CS 536 (Park) **Final** **Dec. 10 (Tue.), 1996**

PROBLEM 1

(a) What is a subnet mask and how is it used in routing? Show a typical routing table configuration (what columns/rows) where subnetting is implemented.

(b) ARQ and forward error correction (FEC) are two fundamental mechanisms for achieving reliable transport over a "noisy" channel. What is the main advantage of FEC vis-a-vis ARQ and what are its two disadvantages?

(c) What are the pros/cons of using link-based congestion control vis-a-vis end-to-end congestion control? Which might be better suited to ATM networks and why?

(d) What is traffic shaping and why is it beneficial to use in computer networks? For what type of traffic is traffic shaping maximally applicable and for what traffic is it minimally suited? Justify your answer.

(e) Assume you are given a transmission medium of bandwidth X Hz. Using a combination of FDM and TDM, sketch a MAC/coding design which achieves full duplex transmission capable of supporting A users "simultaneously" in each direction. Assume each user needs to receive a data rate of Y bps.

PROBLEM 2

(a) Give the reasons why fragmentation is needed in both IP and ATM networks. What are the *generic* algorithmic components needed for achieving the fragmentation task correctly? In what sense can one claim that application packet loss rate is adversely affected by each additional fragmentation process applied at lower layers of the protocol stack?

(b) Let $(X_t)_{t\in\mathbb{R}_+}$ be a Poisson process with rate λ ($\mathbb{R}_+$ represents the set of nonnegative reals) where $X_t \in \mathbb{Z}_+$ for all t. In the packet queueing framework, what are the interpretations or meanings of X_t, $X_{t+T} - X_t$ ($T > 0$)? Define precisely the interarrival process corresponding to X_t (including mean interarrival time etc.). Knowing that $\Pr\{X_t = 0\} = e^{-\lambda t}$, derive the probability density function of the interarrival process from first principles. (*Hint: Remember that the probability density function of a random variable can be obtained by differentiating its distribution function.*)

(c) What are the important traffic classes identified in the ATM network framework and their examples? In what layer(s) of the ATM protocol stack are they to be implemented? Which layer corresponds to IP-based best-effort service? Which traffic classes are least amenable to traffic shaping?

(d) Describe the Slow Start feature of TCP. In what sense is "slow start" a misnomer and in what sense is it an apt description of the algorithm at hand?

(e) Explain the role of VCI and VPI and why the latter came about; what optimization is it trying to affect? Give scenarios in which VPI is least effective and in which it is most effective. What further optimization tricks are possible?

PROBLEM 3

(a) Give a pseudo-code description of an implementation of weighted fair queueing within the ATM framework (i.e., fixed-size packets called cells) with k service (priority) classes with priority weights $\alpha_1 > \alpha_2 > \cdots > \alpha_k > 0$ where $\sum_{i=1}^{k} \alpha_i = 1$. Indicate the packet format (only the relevant information fields to the task at hand) and show how cells are to be enqueued and dequeued, and using what data structures. In what sense is your implementation only an approximation to "true" weighted fair queueing?

(b) Draw the state-transition diagram of a generic congestion control algorithm with four states *underutilized*, *slightly underutilized*, *optimal*, and *overutilized*. On the arcs (or edges), indicate the control action (w.r.t. the mean arrival rate λ) that needs to be taken. Should there be a (direct) transition from *overutilized* to *underutilized* or *slightly underutilized*? Justify your answer. Explain reactive congestion control and proactive congestion control within this framework. Why are reactive schemes considered very "costly" in today's high-bandwidth networks?

(c) Describe the leaky bucket traffic shaping/policing algorithm. What is the token bucket algorithm and in what

sense is it an enhancement of leaky bucket, being more responsive? What are the limitations of traffic shaping algorithms in data networks including ATM? Explain the abstract model of video on demand (VOD) and why traffic shaping can still be effective for such pseudo-real-time traffic.

(d) Explain the difference between system optimal routing vs. user optimal (greedy) routing. What quantity (be precise) is being minimized in Gallager's routing model? Why is it difficult to implement system optimal routing in modern (e.g., ATM) networks? Estimate the total message overhead (in big-O complexity notation) incurred by Bellman-Ford (distance vector) and Dijkstra's (link state) algorithm, respectively. If an efficient broadcasting mechanism is available, which algorithm—other things being equal—should one use?

PROBLEM 4

(a) Assume you are given a congestion-susceptible network given by a unimodal load-throughput function $\mu = \mu(Q)$ where $\mu(Q)$ achieves maximum at the point (Q^*, μ^*). Let the system be described by the following two differential equations, representing the conservation of flow and a control law, respectively:

$$dQ/dt = \lambda - \mu \quad (1)$$

$$d\lambda/dt = \epsilon(Q^* - Q) \quad (2)$$

Give the intuitive meaning of (1) and (2). Is the optimal operating point (Q^*, μ^*) a fixed point (i.e., stays still in the absence of perturbation) of the system? Explain. Draw the vector field or phase portrait for the two-dimensional system; first, explain how this is done. From your drawing, what can you conclude about the stability of (Q^*, μ^*)? What is the relation between the *linear increase/exponential decrease* heuristic to your conclusion at hand? Construct an *asymmetric control law* of the form "if $Q \leq Q^*$ then do this" and "if $Q > Q^*$ then do that" which possesses better stability properties. On what property of the $\mu(Q)$ function does the success of the "if $Q > Q^*$ then do that"-part of the control depend?

(b) Draw the state transition diagram (birth-death process) of an M/M/1 queue with arrival rate λ and service rate μ. Let $X_n(t)$ denote the *probability* that there are n packets in the queue at time t. Let $p_{n,m}(\Delta t)$ denote the *fixed* transition probabilities of going from n packets in the queue to m packets in the queue in a time interval of Δt. Derive, from first principles, the recursive equations for $X_n(t + \Delta t)$ and $X_0(t + \Delta t)$. Explain the process.

The following set of differential equations is obtained via an intermediate step and taking $\Delta t \to 0$:

$$dX_n(t)/dt = -(\lambda + \mu)X_n(t) + \lambda X_{n-1}(t) + \mu X_{n+1}(t) \quad (3)$$

$$dX_0(t)/dt = -\lambda X_0(t) + \mu X_1(t) \quad (4)$$

Describe, in words, what this intermediate step is. What is equilibrium analysis and how is it used to solve (3) and (4)? Explain the underlying justification behind it. From a technical stand point, where in the final solution procedure is the assumption $\lambda < \mu$ needed? What happens if $\lambda \geq \mu$? What is the intuitive interpretation thereof?

(c) Explain, in your own words, what you consider to be the most pressing network research problems in the modern, high-speed network environment. Justify your selection and reasoning and suggest possible approaches to solution.