IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

MSc and EEE/EIE PART III/IV: MEng, BEng and ACGI

Corrected Copy

**COMMUNICATION NETWORKS**

Thursday, 10 December 9:00 am

Time allowed: 3:00 hours

**There are FOUR questions on this paper.**

**Answer ALL questions.**

*All questions carry equal marks*

**Any special instructions for invigilators and information for candidates are on page 1.**

Examiners responsible First Marker(s) : J.A. Barria

Second Marker(s) : J.V. Pitt

## Special information for students

### 1. Mean delay for the M/M/1 system may be taken as

$$t_i = \frac{1}{\mu C_i - \lambda_i}$$

where,

$1/\mu$ = Average length of packet [bits / packet]

$C_i$ = Transmission speed link $i$ [bits / s]

$\mu C_i$ = Service rate (link $i$) [packets / s]

$\lambda_i$ = Arrival rate (link $i$) [packets / s]

### 2. Optimal Routing Problem (ORP)

$Min\ D(x)$ with respect to $\mathbf{x} = \{ x_i \}$

where $D(x) = \sum_{i=1}^{L} \frac{x_i}{C(i) - x_i}$

$C(i)$ = capacity of link $i$,

$x_i$ = flow carried by link $i$,

$L$ = total number of links in the network.

## The Questions

1.

a) For a Stop-and-Wait ARQ protocol, the time to send a frame and receive an ACK (acknowledgement) frame, in the absence of errors, is given by:

$$t_0 = 2t_{prop} + 2t_{proc} + t_f + t_{ack} = 2t_{prop} + 2t_{proc} + \frac{n_f}{R} + \frac{n_a}{R}$$

where, $t_{prop}$ = is the propagation delay; $t_{proc}$ = is the processing delay; $n_f$ = is the number of bits in the information frame; $n_a$ = is the number of bits in the ACK frame, and $R$ = is the bit rate of the transmission channel.

The effective information transmission rate of the protocol in the absence of errors is given by:

$$R_{eff}^0 = \frac{n_f - n_O}{t_0}$$

where, $n_O$ = is the number of overhead bits in a frame (header plus CRC check bits). Define the transmission efficiency $\eta_0$ of this protocol as:

$$\eta_0 = \frac{R_{eff}^0}{R}$$

i) Derive $\eta_0$ as a function of all the protocol parameters appearing in the above expression for $t_0$. [3]

ii) For the expression derived in i) clearly identify and explain all the sources of inefficiency. [6]

b)

i) Explain and discuss why it important to implement a collision avoidance (CA) mechanism in a wireless communication environment. [3]

ii) The protocol 802.11 has an optional feature that enables the implementation of a reservation scheme.

- Explain why a reservation protocol would be needed. [2]

- Discuss under which conditions it would be useful to implement this optional feature. [2]

- Sketch the time sequence of the 802.11 reservation protocol. [4]

2.

a)

i) Describe a mechanism that would allow routers to distinguish between different classes of traffic in a multimedia IP environment.

[4]

ii) Describe a mechanism that will provide a degree of isolation among different traffic classes, so that one packet flow is not adversely affected by another misbehaving flow.

[4]

iii) Describe and discuss a mechanism known to you that needs to be in place in the event that there are not enough resources in the network to support the level of service requested by a new call request.

[4]

b) An optimal routing problem aims at allocating flows $x_i$ to all the links $l_i$ of a network, such that an objective function $D(C,X)$, which represents the network congestion level, is minimised with respect to $X = \{x_i\}$.

**Note:** in function $D(C,X)$:
$C = \{C(i)\}$ is the set of capacities of links $l_i$, and
$X = \{x_i\}$ is the set of flows carried by links $l_i$.

i) Using the results of a single $M/M/1$ queue system, derive an objective function $D(C,X)$ that would represent the mean network delay incurred by packets traversing a network of $M/M/1$ queues. Clearly show all the steps of your derivation.

[4]

ii) Discuss and suggest an additional term to function $D(C,X)$ that will have the effect of controlling the flow of packets that is carried by the network.

[4]

3.

a) In the context of IP mobility support using indirect routing:

i) Describe and discuss the functionalities required of the following entities:

- Foreign agent, [4]

- Home agent. [4]

ii) Explain and discuss why indirect routing requires an encapsulation / decapsulation function. [4]

b) The goal of a statistical shortest path problem is to minimise the length $L_p$ of path $p$:

$$L_p = \Psi(\mu_p) + \Phi(\sigma_p^2)$$

where $\mu_p$ is the mean value of $L_p$; $\sigma_p^2$ is the variance of $L_p$ and, $\Psi(.)$ and $\Phi(.)$ are arbitrary functions.

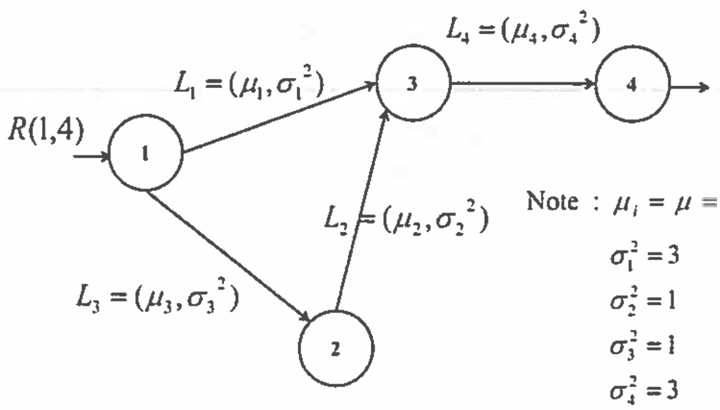
i) Assume that the links' statistics of a network are Gaussian distributed, with mean $\mu_i$ and variance $\sigma_i^2$ for link $i$, and that the links in the network are mutually independent.

- For the network shown in Fig. 3.1, derive an expression of the form $L_p = \mu_p + \sigma_p^2$ for all identifiable paths $p$. Discuss your answer. [2]

- Using the network and information shown in Fig. 3.1 identify the shortest path in terms of $\sigma_p^2$. Explain the logic of your derivation. [3]

ii) Now consider a modified cost function with $\Phi(x) = \sqrt{x}$.

- Is it possible to use the same approximation used in i) to find the shortest path in respect to $\sqrt{\sigma^2} = \sigma$ ? Discuss your answer.




Note : $\mu_i = \mu = 1$

$\sigma_1^2 = 3$

$\sigma_2^2 = 1$

$\sigma_3^2 = 1$

$\sigma_4^2 = 3$

[3]

*Figure 3.1*

4.

a) In the context of multimedia networking, a FIFO (first in first out) queue system requires modifications so that different classes of packets are treated differently.

i) Discuss an alternative way of treating packets arriving to a queue such that arrivals could be receive differential treatment. Describe how you would modify a FIFO queue system to handle differential treatment between two classes of traffic. [4]

ii) Describe what is a weighted fair queueing (WFQ) discipline, and explain how you would implement it. [4]

b) For a TCP dynamic congestion window flow control the following closed-form expression for the latency has been proposed:

$$Latency = 2RTT + \frac{O}{R} + P\left[RTT + \frac{S}{R}\right] - \left(2^{P} - 1\right)\frac{S}{R}$$

where $P = \min\{Q, K-1\}$; $RTT =$ round trip time; $O =$ size of the object; $R =$ transmission rate of the link; $S =$ the size of the MSS (maximum segment size); $K =$ number of windows that covers the object; $W =$ window size; and $Q =$ is the number of times the server would stall if the object contained an infinite number of segments.

i) Show that a bound on the ratio of Latency to the Minimum Latency (Latency assuming that there is no congestion control), namely its efficiency, is given by: [4]

$$\eta_{eff} = \frac{\text{Latency}}{\text{Minimum Latency}} \leq 1 + \frac{P}{[(O/R)/RTT]+2}$$

**Hint:** First determine the Minimum Latency expression.

ii) Discuss the impact of the magnitude of values of the parameters $RTT$ and $O/R$ on the efficiency of the slow start mechanism. [4]

*Question 4 continues next page*

*Question 4 - b) iii)*

iii) For the following parameters: $S = 537$ bytes, $RTT = 100$ ms, $O = 100$ Kbytes and $K = 8$, the following calculations are given:

| $R$ (transmission rate) | Minimum Latency | Latency - SLOW START |
|---|---|---|
| Kbps | s | s |
| 28.0 | 28.8 | 28.9 |
| 100.0 | 8.2 | 8.4 |
| 10.0 | 0.28 | 0.98 |

- What can you say about the effects of the transmission rate $R$ on the efficiency, $\eta_{eff}$, of the slow start? [4]