Computing Principles for Embedded Systems

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Medium Access Control

What is “Media”

Radio

Ring

Shared Wire

Medium Access Sub-layer

Access Protocols

- Who gets to use the channel next?
  - Fixed/Static assignment
  - Demand assignment
  - Contention
  - Turn-Based

Fixed Assignment Protocols

- Static and predetermined allocation of channel access: independent of user activity
- Idle users may be assigned to the channel, in which case channel capacity is wasted
- Examples: TDMA, FDMA

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

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

Demand Assignment Protocols

- Allocate channel capacity to hosts on a demand basis (i.e., only to active users)
- Requires methods for measuring the demand for the channel
  - Polling
  - Reservation schemes

Polling

- A central controller interrogates each host and allocates channel capacity to those who need it
- Good for systems with:
  - Short propagation delay
  - Small polling messages
  - Non-bursty traffic

Reservation Schemes

- Hosts independently reserve the channel for period of time
- Reservations are usually piggybacked on data messages passing along the channel
- Good for systems with :
  - short propagation delay
  - no central controller node
  - non-bursty traffic

Reservation Protocols *(cont'd)*

- Reservation protocol examples:
  - Bit-Map Protocol
  - Binary Countdown Protocol

Contention Access Protocols

- No coordination between hosts
- Control is completely distributed
- Outcome is probabilistic
- Examples: ALOHA, CSMA, CSMA/CD

Contention Access *(cont'd)*

- Advantages:
  - Short delay for bursty traffic
  - Simple (due to distributed control)
  - Flexible to fluctuations in the number of hosts
  - Fairness

Contention Access *(cont'd)*

- Disadvantages:
  - Can not be certain who will acquire the media/channel
  - Low channel efficiency with a large number of hosts
  - Not good for continuous traffic (e.g., voice)
  - Cannot support priority traffic
  - High variance in transmission delays

Contention Access Methods

- Pure ALOHA
- Slotted ALOHA
- CSMA
  - 1-Persistent CSMA
  - Non-Persistent CSMA
  - P-Persistent CSMA
- CSMA/CD

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 channel listening
- no collision, node can send new frame in next slot
- if collision, node retransmits frame in each subsequent slot with probability p until success

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 time than to transmit packets
- clock synchronization

Slotted Aloha efficiency

Efficiency is the long-run fraction of successful slots when there are many nodes, each with many frames to send

- Suppose N nodes with many frames to send, each transmits in slot with probability *p*
- prob that node 1 has success in a slot = $p(1-p)^{N-1}$
- prob that any node has a success = $Np(1-p)^{N-1}$

- For max efficiency with N nodes, find p* that maximizes $Np(1-p)^{N-1}$
- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives 1/e = .37

At best: channel used for useful transmissions 37% of time!

Slotted Aloha efficiency *(cont'd)*

- For max efficiency with N nodes,
  - Step 1: Find p^* that maximizes $Np(1-p)^{N-1}$

$$E(p) = Np(1-p)^{N-1}$$

Take a derivative with respect to p

$$E'(p) = N(1-p)^{N-1} - Np(N-1)(1-p)^{N-2}$$

$E'(p^*) = 0$

$$p^* = \frac{1}{N}$$

Slotted Aloha efficiency *(cont'd)*

- For max efficiency with N nodes,
  - Step 2: Substitute $p = p^*$ into $Np(1-p)^{N-1}$ to compute max efficiency

$$E(p^*) = N\frac{1}{N}(1-\frac{1}{N})^{N-1} = (1-\frac{1}{N})^{N-1}$$

Take limit as N goes to infinity

$$\lim_{N\to\infty} E(p^*) = \lim_{N\to\infty}\left(1-\frac{1}{N}\right)^{N-1} = \lim_{n\to\infty}\left(\frac{N-1}{N}\right)^{N-1}$$

Let $N-1=x$

$$\lim_{N\to\infty} E(p^*) = \lim_{x\to\infty}\left(\frac{x}{x+1}\right)^{x} = \lim_{x\to\infty}(\frac{x+1}{x})^{-x} = \frac{1}{\lim_{x\to\infty}\left(1+\frac{1}{x}\right)^{x}}$$

$$e = \lim_{x\to\infty}\left(1+\frac{1}{x}\right)^{x}$$

$$\lim_{N\to\infty} E(p^*) = \frac{1}{e} = 0.37$$

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 $[t_0-1, t_0+1]$

Pure Aloha efficiency

P(success by given node) = P(node transmits) ×
P(no other node transmits in $[t_0-1, t_0]$ ×
P(no other node transmits in $[t_0, t_0+1]$

$$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$$

$$= p \cdot (1-p)^{2(N-1)}$$

… choosing optimum p and then letting n -> infinity …

$$= 1/(2e) = .18$$

Even worse !

Carrier Sense Multiple Access (CSMA)

- We could achieve better throughput if we could listen to the channel before transmitting a packet
- This way, we would stop avoidable collisions
- To do this, we need “Carrier Sense Multiple Access,” or CSMA, protocols

Assumptions with CSMA Networks

1. Constant length packets
2. No errors, except those caused by collisions
3. No capture effect
4. Each host can sense the transmissions of all other hosts
5. The propagation delay is small compared to the transmission time

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

CSMA *(cont'd)*

- There are several types of CSMA protocols:
  - 1-Persistent CSMA
  - Non-Persistent CSMA
  - P-Persistent CSMA

1-Persistent CSMA

- Sense the channel,
  - If busy, keep listening to the channel and transmit immediately when the channel becomes idle.
  - If idle, transmit a packet immediately.
- If collision occurs,
  - Wait a random amount of time and start over again.

1-Persistent CSMA *(cont'd)*

The protocol is called 1-persistent because the host transmits with a probability of 1 whenever it finds the channel idle.

1-Persistent CSMA

- Sense the channel.
  - If busy, **keep listening to the channel** and transmit immediately when the channel becomes idle.
  - If idle, transmit a packet immediately.
- If collision occurs,
  - Wait a random amount of time and start over again.

1-Persistent CSMA *(cont'd)*

- Even if prop. delay is zero, there will be collisions
- Example:
  - If stations B and C become ready in the middle of A's transmission, B and C will wait until the end of A's transmission and then both will begin transmit simultaneously, resulting in a collision.
- If B and C were not so greedy, there would be fewer collisions

Non-Persistent CSMA

- Sense the channel.
  - If busy, wait a random amount of time and sense the channel again
  - If idle, transmit a packet immediately
- If collision occurs
  - wait a random amount of time and start all over again

Tradeoff between 1- and Non-Persistent CSMA

- If B and C become ready in the middle of A's transmission,
  - 1-Persistent: B and C collide
  - Non-Persistent: B and C probably do not collide
- If only B becomes ready in the middle of A's transmission,
  - 1-Persistent: B succeeds as soon as A ends
  - Non-Persistent: B may have to wait

P-Persistent CSMA

- Optimal strategy: use P-Persistent CSMA
- Assume channels are slotted
- One slot = contention period (i.e., one round trip propagation delay)

The Effect of Propagation Delay on CSMA

Propagation Delay and CSMA

- Contention (vulnerable) period in Pure ALOHA
  - two packet transmission times
- Contention period in Slotted ALOHA
  - one packet transmission time
- Contention period in CSMA
  - up to 2 x end-to-end propagation delay

Performance of CSMA >
Performance of Slotted ALOHA >
Performance of Pure ALOHA

P-Persistent CSMA *(cont'd)*

1. Sense the channel
   - If channel is idle, transmit a packet with probability p
     - if a packet was transmitted, go to step 2
     - if a packet was not transmitted, wait one slot and go to step 1
   - If channel is busy, wait one slot and go to step 1.
2. Detect collisions
   - If a collision occurs, wait a random amount of time and go to step 1

P-Persistent CSMA *(cont'd)*

- Consider p-persistent CSMA with p=0.5
  - When a host senses an idle channel, it will only send a packet with 50% probability
  - If it does not send, it tries again in the next slot.