Paper Number(s): **E4.09**
SO8
ISE4.1
ISE4.3

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
UNIVERSITY OF LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2000

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

COMMUNICATION NETWORKS

Thursday, 18 May 2000, 10:00 am

There are FIVE questions on this paper.

Answer FOUR questions.

All questions carry equal marks.

Corrected Copy

Time allowed: 3:00 hours

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

Special Information for Invigilators: **NIL**

Information for Candidates: **NIL**

1. (a) In the OSI model one of the main functions of the network layer is routing.

   (i) Briefly enumerate the desirable properties of a routing algorithm.
   (ii) Define a framework in order to classify the different routing algorithms known to you.
   (iii) Briefly discuss and compare isolated routing, centralised routing and distributed routing.

   [10]

   (b) The network of Figure 1 is being offered a traffic of R1 [bits/second].

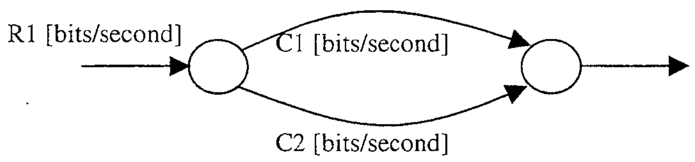


Figure 1

   (i) Explain the meaning of the *Mean Network Delay* function, *T*. Note: Assume that the network of Figure 1 can be modelled as a network of M/M/1 queues.
   (ii) Define and discuss *Fairness* in the context of an Optimal Routing problem. You can use the network of Figure 1 to give an example.
   (iii) Propose and discuss an objective function that could allocate traffic in a *Fair* way. Use the network of Figure 1 to elaborate your answer.

   [10]

2. (a) Define and compare the Fibre Distributed Data Interface (FDDI) and Distributed Queue Dual Bus (DQDB) protocol.

   [10]

   (b) Discuss the effect of propagation delay and transmission rate on a maximum potential efficiency of a half duplex point-to-point line using the stop-and-wait scheme.

   [10]

3. (a) Consider a two-processor (degradable/repairable) system. The processor failure rate is $\gamma = 0.2$ [failures/unit_time], the processor repair rate is $\tau = 4.0$ [repairs/unit _time] and the coverage factor is c = 0.99. In the event of a total failure the system can be replaced at a rate $\rho = 8.0$ [replacements/unit_time].

Assuming that a job can be divided into parallel subtasks, and that the service rate in state *I* is $R_I = 1.0$ [service/unit_time] and that the service rate in state *II* is $R_{II} = 1.6$ [service/unit_time]:

(i) Build up the continuous time Markov chain (CTMC) representing the system in which states *II*, *I* and 0 represent a system with two, one and no operational processor(s), respectively.

(ii) Find the value of $\lim_{t\to\infty} E[W(t)]$, where $W(t) \equiv Y(t)/t$ and *Y(t)* is the accumulated reward per unit of time *t*.

[10]

(b) Network Survivability is an issue of great concern to the telecommunication industry. Define and discuss briefly the following class of survivable network architectures:

(i) Automatic protection switching/diverse protection (APS/DP),
(ii) Dual homing,
(iii) Self healing rings (SHRs),
(iv) Dynamic path reconfigurable mesh architectures.

[10]

4. (a) ITU-T and the ATM Forum have identified a range of traffic control functions to maintain the quality of ATM connections. Describe briefly:

(i) Call Admission Control and Usage Parameter Control,
(ii) Priority control,
(iii) Traffic shaping,
(iv) Fast resource management.

[10]

(b) Define and discuss the following aspects of the Internet infrastructure:

(i) Resource reservation protocol (RSVP),
(ii) Routing Arbitration,
(iii) Border gate protocol.

[10]

5. (a) Consider a combined optimal routing problem and flow control scheme (e.g. a rate adjustment scheme). A proposed formulation for this problem has been suggested as:

$$\text{Minimise} \quad D = \sum_{(i,j)} D_{ij}(F_{ij}) + \sum_{w \in W} e_w(r_w)$$

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

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

$$0 \leq r_w \leq \overline{r_w}, \quad \textit{for all} \quad w \in W$$

(i) State clearly the meaning of all the variables involved in this optimisation problem.

(ii) State clearly with respect to which variables the minimisation is being carried out.

(iii) Discuss your choice of appropriate type of functions e_w. Use graphs if necessary.

(iv) Show that the combined routing and flow control problem is mathematically equivalent to an optimal routing problem.

[10]

(b) Consider an underlying *Communication Network Design* problem:

(i) Briefly state the formulation of a network design problem.

(ii) Briefly describe a network design known to you.

[10]

COMMUNICATION NETWORKS 2000

SOLUTIONS

Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner	Paper Code	EE 4.09
Second Examiner	Question 1	Page 1 out of 11

Question labels in left margin — Marks allocations in right margin

1 a) (i) Some desirable properties:
- Simplicity
- Robustness
- Stability
- fairness
- optimality

(ii) Routing algorithms can be grouped into two major classes:
- non adaptive (not based on measurements or estimates of the current traffic or topology)
- adaptive (attempt to change their routing decisions to reflect changes in topology and traffic pattern)

(iii) Centralise routing: use information collected from the entire network in an attempt to make optimal decisions
Isolated routing: run separately on each node and only use information available there (e.g. queue length)
Distributed Algorithm: use a mixture of global and local information

Centralise routing drawbacks:
- large networks algorithm become time consuming
- one point of failure
- inconsistencies may arise due to different tables in different nodes

Distributed routing issues
- quasi-static assumption
- fast settling time assumption
- synchronous update assumption

10

Examinations : 199 -9 Session	Confidential
MODEL ANSWER and MARKING SCHEME	
First Examiner	Paper Code 409
Second Examiner	Question 1 Page 2 out of
Question labels in left margin	Marks allocations in right margin

1b) (i) $T = \frac{1}{\gamma} \sum_{i=1}^{L} \frac{F_i}{C_i - F_i}$ (mean network delay)

This formula with C_i = Transmission capacity, F_i = flows carried by link i and γ = external workload is proportional to the total number of packet outstanding in the network, i.e. a suitable congestion measure.

(ii) An unfairness measure η can be defined to be the disparity among path delays (best and worst path delay) within the same O-D pair

$$\eta = \left(\frac{\max \mu_i - \min \mu_p}{\min \mu_p} \right)$$

μ_p & μ_i are average packet delay for different paths of the same O-D.

(iii) $$T_1 = \sum_{i=1}^{L} \int_0^{F_i} \frac{f_i}{C_i - f_i} \, df_i$$

which has a first derivative length for path p:

$$\frac{\partial T_1}{\partial x_p} = \sum_{i \in p} \frac{1}{C_i - X_i}$$

for the simple network of figure 1

$$\frac{\partial T}{\partial x_p} = \sum_{i \in p} \frac{C_i}{(C_i - X_i)^2}$$ so

$X_i \sim 0 \quad \frac{\partial T}{\partial x_p} \approx \frac{\partial T_1}{\partial x_p}$

$X_i \to C_i \quad \frac{\partial T}{\partial x_p} \neq \frac{\partial T_1}{\partial x_p}$

T is almost the same if T or T_1 is chosen

10

Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner | Paper Code 409
Second Examiner | Question 2 Page 3 *out of*

Question labels in left margin | Marks allocations in right margin

2a) FDDI = token distributed data Interface
-high speed ring LAN
-employs token ring algorithms
Some differences with Token rings:
-stations emits a new token immediately following the transmission of a frame (i.e. more efficient specially in large rings)
-At any one time, there may be multiple frames circulating the ring
capacity allocation
-FDDI provide support for a mixture of streams and bursty traffic
-FDDI define two type of traffic: synchronous and asynchronous
The allocation is such that:

$$D_{max} + F_{max} + TokenTrip + \sum SA_i \leq TTRT$$

where
SA_i = Synchronous allocation station i
D_{MAX} = propagation time for one complete circuit of the ring
F_{MAX} = Time required to transmit a maximum length packet (4500 oct)
Token Time = time required to transmit a token
TTRT = target token rotation (each station store the same value)

5

Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner

Second Examiner

Paper Code 409

Question 2 Page 4 out of

Question labels in left margin

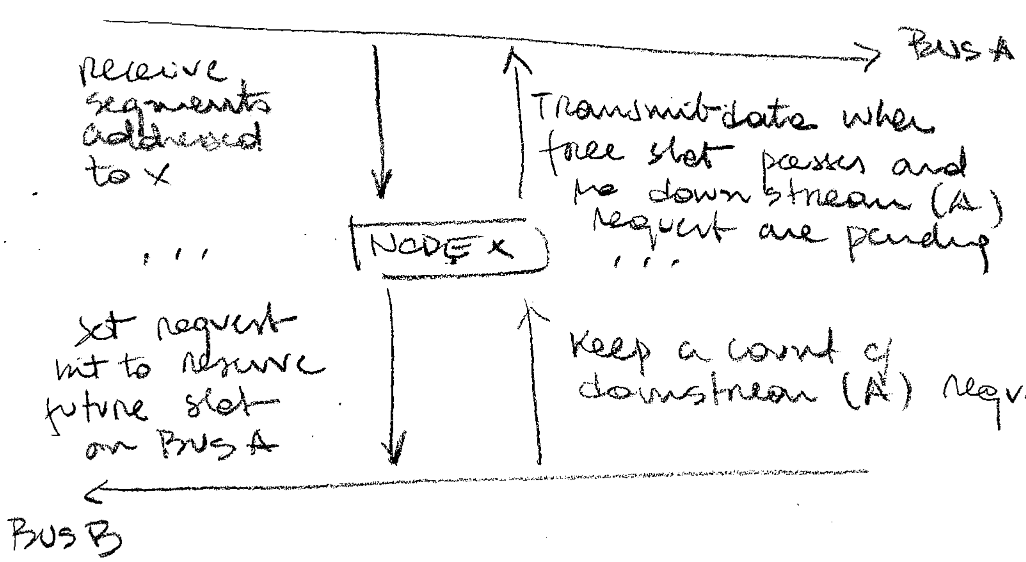
Marks allocations in right margin

2a) DQDB: distributed queue dual bus

DQDB MAC protocol (802.6) is part of IEEE MAN standard

- Use a dual bus configuration
- Transmission on each bus consists of a steady stream of fixed-size slots with a length of 53 octets
- Node read or copy data from slots, they also access to the medium by writing into slots
- The distributed queue access protocol is a distributed reservation scheme
- with light load, delay is negligible, property shared by CSMA/CD protocol
- Under heavy load, virtually all free transmission slots will be utilised (i.e. efficiency approaches 100%) a property shared by token ring protocol
- able to carry - bursty traffic (e.g. interactive users) and sustain stream like traffic (e.g. file transfer)

Basic operation



5

Examinations : 199 -9 Session

Confidential

MODEL ANSWER and MARKING SCHEME

First Examiner

Second Examiner

Paper Code 409

Question 2 Page 5 out of

Question labels in left margin

Marks allocations in right margin

2b) Half duplex point-to-point line using stop and wait scheme

a = propagation delay / transmission delay = t_{prop} / t_{frame}

The total time to send n Frames is:

$T_D = T_I + nT_F$

where T_I is the time to initiate the sequence and T_F time to send one frame

$T_I = t_{prop} + t_{poll} + t_{proc}$

$T_F = t_{prop} + t_{frame} + t_{proc} + t_{prop} + t_{ack} + t_{proc}$

for long sequences of frames, T_I is relatively small and can be neglected. Also assume that the processing time between transmission and reception is also negligible, and that the acknowledgement frame is very small, then:

$T_D = n(2t_{prop} + t_{frame})$

of this time only $n\,t_{frame}$ is actually transmitting data. Thus, the utilisation of the line is:

$$U = \frac{n\,t_{frame}}{n(2t_{prop} + t_{frame})} = \frac{1}{1+2a}$$

The problem here is that only one frame at a time can be in transit. If $a > 1$ the link will be under utilised. The obvious solution is to allow multiple frames to be in transit at one time.

10

Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner

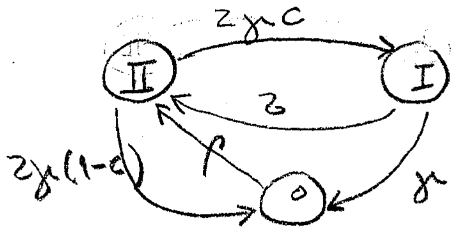
Second Examiner

Paper Code 409

Question 3 Page 6 *out of*

Question labels in left margin — Marks allocations in right margin

3a)



$$Q = \begin{bmatrix} -2\gamma & 2\gamma c & 2\gamma(1-c) \\ z & -(z+\gamma) & \gamma \\ \rho & 0 & -\rho \end{bmatrix}$$

steady state sol:

$$Q = \begin{bmatrix} -0.4 & 0.396 & 0.004 \\ 4.0 & -4.2 & 0.2 \\ 8.0 & 0 & -8.0 \end{bmatrix}$$

$$\begin{bmatrix} -0.4 & 4.0 & 8.0 \\ 0.396 & -4.2 & 0 \\ 0.004 & 0.2 & -8.0 \end{bmatrix} \begin{bmatrix} x_{11} \\ x_1 \\ x_0 \end{bmatrix} = 0$$

$x_{11} + x_1 + x_0 = 1$

Since one is a linear combination of the others:

$$x_{11} = \frac{4.2}{0.396} x_1$$

$$-0.4 \frac{4.2}{0.396} x_1 + 4x_1 + 8\left(1 - x_1 - \frac{4.2}{0.396} x_1\right) = 0$$

$$-4.24 x_1 + 4 x_1 - 8(11.6) x_1 = -8$$

$$\Rightarrow x_1 = 8/93.08 = 0.085939$$

$$x_{11} = \frac{4.2}{0.396} \times 0.085939 \approx 0.911482$$

$$x_{111} = 1 - x_1 - x_{11} \approx 0.002579$$

and $R_{11} = 1.6$, $R_1 = 1$, $R_0 = 0$

$$\lim_{t \to \infty} E[W(t)] = \sum_{i=1}^{11} R_i x_i = \begin{array}{r} 1.458371 \\ +0.085939 \\ \hline 1.544310 \end{array}$$

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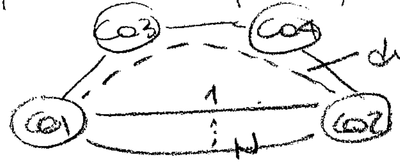
Examinations : 199 -9 Session ***Confidential***

MODEL ANSWER and MARKING SCHEME

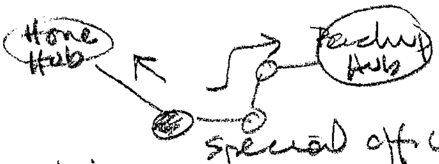
First Examiner	Paper Code 409
Second Examiner	Question 3 Page 7 *out of*

Question labels in left margin | Marks allocations in right margin

3b) i) APS : advantage of being totally automatic and is commonly used to facilitate maintenance and protect working services. 1:N diverse protection structure places the protection fibre, in a physically diverse route

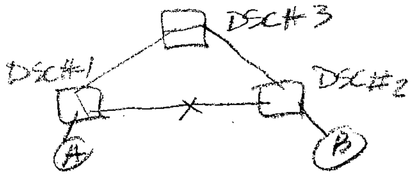


ii) Dual Homing : is an office backup concept that assigns two hubs to each office and requires dual access to other offices. In dual-homing, demand originating from a special CO is split between two hubs : a home hub and a designated foreign hub



iii) Self-healing rings : like the 1:1 diverse protection structure is totally automatic and provide 100% restoration capability for a single cable cut and equipment failure.

iv) Dynamic Path Rearrangeable mesh architectures : these architecture uses digital cross-connect (DCSs) to reroute demands around failure. DSC does not require standby protection facilities dedicated to working systems. Instead it uses spare capacities within working systems to restore affected demand. The penalties for this efficient use of spare capacities are the time and complexity needed for the controller to communicate with network DCSs as well as maintenance



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4a) i) CAC: when a user request a new VPC or VCC, the user must specify the traffic characteristics. The user selects traffic characteristics by selecting a QoS. The network accepts the connection only if it can commit resources. The traffic contracts consist of PCR, CDV, SCR & burst tolerance

UPC: monitors the ATM connection to determine whether the traffic conforms to the traffic contract.
- Peak cell rate Algorithm
- Sustainable cell rate algorithm

ii) Priority control: comes into play when the network discards (CLP=1) cells. The objective is to discard lower-priority cells. No way to discriminate between cells that were labelled as lower priority by source or tagged by UPC function

iii) Traffic shaping: used to smooth out a traffic flow and reduce cell clumping. This can result in a fairer allocation of resources and a reduced average delay time.

iv) Fast Resource Management: Operate on the time scale of the round-trip propagation delay of the ATM connection.

ATM congestion control refers to the set of actions taken by the network to minimise the intensity, spread, and duration of congestion. e.g. Selective discarding and Explicit forward congestion

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Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner	Paper Code 409
Second Examiner	Question 4 Page 9 *out of*

Question labels in left margin | Marks allocations in right margin

4 b) i) RSVP allows source and destination devices to communicate and to reserve intermediate network resources for inelastic applications.

- The RSVP is not a routing protocol; rather, it is an Internet control protocol that establishes and maintains resource reservations over a distribution tree.
- The RSVP uses a receiver-based model; i.e. each receiver in the distribution tree for point-to-multipoint connection determines the QoS needed for the path bandwidth.
- The sender's RSVP path message contains the sender's filterspecs TSpec (traffic characteristics of the data stream the sender will generate: for traffic control, over reservation and failure situations)
- Each receiver sends an RSVP reservation request upstream: each intermediate switch stores the relevant reservation information.
- both message use time-out

ii) Routing Arbitration; To maintain complex routing information, many large NAPs offer Routing Arbiter (RA). The RA provide a Routing Information Database over a Route server directly attached to the NAP. (RADB). When peer with the RA, they get their routing table information from the RADB which is configured with pre-agreed, basic transit/access policies. RADB is periodically checked against and synchronised with the global Internet Routing Registry (IRR) (global view)

iii) BGP4: support interdomain routing based on classless address prefixes as well as policy-based routing. BGP4 also provides the mechanism for address aggregation. The inter-AS routers use BGP4: They keep a global view of the Internet in their Routing Information Bases (RIBs) and know how to forward data encapsulated in IP packets hop-by-hop towards their destination. The primary function of a BGP is to exchange network reachability information with other BGP peers. 10

5a) i) r_w = input rate of an OD pair w
x_p = path flows
F_{ij} = Flow on link (i,j)
$\bar{r}_w$ = desired input by OD pair w (i.e. offered load if no control is exercised)
e_w = penalty for throttling the input r_w

ii) Here the minimisation is carried out jointly with respect to $\{x_p\}$ and $\{r_w\}$.

iii) e_w functions are monotonically decreasing on the set of positive numbers $(0,\infty)$ and tend to ∞ as r_w tends to zero. An interesting class of function is specified by: $e_w'(r_w) = -\left(\frac{a_w}{r_w}\right)^{b_w}$
a_w ~ Influence optimal magnitude of r_w
b_w ~ Influence the priority of OD pair

iv) use $y_w = \bar{r}_w - r_w$
$E_w(y_w) = e_w(\bar{r}_w - y_w) = e_w(r_w)$

minimise $D = \sum_{ij} D_{ij}(F_{ij}) + \sum_{w \in W} E_w(y_w)$

subject to $\sum_{p \in P_w} x_p + y_w = \bar{r}_w \quad \forall \ w \in W$
$x_p \geq 0 \quad \forall \ p \in P_w, w \in W$
$y_w \geq 0 \quad \forall \ w \in W$

10

Examinations : 199 -9 Session *Confidential*

MODEL ANSWER and MARKING SCHEME

First Examiner	Paper Code 409
Second Examiner	Question 5 Page 11 out of 11

Question labels in left margin — Marks allocations in right margin

5b i) given
- geographical location of a collection of nodes that need to communicate with each other
- a traffic matrix representing the input traffic flow between each node

- it is required to design
  - the topology of the communication network
  - the local access network
- considering the following objectives
  - keep ~~the~~ performance design measure within a predefined level
  - satisfy some reliability constraints
  - minimise a combination of capital investment and operational costs

ii) These methods start with a network topology and search locally around an existing topology for another topology that satisfies the constraints and has lower costs.

1) Available current best topology and a trial topology
2) Assign the flows (e.g. ORP)
3) check performance criteria
4) check reliability
5) check cost improvement
6) generate a new trial topology (use appropriate heuristic) go to 2)

Example of heuristic:
i) lower capacity under utilised or eliminate altogether
ii) increase the capacity of some overutilised link
⇒ combine these two into the branch exchange heuristic

10