Paper Number(s): **E3.17**
E4.09
SO8
ISE3.31
ISE4.13

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
UNIVERSITY OF LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2002

MSc and EEE/ISE PART III/IV: B.Eng., M.Eng. and ACGI

COMMUNICATION NETWORKS

Tuesday, 30 April 10:00 am

There are FIVE questions on this paper.

Answer FOUR questions.

Corrected Copy

Time allowed: 3:00 hours.

Examiners responsible:

First Marker(s): Barria,J.A.
Second Marker(s): Mamdani,E.H.

Special Information for Invigilators: **NIL**

Information for Candidates: **NIL**

1. (a) In the context of an automatic repeat request (*ARQ*) scheme, it is known that the probability of a single frame being in error is $P = 0.1$.

   (i) What is the probability that one frame will take exactly i re-attempts to be successfully received.

   (ii) What is the expected number of re-transmissions, Nr, of one frame. [5]

   (b) For a *Go Back N ARQ* scheme, and assuming that each frame in error will generate K re-transmissions:

   (i) derive the expected number of re-transmissions, Nr, of a frame.

   (ii) Derive a simple expression of the performance of this scheme for $N > 2a + 1$ and $N < 2a + 1$.

   Clearly state the meaning of a and N. Clearly state your assumptions and approximations. [5]

   (c) A network is composed of N nodes and L links. Assume you know all possible traffic demand pairs γ_{ij} (from origin i to destination j) in Kbits/seconds.

   Derive an expression for the mean network packet delay, T, as a function of the traffic flow F_i (in Kbits/seconds) carried by link i, and the capacity C_i (in Kbits/seconds) of link i.

   Clearly state any assumptions made at each stage of your derivation. [10]

2. (a) Describe and discuss the relevance of the following Internet routing protocols:

   (i) Reservation Protocol (RSVP).

   (ii) Next Hop Resolution Protocol (NHRP).

   (iii) Multicast routing.

   (iv) Dynamic Host Configuration Protocol (DHCP) and Mobile IP. [8]

   (b) Describe and discuss the following Internet service class models:

   (i) IntServ model.

   (ii) DiffServ model. [12]

3. (a) Describe an application of market-based load control mechanisms and discuss its implementation.

[5]

(b) For the network of *Figure 3.1*, consider the cost function D defined by:

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

where $C(i)$ is the capacity of link i, $F(i)$ is the flow carried by link i and L is the maximum number of links in the network.

(i) Solve the optimal routing problem (ORP) where the network capacity values are $C(1) = C(2) = C(3) = C(4) = C(5) = 10$ Kbits/seconds, and the offered load is $R\_14 = 10$ Kbits/seconds. [5]

(ii) Suppose that you are asked to choose between two alternatives:
- increase the original capacity of $C(5)$ to 20 Kbits/seconds, or
- increase the original capacity of $C(1)$, $C(2)$, $C(3)$ and $C(4)$ to $C(1) = C(2) = C(3) = C(4) = 20$ Kbits/seconds. [5]

Which one would you choose? Discuss your findings. [5]

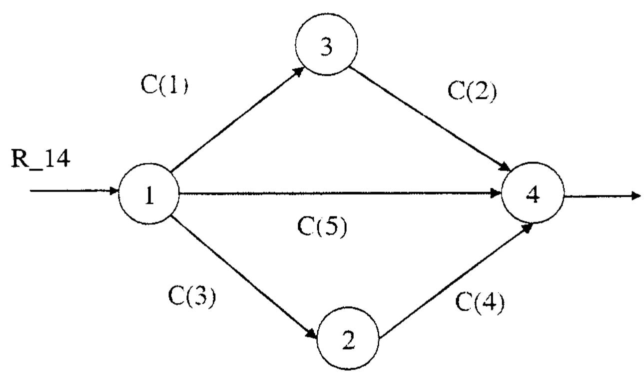


Figure 3.1

4. (a) (i) Describe and define three ATM traffic management functions known to you [6]

(ii) Discuss the importance of Equivalent Capacity functions in ATM call Admission Control schemes. [4]

(b) Consider the network of *Figure 4.1* where *L(i,j)* is the link length between nodes *i* and *j*.

Show all the iterations of the Bellman-Ford shortest path algorithm. [10]

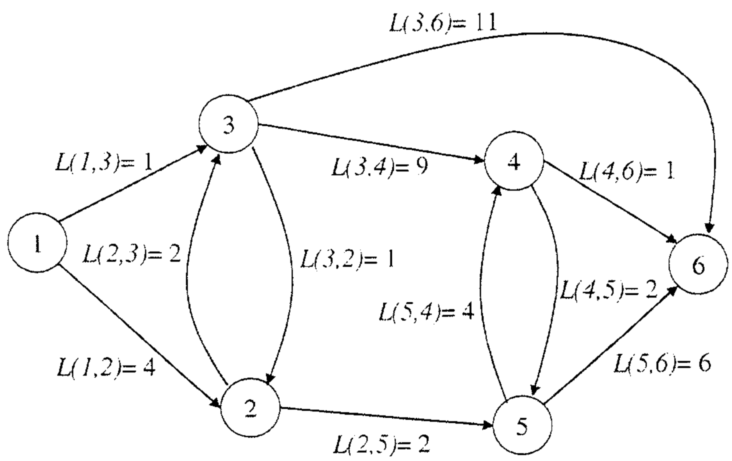


Figure 4.1

5. (a) For a single-voice source, the packet-arrival process can approximately be taken to be a renewal process with an inter-arrival time distribution given by

$$F(t) = [(1-\alpha T) + \alpha T(1-e^{-\beta(t-T)})]U(t-T)$$

where α is the mean talkspurt period, β is the mean silence period and T is the voice packetisation period. For this process the expression for the squared coefficient of variation c_1^2 (which is the variance divided by the square of the mean) of an inter-arrival time is given by

$$c_1^2 = \frac{(1-p^2)}{[T\beta + (1-p)]^2}.$$

Given that: $\alpha^{-1} = 352$ ms; $\beta^{-1} = 650$ ms and $\alpha T = 1-p = 1/22$.

(i) calculate the value of c_1^2. [5]

(ii) discuss the significance of your findings. [5]

(b) In the context of Rate Adjustment Congestion schemes, explain and discuss:

(i) the Time Window flow control scheme. [5]

(ii) the Leaky Bucket algorithm. [5]

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

ISE 3.31, ISE 4.17

Paper Code: 4.09, 3.17, S08, Second Examiner:

COMMUNICATION NETWORKS

Question Number etc. in left margin | Mark allocation in right margin

1a P = probability single frame in error

(i) $P^{i-1}(1-P)$

(ii) $N_R = \sum_{i=1}^{\infty} i P^{i-1}(1-P) = \frac{1}{1-P}$

1b

(i) if each error generates K retransmissions:

$$N_R = \sum_{i=1}^{\infty} f(i) P^{i-1}(1-P)$$

$$f(i) = 1+(i-1)K = (1-K)+Ki$$

$$N_R = (1-K)\sum P^{i-1}(1-P) + K\sum i P^{i-1}(1-P)$$

$$= 1-K + \frac{K}{1-P}$$

$$= \frac{1-P+KP}{1-P}$$

(ii) $$U\ (N > 2a+1) = \frac{1-P}{1+2aP}$$

$$U\ (N < 2a+1) = \frac{N(1-P)}{(1+2a)(1-P+NP)}$$

with the following approximations

$K \sim 2a+1$ if $N > 2a+1$

$K \sim N$ if $N < 2a+1$

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

1c Mean network Delay

$$\gamma \longrightarrow (N, T) \qquad N = \gamma T$$

1. External workload

$$\gamma = \sum_{j=1}^{N} \sum_{k=1}^{N} \gamma_{jk}$$

2. $N \equiv \gamma T$

2.1 Little's in queue i (No packets in link i)

$$q_i = \lambda_i t_i$$

2.2 No of packets in the network

$$\sum_{i=1}^{L} \lambda_i t_i = N = \gamma T$$

Delay at queue i $= t_i = \dfrac{1}{\mu C_i - \lambda_i}$

$1/\mu$ = average length of packet (bits / packet)

C_i = Transmission speed link i (bits / sec)

μC_i = Service rate link i (packets / sec)

λ_i = arrival rate link i (packets / sec)

$$\gamma T = \sum_{i=1}^{L} \lambda_i t_i = \sum_{i=1}^{L} \frac{\lambda_i}{\mu C_i - \lambda_i} \; ; \qquad F_i = \frac{\lambda_i}{\mu}$$

$$T = \frac{1}{\gamma} \sum_{i=1}^{L} \frac{F_i}{C_i - F_i}$$

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

2a (i) - RSVP is essentially a network-level signalling protocol operating on top of IP
  - Host request of a specific QoS for a particular flow
  - Routers provide the requested QoS along the path(s)
- RSVP routers responsible for:
  - Dedicated requested resources
  - Maintain state for the signalled connection
  - Accept / Refuse new connection based on available resources
  - Guarantee the service level of existing calls
- Discussion on RSVP limitations

(ii) NHRP enables a station connected to an ATM network to:
  - Resolve an ATM address from an IP address
  - Find the most efficient shortcuts to traverse multiple logical IP subnetworks

(iii) Multicast routing: each packet is transmitted once per link (saving bandwidth in large scaled networks).

(iv) - DHCP automatically configures hosts that connect to a TCP/IP network
- DHCP provides mechanism for assigning temporary IP network addresses to host
- Used by ISPs to maximise usage of their IP address space

2b (i) IntServ Model
- Packet classifiers: identify flows to receive specific QoS
- Packet schedulers: Handle forwarding different packet flows
- Admission control: Determine if a route has sufficient resource
- Explicit resource reservation (RSVP): bandwidth and buffers reserved for a data flow

(ii) DiffServ model
- The DS model is simpler and more scalable than IntServ model
  - per flow is replaced with per aggregate service
  - Complex processing is moved from the core of the network to edge

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

2b (ii) A Service level agreement (SLA) is necessary
- A customer or organisation wishing to receive differentiated service must first have a SLA
- A SLA includes a traffic conditioning agreement.

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

3a (ii) Using a price mechanism we could e.g., divide the traffic between delay-sensitive and delay-insensitive traffic.

If users are charged lower rate at e.g. night, they will have an incentive to shift the delay-insensitive traffic to those periods

A price-oriented model is build by specifying three elements

- User demand for service
- Network capacity
- amount of service that network can supply

In the case of a single service and a two period scheme, the user's preference of e.g. sending an e-mail or browse through a WWW could be modelled by the utility function:

$$u_t(x) = u(x) - d_t x_t \qquad x \geq 0 \quad , t = 1,2$$

where x = amount of traffic

$d_t x$ = is the loss or benefit reduction suffered from sending x in period t

If the price of sending in $t=1$ is p_t the user will transmit at the time that maximise her benefit i.e.

$$\max u_t(x) = u(x) - d_t x - p_t x$$

It can be shown that the optimal price for the system is given by

$$\frac{\partial u^i}{\partial x_t^i} = p_t + d_t^i$$

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

3a (iii) One possible application: The user i will choose to transmit at rate λ_i which will be the solution of the following problem

$$\max_{\lambda_i} \; u^i(\lambda^i) - \mu^i d \lambda^i - p_c \lambda^i$$

i.e.

$$\frac{\partial u^i}{\partial \lambda^i} = \mu^i d + p_c$$

The system will receive the aggregate demand $\Lambda = \sum \lambda_i$

A central planner chooses λ^i on behalf of user i so as to maximise the total benefit

$$\sum_i \left[u^i(\lambda^i) - \mu^i d \lambda^i \right]$$

e.g. if $d = f(\Lambda, M)$

$$\frac{\partial u^i}{\partial \lambda^i} = \mu^i f(\Lambda, M) + \frac{\partial f}{\partial \Lambda}(\Lambda, M) \sum_j \mu^j \lambda^j$$

Note that the second term is the delay cost suffered by all users due to a unit increase on user i's traffic rate equal to congestion price

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

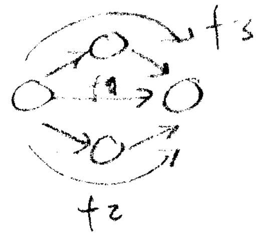
Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

3b

$$\frac{\partial D}{\partial x_p} = \sum_{i \in p} \frac{c_i}{(c_i - f_i)^2}$$



(i)

$$f_1 + f_2 + f_3 = 10$$

$$f_2 = f_3 \Rightarrow f_1 = 10 - 2f_2$$

consider f_1 and f_2

$$\frac{10}{(10-f_1)^2} = \frac{2 \times 10}{(10-f_2)^2} \Rightarrow (10 - f_2) = \sqrt{2}(10 - f_1)$$

$$10 - \sqrt{2}.10 = f_2 - \sqrt{2} f_1 = f_2 - \sqrt{2}(10 - 2f_2)$$

$$10 - \sqrt{2}.10 = f_2 - \sqrt{2}.10 - \sqrt{2}\, 2 f_2$$

$$f_2 = \frac{10}{1 + 2\sqrt{2}} = f_3 = 2.617$$

$$f_1 = 4.766$$

(ii) ⓐ $C_5 = 20 \Rightarrow D = 1$

ⓑ $C_1 = .. = C_4 = 20 \Rightarrow D = 1\,\frac{1}{4}$

choose min D

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

4a ATM traffic management functions

(i) Any three of the following function should be described and discussed:

- Call admission control (CAC) and resource management (RM)
- Usage parameter control (UPC/NPC)*
  - *GCRA suggested at Public UNI, but other mechanisms permitted
- Priority control (PC)
- Traffic shaping (TS)
- Explicit Forward Congestion Indicator (EFCI)
- Congestion control functions

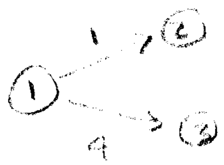
Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

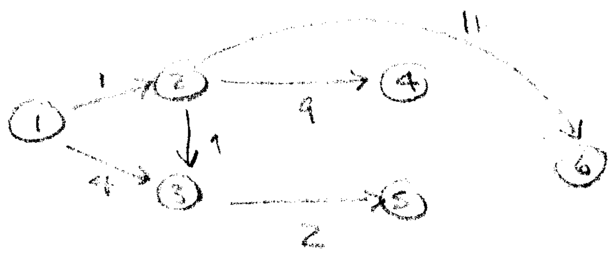
Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

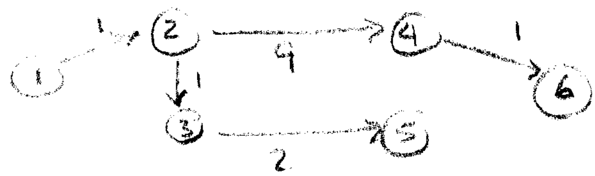
4b



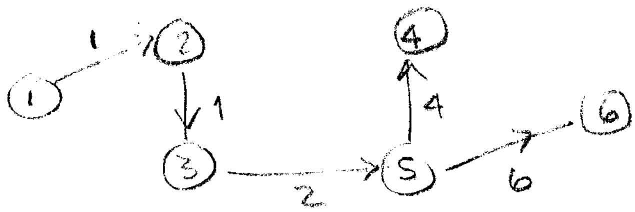
M = 1



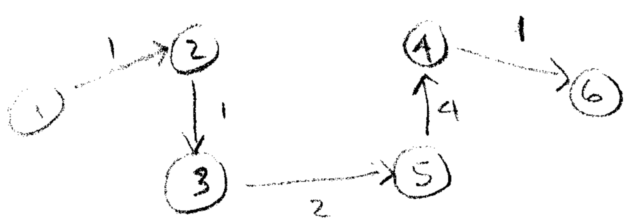
M = 2



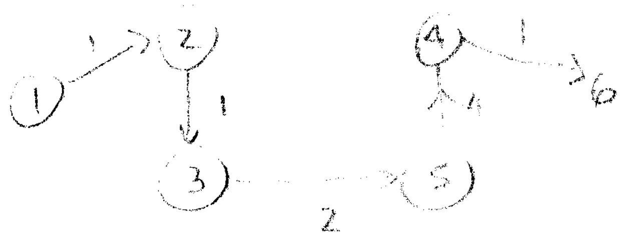
M = 3



M = 4



M = 5



M = 6 (STOP)

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

Question Number etc. in left margin | Mark allocation in right margin

5a

(i)

$$c_1^2 = \frac{(1-p^2)}{[T\mu + (1-p)]^2}$$

$$p = 1 - 1/22 = 0.954545$$

$$p^2 = 0.911157$$

$$\mu T = \frac{\alpha^{-1}}{\mu^{-1}} \propto r = \frac{352}{650} \times \frac{1}{22} = 0.02461538$$

$$1-p^2 = 0.088843$$

$$T\mu + (1-p) = 0.0700699$$

$$[T\mu + (1-p)]^2 = 4.9097 \times 10^{-3}$$

$$c_1^2 \approx 18.09$$

(ii) c_1^2 for a Poisson process is 1 (one)

Comparison and discussion

Department of Electrical and Electronic Engineering Examinations 2002 **Confidential**

Model Answers and Mark Schemes First Examiner:

Paper Code: 4.09 Second Examiner:

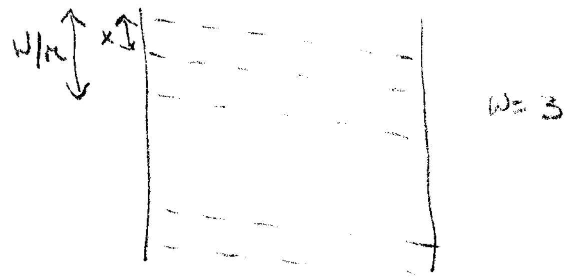
Question Number etc. in left margin | Mark allocation in right margin

5b (i) Rate control schemes

Idea: give each station a guarantee data rate (according to its needs)

goal - generate desired rates for various connections

- Time window flow control with W=3 (figure). The count of packet allocation is decreased when a packet is transmitted and increased W/R seconds later (instead of after a round-trip delay when the corresponding permits returns).



(ii) - leaky-bucket scheme: To join the transmission queue, a packet must get a permit from the permit queue. A new permit is generated every 1/R seconds, where R is the desired input rate, as long as the number of permits does not exceed a given threshold.