E3.17
SO8
ISE3.31

IMPERIAL COLLEGE LONDON

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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2007

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

COMMUNICATION NETWORKS

Tuesday, 8 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR 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) :	P.J. Beevor

Special instructions for students

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

$$T = \frac{1}{\mu - \lambda}$$

where,

λ = arrival rate to M/M/1 system [packets / s]

μ = service rate of M/M/1 system [packets / s].

1.

a)

i) For a point to point link connection briefly define

- Propagation time,
- Transmission time.

[4]

ii) Discuss the impact of propagation time and transmission time on link utilisation. Derive the maximum efficiency of a half duplex point to point link using a stop and wait scheme.

[6]

b)

i) Describe a sliding window flow control scheme known to you.

[3]

ii) State the condition under which a Host sender A will receive acknowledgement of Frame 1 before all the window frames have been sent.

[4]

iii) Derive the utilisation of the link if the condition in b) ii) is not met.

[3]

2.

a) Little's theorem can be stated by the following expression:

$N = \lambda T$.

Define and discuss the meaning of λ, N and T.

[8]

b) In a Jackson network of queues the numbers of packets in link i can be represented by:

$q_i = \lambda_i t_i$.

i) Define and discuss the meaning of q_i, λ_i and t_i.

[3]

ii) Define and derive and expression for the mean network delay of a Jackson network in terms of q_i. Clearly state all assumptions made.

[9]

3.

a) Routing algorithms can be classified amongst others as global or decentralised.

i) Define and describe a global routing algorithm known to you. Give an example on how it operates using the network and link length *l(k), k=1,...,5* of Figure 3.1.

[5]

ii) Define and describe a decentralised routing algorithm known to you. Give an example on how it operates using the network and link length *l(k), k=1,...,5* of Figure 3.1.

[5]

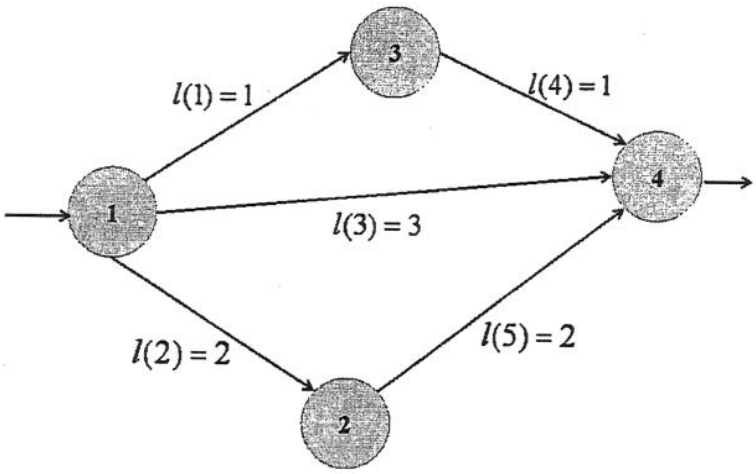

Figure 3.1

b)

i) Classify and, briefly describe and discuss the main characteristics of the Routing Information Protocol.

[5]

ii) Classify and, briefly describe and discuss the main features of the Open Shortest Path First algorithm.

[5]

4.

a) INSERV provides specifications of a number of service classes and mechanisms to support them.

Briefly describe and discuss four INTSERV support mechanisms known to you.

[10]

b) Briefly discuss INTSERV and DS models in terms of:

- coordination for service differentiation,
- scope of service differentiation,
- scalability,
- network accounting,
- network management,
- inter-domain deployment.

[10]

5.

a)

i) For the network of Figure 5.1 state the optimal routing problem. That is, clearly define and explain variables, objective function, constraints etc.

[3]

ii) Define the optimality condition for the problem introduced in i) if the objective is to minimise the following function.

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

where

$C(i)$ = capacity of link i, and $f(i)$ = flow carried by link i.

[3]

iii) Assuming that $C(1) > C(2)$ in Figure 5.1, derive the condition under which only $C(1)$ will carry traffic.

[4]

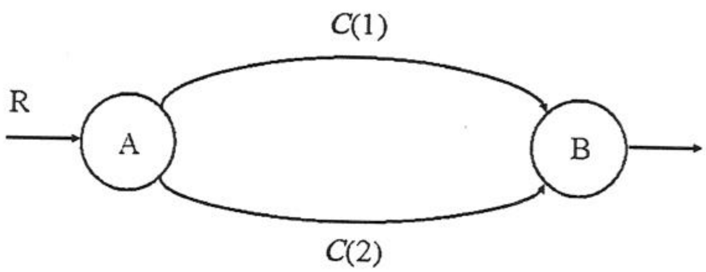

Figure 5.1

b)

i) Explain the importance and usefulness of source descriptors in ATM networks

[5]

ii) Explain one mechanism that would monitor *connection contracts* established between end-users and the ATM network.

[5]

6. For the network in Figure 6.1

Network

a) Derive the mean packet delay.

[10]

b) Derive the mean number of outstanding packets in links $i = 1, 2$ and 3.

[10]

Assume an average packet length $1/\mu$ of 1000 [bits/packet].

Notation:

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

$C(i)$ = transmission speed link i [bit / s]

γ_{ij} = arrival rate (node i to node j)][packets / s]

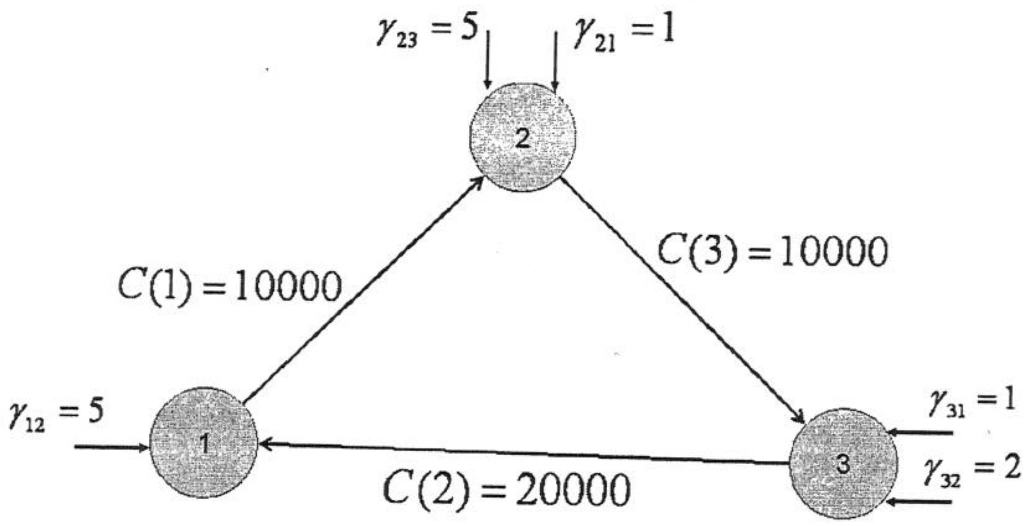

Figure 6.1

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Model Answers and Mark Schemes First Examiner: J.A. Barria

communication Networks

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Question Number etc. in left margin Q1 Mark allocation in right margin

a i) Propagation time: the time it takes a signal to propagate from one node to the next (distance / velocity)

Transmission time: time it takes a transmission to send out a block of data (length of frame / data rate)

ii) Effect of propagation time and transmission time. Define

a = propagation time / transmission time 4

In a Half-duplex point to point line using a stop and wait scheme long messages are sent as a sequence of n frames. So the time it takes to transmit n frame - assuming that the acknowledge frame is very small - is

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

Hence an approximation to the max utilisation in this scheme is

$$U = \frac{n t_{frame}}{n(2t_{prop} + t_{frame})} = \frac{1}{1+2a}$$ 6

b i) sliding window protocol

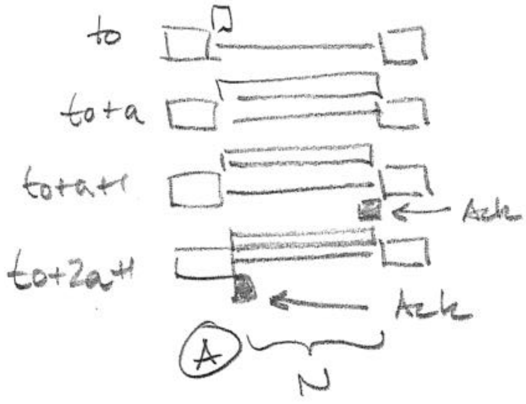
- sender: keep a list of sequence number allow to be sent
- keep frames in memory until acknowledge
- if buffer full: stop transmitting

- Receiver: keep a window size with the number of frame sequence it is permitted
- Frames falling outside window are discarded 3

Question Number etc. in left margin

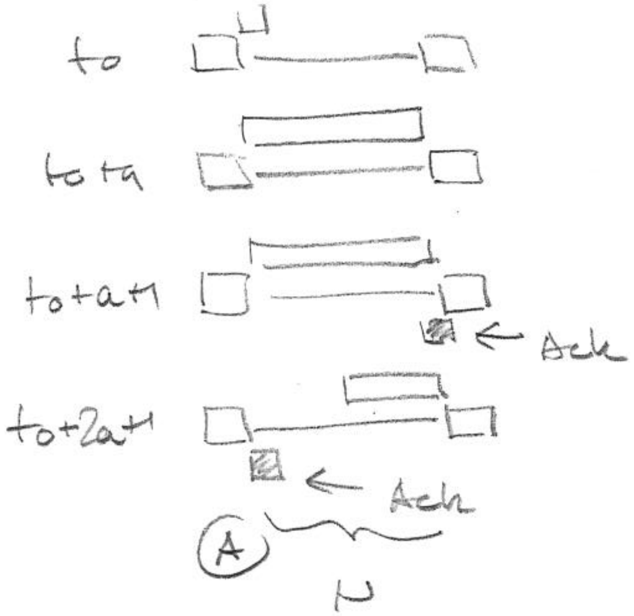
Mark allocation in right margin

b ii) The condition is $N > 2a+1$ (N the size of the window)



$N > 2a+1 \cdot U = 1$ 4

b iii) if $N < 2a+1$ the sequence looks



if $N < 2a+1$: $U \simeq \dfrac{N}{2a+1}$ 3

(Bookwork extension)

Question Number etc. in left margin Q2 Mark allocation in right margin

a) Little's result expresses the natural idea that crowded systems (large N) are associated with long customer delays (large T).

- $N(t)$ = number of customers in the system at time t
- $\alpha(t)$ = number of customers who arrived in $[0,t]$
- T_i = time spent in the system by the ith arriving customer

Take the time averages

$$N = \lim_{t\to\infty} N_t \qquad N_t = \frac{1}{t}\int_0^t N(\tau)\,d\tau$$

$$\lambda = \lim_{t\to\infty} \lambda_t \qquad \lambda_t = \alpha(t)/t$$

$$T = \lim_{t\to\infty} T_t \qquad T_t = \sum_{i=0}^{\alpha(t)} T_i \Big/ t$$

then $N = \lambda T$ 8

bi) λ_i = arrival rate link i (packets/s)

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

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

C_i = Transmission speed link i [bits/second]

q_i = number of packets in link i

from M/M/1 analysis 3

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bii) Average number of packet in the Network

$$N = \gamma T$$

Average number of packets in link i

$$q_i = \lambda_i t_i$$

so

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

but (M/M/1)

$$t_i = \frac{1}{\mu C_i - \lambda_i} \quad \text{(see part bi)}$$

$$N = \sum_{i=1}^{L} \frac{\lambda_i}{\mu C_i - \lambda_i}$$

defining $F_i = \lambda_i / \mu$

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

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(bookwork + calculation for a new example)

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Q 3

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a i) Global routing algorithm

- Calculate least-cost path using complete, global knowledge about the network
- Need mechanism to obtain this information before calculations
- The calculations can be performed in one site or can be replicated at multiple sites
- They are normally referred to as link-state algorithms

Example : Dijkstra's sh-p. algorithm (use Fig 3.1)

a ii) Decentralised routing algorithm

5

- Calculate the least-cost path in an iterative, distributed manner
- Each node begins with only the knowledge of the cost of its attached links
- Then by exchanging information with neighbouring nodes a node gradually calculate the least-cost path
- They are normally known as distance-vector algorithm

Example : Bellman-Ford's algorithm (use Fig 3.1) 5

(bookwork) + (calculation of new example)

6/

Q3

bi) RIP
- IGP
- Runs on top of UDP (distance-vector)
- 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 30s
- RIP uses mechanism to reduce route loops

bii) OSPF
- IGP
- runs over IP (link-state)
- enables each router to 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 allows each router to build an identical complete network topology.

(Book work)

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Q4

a) INTSERV mechanism

Flowspec: provide the network with flow information 2

Admission control: ask the network to provide a particular service 3

Resource reservation: Exchange of information which results in resource reservation using RSVP signalling scheme 3

Manage packets – queue and scheduled in routers. That is packet scheduling and traffic policing 2

b)

	INTSERV	DS	
Coordination for service diff.	– End-to-end	– local (per-hop)	2
– Scope of service diff.	– Unicast or multicast	– Anywhere in a network or in specific paths	2
– scalability	– limited by nr. of flows	– limited by the nr of classes	
– Network Accounting	– Based on flow characteristics and QoS requirements	– Based on class usage	2
– Network management	– similar to circuit switching	– similar to IP networks	2
– Inter domain deployment	– Multilateral agreements	– Bilateral agreements	2

(Bookwork + new explanation)

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Q5

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a i)

$$D(x) = \sum_{i=1}^{2} \frac{x_i}{c_i - x_i} = \frac{x_1}{c_1 - x_1} + \frac{x_2}{c_2 - x_2}$$

$x_1 + x_2 = R$ $\qquad x_1 \geq 0 \;;\; x_2 \geq 0$

$c_1 + c_2 \geq R$ $\qquad c_1 > c_2$

3

ii)
$$\frac{\partial D(x)}{\partial x_1} = \frac{c_1 - x_1 + x_1}{(c_1 - x_1)^2} + \frac{-(c_2 - R + x_1) - (R - x_1)}{(c_2 - R + x_1)^2}$$

$$\frac{\partial D(x)}{\partial x_1} = 0 \Rightarrow \frac{c_1}{(c_1 - x_1)^2} = \frac{c_2}{(c_2 - x_2)^2}$$

3

iii)
$$\frac{c_1}{(c_1 - R)^2} \leq \frac{c_2}{(c_2 - 0)^2} = \frac{1}{c_2}$$

$$R \leq c_1 - \sqrt{c_1 c_2}$$

4

(calculation of new example)

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QS

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b i) Source descriptors / connection contract

- The capability of the network to provide QoS depends on the manner in which the connection produces cells for transmission
- PCR: Peak cell rate. This is an upper bound on the cell rate submitted to an ATM connection
- SCR: sustainable cell rate. Upper bound on the average cell rate
- MBS: Maximum burst size: upper bound on the variability in the pattern on cell arrivals with reference to the sustainable cell rate
- MCR: Minimum cell rate: minimum average cell rate that the source is always allow to send
- CDV: cell Delay variation tolerance: upper bound on the variability in the pattern on cell arrivals with reference to the peak rate

A connection contract between the end-use and the network must be specified 5

ii) Traffic policing mechanism will monitor the calls that are established

- Usage parameter control (UPC) is the process of enforcing the traffic agreement at the UNI
- One possible implementation of a generic cell rate algorithm (GCRA) is the leaky bucket algorithm
- Description and discussion of leaky bucket algorithm 5
- other: window policing mechanism, rate control and traffic shaping

(Book work)

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Q6

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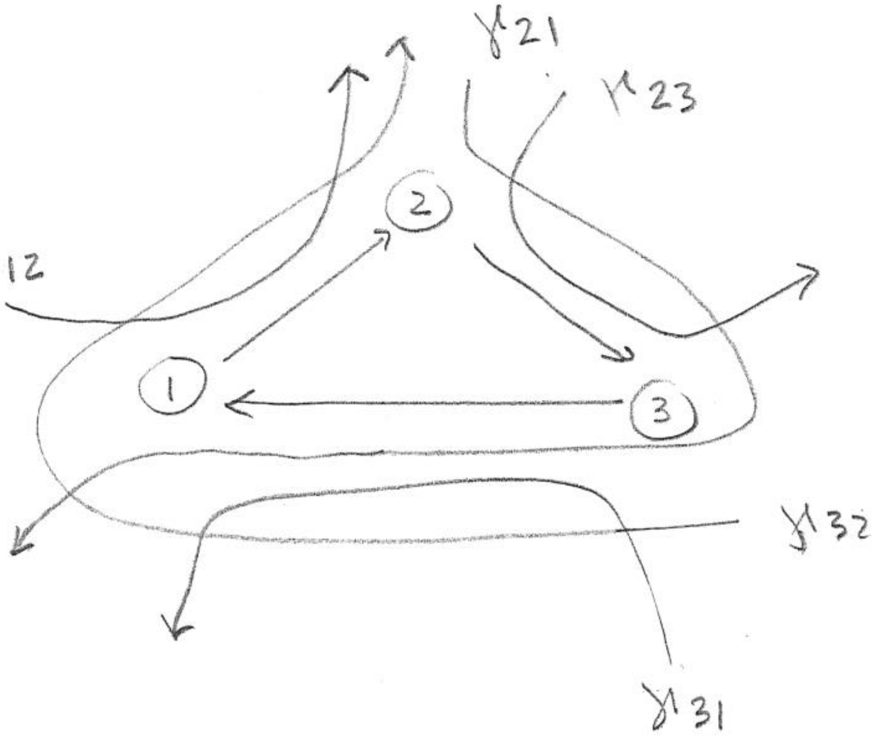

i) $q_{ij} = d_{ij} \cdot t_{ij} = \dfrac{d_{ij}}{\mu C_{ij} - d_{ij}}$ 5

$q_{12} = \dfrac{\gamma_{12} + \gamma_{32}}{\mu C_{12} - (\gamma_{12} + \gamma_{32})}$ $q_{23} = \dfrac{\gamma_{21} + \gamma_{23}}{\mu C_{23} - (\gamma_{21} + \gamma_{23})}$ 5

$q_{31} = \dfrac{(\gamma_{21} + \gamma_{31} + \gamma_{32})}{\mu C_{31} - (\gamma_{21} + \gamma_{31} + \gamma_{32})}$ 5

ii) using Little's $N = \gamma T = \sum_{i=1}^{L} d_i t_i = \sum_{(i,j)} q_{ij}$ 5

$T = \dfrac{1}{\gamma} \left(q_{12} + q_{23} + q_{31} \right)$

(✓ calculate numerical example)