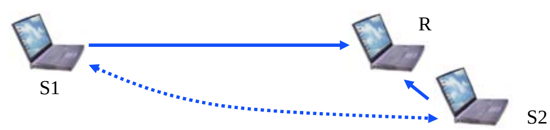
- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - » Clear Channel Assessment (CCA) threshold

Exposed Terminal Problem



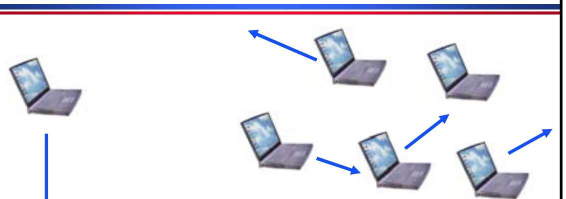
- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold

Capture Effect



- Sender S2 will almost always "win" if there is a collision at receiver R.
- Can lead to extreme unfairness and even starvation.
- Solution is power control
  - » Diffucult to manage

Wireless Packet Networking Problems




- Some nodes suffer from more interference than others
  - » Node density
  - » Traffic volume sent by neighboring nodes
- Leads to unequal throughput
- Similar to wired network: some flows traverse tight bottleneck while others do not

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Why ALOHA

Pure ALOHA

- Developed in University of Hawaii in early 1970's.
- It does not get much simpler:
  1. A user transmits at will
  2. If two or more messages overlap in time, there is a collision – receiver cannot decode packets
  3. Receive waits for roundtrip time plus a fixed increment – lack of ACK = collision
  4. After a collision, colliding stations retransmit the packet, but they stagger their attempts randomly to reduce the chance of repeat collisions
  5. After several attempts, senders give up
- Although very simple, it is wasteful of bandwidth, attaining efficiency of at most 1/(2e) = 0.18

Poisson Distribution

- Above definitions lead to: Probability P(k) that there are exactly k events in interval of length T is then,

$$P(k) = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$

- We call the above probability the "Poisson distribution"
- Its mean and variance are:

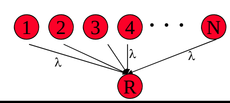
$$E(k) = \lambda T$$

$$\sigma_k^2 = E(k^2) - E^2(k) = \lambda T$$

- Many nice properties, e.g. sum of a N independent Poisson processes is a Poisson process

Pure ALOHA: Model

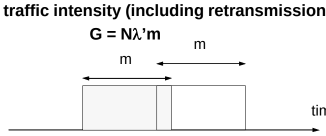
- Let there be N stations contending for use of the channel.
- Each station transmits λ packets/sec on average based on a Poisson arrival process
- All messages transmitted are of the same fixed length, m, in units of time
- Let new traffic intensity be $S \equiv N\lambda m$
- Since all new packets eventually get through, 'S' is also the network throughput



Pure Aloha: Vulnerability

- Simplification: assume the retransmitted messages are independent Poisson process as well
- The total rate of packets attempting transmission = newly generated packets + retransmitted ones = $\lambda' > \lambda$
- The total traffic intensity (including retransmissions) is ,

$G = N\lambda' m$



Collision between two messages

- The "vulnerable period" in which a collision can occur for a given packet is 2 x m sec

Pure Aloha: Analysis

- Calculate "Probability of no collision" two ways:

1. Probability that there is no arrival in interval 2 x m:

   P(no arrival in 2 x m sec) = $e^{-2N\lambda' m} = e^{-2G}$

2. Since all new arrivals eventually get through, we have

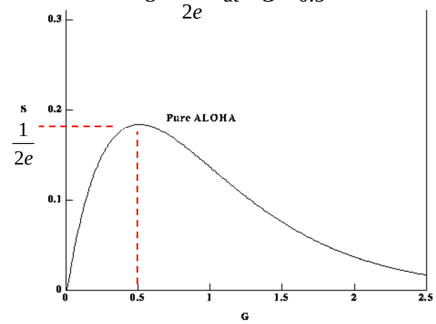
   λ/λ' = S/G = Fraction of transmissions that are successful

- So, S/G = Probability of no collision
  = P(no arrival in 2m sec)
- Thus,

  $S/G = e^{-2G}$
  $S = Ge^{-2G}$ ⟶ Maximum Throughput of Pure Aloha

Analysis Conclusion

- S is maximum at $S = \frac{1}{2e}$ at $G = 0.5$



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Application of Pure ALOHA

- Maximum throughput of ALOHA is only very low 1/(2e) = 18%, but
- Has very low latency under light load
- Maybe be sufficient for some applications, e.g. highly bursty interactive traffic, very lightly loaded networks
- But not appropriate for as a general purpose network technology
- Especially when capacity is a scarce resource
  - » As is often the case in wireless

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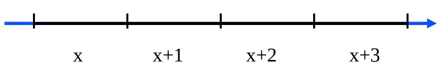
Slotted ALOHA

- Competition to send only occurs at the start of each slot of length T
- Vulnerable period is T
  - » Period is 2 x T in Aloha
- Doubles maximum throughput.
  - » Result based on many assumptions



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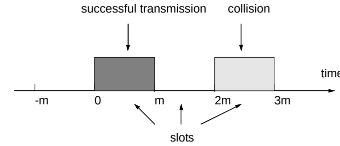
Slotted ALOHA

- Slot the time scale into units of time *m* (equal to message length)
- Modify Aloha by allowing users to attempt transmission at the beginning of a time slot only
- All users need to be synchronized in time.



Transmission in slotted ALOHA

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Slotted ALOHA Analysis

- Collisions occur if two or more users attempt transmission in the same slot.
- Key point: The "vulnerable period" of the packet of size *m* has been reduced from 2*m* to only *m* !
- Since Poisson arrivals, Note: Not 2G
  P(successful transmission) = e^{-G}
- The throughput is then,
  S = Ge^{-G}
- The throughput S has maximum value of 1/e = 0.368 at G = 1.

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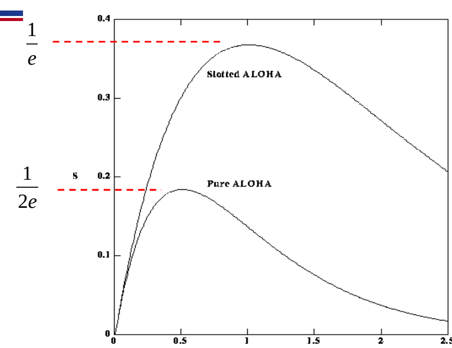
Analysis Results Slotted ALOHA



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Discussion of Slotted ALOHA

- **Twice the performance of basic Aloha, but performance is still very poor**
  - » **Slotted design is also not very efficient when carrying variable sized packets!**
  - » **Also (slightly) longer delay than pure Aloha**
- **What is missing?**
- **Carrier sense**
  - » **Next lecture**