

>>> SOLUTION <<<

Welcome to Exam #1 in Computer Networks (CIS 6930). You have 75 minutes. Read each problem carefully. There are eight required problems (each worth 12.5 points). You may have with you a calculator, pencils, eraser, blank paper, lucky rabbit's foot, and one 8.5 x 11 inch "formula sheet". On this formula sheet you may have anything you want (definitions, formulas, etc.) as written, typed, or drawn by you. Photocopies or scans are not allowed on this sheet. Please submit your formula sheet with your exam. Please start each numbered problem on a new sheet of paper and do not write on the back of the sheets (I do not care about saving paper!). Submit everything in problem order. No sharing of calculators. Good luck and be sure to show your work.

Problem #1

Answer the following general questions regarding research in the area of networks.

a) Give the names of four conferences in which networking research results are presented.

IEEE INFOCOM, IEEE GLOBECOM, IEEE LCN, ACM SIGCOMM

b) Give the names of two journals in which networking research results are published.

IEEE/ACM Transactions on Networking, IEEE Journal on Selected Areas in Communications

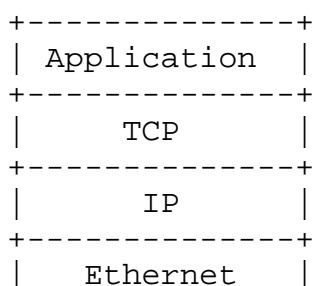
c) Give the names of four individuals who have made significant research contributions in the area of networks. Very briefly state their contributions. I am *not* one of the four names.

Leonard Kleinrock - invented packet switching, applied queueing theory to network performance modeling  
Raj Jain - First work in traffic modeling showing the traffic is not Poisson  
Robert Metcalfe - Invented Ethernet  
Will Leland - First person to identify self-similarity in network traffic

Problem #2

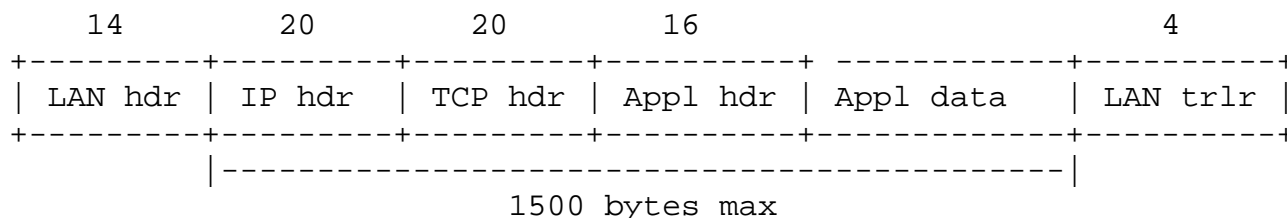
Consider a 4-layer protocol implementation with application, TCP, IP, and Ethernet layers in that order (top to bottom). Each layer requires a header except the Ethernet layer, which requires a header and trailer. The application header is 16 bytes in length, TCP header 20 bytes, IP header 20 bytes, and let the Ethernet header be 14 bytes, and the trailer 4 bytes (ignore the preamble and gap). Answer the following questions:

a) Sketch and label the layered protocol model (do so in the same fashion that we sketched the OSI model).



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b) Sketch a packet for this system carefully showing and labeling all fields.



c) Assume a maximum data field for an Ethernet frame of 1500 bytes. What is the overhead (in %) for a 4096-byte application message? Hint: the message must be segmented into multiple frames and be careful of how you consider the data field in the Ethernet frame.

The LAN data field includes 56 bytes of IP, TCP, and Appl headers leaving 1444 bytes for Appl data. A 4096 byte message segments into 3 frames with 1444 bytes payload, 1444 bytes payload, and 1208 bytes payload. Thus, we have  $3 * (14 + 20 + 20 + 16 + 4)$  bytes of overhead to transport 4096 bytes, or  $222 / (4096 + 222) = 5.1\%$  overhead.

### Problem #3

Answer the following questions regarding circuit and packet switching.

a) Describe circuit switching.

Circuit switching entails a dedicated (non-shared) path between a sender and a receiver. Circuit switching requires circuit establishment, data transfer, and disconnect.

b) Describe the two “flavors” (or fundamental methods) of packet switching.

The two flavors of packet switching are datagram and virtual circuit. In datagram PS each packet is handled independently by the network (and packets may arrive out of order). In virtual circuit PS a path is established before data transfer and all packets in a session take the same path.

c) Describe the overheads present in packet switching and in circuit switching.

In packet switching there are overhead bits in all packets (headers and trailers) needed for protocol communication. In circuit switching, the overhead is in the time to establish a circuit and tear it down before and after data transfer.

d) In the context of circuit switching, what is “blocking”?

A blocking switching may deny connections due to resource limitation. That is, two idle connected stations may not be able to communicate due to lack of resources in a switch caused by other connections.

**Problem #4**

Answer the following questions regarding fundamental queueing theory.

- a) Define “stable” in terms of a queueing system. Be precise. What is the mean queue length for an unstable queueing system?

Let  $\lambda$  be the arrival rate and  $\mu$  be the service rate. Then, for system to be stable,  $\lambda \leq \mu$  must hold.

- b) Assume a stable queueing system with a known service rate. Given the arrival rate of customers and the mean number of customers in the system, how can the mean system waiting time be found? How can the mean queue waiting time be found? Be precise.

We can use Little’s Law.  $W = L / \lambda$ . Then,  $W_q = W - (1 / \mu)$

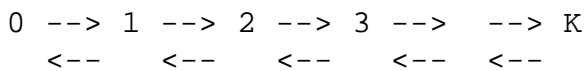
- c) At 95% utilization what is the relative ordering of mean queue lengths for an M/M/1, D/D/1, and M/D/1? State which system will have the longest, shortest, and “in between” queue length and explain your answer.

The ordering (longest to shortest) is M/M/1, M/D/1, and D/D/1. This is due to the amount of variability in the arrival and service processes (with M/M/1 have the greatest amount and D/D/1 having no variability). Queue length is largely a function of variability.

**Problem #5**

Set-up the derivation for L (mean number of customers in the system) for an M/M/1/K queueing system. Hint: Start with the Markov chain. Extra credit (10 pts) for completing the derivation.

The Markov chain looks like this...



with left-to-right transition rate being the arrival rate  $\lambda$  and the right-to-left transition rate being the service rate  $\mu$ .

Then,

$$\pi_0 = \frac{1}{\sum_{n=0}^k \rho^n} \tag{1}$$

where  $\rho = \frac{\lambda}{\mu}$  (arrival rate divided by service rate) and,

$$\pi_0 = \frac{\rho - 1}{\rho^{k+1} - 1} \tag{2}$$

So,

$$L = \sum_{n=0}^k n \cdot \left[ \frac{\rho - 1}{\rho^{k+1} - 1} \right] \cdot \rho^n \quad (3)$$

It is "OK" to put (1) in (3) if cannot solve for (2) from (1).

### **Problem #6**

Answer the following questions regarding the Poisson process.

a) What is the distribution for interarrival times in a Poisson process? Prove it.

The distribution for interarrival times is exponential. The probability function for the Poisson distribution is,

$$f(x) = \Pr[X = x] = \left( \frac{(\lambda t)^x}{x!} \right) e^{-\lambda t} \quad (1)$$

where,  $\lambda$  is the mean rate of arrivals and  $t$  is a period of time. Defining  $T$  as the time of an event (a random variable), we have (by definition),

$$F(t) = \Pr[T \leq t]. \quad (2)$$

This is equal to,

$$F(t) = \Pr[T \leq t] = 1 - \Pr[T > t] \quad (3)$$

where,

$$\Pr[T > t] = \Pr[\text{zero events occur in time } 0 \text{ to } t] = \Pr[X = 0] = \left( \frac{(\lambda t)^0}{0!} \right) e^{-\lambda t} = e^{-\lambda t} \quad (4)$$

Now, we plug in our result for  $\Pr[T > t]$  into our equation (3) and we get,

$$F(t) = 1 - e^{-\lambda t} \quad (5)$$

b) What are some of the properties of a Poisson process? How are these properties of significance to us?

Merging of Poisson streams results in a Poisson stream. Equally, probabilistic splitting of a single Poisson stream results in multiple Poisson streams. These properties are of significance in how they simplify modeling of computer networks. Without these properties it would be very difficult to model merging and splitting of traffic streams.

### **Problem #7**

Answer the following questions regarding traffic characterization and self-similar processes.

a) What is an invariant? Why search for invariants?

An invariant is an observation that applies across multiple data sets taken from different systems or configurations. Invariants represent universal truths and are useful to know because they enable common design points for systems that may serve different and diverse user groups.

b) Precisely and formally define Long Range Dependence (LRD).

An LRD process has a non-summable (i.e. infinite) autocorrelation. That is, sum all of the autocorrelations for lag 1 through infinity. For an SRD process this sum will be finite.

c) Why is it significant if network traffic is self-similar?

A self-similar time series "looks the same" across multiple time scales. This means that burstiness, if present at a short time scale, will also be present at a long time scale. The significance of self-similarity is that merged traffic streams (i.e., an increase in time scale) would not tend to a smoothed Poisson process, but would maintain the component burstiness of the individual streams. Thus, using a Poisson model for capacity planning (e.g., to bound packet loss to a certain percentage) would result in LESS THAN SUFFICIENT capacity being provisioned.

d) Why is self-similarity intrinsically difficult to "believe in"?

It is intuitively difficult to understand how events separated by large time periods (e.g., 100's of seconds for packet interarrival times and 100's of years for Nile river floods) can be correlated. Certainly, near term events can be (intuitively) understood to be correlated (for example, a short burst of packets will likely all be for the same destination and with similar interarrival time if they comprise a file being transferred).

### **Problem #8**

Answer the following questions regarding multiple access networks.

a) Assume that signal propagation is 1 foot per nanosecond. Given a 10-mile span (there are 5280 feet in a mile) between two stations and a data rate of 1-Mbps, what is the minimum frame size for CSMA/CD to work? You may assume that no repeaters are needed. Is CSMA/CD a viable protocol for this use?

$$T_{pr} = 5280 \text{ ft/mi} * 10 \text{ mi} * 1e-9 \text{ sec/ft} = 52.8 \text{ microseconds}$$

So, a slot time is 105.6 microseconds

At 1-Mbps a bit is 1 microsecond, so the minimum frame size is 105.6 bits, or about 14 bytes. Thus, CSMA/CD is viable for this application.

b) Explain how a simple ALOHA system works and explain what improvement can be made to increase the throughput. Carefully explain why the throughput increases for your proposed improvement.

In simple ALOHA a stations transmits at will. This results in a vulnerable period of two frame times for a collision. By adding slots the vulnerable period is reduced to one frame time and this then doubles the achievable throughput.

c) Show that to maximize throughput in a CSMA/CD system the probability of a station transmitting on a given transmission opportunity should be  $1/N$  (for  $N$  stations with queued frames). Make reasonable assumptions.

Given  $N$  independent stations and probability  $P$  of a station transmitting, we wish to compute and maximize the probability,  $A$ , of only one station transmitting on a given transmission opportunity. This is a binomial probability,

$$A = \binom{N}{1} P^1 \cdot (1-P)^{N-1} = N \cdot P \cdot (1-P)^{N-1}$$

Then from,

$$0 = \frac{d}{dP} (N \cdot P \cdot (1-P)^{N-1})$$

We find that  $P = 1/N$ .

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