Medium Access Control

Part I

Fundamental Problem

- N nodes in vicinity want to transmit (to say, N other nodes).
- How to do this "interference free"?
- Definition: Collision -> We say packets collide if SINR < β.
- Assume a simple but common scenario: All nodes are so close that two simultaneous transmissions will always collide. Also, assume that they are all in the same channel.

General Solution

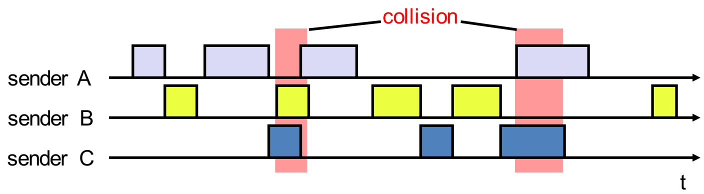
- Multiplex transmissions over time.
- Coordinated access:
  - Each node is somehow "scheduled" to transmit in certain intervals of time.
  - Schedule chosen to avoid collision simultaneous transmissions.
  - Problem: Who does the coordination? How? Need a "coordinator". Need to know who has packet when.
- Random access:
  - Simple alternative. Nodes transmit at random times.
  - Simply hope that they do no collide.

Aloha/Slotted Aloha

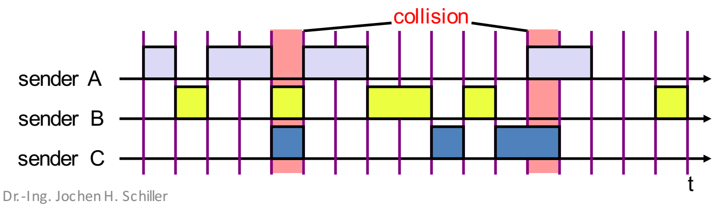
- Transmit packets immediately (if not transmitting already).
- Appears random as packets are generated randomly.
- Slotted Aloha is similar except that it assumes packet transmissions are synchronized with time slots.

Aloha/slotted aloha

- Aloha



- Slotted Aloha



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Slotted Aloha

- One slot = one packet
- Each slot has one of three states
  - Successful (S): Exactly one node transmits.
  - Collision (C): More than one node transmits.
  - Idle (I): No node transmits.
- Assume that each node transmits in a slot with probability p . The #nodes is n .
- Normalized throughput

  = throughput / capacity

  = #successful slots/ total #slots (think why?)

  = Prob. of a slot being successful.

  This is also same as utilization.

Slotted Aloha Throughput Analysis

Prob. of a slot being successful

= Prob. that exactly one node transmits

= $np(1-p)^{n-1}$

This value is maximized when $p = \frac{1}{n}$. (Show this.)

This is the optimal throughput.

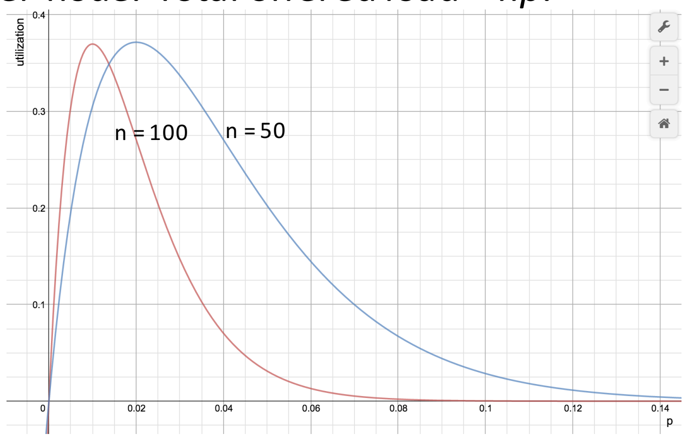
This value tends to $1/e$ or 0.36, when $n \to \infty$. (Show this.)

Unslotted Aloha

- Partially overlapped packets also collide. More waste.
- Assume, all packets are of same size.
- Each packet overlaps with up to 2 packets of other nodes.
- Normalized throughput = $np(1-p)^{2(n-1)}$
- Optimal = $1/2e$ = 0.18

Numerical Results

- Note, *p* is same is offered load (in packets/slot) per node. Total offered load = *np*.



Carrier Sense Multiple Access (CSMA)

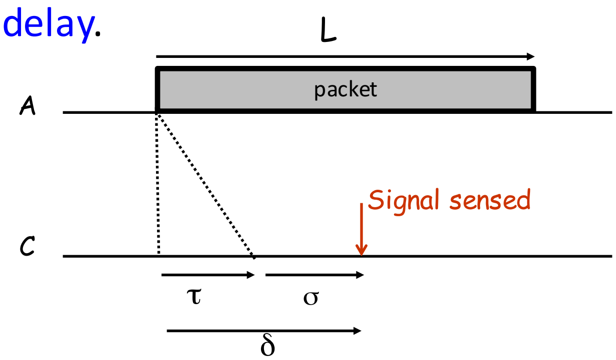
- Normalized throughput = 36% is considered too poor. How to improve it?
- Avoid collision. Listen before talk. A node may transmit only when the medium is sensed idle.
- Need to implement channel sensing. Also, called carrier sensing. In standards, sometimes also called clear channel assessment (CCA).

Carrier Sensing

- Typically performed via energy (or power) detection.
- Potential implementation:
  - Listen to channel and measure the received power.
  - If power exceeds given threshold, channel busy.
  - This threshold is called carrier sense threshold P_{CS}
- It takes non-zero time to sense carrier. Called carrier sensing delay.

Slotted CSMA Protocol

- Packet size = *L* (in time units).
- Slot size = $\delta = \tau + \sigma$, where τ is worst case propagation delay and σ is worst case carrier sensing delay.

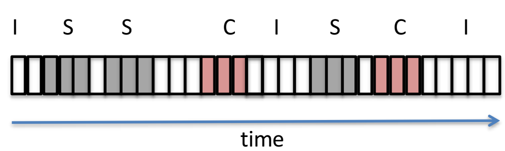


P-persistence

1. If wish to transmit in a slot *i*, sense carrier first.
2. Channel busy -> go to next slot *i+1*.
3. Channel idle -> still go to next slot *i+1*. (Note channel sensing can take a whole slot.) Transmit with probability *p* in slot *i+1*.
4. If no transmission in slot *i+1*, still sense carrier. Repeat.

Throughput Analysis

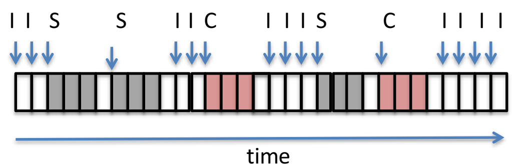
- Each slot can be successful (S), collision (C) or idle (I) as before.
- Slot size = δ . Packet size $L = 3\delta$ (assume)



- Duration required for transmission/collision = $L + \delta$

Throughput Analysis

- Identify transmission opportunities.



- Classify opportunities into S, C and I. Derive probabilities.

$$P_{success} = np(1-p)^{n-1}$$
$$P_{none} = (1-p)^{n}$$
$$P_{collision} = 1 - P_{success} - P_{none}$$

Throughput Analysis

- The above probabilities provide the probabilities that a transmission opportunity will result in S, C, or I.
- Each of these events last for some time.
- S and C last for duration $L+\delta$. I lasts for duration δ .
- Normalized throughput = fraction of time occupied by successful transmissions.

Throughput Analysis

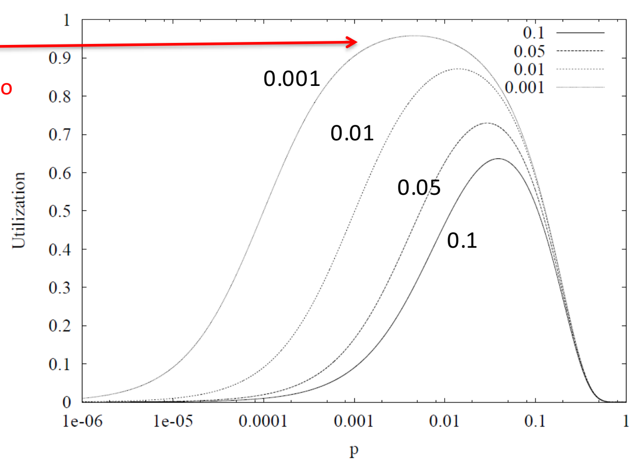
- Normalized throughput =

$$\frac{P_{success}\ L}{P_{none}\delta + (1 - P_{none})\ (L+\delta)} = \frac{P_{success}\ L}{\delta + (1 - P_{none})\ L}$$

- This is based on Renewal-Reward Theorem. Roughly stated: If a "reward" is earned during a "cycle," where cycle length and reward are all random, the "reward rate" is expected reward over a cycle divided by the expected cycle length.
- Cycle length = time between successive transmission opportunities. This is 1 slot (if nobody transmits), or 1 packet length + 1 slot (if there is a transmission).
- Reward = packet length if successful, otherwise 0

Numerical Results

Very good performance provided packets are large compared to slot



Various values of δ/L are chosen from 0.001 to 0.1

Of note, L/δ is packet size in slots

$n = 10$

[Utilization is same as normalized throughput]

[From Nitin Vaidya's notes]

Sense any problem?

- No problem for large packets relative to slot size.
- How large are slots? Consider two WiFi standards – old and new.
  - Was 20us for 802.11b, now 9us for 802.11ac.
  - Max date rate for 802.11b was 11Mbps. Max data rate for 802.11ac is 0.4 to 5+ Gbps.
- Factor of 2 improvement in slot size. But factor of 10-100 improvement in data rate. [Why?]
- This means, δ/L getting larger. Value of 0.1-1 may not be uncommon.
  - This limits throughput.
  - Currently considered the most important technology limitation of high speed wireless LAN.

Backoff

- Backoff is a simple way to implement p-persistence in practical protocols.
- Backoff = number of valid transmission opportunities skipped before actual transmission.
- Randomly chosen, but bounded.
- Example:
  - Backoff interval is chosen uniformly at random in range [Bmin, Bmax].
  - Initialize a counter by this value.
  - Decrement counter after each slot at each valid transmission opportunity (i.e., slot detected idle).
  - On a valid opportunity, if counter 0, transmit.

Responding to Packet Losses

- Packet losses can occur due to collisions. Multiple nodes can decide to start transmission in the same slot.
- To reduce collision, access probability (*p*) must be reduced.
  - Can be achieved by increasing the window over which the backoff interval is chosen.
  - Exponential backoff: [0,cw-1] -> [0,2*cw-1] on packet loss.

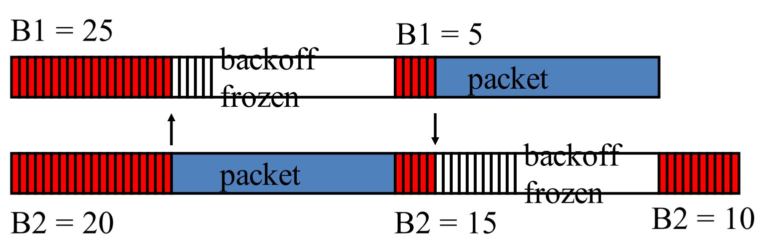
WiFi: 802.11

- IEEE 802.11 is the most predominant wireless LAN (WLAN) standard. Commonly called WiFi.
- Many variations 802.11a/b/g/n/ac – but broad features at the MAC layer is very similar, though significant differences in the PHY layer.
- Uses carrier sensing with backoff.

Backoff in 802.11

- Backoff is chosen uniformly randomly within the range [0,cw-1] slots, where cw is called the contention window.
- Count down a backoff counter when medium is idle.
  - Medium is sensed continuously during backoff.
  - Countdown is frozen when medium is busy.
- Transmit when backoff counter reaches 0.

Backoff Countdown Example



cw = 32

B1 and B2 are backoff intervals at nodes 1 and 2

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Contention Window in 802.11

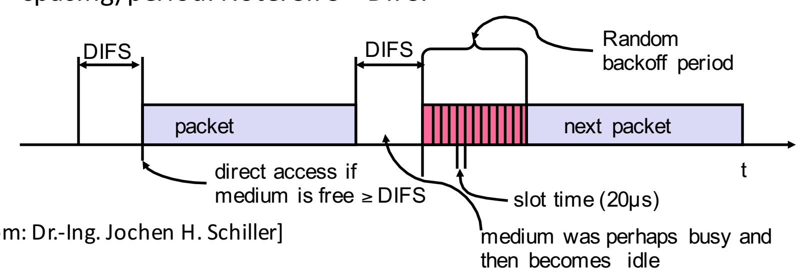
- When starting afresh, cw = CWmin.
  - [CWmin is typically 32.]
- cw is doubled if packet is lost (perhaps due to collision) and packet is retransmitted with the new backoff.
- Packet loss is detected via lack of ACK.
- After successful transmission cw is reset to CWmin.

802.11 MAC

- Sometimes called DCF (distributed coordination function). Slightly different from the idealized description before.
- Called CSMA/CA – CSMA with Collision Avoidance. CA is simply another way to describe p-persistence.

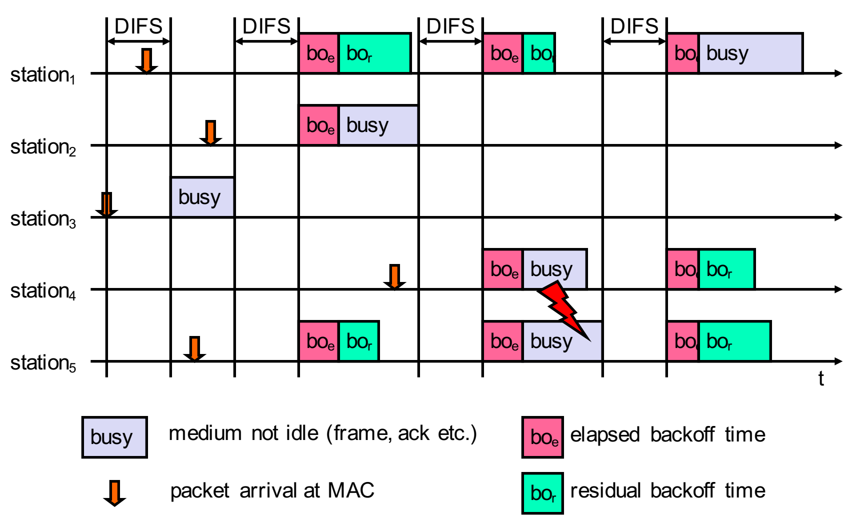
Protocol

- If a node wishes to transmit a packet, it first does carrier sensing.
- If the medium is free for a duration of DIFS (distributed inter-frame spacing), the node transmits.
- Else, the node waits until the medium is free and then enters a random backoff period (same contention window mechanism as in previous slide).
- Backoff must be on idle medium. Backoff counter is frozen if medium becomes busy in the interim.
- The node transmits when the backoff counter reaches 0.
- The receiver sends an ACK after waiting for a SIFS (short inter-frame spacing) period. Note: SIFS < DIFS.



[From: Dr.-Ing. Jochen H. Schiller]

802.11 - Competing Nodes



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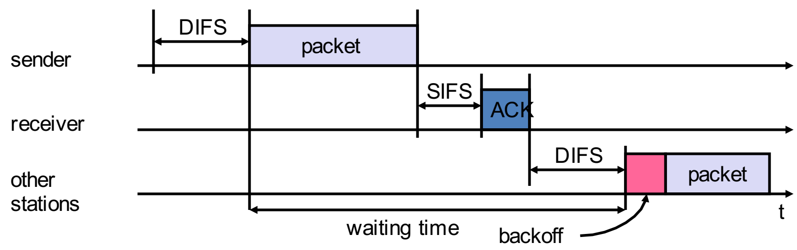
Showing ACKs



- Note, DIFS, SIFS, ACK and Packet times are not to scale.