Computer Networks (CS 453), Fall 2014
Homework 1
Instructor: V. Arun

Notes: Please show as much of your work as you can. *Whenever possible, use variable names before plugging in numerical values*. Plug in numbers only in the very last step. This way, even if you get the answer wrong, you can get partial credit if you show your approach clearly. It will help us tell you where you made a mistake. If you plug in numbers right upfront and your answer is wrong, we have little basis to give you partial credit.

In case you ignored the above as yadda-yadda, here it is once more: plugging in numbers right upfront will quite likely result in a wrong answer and little credit.

Unless otherwise stated, all sub-parts of a question have equal points. That may not necessarily imply they are equally easy or hard.

Problem 1: Quickies (26 points) *Precise-and-concise* is the mantra for quickie questions. The longer your answer, the more likely it is that you are trying to secure all bases by listing everything you know about the topic. Don't beat around the bush. A sentence or two of an answer is sufficient for these questions.

A. Give one advantage and one disadvantage of circuit-switched networks over packet-switched networks.

   Advantages: Guaranteed service, which is useful for real-time applications like voice or live video.

   Disadvantages: Reserving resources results in wastage when users are idle. The mechanisms required to reserve resources are more complex compared to packet switching.

B. Give three examples of *access networks*. State their typical speeds and whether they provide *shared* or *dedicated* access

   Cable modem is a shared access networks. Typical speeds are asymmetric ranging from 1-2Mbps for uploads and up to tens of Mbps for downloads.

   DSL is a dedicated access network. Typical speeds are asymmetric and are comparable to cable modem speeds but are typically lower.

Fiber-to-the-home (FTTH) that is shared or dedicated depending on whether the optical switching is passive or active with speeds ranging from tens of Mbps to 1Gbps.

Other examples: WiFi, Ethernet, cellular LTE, etc. Refer to the textbook.

C. Give two examples of *guided physical media* and two examples of *unguided physical media*, and state their typical speeds.

Guided: Twisted pair, co-axial cable, fiber optic cable, etc.
Unguided: WiFi, cellular, satellite, terrestrial microwave, etc.

D. List four factors that contribute to the end-to-end delay in a packet-switched network. Which of these are constant and which of these depend on the load in the network? Explain. (4)

Processing delay: A relatively small fixed delay incurred to inspect packet headers, check for error-freeness, and queue the packet in the correct queue.

Queuing delay: A variable delay incurred by a packet when it is waiting for packets queued ahead of it to be transmitted. This delay depends upon the current queue size that depends upon the load in the network.

Transmission delay: A fixed delay incurred in putting a packet on the link. If a packet is of size S (bits) and the link has bandwidth C (bits/sec), the transmission delay is S/C.

Propagation delay: A fixed delay incurred by a packet in traveling from one end of a link to the other at the speed of light. If the length of the link is D and the speed of light on that medium is V, the propagation delay is D/V.

Notes:
- Propagation delay does not depend upon either the size of the packet or the link bandwidth.

- Queuing delay is incurred only while waiting for earlier packets to be transmitted, not transmitted and propagated, i.e., the next packet can begin transmission while the previous packet is still propagating along the link.

- One could argue that processing delay depends weakly on the load in the network. Routers after all run operating systems where the delay of each operation is somewhat higher at higher loads. So if you answered that processing delay depends on the load, that is also acceptable.

E. What is the key difference between a tier-1 ISP and a tier-2 ISP?

A tier-1 ISP *provides* transit service to a tier-2 ISP that is its *customer*. A tier-2 (customer) ISP pays its provider tier-1 ISP irrespective of which direction bytes traverse (just like UMass pays its provider ISP for downloads as well as uploads).

F. Give two differences between TCP and UDP.

TCP provides reliable, in-order delivery. UDP provides neither.

TCP is connection-oriented, i.e., it requires connection setup to initiate connection state at both ends. UDP is connectionless.

TCP can be unnecessarily inefficient for traffic with real-time constraints. UDP is better suited for such traffic.

G. What is the difference between a virus, a worm, and a Trojan horse?

A virus requires user assistance to propagate and infect other machines, e.g., because of a user clicking an attachment containing malware.

A worm is truly self-propagating without user assistance.

A Trojan horse is malware that is hidden inside another program, e.g. a browser plug-in that also secretly snoops upon and sends your credit card number to a colluding remote host.

H. Suppose you would like to urgently deliver S=40 terabytes data from Boston to Los Angeles. You have available a C=100Mbps dedicated link for data transfer. Would you prefer to transmit the data via this link or instead use Fedex overnight delivery? Explain. (4)

Here, we need to check if the transmission delay is less or more than a day. The transmission delay is the size of the data divided by the link bandwidth, i.e., S/C = 40*1012*8 / (100*106) = 3.2 million seconds, which is much greater than a day or 86400 seconds. So, you would prefer Fedex overnight delivery in this case.

Problem 2 (Circuit vs. packet switching, 24 points): Consider a network with a capacity of C = 3 Mbps. Suppose that each user requires a fixed rate R=150kbps when transmitting, but each user independently transmits only 20% of the time or with probability p=0.2.

This problem is identical to the example we saw in class.

A. Using circuit switching, what is the maximum number of users that can be supported? (4)

   C/R = 20. This is because circuit switching must guarantee a bandwidth of R to each user even though the user actively transmits only 10% of the time.

B. What is the above circuit-switched network's expected *utilization*, i.e., the fraction of its resources being used on average?

   With C/R = 20 users as above, the expected utilization is simply 20% (or p). If all 20 users were active, the expected utilization would be 100%. But given that each user is independently active with probability p, the expected number of active users is pC/R. Their combined sending rate is (pC/R)*R = pC. So, the expected utilization as defined is pC/C = p.

C. For the rest of this problem, assume packet switching is used with a total of N=40 users. What is the probability the users 1, 3, and 7 are active and the rest inactive?

   For all probability problems, you must use one or more of the following three rules to justify each step. If you can not use one of these rules to justify any step, you are most likely wrong.

   P[A & B] = P[A]*P[B] if A and B are independent events.
   P[A || B] = P[A] + P[B] – P[A & B] (= P[A] + P[B] if A and B are mutually exclusive)
   P[!A] = 1 – P[A]

   Here, we need the first and the third rule. Let us define the following events:

   A1 = user 1 is active
   A2 = user 2 is inactive
   A3 = user 3 is active
   A4 = user 4 is inactive
   A5 = user 5 is inactive
   A6 = user 6 is inactive
   A7 = user 7 is active
   A8 = user 8 is inactive
   ...
   A40 = user 40 is inactive

   Note that P[A1] = PA3] = P[A7] = p and the probabilities of the other 37 events are each 1-p as given in the question.

The question asks for
P[A1 & A2 & … & A40]
= P[A1]*P[A2]*…*P[A40]
= p*(1-p)*p*(1-p)*(1-p)*(1-p)*p*(1-p)*…*(1-p)
= p^3*$(1-p)^{37}$

D. What is the probability that exactly K=20 users are active?

Here we need all three rules. Let us define the following events.

A1 = the first 20 users are active and the rest inactive
A2 = users 2 to 21 are active and the rest inactive
…
Am = the m'th combination of 20 users that are active with the rest being inactive, where *m* is the number of different ways of choosing K=20 out of N=40 users, i.e., m = C(N,K)

Similar to part B, we can compute using the first and third rules that
P[A1] = P[A2] = … = P[Am] = $p^K(1-p)^{N-K}$

This question asks us for P[A1 || A2 || … || Am]
= P[A1] + P[A2] + … + P[Am] (as all m events are mutually exclusive)
= C(N, K) $p^K(1-p)^{N-K}$

Notes (not needed to solve this problem): Note that we could apply the second rule using a simple sum only because A1,…,Am are all mutually exclusive. That is, it is not possible that A1 is true as well as A2 is true, and so on. In general the second rule is more complicated for more than two events and can be derived using just the three basic rules involving two events. For example, for three events,
P[A || B || C] = P[A] + P[B] + P[C] – P[A & B] – P[A B & C] – P[C & A] + P[A & B & C]

Similarly, for four events
P[A || B || C || D] = P[A] + P[B] + P[C] + P[D] – (P[AB] + P[BC] + P[CD] + P[DA] + PAC] + P[BD]) + (P[ABC] + P[BCD] + P[CDA] + P[ABD]) - P[ABCD]
where we have used the shorthand AB for A & B, and so on.

You can generalize this to m events as
P[A1 || A2 || … Am] = ∑P[Ai] - ∑P[Ai & Aj] + ∑P[Ai & Aj & Ak] - … + $(-1)^{m+1}$ ∑P[A1

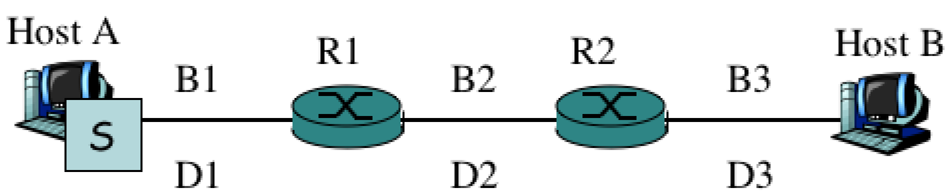
& A2 & … & Am]
where the first sum is over m terms, the second sum is over C(m,2) terms, and the r'th sum is over C(m,r) terms.

In general, it is a good idea to try to solve a probability problem by breaking it down into *independent* and *mutually exclusive* events so that you can apply the first and second rules easily to combinations of many events.

E. What is the probability that more than K users are active?

P[> K users are active] = P[exactly K+1 active] + P[exactly K+2 active] + … + P[exactly N active]
$= \sum_{i=K+1 \text{ to } N} C(N, i)\, p^i (1-p)^{N-i}$
from part C. Note that as before we could apply the second rule as a simple sum as all the events are mutually exclusive, e.g., it is not possible that exactly K+1 users are active as well as exactly K+2 users are active.

Problem 3 (Packet switching delays, 36): Consider the figure below. Suppose host A has a packet of size S=1500B to send to host B at time t=0. Let B_1=10 Mbps, B_2=20 Mbps, B_3=30Mbps be the bandwidth capacities of the three links respectively. Let D_1, D_2, and D_3 be the corresponding lengths of the three links and let V denote the speed of light. Assume that processing delays are negligible at all nodes. In the questions below, just leave the final answer in terms of the variable names, i.e., don't bother plugging in numbers at all.



A. At what time T_1 does the packet leave R_1? The packet is said to *leave* a router when it has been fully transmitted on to the next link.

T1 = transmission delay on to link 1 + propagation delay across link 1 + queuing delay at R1 + transmission delay on to link 2
= S/B1 + D1/V + 0 + S/B2

B. At what time T_2 does the packet leave R_2?

T2 = T1 + D2/V + 0 + S/B3

C. At what time T_3 does the packet reach host B?

T3 = T2 + D3/V

D. Now suppose host A has a second packet also of size S to be sent to host B and it sends the two packets back to back, i.e., it sends both at time t=0. At what time T_4 does the second packet reach R_1? Is this before or after time T_1 when the first packet left R_1? Consequently, will the second packet experience queuing at R_1 or not? (6)

The second packet will experience *queuing* at host A as it can not begin *transmission* before the first packet has completed transmission. Thus, the second packet will begin transmission at time S/B1. Thus, the second packet will reach R1 at time
T4 = queuing delay at A + transmission delay on to link 1 + propagation delay on link 1
= S/B1 + S/B1 + D1/V

We find that T4 > T1 as B2 > B1. Thus, the second packet reaches R1 after the first has left R1, i.e., the second packet experiences no queuing at R1.

E. At what time T_5 does the second packet reach R_2? Is this before or after the time T_2 when the first packet left R_2? Will the second packet experience queuing at R_2?

T5 = T4 + S/B2 + D2/V = 2S/B1 + D1/V + S/B2 + D2/V
From above, we know that T2 = S/B1 + D1/V + S/B2 + D2/V + S/B3
Thus, T5 > T2 as B1 < B2 < B3, so the second packet experiences no queuing at R2.

F. At what time T_6 does the second packet arrive at host B?

T6 = T5 + S/B3 + D3/V

G. Now suppose the link B_3 has capacity 5Mbps (instead of 30 Mbps as above). Does the second packet experience any queuing at R_2? Recalculate T5 and T2 to arrive at the answer. (6)

From above,
T2 = S/B1 + D1/V + S/B2 + D2/V + S/B3
T5 = 2S/B1 + D1/V + S/B2 + D2/V
T2 – T5 = S/B3 – S/B1 > 0
Thus, the second packet reaches R2 before the first packet leaves R2, so the second packet will experience a queuing delay equal to T5 – T2 = S/B3 – S/B1

H. For the case when B3=5 Mbps as in part F, recalculate the time T6 when the second packet arrives at host B.

T6 now changes to T5 (as calculated above) + queuing delay at R2 + transmission

delay on to link 3 + propagation delay on link 3
$= T5 + (S/B3 - S/B1) + S/B3 + D3/V$
$= 2S/B1 + D1/V + S/B2 + D2/V + (S/B3 - S/B1) + S/B3 + D3/V$
$= S/B1 + D1/V + S/B2 + D2/V + S/B3 + S/B3 + D3/V$

Problem 4 (File and packetization delays, 14 points): Suppose host A and host B are separated by D=2000 Kms and are connected by a direct link of R=2 Mbps. Suppose the propagation speed over the link is C=2.5x10^8 m/s.

A. Consider sending a file of size S=800,000 bits from host A to host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits on the link at any time? Note: this value is also called the bandwidth-delay product. (4)

   The maximum number of bits is equal to RD/C, i.e., the bandwidth (R) times the propagation delay D/C. The justification for the answer is that the first bit takes D/C time to propagate along the link to the other end. The number of bits that can be put on the link during this time at a rate R is equal to D/C times R.

B. Now suppose the file is chopped up into packets each of which is of size L=1500B. Suppose the sizes of the link layer, network layer, and transport layer headers are each H=20B long. Assume that the packets are sent back-to-back and no packets are lost. At what time is the transfer complete? (4)

   The size of the packet along with the headers is L+3H. The total number of packets is equal to S/L and the total size of all packets is S/L*(L+3H) = S(1+3H/L). Thus, the total transmission time, i.e., the time to put all of the data in the file along with the headers on the link, is equal to S(1+3H/L)/R.

   If you interpreted L as including the headers of size 3H, that is also acceptable. In this case, the number of packets is S/(L-3H) and each packet is of size L. So the total transmission time is S/(L-3H)*L/R.

Now suppose that host A must send a packet and wait for an acknowledgment before it can send the next packet. Assume that the transmission time of the acknowledgment (but not the propagation time) is negligible. How long does it take to transfer the entire file? (6)

   Assuming the first interpretation above, the number of packets is S/L. The time corresponding to each packet is the transmission time plus the round-trip propagation time, which is L/R + 2D/C. Thus, the total time to transfer the entire file is S/L*(L/R+2D/C).

   Note that while computing numerical values, you should remember to convert all values to standard units. For example, L/R = 1500*8/(2*10^6) seconds. Similarly, D/C = 2000*10^3/(2.5*10^8) seconds. It would be *incorrect* to compute L/R+2D/C as 1500/2 + 2*2000/(2.5*10^8).

Common mistakes overall:

- Not using variable names and getting muddled up in wrong numerical calculations. Read the “Note” at the top of the homework. *Use variable names before plugging in numerical values*. For example, if in 2A, you said the answer is 7, then you would have gotten 0 partial credit. But if you said the answer is C/R = 5, then I gave full credit even though the numerical value of the answer is wrong because I could see that you understood the underlying concept. In general, the numerical value of the answer will carry at most 10% of the credit, so make that the very last step of your solution.
- Not understanding how queuing delay works. Some people incorrectly assumed that, in Problem 3, the second packet will not begin transmission until the first packet is transmitted and propagated to the other end. The second packet can begin transmission while the first is propagating. Re-read the examples in Chapter 1 to understand how the four kinds of delays occur.
- Incorrectly computing probabilities in Problem 2 by some ad hoc combination of multiplying and adding probabilities. Revisit the three basic probability rules introduced in class and listed and exemplified above. If you can not justify your answer using one or more of the these three rules, then you are most likely wrong.