Paper Number(s): **E4.09**
**SO8**
**ISE4.13**

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
UNIVERSITY OF LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2001

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

**COMMUNICATION NETWORKS**

Thursday, 17 May 10:00 am

There are FIVE questions on this paper.

Answer FOUR questions.

Time allowed: 3:00 hours

**Corrected Copy**

Examiners: Barria,J.A. and Pitt,J.V.

**Special Information for Invigilators:** NIL

**Information for Candidates:** NIL

1. (a) Briefly describe and derive expressions for the performance of two different Media Access Control (MAC) protocols.

[10]

(b) Derive expressions for the performance of three different Automatic Repeat Request (ARQ) protocols.

[10]

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

(i) Routing Information Protocol (RIP),
(ii) Open Shortest Path First (OSPF),
(iii) Border Gate version 4 (BGv4).

[10]

(b) Describe and discuss:

(i) IP switching forwarding models, and contrast briefly overlay models to peer models,

[5]

(ii) Three different forwarding models or protocols known to you.

[5]

3. (a)

(i) For a two-node two-link network, formulate mathematically an Optimal Routing Problem (ORP), considering the requirement to minimise the mean network delay.

[5]

(ii) Solve the ORP for the network shown in Figure 1. There is only one Origin-Destination demand pair R12 = 15 kbits/s, and the value of the capacities are $C(1,2) = 10$ kbits/s and $C(1,3) = C(3,2) = 20$ kbits/s.

[5]

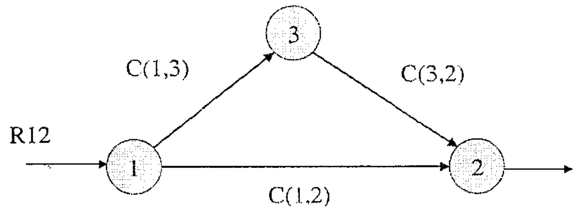



*Figure 1*

(b)

(i) Formulate mathematically a combined Optimal Routing (OR) and flow control scheme so as to obtain algorithms for input rate adjustment at the network layer.

[4]

(ii) Solve the combined OR and flow control problem for the two-node one-link network shown in Figure 2. There is only one Origin-Destination demand pair R12 = 15 kbits/s, and the capacity of the link is $C(1,2) = 9$ kbits/s. Take the cost function to be:

$$D = \frac{r}{C(1,2) - r} + \frac{a}{r}$$

where $a = 9$ kbits/s.

[4]

(iii) State the conditions under which flow control will be active. What is the effect of changing the parameter $a$?

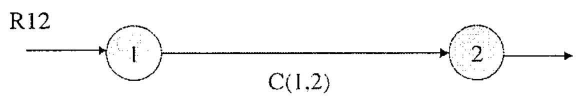



*Figure 2*

[2]

4. Consider the computer system shown in Figure 3 (three identical computers connected to each other by duplicated buses).

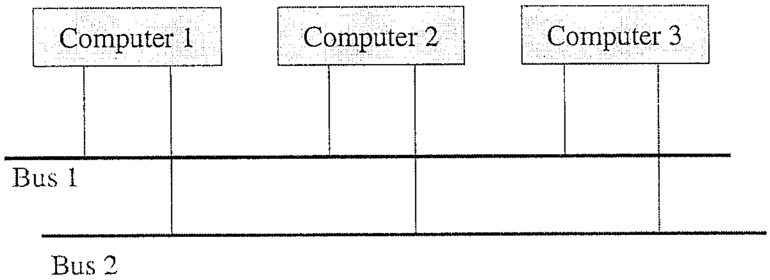



*Figure 3*

Assume that at least two computers and one bus should be operational in order to maintain the required minimum performance level, and that the computer system can be fully repaired only if it has failed.

If the state of the system is defined to be:

E = (Number of operational computers, Number of operational buses)

(a) Derive all possible states in which the system can be.

[6]

(b) Derive the state-space transition diagram (or the generator matrix, Q) of this system.

Assuming that the system can be represented by a Markov model, and the following parameters:

hp(t) = failure rate of each computer,
hb(t) = failure rate of each bus,
r(t) = repair rate of the system.

[8]

(c) How will the state-space transition diagram (or generator matrix, Q) of this system change if a coverage factor cb (= coverage factor of bus) is taken into account ?

[6]

5. (a) In the context of broadband traffic characterisation:

   (i) Describe and discuss a simple single voice source model.
   (ii) Describe and discuss a simple $N$ voice source model.
   (iii) Derive the steady state probability of an $N$ independent voice sources multiplexer.

[10]

(b) For the generic time-slotted packet switch of Figure 4 with $N$-input lines and $N$-output lines, you may assume the following:

$p$ is the probability that a given time slot contains an active cell and $p = 1$ corresponds to each and every input time slot being filled,

$p/N$ is the probability that a given time slot on a given input contains a cell destined for particular output.

Determine:

   (i) The average number of lost packets, $L$, and,
   (ii) The average amount of traffic, $F$, which is carried by any output of the switch per time slot.

[10]

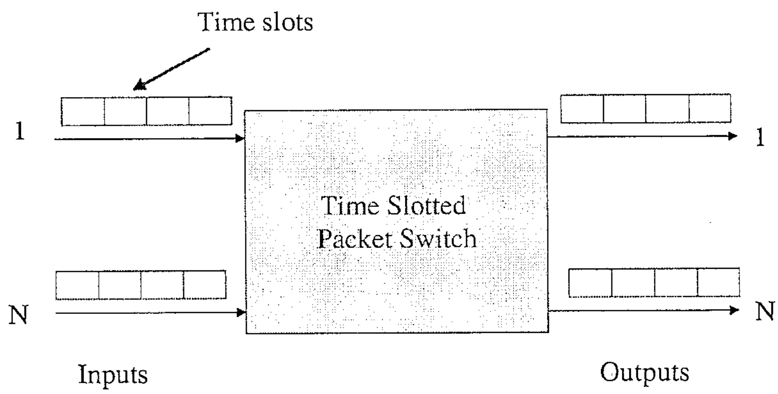



***Figure 4***

E4.09 - Comm'n Networks

| Examinations : | Session 00/01 | Confidential |
|---|---|---|

**MODEL ANSWER and MARKING SCHEME**

| | |
|---|---|
| First Examiner J. BARRIA | Paper Code |
| Second Examiner J. PITT | Question Page 1 out of 16 |

Question labels in left margin — Marks allocations in right margin

Q1 (a)

1-persistent CSMA/CD (802.3)

$$A = \binom{N}{1} P(1-P)^{N-1} = NP(1-P)^{N-1}$$

N = nr. of stations

P = prob. that a station transmit during an available time slot

slot = twice the end to end propagation = $2t$

A = Probability that exactly one station attempts to transmit in a slot

- Probability that a contention interval has j slots

$A(1-A)^{j-1}$

- Mean nr. of slots per contention

$$\sum_{j=0}^{\infty} j A(1-A)^{j-1} = 1/A$$

- Mean contention interval

$2t/A$

- channel efficiency

$$C_{eff} = \frac{L}{L + 2t/A}$$

L = size frame

| | |
|---|---|
| First Examiner | Paper Code |
| Second Examiner | Question Page 2 out of |

Question labels in left margin Marks allocations in right margin

Q1 (a)

Token Ring (802.5)

Assumptions:

- Normalised throughput to system capacity
- packet transmission = 1
- propagation delay = a
- N stations ready to transmit
- All stations are placed in equidistant to each other

(i) $a < 1$

- beginning of transmission $t_0$
- leading edge received $t_0 + a$
- Transmission complete and emit token $t_0 + 1$
- Token arrive at next station $t_0 + 1 + a/N$
- Cycle $1 + a/N$

Throughput $S = \dfrac{1}{1 + a/N}$

(ii) $a > 1$

- beginning of transmission $t_0$
- Transmission completed $t_0 + 1$
- leading edge received and emit token $t_0 + a$
- Token arrives at next station $t_0 + a + a/N$
- cycle $a + a/N$

Throughput $S = \dfrac{1}{a + a/N}$

Q1 (b) Performance of ARQ protocols

$$U = \frac{\text{transmission time}}{N_R [\text{time line engaged}]}$$

$P$ = probability a single frame in error

$f(i)$ = number of frame transmission if the original frame must be transmitted $i$ times

$N_R$ = expected number of retransmissions

Assumption: Ack and Neg-Ack frames are error free

$P^{i-1}(1-P)$ = probability that a transmission will take exactly $i$ attempts

$$N_R = \sum_{i=1}^{\infty} i P^{i-1}(1-P) = \frac{1}{1-P}$$ = expected no. of retransmission of one frame

(i) Stop and Wait

$$U_{\text{stop-and-wait}} = \frac{1-P}{1+2a}$$

(ii) Selective repeat ARQ

$$U_{\text{select-rep}} (N > 2a+1) = 1-P$$

$$U_{\text{select-rep}} (N < 2a+1) = \frac{N(1-P)}{1+2a}$$

Examinations : · Session *Confidential*

**MODEL ANSWER and MARKING SCHEME**

| | |
|---|---|
| First Examiner | Paper Code |
| Second Examiner | Question Page 4 *out of* |

Question labels in left margin | Marks allocations in right margin

Q1 (v) (iii) Go back N ARQ

– each error generates K retransmission

$$N_R = \sum_{i=0}^{\infty} f(i)\, P^{i-1}(1-P)$$

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

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

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

$$U_{\text{Go-back-N}}\ (N > 2a+1) = \frac{1-P}{1+2aP}$$

$$U_{\text{Go-back-N}}\ (N < 2a+1) = \frac{N(1-P)}{(1+2a)(1-P+NP)}$$

with the following approximation

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

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

Q2 (a) RIP:

- runs on top of UDP (distance-based)
- In RIP each router learns from its neighbours the distance to each destination
- metric for computation of shortest path is typically number of hops (max 15)
- A Router sends an update message to its neighbours every 30 seconds
- RIP uses mechanism to reduce routing loops

OSPF:

- Runs over IP (link-state based)
- OSPF enables each router learn the complete network topology
- Each router monitors the cost (link state) of the link to each of its neighbours.
- floods the link-state information to other routers on the network
- This scheme allow each router to build an identical complete network topology

BGPv4:

- de facto interdomain routing protocol
- based on classless address prefixes as well as policy based routing
- provide mechanism for address aggregation
- The routers that use BGP keep a global views of the internet in their Routing information Bases (RIBs)
- BGP routers exchange network reachability information containing e.g. sequence of ASs that packet must traverse to reach a destination

**Examinations :** · **Session** *Confidential*

**MODEL ANSWER and MARKING SCHEME**

| | |
|---|---|
| First Examiner | Paper Code |
| Second Examiner | Question Page 6 *out of* |

Question labels in left margin — Marks allocations in right margin

Q2 (9)

Multicast Routing

- For some application there is a need to send packets to multiple destinations simultaneously.
- Unicast routing: the packet is copied as many times as the destination
- Multicast routing: each packet is transmitted once per link (saving bandwidth in large sized networks)

DHCP

- A host requires three elements to connect to the internet
  - An IP address
  - A subnet mask
  - The address of nearby router
- Each time a user moves or relocates these elements must be reconfigured.
- DHCP automatically configure hosts that connect to a TCP/IP network
- provides mechanism for assigning temporary IP network addresses to host

Mobile IP

- Allows portable devices called mobile hosts (MHs) to roam while maintaining the communication sessions
- A legacy host communicating with an MH and the intermediate routers should not be modified
- Hence MH must continuously use its permanent IP address even as it roams to another area.

Examinations : · Session *Confidential*

**MODEL ANSWER and MARKING SCHEME**

| | |
|---|---|
| First Examiner | Paper Code |
| Second Examiner | Question Page 7 *out of* |

Question labels in left margin — Marks allocations in right margin

Q2 (c) (i) High performance forwarding
- Pure destination based forwarding
- switching forwarding
  - overlay model
  - Peer model

Overlay model
- IP seen as the dominant internetworking layer
- ATM is perceived as an economical switching solution for high-speed backbone networks
- overlay IP protocol on top of ATM.

Peer model
- IP routing and addressing set up ATM flows, and only a single network infrastructure needs to be managed

(ii) Any three of the following models / protocols should be described and discussed:
- Classical IP over ATM
- Next Hop Resolution Protocol
- LAN emulation
- multiprotocol label switching (MPLS)
- Integrated services (IntServ)
- reservation protocol (RSVP)
- Differentiated services. (DiffServ)
- Per Hop Behaviour (PHB)

Confidential

Examinations : . Session

MODEL ANSWER and MARKING SCHEME

First Examiner

Second Examiner

Paper Code

Question

Page 8 out of

Question labels in left margin

Marks allocations in right margin

Q 3(a) (i)

$$\min \sum_{(i,j)} D_{ij}\left[\sum_{\substack{\text{all path } p \\ \text{containing } (i,j)}} x_p\right]$$

$$\text{subject to} \quad \sum_{p \in P_w} x_p = r_w \quad \text{for all } w \in W$$

$$x_p \geq 0 \quad \text{for all } p \in P_w,\ w \in W$$

The problem is formulated in terms of the unknown path flows $\{x_p \mid p \in P_w, w \in W\}$

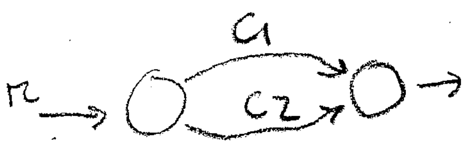
$W$ = set of all OD pairs

$P_w$ = set of all directed path connecting the originating and destination nodes of OD pair $w$

$r_w$ = traffic arrival rate entering the network at node $i$ and destined for node $j$.

$x_p$ = flow of path $p$

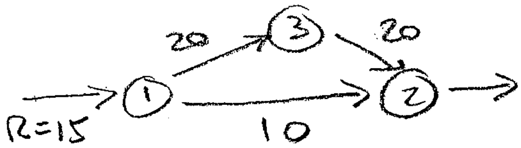
$D_{ij}[\ ]$ = Average number of packets in the system based on the hypothesis that each queue behaves as an M/M/1 queue of packets




$$\min \quad D_1[x_1] + D_2[x_2] = \frac{x_1}{C_1 - x_1} + \frac{x_2}{C_2 - x_2}$$

$$T = \frac{1}{r}\left(\frac{x_1}{C_1 - x_1} + \frac{x_2}{C_2 - x_2}\right)$$

Q3(a)
(ii)




$$D_i(x_i) = \frac{x_i}{c_i - x_i}, \quad T = \frac{1}{\gamma}\left(\frac{x_1}{c_{12}-x_1} + \frac{x_2}{c_{13}-x_2} + \frac{x_2}{c_{32}-x_2}\right)$$

$$x_1^* + x_2^* = R$$
$$x_1^* \geq 0, \; x_2^* \geq 0$$

$\Rightarrow$ according to the shortest path conditions

$$\frac{c_{12}}{(c_{12}-x_1^*)^2} = \frac{2c_{13}}{(c_{13}-x_2^*)^2}, \quad x_1^* + x_2^* = R \Rightarrow$$

$$\sqrt{c_{12}}\,(c_{13} - x_2^*) = \sqrt{2c_{13}}\,(c_{12} - x_1^*)$$

$$\sqrt{c_{12}}\,(c_{13} - R + x_1^*) = \sqrt{2c_{13}}\,(c_{12} - x_1^*)$$

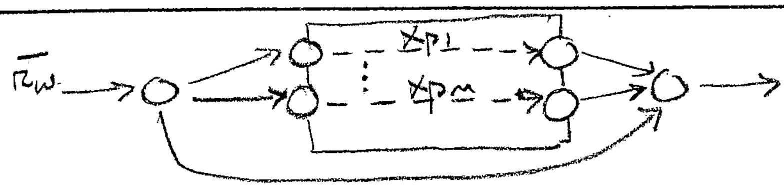
$$\sqrt{c_{12}}\,c_{13} - \sqrt{c_{12}}\,R + \sqrt{c_{12}}\,x_1^* = \sqrt{2c_{13}}\,c_{12} - \sqrt{2c_{13}}\,x_1^*$$

$$x_1^*\left(\sqrt{c_{12}} + \sqrt{2c_{13}}\right) = \sqrt{2c_{13}}\,c_{12} + \sqrt{c_{12}}\,R - \sqrt{c_{12}}\,c_{13}$$

$$x_1^* = \frac{\sqrt{2c_{13}}\,c_{12} + \sqrt{c_{12}}\,R - \sqrt{c_{12}}\,c_{13}}{\sqrt{c_{12}} + \sqrt{2c_{13}}}$$

$$x_2^* = R - x_1^*$$

Q3(b) (i)




$y_n = \bar{R}_W - R_W$

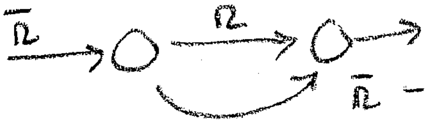
$$\min \sum_{(i,j)} D_{ij}(F_{ij}) + \sum_{w \in W} E_w(y_w)$$

subject to
$$\sum_{p \in P_w} x_p + y_w = \bar{R}_W \quad \text{for all } w \in W$$
$$x_p \geq 0 \quad \text{for all } p \in P_w,\ w \in W$$
$$y_w \geq 0 \quad \text{for all } w \in W$$

$$E_W(y_W) = e_W(\bar{R}_W - y_W)$$

$$e'_W(R_W) = -\left(\frac{a_W}{R_W}\right)^{b_W}, \quad a_W > 0,\ b_W > 0$$

(ii)




$\bar{R} - R = y$

$$D = \frac{R}{C-R} + \frac{a}{R}$$

$$\min \left( \frac{R}{C-R} + \frac{a}{\bar{R}-y} \right)$$

subject to $\quad R + y = \bar{R} \qquad R \geq 0,\ y \geq 0$

According to the optimality condition

$$\frac{c}{(c-\bar{r})^2} = \frac{a}{(\bar{r}-y)^2}$$

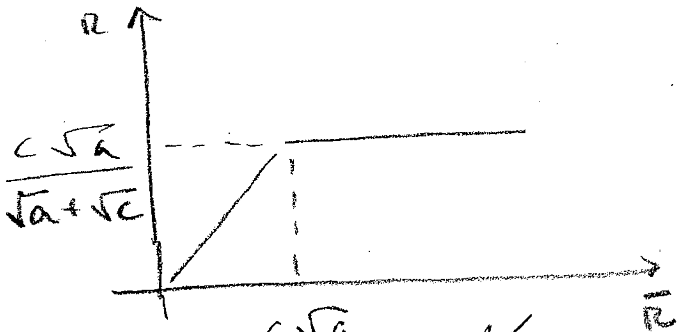
(i) No flow if:

$$\bar{r} < c \frac{\sqrt{a}}{\sqrt{a}+\sqrt{c}}$$

(ii) There is flow control when:

$$\bar{r} \geq c \frac{\sqrt{a}}{\sqrt{a}+\sqrt{c}}$$

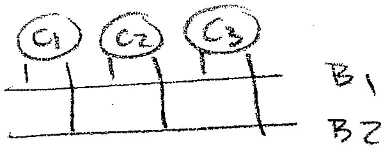
Q3(b)
(iii)




$$\frac{c\sqrt{a}}{\sqrt{a}+\sqrt{c}} = 4.5$$

a = influence the optimal magnitude of input rw

Q4 (a)




E = (# operational computers, # operational buses)

At least E = (2,1) to be operational therefore, all possible states

(3,2) = fully operational system

(3,1) = one bus down

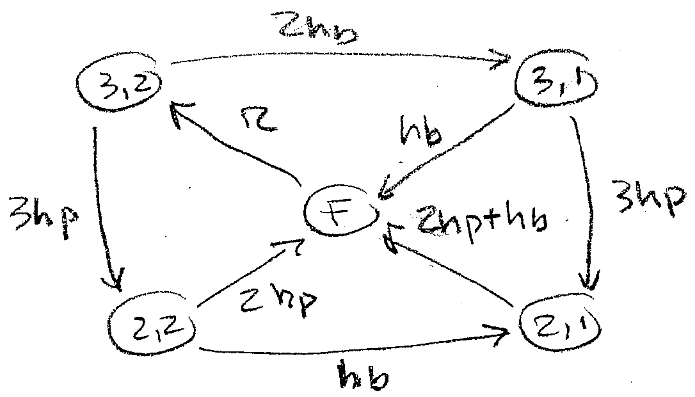
(2,2) = one computer down

(2,1) = one computer and one bus down

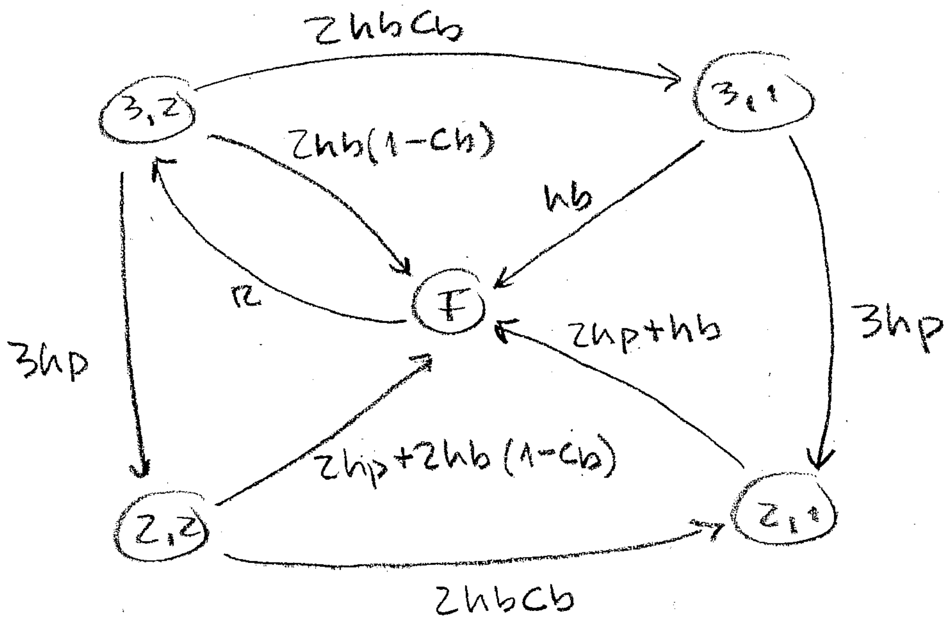
(x,x) = system in failed conditions

x = all other possible states

Q4 (b)


2hb
3,2
3,1
r2
hb
3hp
F
2hp+hb
3hp
2,2
2hp
2,1
hb

(c)


2hbCb
3,2
3,1
2hb(1-Cb)
hb
r2
F
2hp+hb
3hp
3hp
2hp+2hb(1-Cb)
2,2
2,1
2hbCb

Examinations : · Session *Confidential*

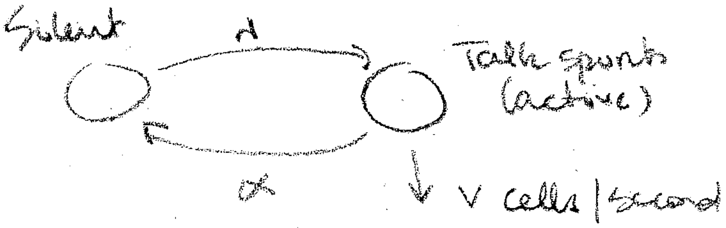
**MODEL ANSWER and MARKING SCHEME**

First Examiner | Paper Code
Second Examiner | Question | Page 14 *out of*

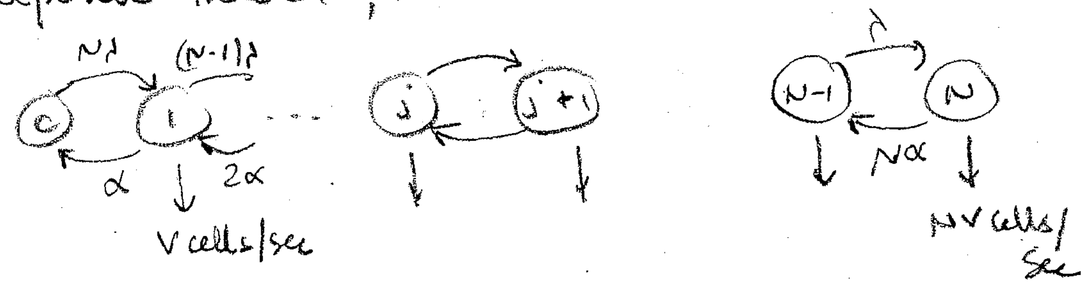
Question labels in left margin | Marks allocations in right margin

Q5 (a) Packet Voice Modelling

- A single voice source can be represented by a two-state process
  - alternating Active periods (talk spurts) with silence periods




Composite model, N voice sources

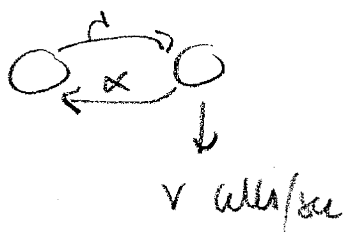



N-Multiplexed Independent Voice Sources

- If N-sources are independent; the probability of having i sources on is:

$$\Pi_i = \binom{N}{i} p^i p^{N-i} \quad , \quad p = \frac{\lambda}{\alpha+\lambda} \quad , \quad 1-p = \frac{\alpha}{\alpha+\lambda}$$

from:




$$Q = \begin{pmatrix} -\lambda & \lambda \\ \alpha & -\alpha \end{pmatrix}$$

$$\pi = \left[ \frac{\lambda}{\lambda+\alpha} , \frac{\alpha}{\lambda+\alpha} \right]$$

Q5 (b)

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

The 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

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

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 maximises her net benefit i.e.

$$\text{Max} \quad u_t(x) = u(x) - d_t x - p_t x$$

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

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

Q5 (c) (i)

$p$ = input fill factor

$\frac{p}{N}$ = probability that a given time slot on a given input contain a cell destined for a particular output

since cell arrival are uncorrelated among the various inputs the number of cells, K, bound for a particular output is a discrete RV

$$P(K=k) = \binom{N}{k}\left(\frac{p}{N}\right)^k\left(1-\frac{p}{N}\right)^{N-k} \qquad k=0,1,\dots,N$$

Since the switch is assumed to be buffer free, cells will be lost if two or more cells should simultaneously arrive bound for a common output

$$\langle L\rangle = \sum_{k=2}^{N}(k-1)\binom{N}{k}\left(\frac{p}{N}\right)^k\left(1-\frac{p}{N}\right)^{N-k}$$

$$= \sum_{k=0}^{N}(k-1)\binom{N}{k}\left(\frac{p}{N}\right)^k\left(1-\frac{p}{N}\right)^{N-k} + \left(1-\frac{p}{N}\right)^N$$

$$= N\left(\frac{p}{N}\right) - 1 + \left(1-\frac{p}{N}\right)^N$$

$$\langle L\rangle = p + \left(1-\frac{p}{N}\right)^N - 1$$

$$\langle F\rangle = p - \langle L\rangle = 1 - \left(1-\frac{p}{N}\right)^N$$