Logistics

- Practice Link layer: HW5sol posted
- Final from F13: exam solution posted

- Evaluations
  - open until Sunday Dec. 10th
  - +1% for completing it (so far ~60%)

- Office hours next week
  - Usual times: Mon (10-12) – instructor will join, Tue (2-4), Wed (2-4), Thu (12-2) Fri; and place (all in EH 4404)

- 2 extra v7 books on hold at the library

Final Exam

- Tue 12/12 (A) and Thu 12/14 (B), 4-6pm in class

- Same format as midterm
  - Open books/notes/paper materials
  - No phones/laptops/any electronics
  - Randomized seating
  - Come early + bring your Ids
  - There will be extra books to borrow
- All inclusive **but** more focus on later chapters
  - everything we covered minus some sections (see next)

- Sample Final and Solution posted (F13)

How to prepare

- Lectures + Discussions: slides
- Class website: homeworks + solutions, Midterm, Sample Exams
- Book:
  - Reading: only sections listed in black in this review (not the ones in gray)
  - Problems at the end of each chapter
  - Companion website: interactive exercises, self-assessment, applets
    - https://media.pearsoncmg.com/aw/ecs_kurose_compnetwork_7/cw/login/sign-in.php
- Focus on 2^{nd} part, but all inclusive
  - See sample final+solution from F13
- Predictable and familiar (≠trivial)

Chapter 1: Introduction

1.1 What is the Internet?

1.2 Network edge

1.3 Network core

1.4 Performance (delay, loss, throughput), Network Core

1.5 Protocol layers, service models

~~1.6 Networks under attack: security~~

~~1.7 History~~

Chapter 2: Application layer

2.1 Principles of network applications

2.2 Web and HTTP

2.3 Electronic Mail

2.4 DNS

2.5 P2P applications

2.6 Video Applications

2.6 Socket programming with TCP

2.7 Socket programming with UDP

Chapter 3: Transport Layer

3.1 Transport-layer services

3.2 Multiplexing and demultiplexing

3.3 Connectionless transport: UDP

3.4 Principles of reliable data transfer

3.5 Connection-oriented transport: TCP

- segment structure
- reliable data transfer
- flow control
- connection management

3.6 Principles of congestion control

3.7 TCP congestion control

Ch. 4: Network Layer –Data Plane

4.1 Overview of Network layer

4.2 What's inside a router

- Destination-based Forwarding ++

4.3 IP: Internet Protocol

- datagram format, fragmentation, IPv4 addressing, network address translation, IPv6

4.4 Generalized Forward and SDN

- Match, Action, OpenFlow

Ch.5: Network Layer – Control Plane

5.1 Introduction

5.2 Routing protocols

- link state
- distance vector

5.3 Intra-AS routing in the Internet: OSPF

5.4 Routing among the ISPs: BGP

5.5 The SDN control plane

~~5.6 ICMP: The Internet Control Message Protocol~~

~~5.7 Network management and SNMP~~

Chapter 6: Link layer and LANs

6.1 Introduction

6.2 error detection, correction

6.3 Multiple access protocols

- 6.3.1: Channel partitioning: TDMA, FDMA, (CDMA)
- 6.3.2: Random access: Aloha, Slotted Aloha, CSMA, CSMA/CD
- Taking turns, DOCSIS

6.4 LANs

- addressing, ARP, Ethernet, switches, VLANs

~~6.5 link virtualization: MPLS~~

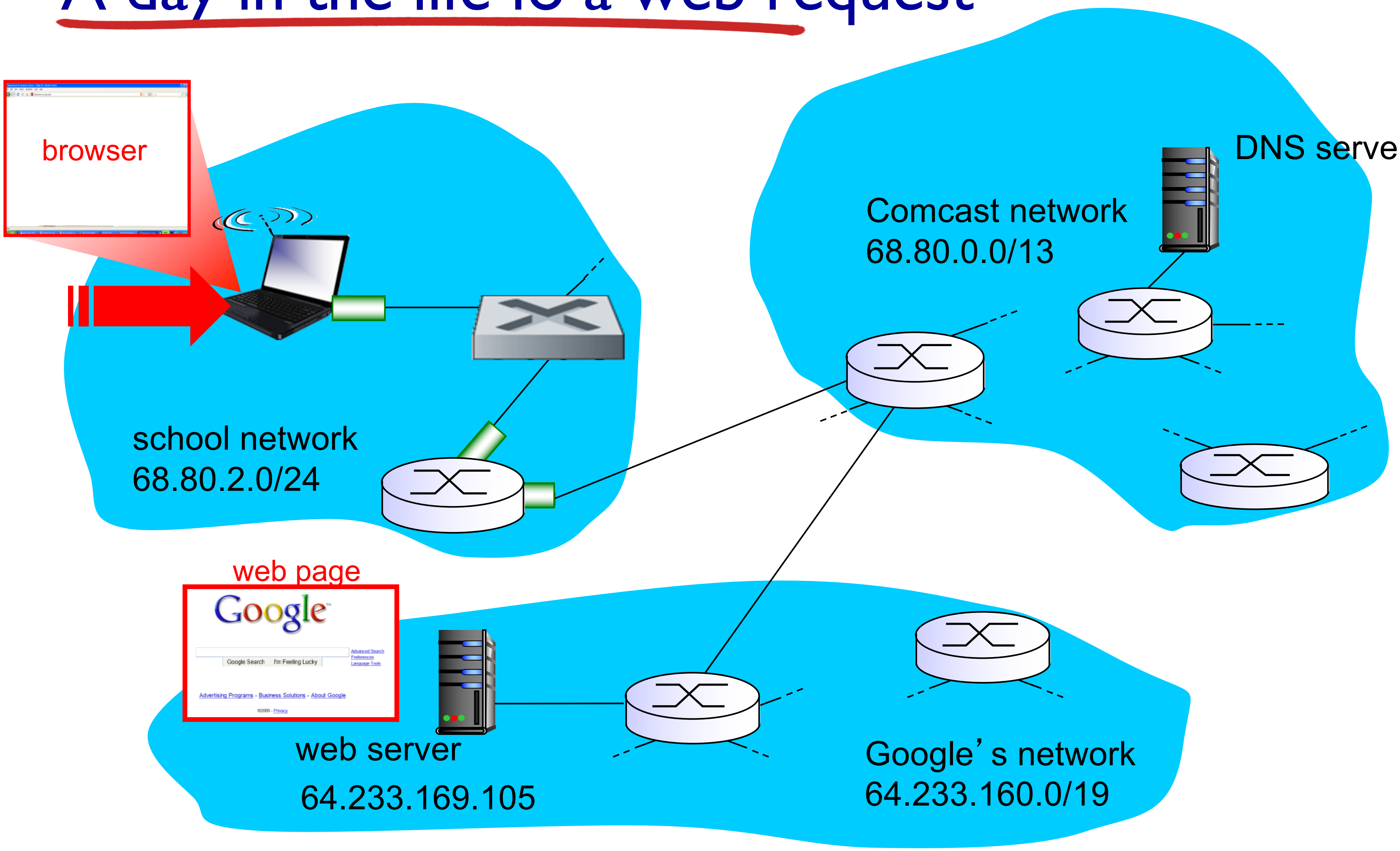
6.6 More link layers

data center networking; WiFi (7.3)

6.7 A day in the life of a web request

- practice on your own!

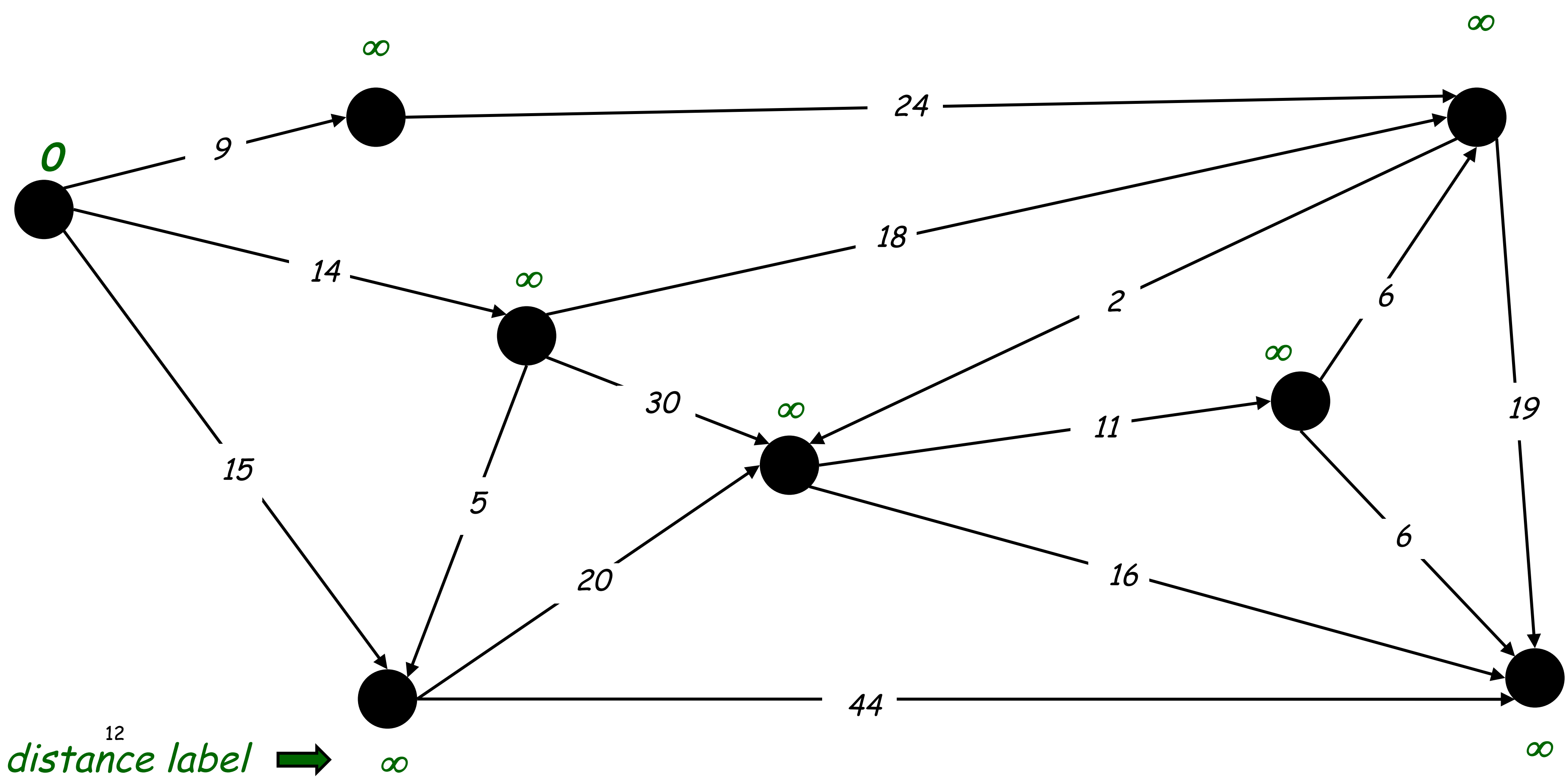
A day in the life fo a web request



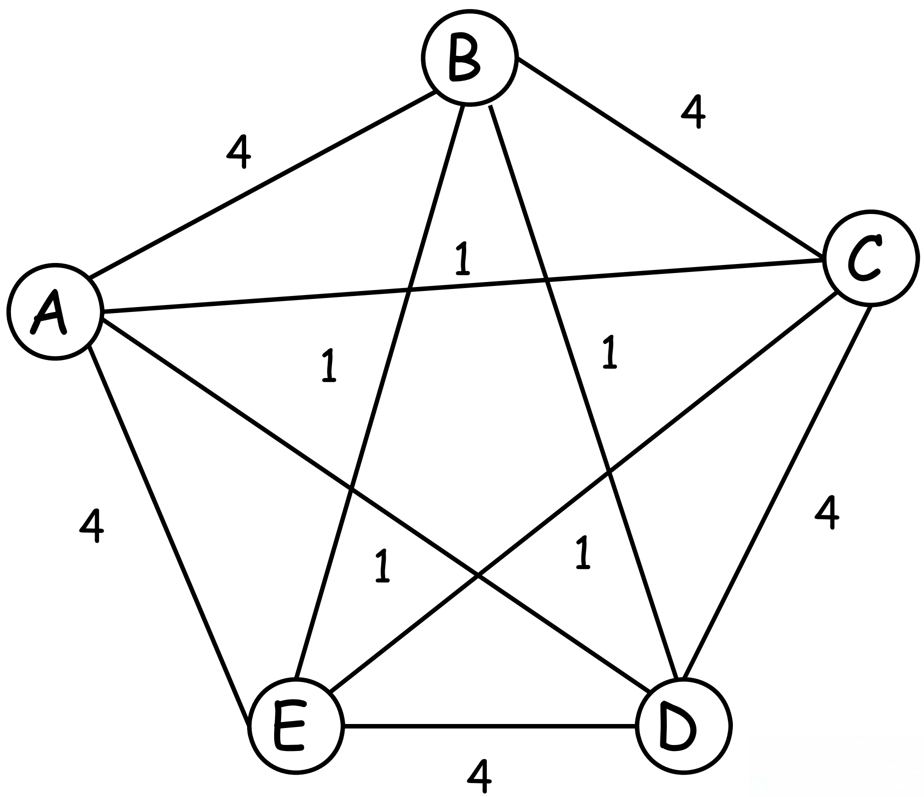
Review Topics

- Groups of problems
  - Routing
  - Multiple Access
  - LANs/switching
  - TCP congestion
  - Reliability: per link vs. e2e

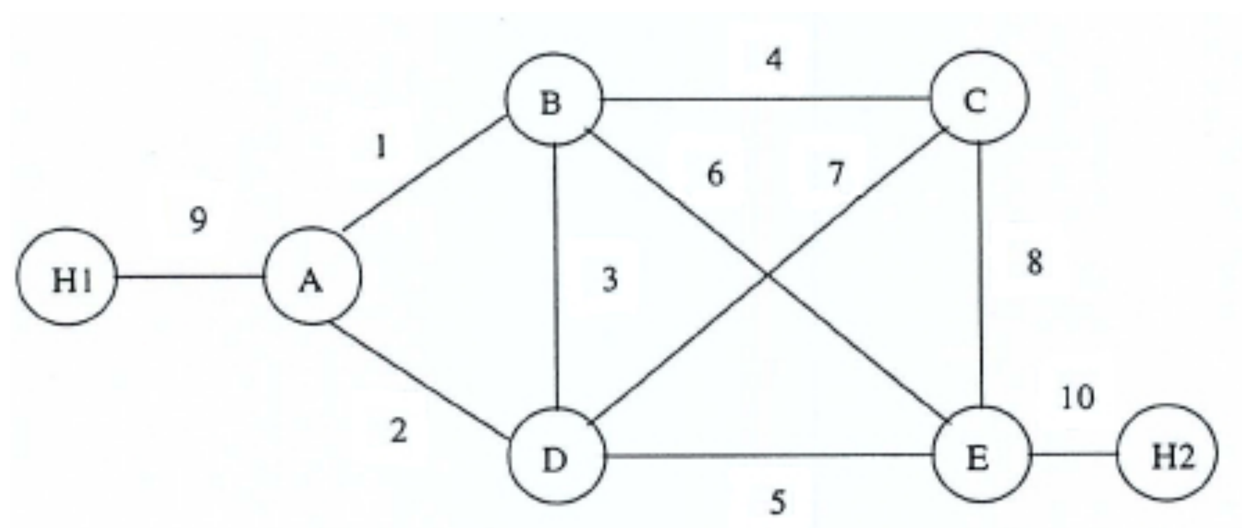
Dijkstra/Bellman Ford/Failures



Final S12



Your HW3



Routing & Forwarding

- HW4, HW5, sample final

- Dijkstra, Bellman-Ford (synchronous, asynchronous)
- Recalculate after failures/changes

- From routing to forwarding tables
- Assign MAC and IP addresses
  - Subnets, Prefixes

- Packet forwarded across a LAN
  - Switches/switching tables/MAC addresses/ARP
  - Routers, assigning IP addresses

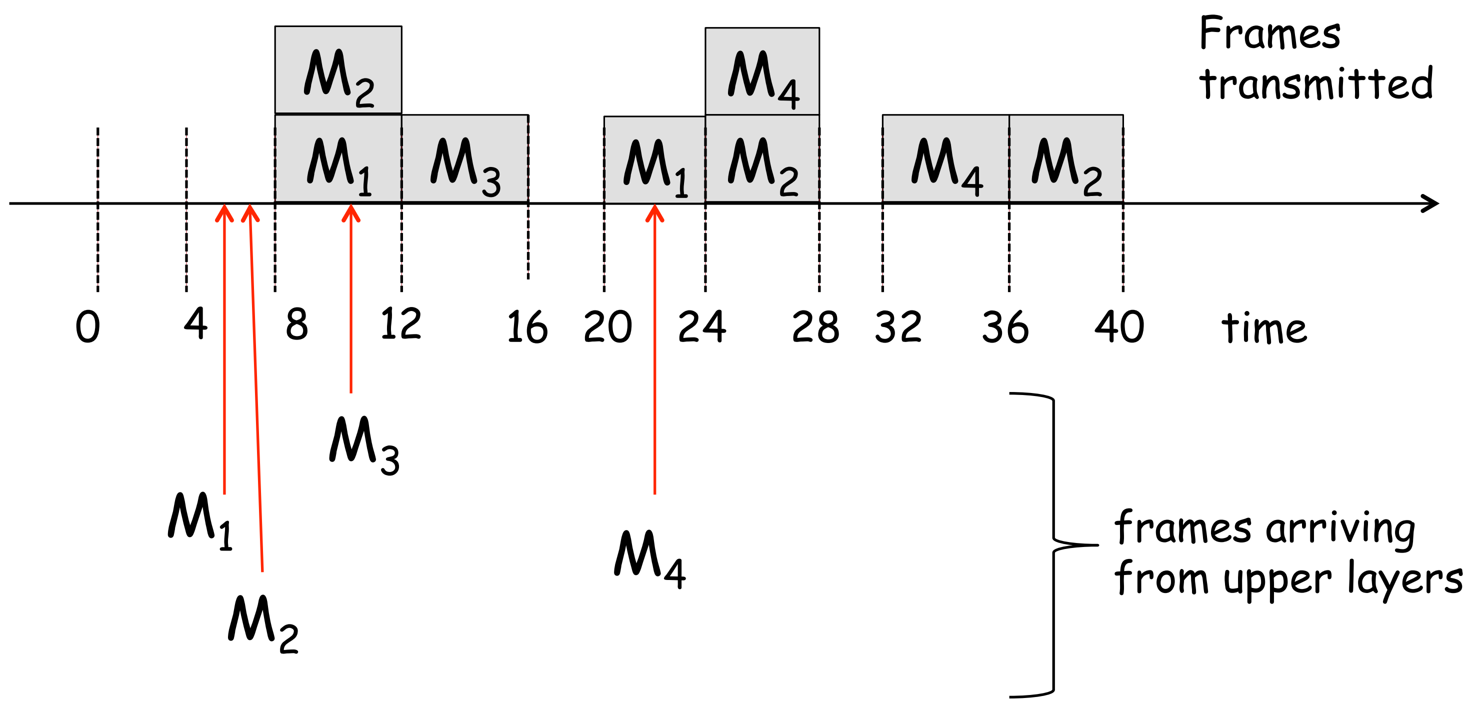
Review: Multiple Access Protocols:

- Topics
  - TDMA,…
  - Aloha, Slotted Aloha, CSMA, CSMA/CD

- Practice
  - HW5
  - Discussion Session
  - Sample Final

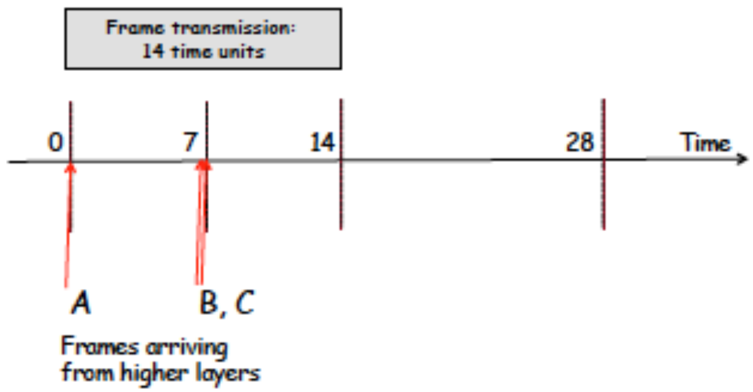
- Type of question:
  - Complete the diagram…
  - Which protocol is it?
  - Compute a probability, throughout etc
  - Multiple choice+justification

Is this: Aloha? Slotted Aloha? CSMA? w. exp.backoff? CSMA/CD?



Slotted Aloha, CSMA-CD (sample F13)

2. *(20 Points)* **Random Access Protocols.** Consider hosts A,B,C that transmit on a shared medium, using a random access protocol. Each host has exactly one frame to send, with transmission time = 14 time units. Host A wants to transmit at time $t = 0$. Hosts B,C both want to transmit at time $t = 7$, as shown in the figure below. Time is slotted and all hosts are synchronized to the clock.



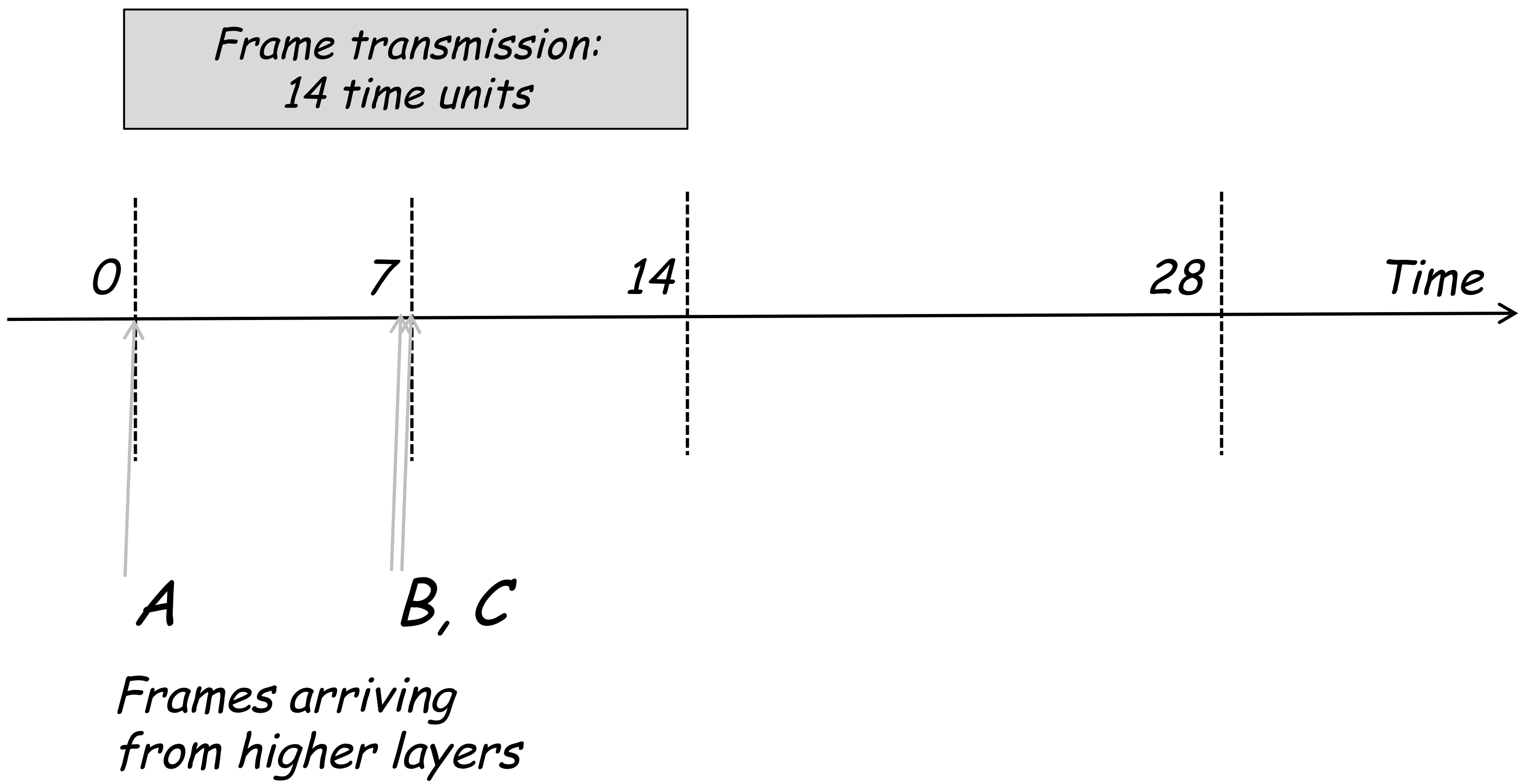
If needed to make randomized decisions, each host has access to the following sequence of random numbers, drawn uniformly at random between 0 and 1:

- Station A draws numbers: 0.45, 0.11, 0.71....
- Station B draws numbers: 0.10, 0.65, 0.91....
- Station C draws numbers: 0.83, 0.41, 0.25 ....

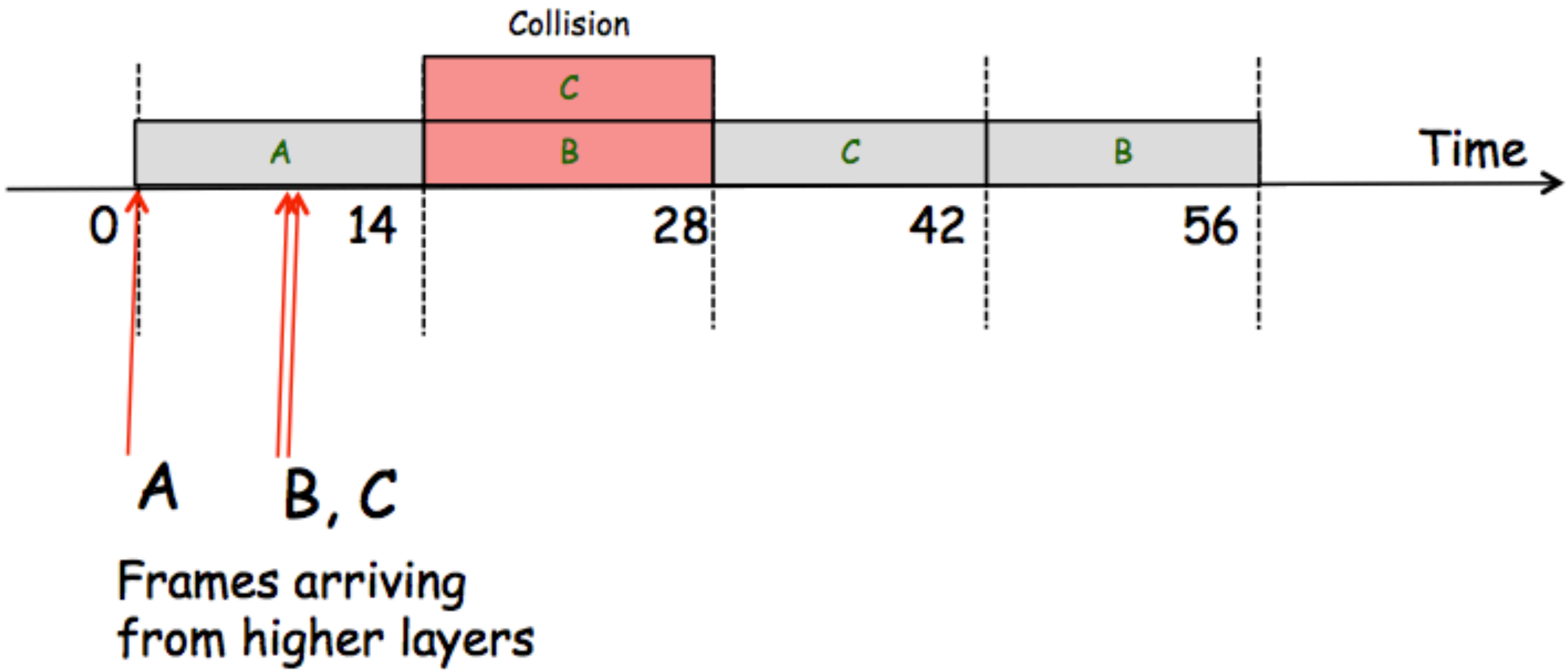
(a) *(9 Points)* Consider that nodes run a **Slotted Aloha** protocol, where the time slot equals the fixed duration of each frame =14 time units; i.e., slots start at time $0, 14, 28, \ldots$ etc. Show all transmissions that take place according to the Slotted Aloha Protocol, until all three frames are successful.

(b) *(9 Points)* Consider a **CSMA/CD** protocol with negligible propagation delay. This means that all stations can detect very quickly whether there is a collision, let's say within one time-unit, which defines the contention slot ("mini-slot") for CSMA/CD to be one time unit. Frames are still 14 time units long.

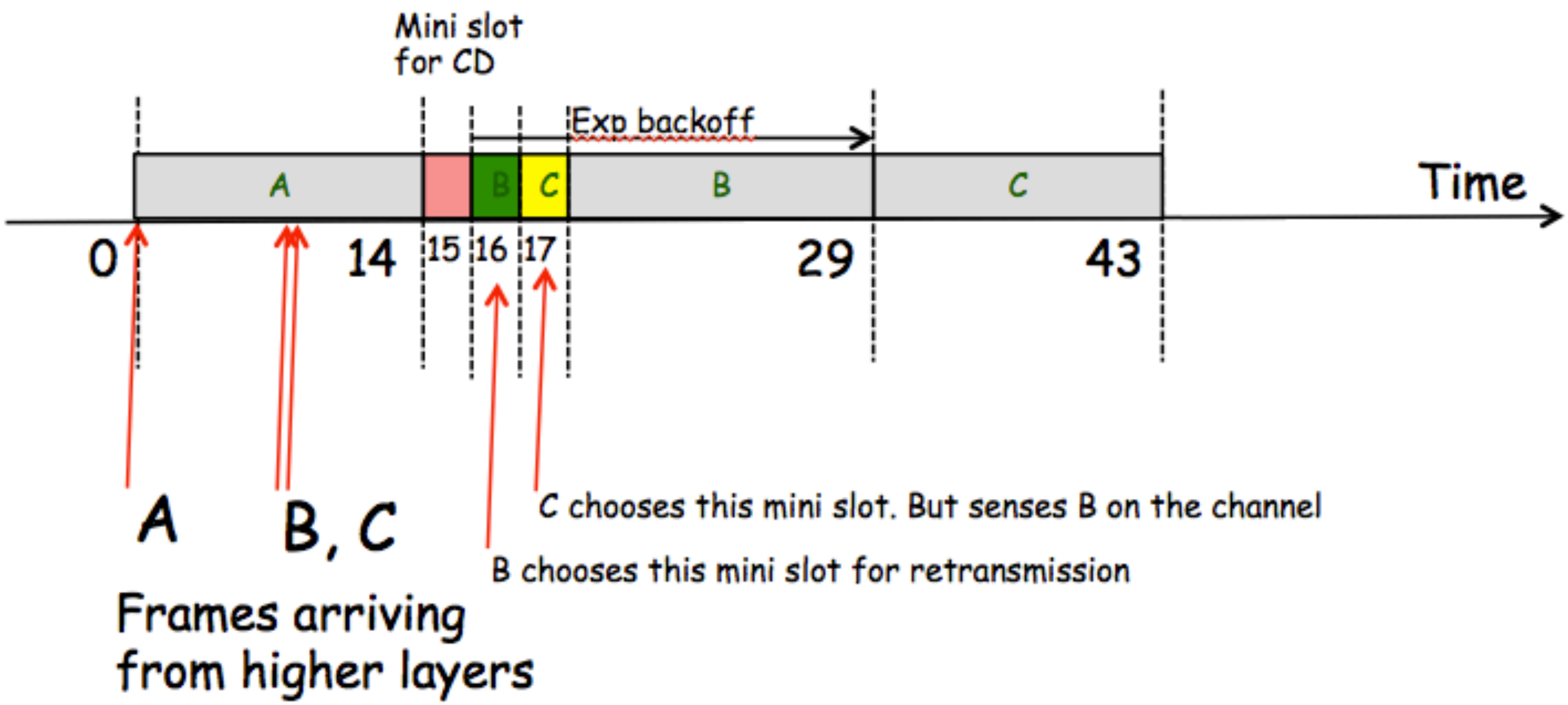
LANS, F13, Problem 2



Solution: Slotted Aloha



Solution: CSMA/CD



Example (final S12-HW6)

3. *(20 Points)* **Random Access.** 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.

   (a) 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.....

   (b) 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:

      i. maximize the efficiency of the protocol?
      ii. maximize fairness among the four stations?

   (c) Will the efficiency increase or decrease if we modify slotted aloha as follows:

      i. Get rid of slots and allow stations to transmit immediately?
      ii. Implement carrier sensing?
      iii. Implement collision detection?
      iv. Implement collision avoidance?

Slotted Aloha with 2 users

P10. Consider two nodes, A and B, that use the slotted ALOHA protocol to contend for a channel. Suppose node A has more data to transmit than node B, and node A's retransmission probability p_A is greater than node B's retransmission probability, p_B.

a. Provide a formula for node A's average throughput. What is the total efficiency of the protocol with these two nodes?

b. If $p_A = 2p_B$, is node A's average throughput twice as large as that of node B? Why or why not? If not, how can you choose p_A and p_B to make that happen?

c. In general, suppose there are N nodes, among which node A has retransmission probability $2p$ and all other nodes have retransmission probability p. Provide expressions to compute the average throughputs of node A and of any other node.

Other variants: N users same p (Pr.8), 2 users different p (Pr.10), N→∞ (Pr.8), classes of users, unslotted Aloha (Pr.9)….

Slotted Aloha with 2 users (~HW5: 4 users)

(a) *(24 Points)* **Slotted Aloha with 2 users.** Consider a slotted aloha protocol with 2 users. All frames have the same size and the slot duration is equal to the transmission time of one frame. Each user has an infinite number of frames to send. In each time slot, users 1 and 2 transmit with probability p_1 and p_2, respectively. If the transmission is successful, the frame is not considered for future transmission. If there is collision, the user detects the collision before the end of the frame and considers the frame for future transmission.

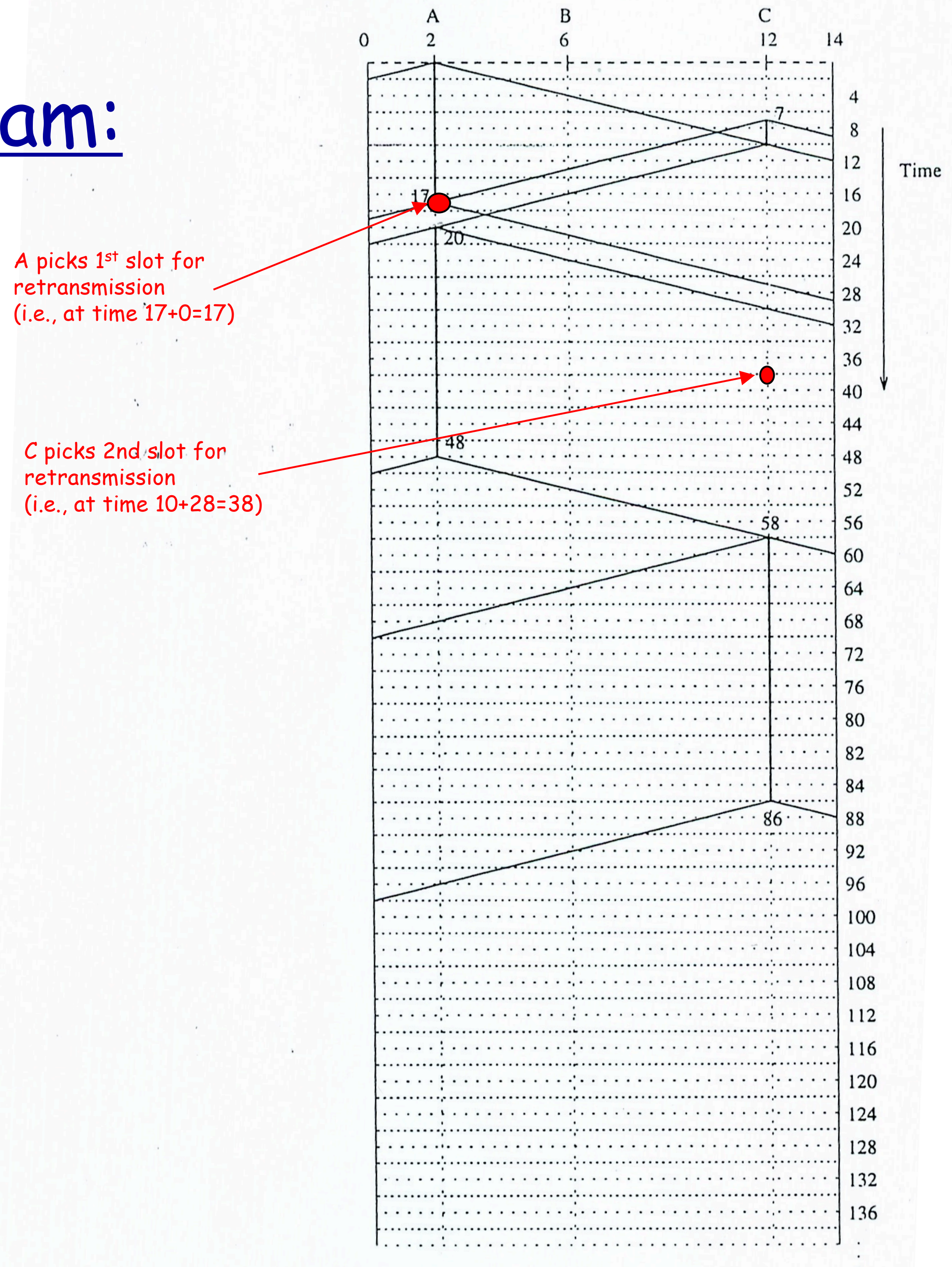
i. *(10 Points)* Compute the probability of successful transmission S_i by user $i = 1, 2$ as a function of p_1, p_2. Also compute the efficiency of the protocol S (defined as the probability that a slot leads to a successful transmission). (Throughput)

ii. *(4 Points)* It is true (take it as given without proof) that the maximum efficiency of the protocol is achieved when $p_1 + p_2 = 1$. Explain the intuition of this statement. What does $p_1 + p_2 = 1$ mean? What do $p_1 + p_2 > 1$ and $p_1 + p_2 < 1$ mean? (Max Throughput)

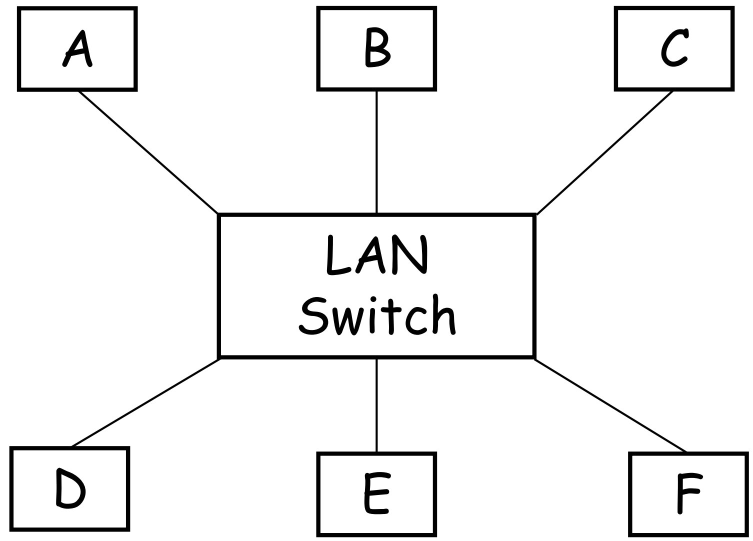
iii. *(10 Points)* Consider again the maximum efficiency case (*i.e.*, it holds that $p_1 + p_2 = 1$). Plot S_1, S_2, and S as a function of p_1. What is the best choice of p_1 and p_2 in terms of efficiency S? What is the best choice of p_1 and p_2 in terms of fairness between the two users? (Throughput vs. Fairness)

Complete the Diagram:

- The signal travels 1 unit distance in 1 unit time
- Frame=2*14=28 units
- A wants to send a frame at time =0
- C wants to send a frame at time =7
- More stations want to send
- Random numbers in [0,1] chosen by each station are given:
  - A: 0.45, 0.11, 0.71
  - C: 0.83, 0.41, 0.25
- Protocol:
  - Aloha, Slotted Aloha
  - CSMA, CSMA/CD

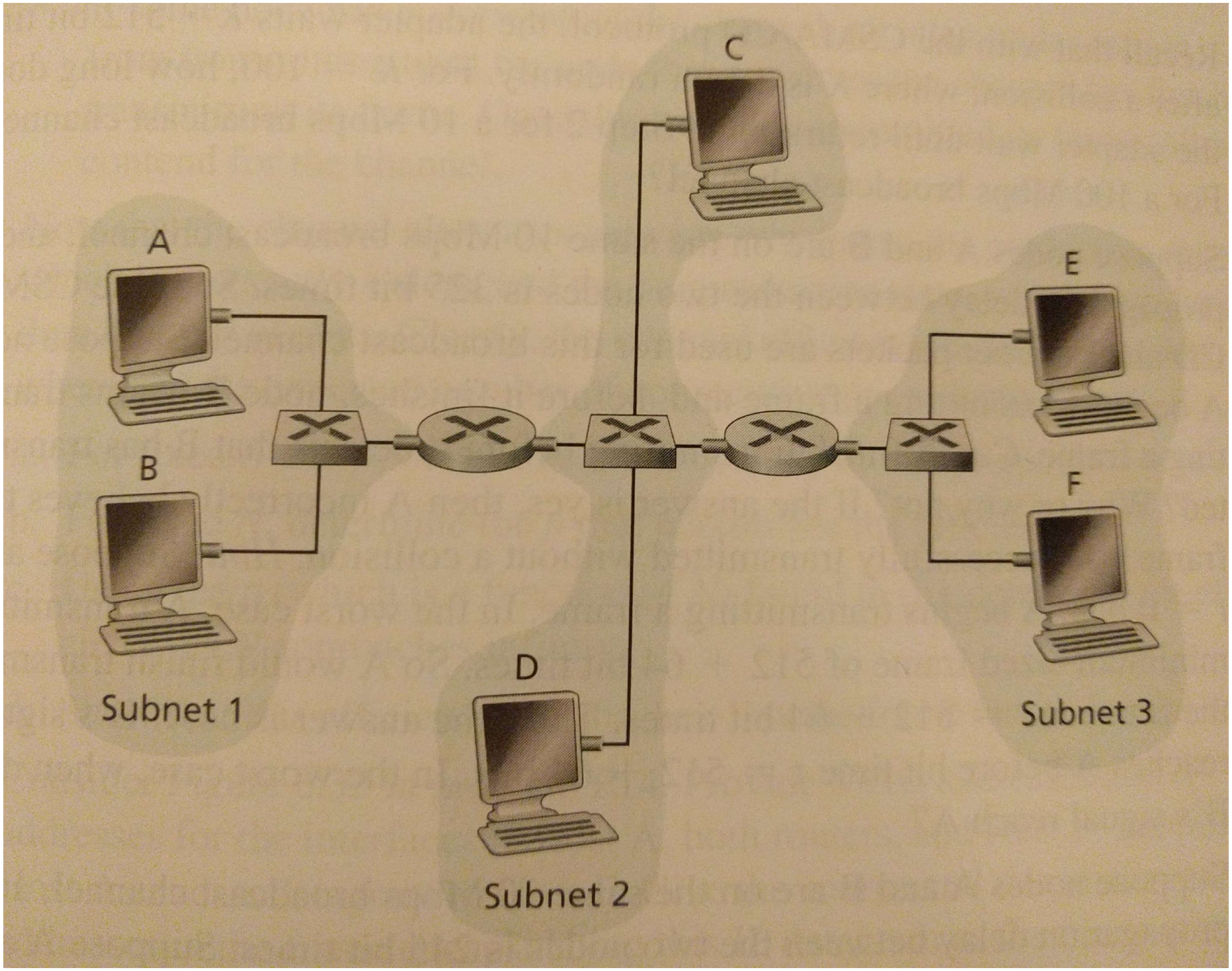


LANs, HW5, Problem 26

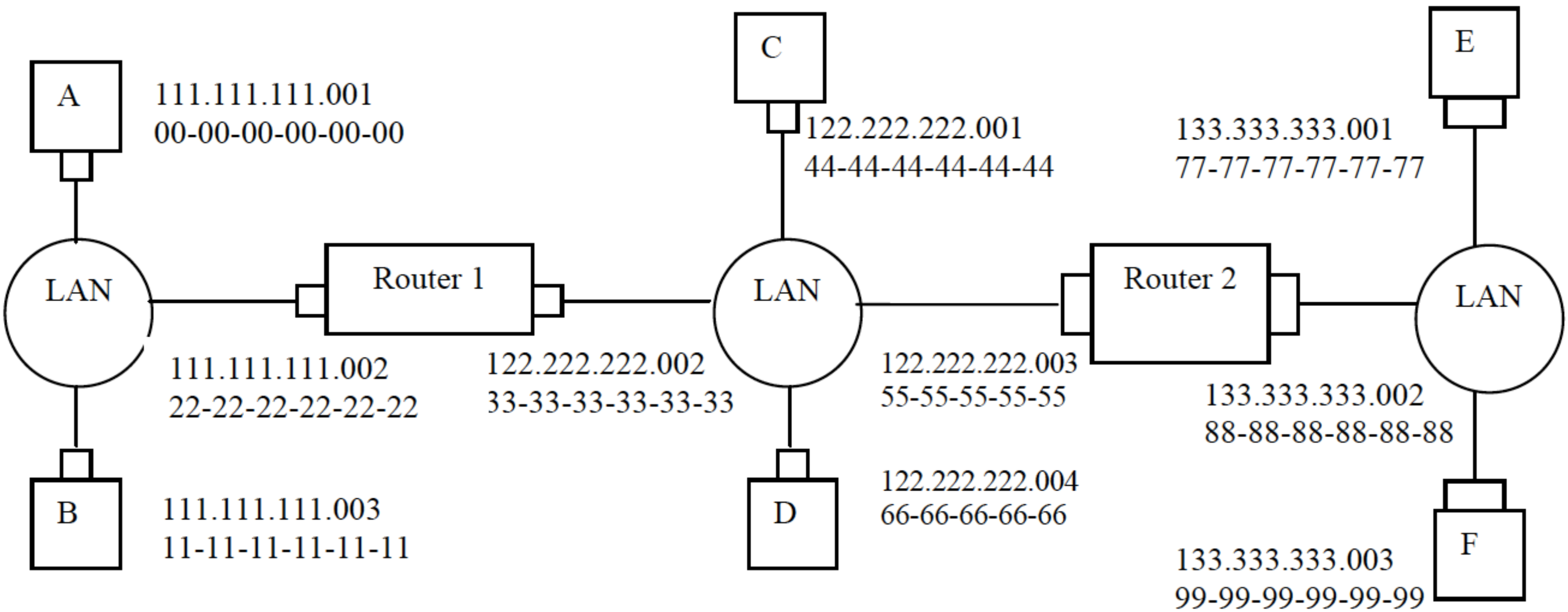


Event	Switch Table State	Frame is forwarded to these links:
B sends a frame to E		
E sends a frame to B		
A sends a frame to B		
B sends a frame to A		

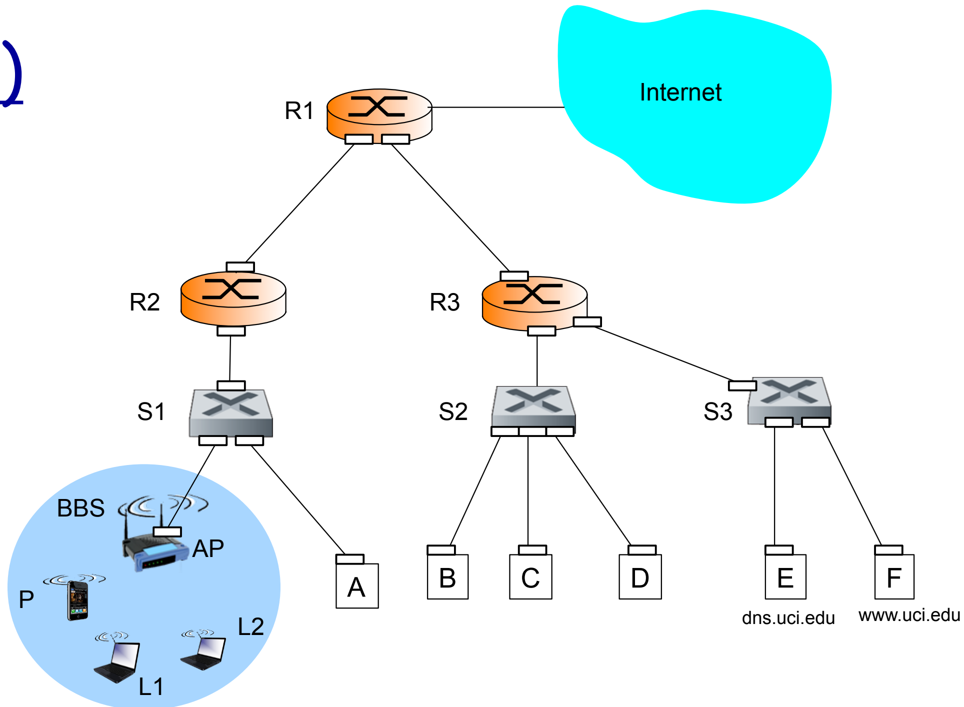
LANs, HW5, Problem 2(b)



LANs, HW5, Problem 2(a)



LANs (sample F13, Pr.3)

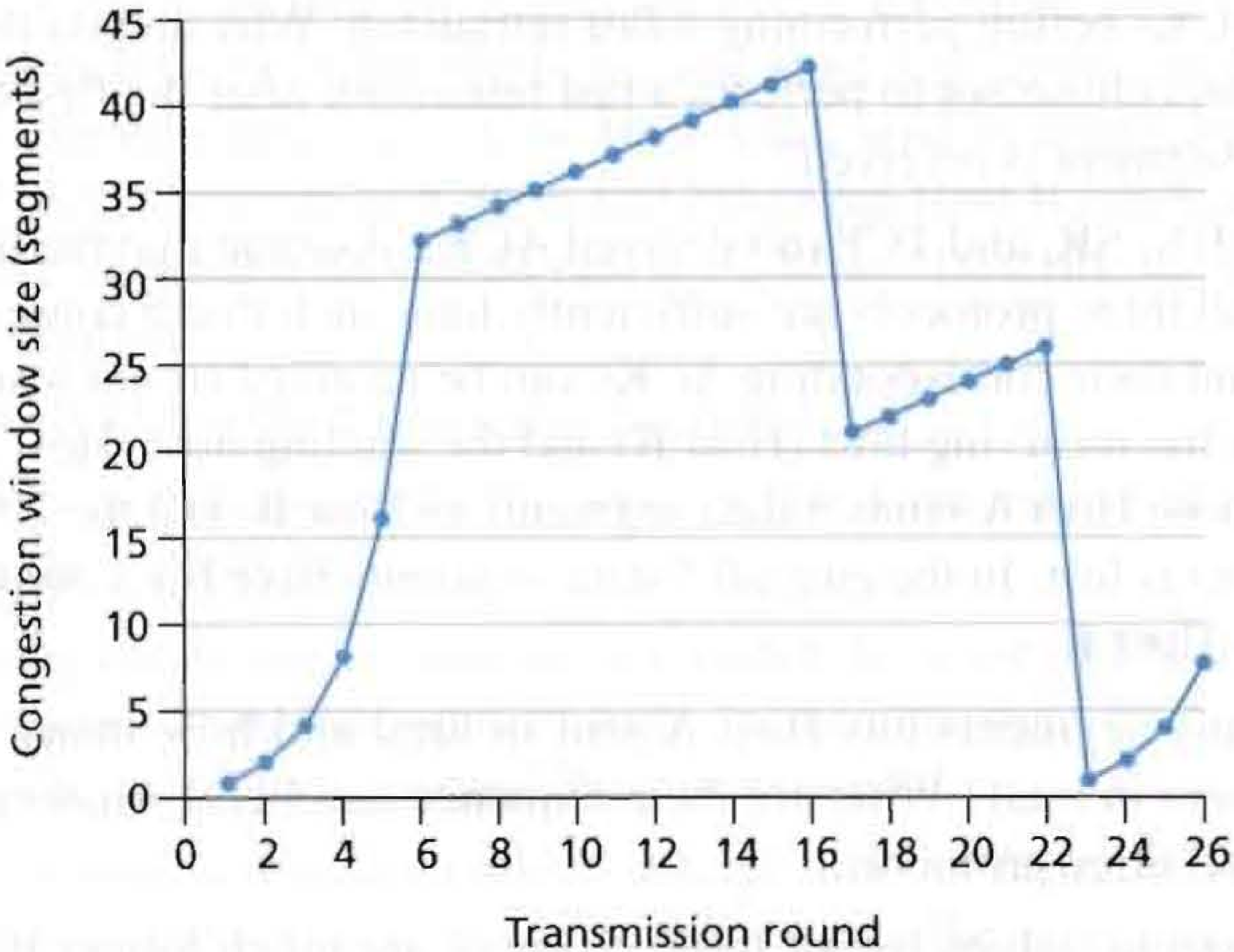


- How many subnets? Routing tables?
- What is the first thing that Laptop does when it arrives fo BSS?
- Describe MAC frames if B sends packet to D for the first time
- Describe MAC frames if B sends a packet to F for the first time
  - TCP SYN?
  - HTTP?

Review: TCP

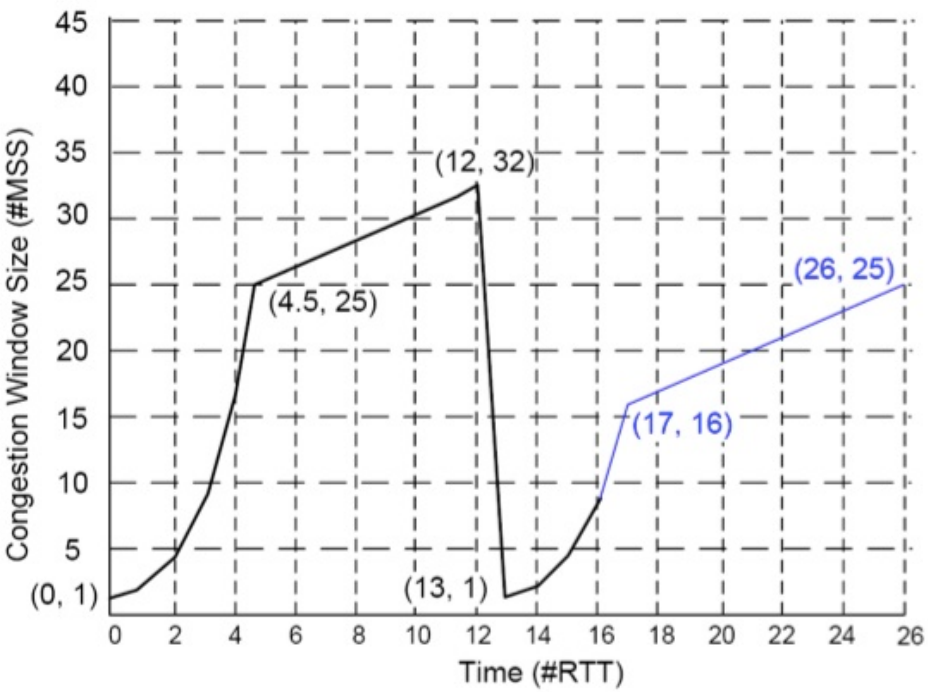
Reliability
Congestion Control

TCP Congestion Control (HW, S11)

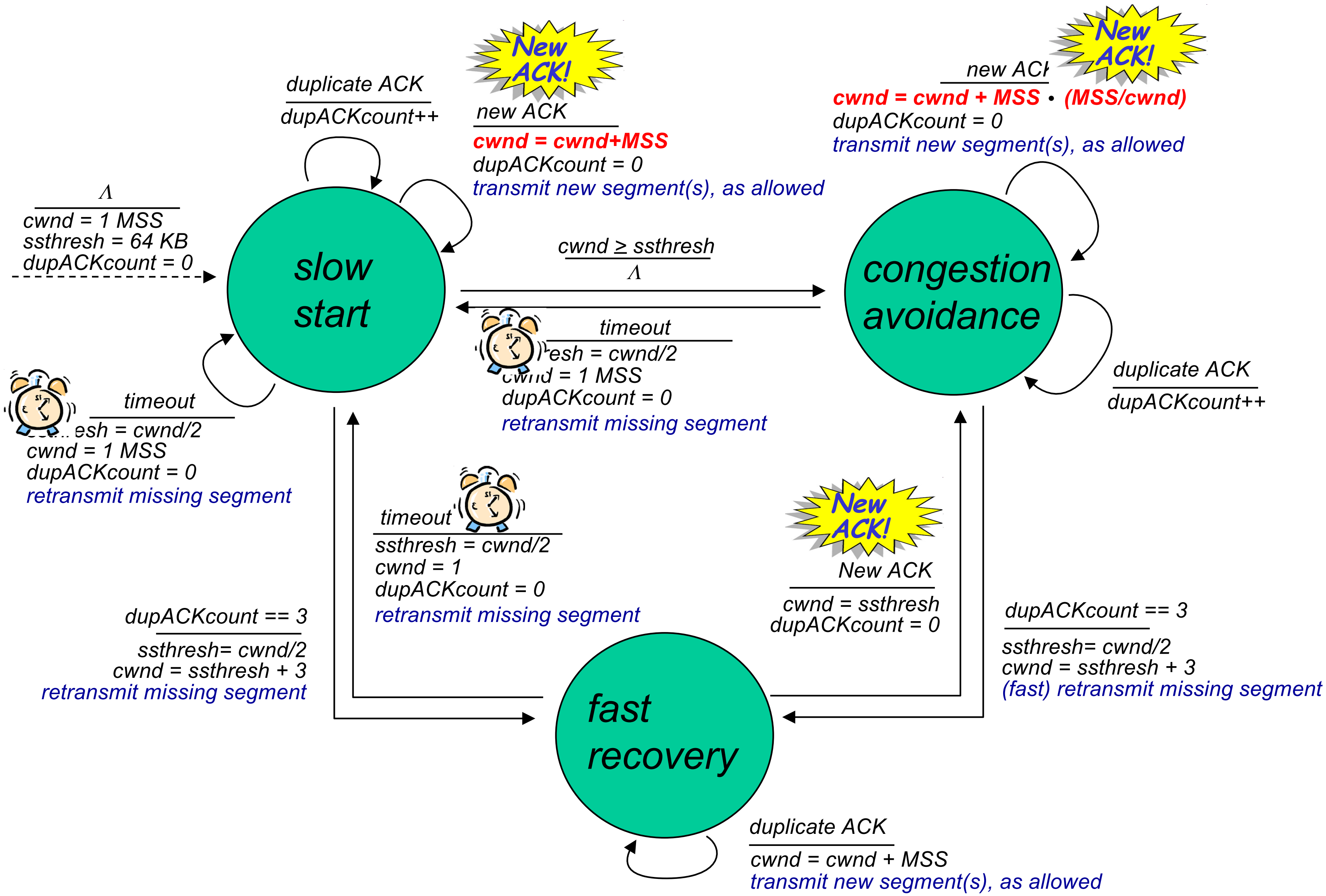


TCP Congestion Control: F13, Pr1

- Identify the intervals of time when TCP slow start is operating. What is the respective SSThres (slow start threshold) in TCP congestion control?
- (0,4.5) and (13, 16). The SSThres are 25 and 16, respectively
- Identify the interval(s) of time when TCP congestion avoidance is operating. What is the respective SSThres in TCP congestions control?
- (4,5, 12). The SSThres is 25.
- How many segments are lost from time 0 to 16?
- 1?
- Assume that no packet is lost during time 16-26. Complete the TCP congestion window curve from time 16 to 26.
- The critical information in the curve was the y-coordinate of the turning point in what you add, which is the indicator of the SSThres.



Summary: TCP Congestion Control



Compare TCP (transport layer) to Exponential Backoff (Link layer)

- Both perform distributed congestion control
  - i.e. don't know how utilized the link/network is
  - conflicting goals: throughput and fairness

- TCP increases sending rate and backs off when it experiences loss
  - Decrease depends on level of congestion

- CSMA with Exp.Backoff send at data arrival rate, until it experiences collision
  - backoff adjust to level of congestion

- Both combine Reliability and Congestion Control

Reliable Transfer

- Link-Layer vs End-to-End Retransmissions
  - Ex. Consider the multihop example (HW1, midterm) and packet switching, loss on the links
  - You can do end-to-end retransmissions using window W, or link-by-link retransmissions with same W
  - Compare the throughput
  - Compare the average delay
  - BER vs PER bs link/e2e reliability

Note: This is a question that spans Chapters 1,3,5,6.