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Intro to Computer Networks
CompSci 132/EECS148

Homework 5, Solution Sketch

Topic: Link Layer (Chapter 5)

Posted on Sat. June 4th

1. *(50 Points)* **Random Access Protocols.**

   (a) *(10 Points)* **Analysis of Slotted Aloha.** Problem 11.
   Answer:

   (a) $(1 - p(A))^4 \cdot p(A)$ where:
   $p(A)$ = probability that A succeeds in a slot= p(A transmits and B does not and C does not and D does not) = p(A transmits) $\cdot$ p(B does not transmit) $\cdot$ p(C does not transmit) $\cdot$ p(D does not transmit) = $p(1p)(1p)(1 - p) = p(1p)^3$
   Hence, p(A succeeds for first time in slot 5) = $(1-p(A))^4 p(A) = (1-p(1-p)^3)^4 p(1-p)^3$

   (b) p(A succeeds in slot 4) = $p(1 - p)^3$
   p(B succeeds in slot 4) = $p(1 - p)^3$
   p(C succeeds in slot 4) = $p(1 - p)^3$
   p(D succeeds in slot 4) = $p(1 - p)^3$
   p(either A or B or C or D succeeds in slot 4) = $4p(1 - p)^3$, because these events are mutually exclusive.

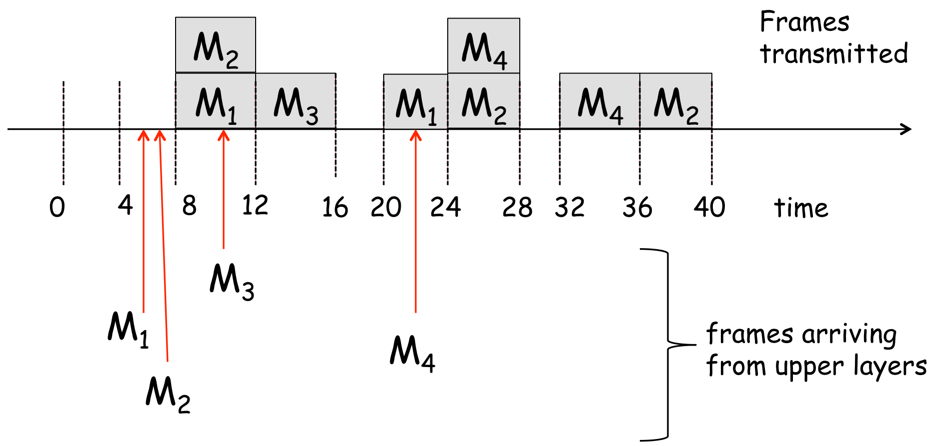
   (c) p(some node succeeds in a slot) = $4p(1 - p)^3$
   p(no node succeeds in a slot) = $1 - 4p(1 - p)^3$
   Hence, p(first success occurs in slot 3) = p(no node succeeds in first 2 slots) $\cdot$ p(some node succeeds in 3rd slot) = $(1 - 4p(1 - p)^3)^2 4p(1 - p)^3$

   (d) efficiency = p(success in a slot) =$4p(1 - p)^3$

   (b) *(20 Points)* **Comparing protocols.** Consider the following time diagram of transmissions in a shared medium. All frames have the same size (=4 time units). Assume that the maximum propagation delay is negligible (*e.g.*, one hundredth of the frame's transmission time). There are 4 nodes that want to transmit frames M_1, M_2, M_3, M_4, respectively. Those frames arrive from upper layers at times indicated by the arrows. When frames are shown on top of each other, this means that they are transmitted simultaneously.

   i. Can these transmissions have been generated by a Pure Aloha protocol?
   Answer: NO. These transmissions start at beginning of each slot not immediately after frames arrive.

   ii. Can these transmissions have been generated by a Slotted Aloha protocol?
   Answer: YES. The frames start transmitting in the next slot after they arrive. After collisions, stations decide probabilistically whether to transmit on each subsequent slot, until they successfully transmit.



iii. Can these transmissions have been generated by CSMA?
Answer: YES. The stations implement carrier sensing: when they sense the medium busy, they do not transmit.

iv. Can these transmissions have been generated by CSMA/CD?
Answer: NO. Frames are completely transmitted and no transmissions get aborted after collision detection.

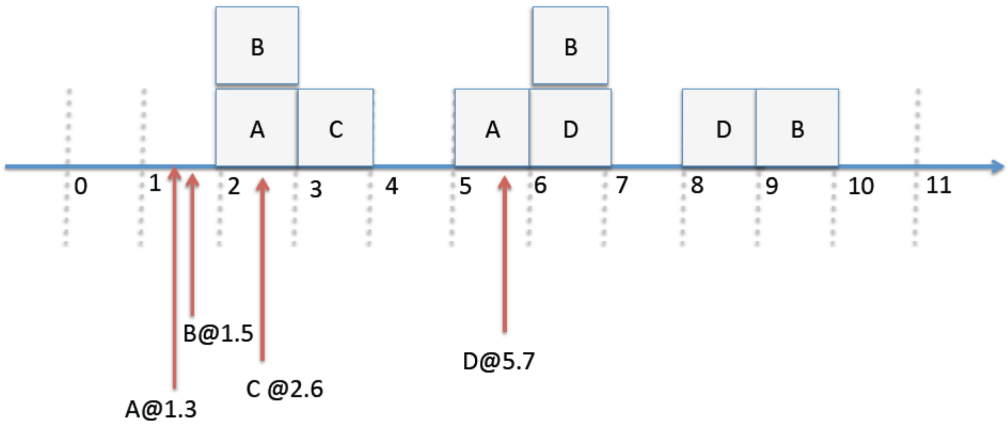
v. Can these transmissions have been generated by an algorithm with exponential backoff? Justify your answer. If your answer is no, point to a part of the example that violates the protocol. If your answer is yes, explain the decisions at the nodes that led to the observed transmissions (e.g., flipping a coin, outcome, etc).
Answer: NO. Consider the first collision of M1 and M2 in the 3rd timeslot. If the stations used exponential backoff, each should pick on of the next two slots (slot 0: [12,16] and slot 1: [16,20]) to transmit. However, they both transmit later, which is incompatible with exponential backoff.

(c) *(10 Points)* **Slotted Aloha in Action.** Consider a slotted Aloha system, where the time slot equals the fixed duration of each packet. Assume that there are 4 stations A,B,C,D sharing the medium.

i. Stations A,B,C,D receive one packet each from higher layers at times 1.3, 1.5, 2.6, 5.7 respectively. Show which transmissions take place when, according to the Slotted Aloha Protocol; describe all transmissions until all four packets have been successful. If needed, each station has access to the following sequence of random numbers, provided by a random number generator and drawn uniformly between 0 and 1:

- Station A draws numbers: 0.31, 0.27, 0.78, 0.9, 0.9, 0.11, 0.22....
- Station B draws numbers: 0.45, 0.28, 0.11, 0.83, 0.37, 0.22, 0.91....
- Station C draws numbers: 0.1, 0.2, 0.3, 0.4, 0.5, ...
- Station D draws numbers: 0.36, 0.77, 0.9, 0.1, 0.1, 0.1, 0.1, 0.83.....

Answer: See figure below.
This is *slotted* aloha, so frames wait until the beginning of the next time slot to be transmitted. Station A wants to transmit at time 1.3 but wait and transmits from 2 to 3. Similarly, B wants to transmit at 1.5 but waits and transmits from 2 to 3 as



well. C wants to transmit but starts at 3, and D wants to transmit at time 5.7 but starts at time 6.

After a *collision*, each station "flips a fair coin" to decide whether to transmit or not, in each subsequent timeslot until success. Let's assume that each station uses a value produced by its random generator as follows: if the random number is in [0,0.5] then the station does not transmit, if it is in (0.5,1] then the station transmits. *(Note: It is ok if you asusme that each station uses a biased coin, e.g. transmits with prob.* $\frac{1}{3}$ *instead of* 0.5*, as long as you state your assumption and use the random numbers accordingly.).*

During the 2nd slots (from 2 to 3), A and B collide. In the time slots 3 and 4 A draws $0.31 < 0.5$ and $0.27 < 0.5$, thus it does not transmit. In timeslot 5 it draws $0.78 > 05$ and thus transmits. Similarly B, draws $0.45, 0.28, 0.11, 0.83$ which means it transmits in slot 6. However, D also transmits in slot 6, thus there is a collision. B and D continue to draw random numbers to decide whether to transmit or not, as depicted in the figure, until all frames are successfully transmitted.

ii. In slotted aloha, a station transmits in each time slot with a given probability. What probabilities would you assign to each of the four stations so as to:
   - maximize the efficiency of the protocol?
   - maximize fairness among the four stations?

Answer:
Fairness means that all stations use the same prob. of transmission $p_1 = p_2 = p_3 = p_4 = p$. For *efficiency*, we would like to have $p_1 + p_2 + p_3 + p_4 = 1$ to fully utilize the all slots as transmissions opportunities. Intuitively, $p_1 + p_2 + p_3 + p_4 > 1$ means that there will be congestion (more transmissions than slots, thus many slots spent on collisions), while $p_1 + p_2 + p_3 + p_4 < 1$ means that the channel will be underutilized (less attempted transmissions than slots, thus unnecessarily empty slots). The choice that is both fair and maximizes efficiency is $p_1 + p_2 + p_3 + p_4 = \frac{1}{4}$.

To be more precise, let's assume that $p_1 = p_2 = p_3 = p_4 = p$. Then the efficiency is simply: $E(p) = Prob(\textit{some node succeeds in a slot}) = P(A) + P(B) + P(C) + P(D) = 4p(1-p)^3$ The efficiency is maximized for the value of p^* that makes the derivate zero: $\frac{\partial F(p)}{\partial p} \longrightarrow p^* = \frac{1}{4}$.

2. *(50 Points)* **LANs: Addresses and Switches.**

3. *(25 Points)* MAC and IP addresses: (**Problem 14** and) **Problem 21**. *(Note: Problem 14 was NOT part of the Homework 5. However, it ties nicely with it and is provided here as they share common parts.)*

   Answer: to **Problem 14.**

   (a,b) See the corresponding figure. Please notice that the solution is not unique - there are several possible valid assignments of addresses.

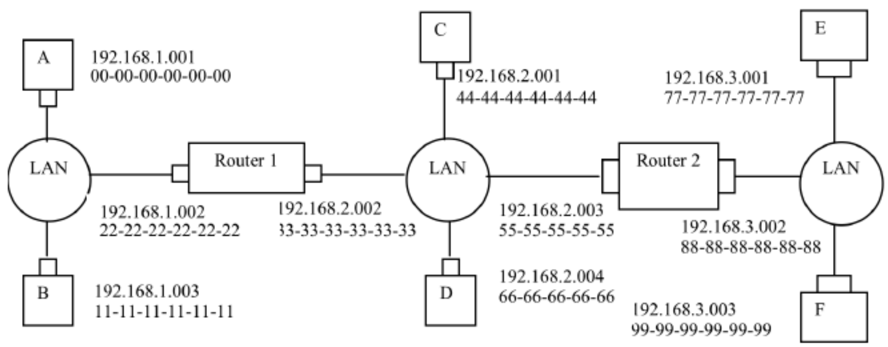


Figure 1: Problem 14.

   (c) The steps are the following:

      (a) Forwarding table in E determines that the datagram should be routed to interface 192.168.3.002.

      (b) The adapter in E creates and Ethernet packet with Ethernet destination address 88-88-88-88-88-88.

      (c) Router 2 receives the packet and extracts the datagram. The forwarding table in this router indicates that the datagram is to be routed to 198.162.2.002.

      (d) Router 2 then sends the Ethernet packet with the destination address of 33-33-33-33-33-33 and source address of 55-55-55-55-55-55 via its interface with IP address of 198.162.2.003.

      (e) The process continues until the packet has reached Host B.

   (d) ARP in E must now determine the MAC address of 198.162.3.002. Host E sends out an ARP query packet within a broadcast Ethernet frame. Router 2 receives the query packet and sends to Host E an ARP response packet. This ARP response packet is carried by an Ethernet frame with Ethernet destination address 77-77-77-77-77-77.

Answer: to **Problem 21.**

Note: You can use any valid assignment of IP and MAC addresses. For example, you could use an assignment from Problem 14. Here, let's use the one shown in the corresponding figure as a starting point.

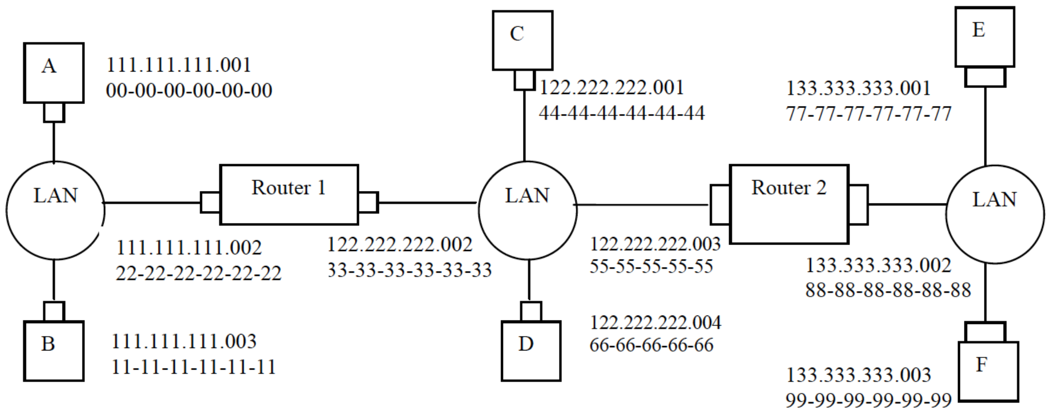


Figure 2: Problem 21.

(a) from A to left router:
- Source MAC address: 00-00-00-00-00-00
- Destination MAC address: 22-22-22-22-22-22
- Source IP: 111.111.111.001
- Destination IP: 133.333.333.003

(b) from the left router to the right router:
- Source MAC address: 33-33-33-33-33-33
- Destination MAC address: 55-55-55-55-55-55
- Source IP: 111.111.111.001
- Destination IP: 133.333.333.003

(c) from the right router to F:
- Source MAC address: 88-88-88-88-88-88
- Destination MAC address: 99-99-99-99-99-99
- Source IP: 111.111.111.001
- Destination IP: 133.333.333.003

4. *(25 Points)* Learning Switches: **Problem 26**.

Answer:

Action	Switch Table State	Link(s) packet is forwarded to	Explanation
B sends a frame to E	Switch learns interface corresponding to B	A, C, D, E, and F	Since switch table is empty, so switch does not know the interface corresponding to MAC address of E
E replies with a frame to B	Switch learns interface corresponding to MAC address of E	B	Since switch already knows interface corresponding to MAC address of B
A sends a frame to B	Switch learns the interface corresponding to MAC address of A	B	Since switch already knows the interface corresponding to MAC address of B
B replies with a frame to A	Switch table state remains the same as before	A	Since switch already knows the interface corresponding to MAC address of A