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**E4.09**  
**SO8**  
**ISE3.31**  
**ISE4.13**

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE  
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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,  $N_r$ , 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,  $N_r$ , 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  $\gamma_{ij}$  (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]

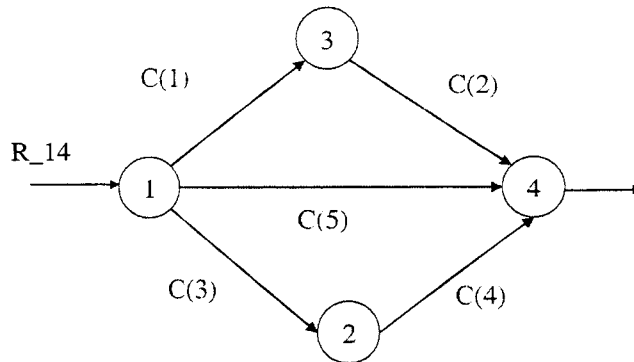
- (b) For the network of *Figure 3.1*, consider the cost function  $D$  defined by:

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

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]

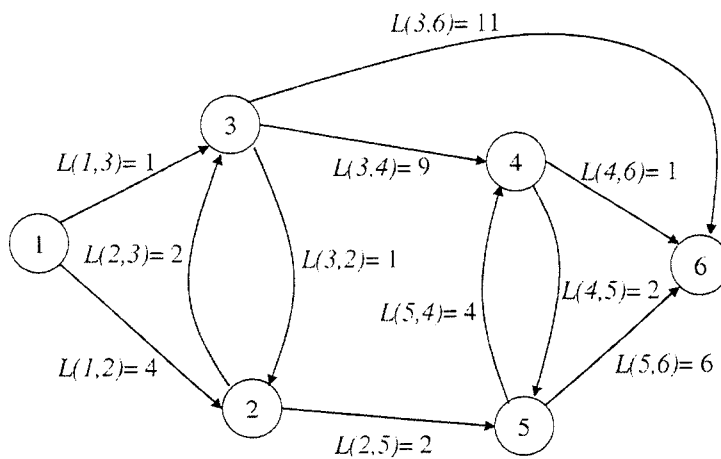


*Figure 3.1*

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  $\alpha$  is the mean talkspurt period,  $\beta$  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]

COMMUNICATION NETWORKS

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1a P = probability single frame in error

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

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

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

$$K \approx 2a+1 \quad \text{if } N > 2a+1$$

$$K \sim N \quad \text{if } N < 2a+1$$

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3c Mean network Delay



1. External workload

$$\lambda = \sum_{j=1}^M \sum_{k=1}^M \lambda_j \lambda_k$$

$$2. N = \lambda T$$

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

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

$$\text{Delay at queue } i = t_i = \frac{1}{\mu_i - \lambda_i}$$

 $1/\mu$  = average length of packet (bits/packet) $c_i$  = Transmission speed link  $i$  (bits/sec) $\mu_i$  = service rate link  $i$  (packets/sec) $\lambda_i$  = arrival rate link  $i$  (packets/sec)

$$\lambda T = \sum_{i=1}^L \lambda_i t_i = \sum_{i=1}^L \frac{\lambda_i}{\mu_i - \lambda_i} \quad ; \quad F_i = \frac{\lambda_i}{\mu}$$

$$T = \frac{1}{\mu} \sum_{i=1}^L \frac{F_i}{c_i - F_i}$$



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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 connections 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 (saves bandwidth in large sized 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 maximize 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 resources
  - 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

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24  
(ii)

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

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3a

(iv)

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 modeled by the utility function:

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

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 maximizes 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

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

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3a

(ii)

One possible application: The user  $i$  will choose to transmit at rate  $d_i$  which will be the solution of the following problem

$$\max_{d_i} u^i(d_i) - \int_0^{d_i} c^i d^i - p_c d^i$$

$$\text{i.e.} \quad \frac{\partial u^i}{\partial d^i} - \int_0^{d^i} c^i + p_c$$

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

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

$$\sum_i [u^i(d^i) - \int_0^{d^i} c^i]$$

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

$$\frac{\partial u^i}{\partial d^i} = \int_0^{d^i} c^i + \frac{\partial f}{\partial \Lambda}(\Lambda, M) \sum_j \int_0^{d^j} c^j$$

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

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3b

$$\frac{\partial D}{\partial x_i} = \sum_{i \neq j} \frac{c_i}{(c_i - f_i)^2}$$

(i)

$$f_1 + f_2 + f_3 = 10$$

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

consider  $f_1$  and  $f_2$

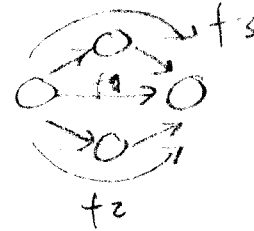
$$\frac{10}{(10 - f_1)^2} = \frac{2 \times 10}{(10 - f_2)^2} \Rightarrow (10 - f_2) = \sqrt{2} (10 - f_1)$$

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

$$10 - \sqrt{2} \cdot 10 = f_2 - \sqrt{2} \cdot 10 + \sqrt{2} \cdot 2 f_2$$

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

$$f_1 = 4.766$$



(ii)

(a)  $c_5 = 20 \Rightarrow D = 1$

(b)  $c_1 = \dots = c_4 = 20 \Rightarrow D = 1 \frac{1}{4}$

choose min D

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4a ATM traffic management Functions

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

- Call admission control (CAC) and resource management (RM)

- Usage parameter control (UPC/NPC)\*

\* GCRN suggested at Public USF, but other mechanisms permitted

- Priority control (PC)

- Traffic Shaping (TS)

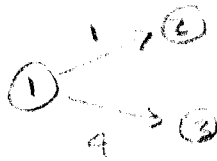
- Explicit Forward Congestion Indicators (EFCI)

- Congestion Control Functions

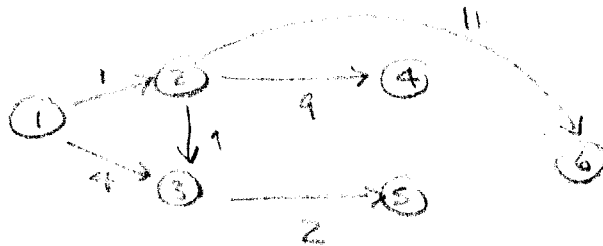
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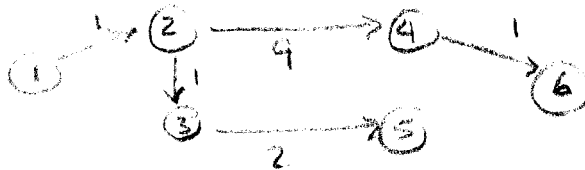
4b



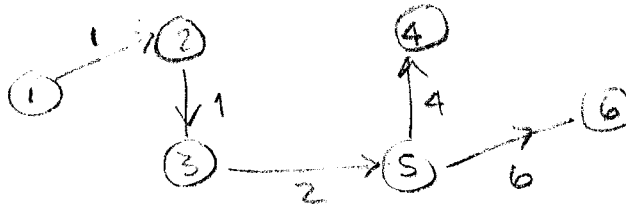
$M=1$



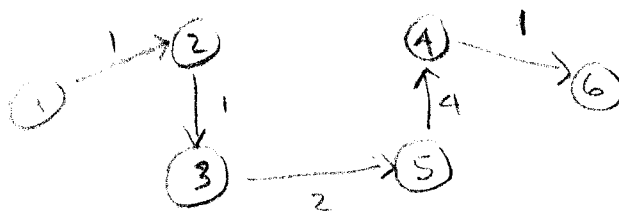
$M=2$



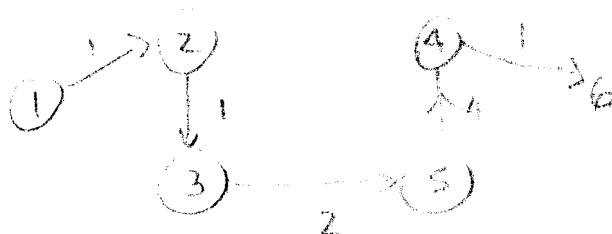
$M=3$



$M=4$



$M=5$



$M=6$  (STOP)

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5a.

(i)

$$C_1^2 = \frac{(1-p^2)}{[\Gamma/p + (1-p)]^2}$$

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

$$p^2 = 0.911157$$

$$\beta T = \frac{\alpha^{-1}}{\beta^{-1}} \quad \alpha T = \frac{352}{650} \times \frac{1}{22} = 0.02461538$$

$$1-p^2 = 0.088843$$

$$\Gamma/p + (1-p) = 0.0700699$$

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

$$C_1^2 \approx 18.09$$

(ii)

$C_1^2$  for a Poisson process is 1 (one)

Comparison and discussion



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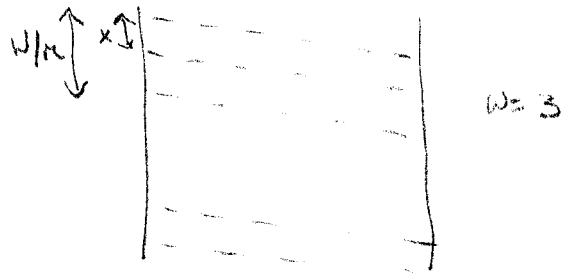
5b  
(i)

Route control schemes

Idea: give each station a guaranteed 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.

