ETSN01 Exam

August 23rd 2017
8am–1pm

Instructions

- Clearly label each page you hand in with your name or identifier and the page number in the bottom right hand corner.
- Materials allowed: calculator, writing material. No other material or notes are allowed in the examination hall. If your calculator is programmable, the memory must be erased prior to the exam.
- Your answers must be given in clear, legible handwriting. If an answer is not able to be read, it will not be marked.
- All questions should be answered in the booklets provided.
- The exam contains 9 questions and is 9 pages long. It is out of a total of 100 marks.

Part A: Short answer questions (30 marks)

Question 1 (30 marks)

(a) (2 marks) What is the difference between a probability distribution function (PDF) and a cumulative distribution function (CDF)?

(b) (3 marks) Give examples of pairs of random variables that are

  (a) Correlated and dependent
  (b) Uncorrelated but dependent
  (c) Uncorrelated and independent

(c) (3 marks) Explain the role of each of the following layers in the networking stack.

  (a) Application layer
  (b) Transport layer
  (c) Physical layer

(d) (2 marks) What is the main advantage and disadvantage of using reservation schemes for medium access control, compared with random access schemes?

(e) (2 marks) What is meant by saying the subcarriers in OFDM are orthogonal?

(f) (2 marks) Explain what is meant by a collision in a random-access wireless network.

(g) (2 marks) When using CSMA, why does the utilisation drop as the propagation delay increases?

(h) (2 marks) What does it mean for an arrival process to be Markovian (memoryless)?

(i) (2 marks) Why is the steady-state solution for a queueing system with an infinite buffer only valid for $\rho < 1$?

(j) (2 marks) Why is the unit disc model of radio transmission unrealistic?

(k) (2 marks) What is the main difference in the core network architecture between LTE and UMTS?

(l) (2 marks) What is the difference between a simulation and any other type of model?

(m) (2 marks) What is the benefit of using an adaptive retransmission timeout (RTO) for TCP congestion control?

(n) (2 marks) Why is exponential averaging used to calculate the RTO instead of weighting each observation equally?

Part B: Long answer questions (70 marks)

Question 2 (6 marks)

We have a transmitter T and a receiver R, that communicate over a noisy channel; they can only exchange two symbols $\{0, 1\}$, i.e. it is a binary channel; you know from previous measurements that a symbol is accurately detected 75% of the time (i.e. if you transmit a 1, it will be correctely detected as a 1 75% of the time, the same for a 0); you also know that only 40% of the messages are transmitted as 1. What is the probability that having received a 1, the symbol is correct?

Question 3 (6 marks)

Check whether these CDMA chip codes are mutually orthogonal:

(a) (3 marks)

(i) 1 1 1 1 1 1

(ii) 1 -1 1 -1 -1 1

(iii) 1 -1 -1 1 -1 -1

(b) (3 marks)

(i) 1 1 1 1 1 1 1 1

(ii) 1 -1 1 1 -1 -1 1 -1

Question 4 (6 marks)

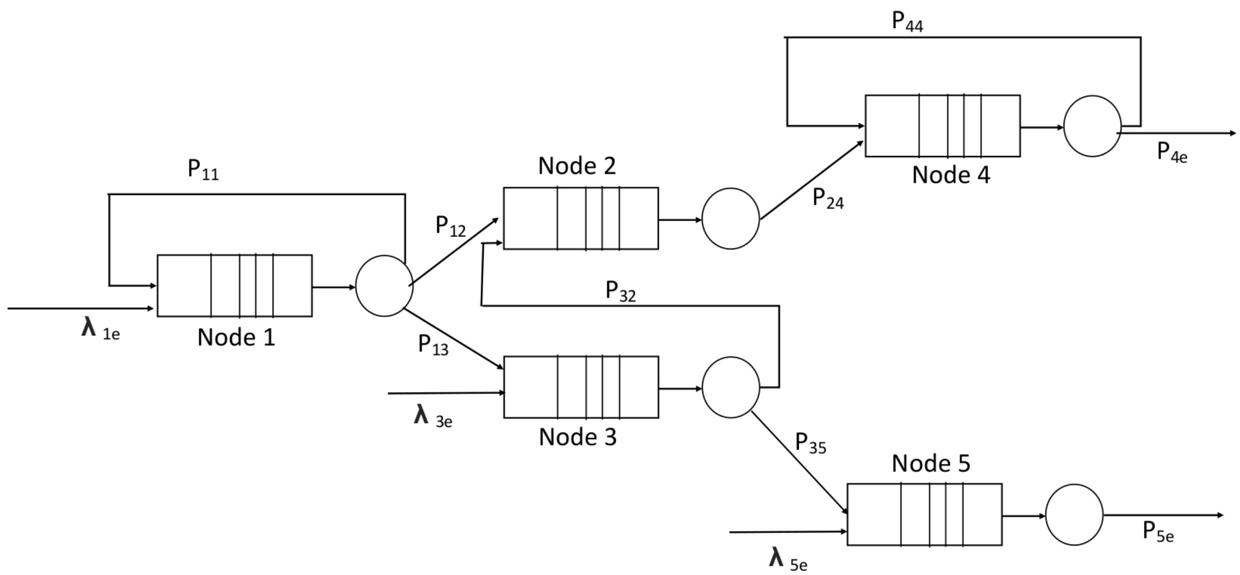
For TCP congestion control, the round trip time can be estimated using smoothed round trip time (SRTT). Choose $\alpha = 0.8$ and SRTT(0) = 2 seconds, and assume all measured RTT values = 0.5 seconds and no packet loss. What is SRTT(9)?

Question 5 (8 marks)

A disadvantage of a broadcast network is the capacity wasted when multiple hosts attempt to access the channel simultaneously. Consider the following example, suppose time is divided into discrete slots with each of n hosts attempting to access the channel with a probability p during each slot. What fraction of slots will be wasted due to collisions?

Question 6 (10 marks)

Given the network of M/M/1 queues shown in the diagram, and the external arrival rates and transition probabilities listed, determine the total arrival rate for each node in the network.



External arrival rates:
$\lambda_{1e} = 5$ packets/s
$\lambda_{3e} = 3$ packets/s
$\lambda_{5e} = 7$ packets/s

Transition probabilities:
$P_{11} = 0.1$
$P_{12} = 0.6$
$P_{13} = 0.3$
$P_{24} = 1.0$
$P_{32} = 0.6$
$P_{35} = 0.4$
$P_{44} = 0.2$
$P_{4e} = 0.8$
$P_{5e} = 1.0$

Question 7 (10 marks)

(a) (3 marks) Consider a Reservation ALOHA system with N nodes. Assume a Poissonian packet generation process for each node with parameter λ. The round length is T_s seconds; that is, every T_s seconds contains a reservation phase and a data transmission phase. Each data transmission phase contains k timeslots. What is the probability that a given node will have at least one packet to send in the second round? You can assume that all nodes begin the first round with no packets queued to send.

(b) (3 marks) What is the expected number of nodes with at least one packet to send in the second round?

(c) (4 marks) Each node that wishes to transmit selects a slot to reserve at random (with a uniform distribution), and each node may only send one packet per round, even if it has more packets queued to send. For N = 3, what is the probability of a collision in the reservation phase of the second round?

Question 8 (10 marks)

(a) (6 marks) You are designing a network to help emergency workers rescue people caught in avalanches in the mountains. The network consists of a number of autnomous drones that fly around the avalanche area and track rescue workers as well as take images and video of the terrain. The drones move constantly and are often streaming video, so they send a large amount of data. Rescue workers can trigger an alarm message when they find someone to rescue. Alarm messages should be transmitted quickly and reliably throughout the network, whereas video data can tolerate a relatively high level of packet loss.

How would you design the network (i.e. what protocols, queueing disciplines, or other operating parameters would you recommend)?

(b) (4 marks) Suppose that instead of using drones for the network, the nodes are instead beacons that can be placed by the rescue workers. Once placed, a beacon will typically remain there for some time (at least 30 minutes), before being moved to a new location. The same data characteristics and requirements apply as in part (a).

What would you change in your design to make it suitable for use with beacons instead of drones?

Question 9 (14 marks)

An LTE base station has a large number of users currently connected in its cell. These users request bearers according to the following traffic model:

- The users collectively make video calls following a Poisson distribution, with an average interarrival time of 1.6 seconds. The call length follows a negative exponential distribution, with an average call length of 5 minutes.
- The users generate web traffic with an average of 50 concurrent web connections open at any given time. The web traffic has low variance when considered over the set of all users, so can be modelled using only the average value (i.e. a constant, deterministic distribution).

Each video call requires a minimum guaranteed bitrate (GBR) bearer with 500kbps of bandwidth allocated to it. Web traffic, on the other hand, uses non-guaranteed bitrate bearers. In total, the base station has 100 Mbps of capacity available for Web and video call traffic.

(a) (3 marks) How many video calls can be served simultaneously?

(b) (4 marks) Write an expression for the probability that a video call will be blocked, that is, there will not be sufficient capacity available to allocate a bearer for the call. (Note: you do not need to solve for this probability numerically.)

(c) (4 marks) If the blocking probability is 2%, how much capacity is available for web traffic on average?

(d) (3 marks) If the web traffic were to instead use guaranteed bitrate bearers, with 200 kbps allocated to each connection, would the voice call blocking probability increase or decrease, and why?

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ETSN01 Formula Sheet

Probability

$$P(\bar{A}) = 1 - P(A)$$
$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$
$$P(A|B) = \frac{P(A \cap B)}{P(B)}$$

A, B mutually exclusive:

$$P(A \cap B) = 0$$

A, B independent:

$$P(A \cap B) = P(A)P(B)$$

CDF:

$$F(x) = P(X \leq x)$$

PDF:

$$p_k = p(k) = P(X = k)$$

Discrete random variables

Mean:

$$\mu = \sum k p_k$$

Variance:

$$Var(X) = \sum (k-\mu)^2 p_k = E[X^2] - (E[X])^2$$

Standard deviation:

$$\sigma = \sqrt{(Var(X))}$$

$$E[aX + b] = aE[X] + bVar(aX + b) = a^2 Var(X)$$

Bernoulli random variable:

$$p_0 = p$$
$$p_1 = 1 - p$$
$$\mu = p$$
$$\sigma^2 = p(1-p)$$

Geometric:

$$p_k = (1-p)^{k-1} p$$
$$\mu = \frac{1}{p}$$
$$Var(X) = \frac{1-p}{p^2}$$

Poisson random variable:

$$p_k = e^{-\lambda} \frac{\lambda^k}{k!}$$
$$\mu = \lambda$$
$$\sigma^2 = \lambda$$

Continuous random variables

Mean:

$$\mu = \int x p(x) \mathrm{d}x$$

Variance:

$$Var(X) = \int (x-\mu)^2 p(x) \mathrm{d}x$$

Negative exponential:

$$p(x) = \alpha e^{-\alpha x}$$
$$P(X \leq x) = 1 - e^{-\alpha x}$$
$$\mu = \frac{1}{\alpha}$$
$$Var(X) = \left(\frac{1}{\alpha}\right)^2$$

Gaussian:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Multiple random variables

Joint CDF:

$$F(x, y) = P(X \leq x, Y \leq y)$$

X, Y independent:

$$F(x, y) = F(x)F(y)$$

$$E[X + Y] = E[X] + E[Y]$$
$$E[XY] = E[X]E[Y]$$
$$Var(X + Y) = Var(X) + Var(Y)$$

Properties of random variables X, Y, constants a, b:

$$E[aX + b] = aE[X] + b$$
$$Var(aX + b) = a^2 Var(X)$$
$$E[X + Y] = E[X] + E[Y]$$

Covariance:

$$Cov(X, Y) = E[(X - E[X])(Y - E[Y])] = E[XY] - E[X]E[Y]$$

Correlation coefficient:

$$r(X, Y) = \frac{Cov(X, Y)}{\sigma_x \sigma_y}$$

Stochastic Processes

Autocorrelation:

$$R(t_1, t_2) = E[x(t_1)x(t_2)]$$

Autocovariance:

$$C(t_1, t_2) = Cov(x(t_1), x(t_2))$$

Sampling and random numbers

Sample mean:

$$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i$$

Sample variance:

$$\hat{V} = \frac{1}{n}\sum_{i=1}^{n}(z_i - \bar{z})^2$$

Unbiased sample variance (Bessel's correction):

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(z_i - \bar{z})^2$$

Confidence intervals:

$$\text{Confidence} = Pr(|\bar{z} - \mu| \leq \alpha \times \frac{\sigma}{\sqrt{n}}$$

$\alpha = 1.96$ gives confidence of 95%. Inverse method:

$$X = F^{-1}(Y)$$

Medium Access Control

FDMA/TDMA rate of work:

$$\eta = \frac{1}{n \times \nu}\sum_{i=1}^{n} \rho_i$$

Polling efficiency:

$$E = \frac{T_t}{T_t + T_{idle} + T_{poll}}$$

ALOHA throughput:

$$S = Ge^{-G}$$

Slotted ALOHA throughput:

$$S = Ge^{-2G}$$

1-persistent CSMA throughput:

$$S = \frac{Ge^{-G}(1+G)}{G + e^{-G}}$$

Non-persistent CSMA throughput:

$$S = \frac{G}{1+G}$$

CSMA utilisation:

$$A = kp(1-p)^{k-1}$$

$$E[w] = \frac{1-A}{A}$$

$$U = \frac{1}{1 + 2a + a(1-A)/A}$$

Queueing Systems

Kendall Notation parameters:

1. Arrival distribution
2. Service distribution
3. Number of servers
4. Total capacity (default: infinite)
5. Population size (default: infinite)
6. Service disciplien (default: FIFO)

Little's Law:

$$E[R] = \lambda E[T_R]$$

Occupancy:

$$\rho = \frac{\lambda}{\mu}$$

M/M/1

Queue length:

$$E[R] = \frac{\rho}{1-\rho}$$

Total time in system:

$$E[T_R] = \frac{1}{\mu(1-\rho)}$$

Waiting time:

$$E[T_W] = \frac{\rho}{\mu(1-\rho)}$$

Delay bound:

$$Pr(T_R \leq t) = 1 - e^{-\mu(1-\rho)t}$$

M/M/1/n

Blocking probability:

$$P_B = \frac{1-\rho}{1-\rho^{n+1}}\rho^n$$

Carried traffic:

$$\gamma = \lambda(1 - P_B)$$

Little's Law:

$$E[R] = \gamma E[T_R]$$

Queue length:

$$E[R] = \frac{1-\rho}{1-\rho^{n+1}}\sum_{i=0}^{n} i\rho^i$$

Erlang (M/M/n/n)

Offered traffic:

$$A = \lambda h$$

Service rate:

$$\mu = \frac{1}{h}$$

Erlang loss function:

$$E_n(A) = P_B = \frac{\frac{A^n}{n!}}{\sum_{j=0}^{n} \frac{A^j}{j!}}$$

Carried traffic:

$$A_c = A(1 - P_B)$$

Lost traffic:

$$A - A_c$$

Jackson Networks

Probability a packet leaves the network from node i:

$$1 - \sum_{j=1}^{n} r_{ij}$$

Total arrival rate to node i:

$$\lambda_i = \gamma_i + \sum_{j=1}^{n} \lambda_j r_{ji}$$

Queueing Disciplines

Kleinrock Conservation Law:

$$\sum_{n=1}^{N} \rho_n q_n = C$$

Processor Sharing:

$$F_i^\alpha = S_i^\alpha + P_i^\alpha$$

$$S_i^\alpha = \max\{F_{i-1}^\alpha, A_i^\alpha\}$$

Generalised Processor Sharing:

$$F_i^\alpha = S_i^\alpha + \frac{P_i^\alpha}{w_\alpha}$$

Network Architectures

Capacity for nodes distributed on a unit disc[1]:

$$\frac{W}{\sqrt{n \log(n)}}$$

With optimally places nodes:

$$\frac{W}{\sqrt{n}}$$

[1] Natural logarithm, base e.

Packet reception rate:

$$PRR = \frac{S}{T}$$

Cellular frequency re-use:

$$D = R\sqrt{3K}$$

Congestion Control

Token bucket:

$$R = \rho T + \beta$$

TCP

Max bandwidth:

$$BW_{max} = \frac{MSS \times C}{RTT \times \sqrt{p}} \qquad C = \sqrt{\frac{3}{2}}$$

Normalised throughput:

$$S = \begin{cases} 1 & W \geq 2RD \\ \frac{W}{2RD} & W < 2RD \end{cases}$$

Expected (average) round trip time:

$$ERTT(K+1) = \frac{K}{K+1} ERTT(K) + \frac{1}{K+1} RTT(K+1)$$

Smoothed round trip time:

$$SRTT(K+1) = \alpha \times SRTT(K) + (1-\alpha) \times RTT(K+1)$$

Retransmission timeout with SRTT:

$$RTO(K+1) = \min\{UB, \max\{LB, \beta \times SRTT(K+1)\}\}$$

Van Jacobson's algorithm:

$$DRTT(K+1) = (1-\alpha) \times DRTT(K) + \alpha \times (SRTT - ERTT)$$

$$RTO = ERTT - 4 \times DRTT$$

Exponential backoff:

$$RTO_{i+1} = q \times RTO_i$$

Other useful formulas

Geometric series:

$$\sum_{k=0}^{n-1} ar^k = a\frac{1 - r^n}{1 - r}$$

$$\sum_{k=0}^{\infty} ar^k = \frac{a}{1 - r}$$

Expectation of geometric series:

$$\sum_{k=0}^{n} kar^k = \frac{ar}{(1 - r)^2}$$