E3.17
SO8
ISE3.31

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2010

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

Corrected Copy

Q1, Q3

COMMUNICATION NETWORKS

Thursday, 13 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) : C. Ling

Special information for students

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

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

where

λ = arrival rate at M/M/1 system [$packets / s$], and

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

2. Velocity of propagation

Velocity of unguided transmission through air or space = speed of light = $3 \cdot 10^8 [m/s]$

Velocity of guided transmission (e.g. optical fibre and copper media) ≈ 0.67 the speed of light.

3. Optimal Routing Problem (ORP)

$$Min\ D(F) = \sum_{i=1}^{L} \frac{F_i}{C_i - F_i} \quad \text{with respect to } \{F_i\}$$

C_i = Capacity of link l_i.
F_i = Flow carried by link l_i.

The Questions

1.

a) Derive the maximum potential efficiency, ***U***, for a half duplex point to point link using a stop and wait mechanism. Clearly show all the steps in your derivation. [4]

b) For a high speed wide area network (WAN) link using a stop and wait mechanism assume:

- standard data rate = 155.52 [*Mbps*] (e.g. using optical link)
- distance between two adjacent stations = 1000 [*km*]
- frame size = 53 [*octects*]

Calculate the maximum potential efficiency ***U***. [2]

c) For a Local area network (LAN) using a stop and wait mechanism assume:

- standard data rate = 10 [*Mbps*] (e.g. using coaxial cable)
- distance between two adjacent stations = 1.0 [*km*]
- frame size = 1000 [*bits*]

Calculate the maximum potential efficiency ***U***. [2]

10:20am d) Discuss the results of your calculations in parts ~~a) & b)~~ b) & c). Identify the key factor(s) that will limit the maximum efficiency attainable. [5]

10:20am e) Explain what you would need to do to improve the efficiency of the stop and wait mechanism investigated in parts ~~a) & b)~~. b) & c) [2]

10:20am. f) Discuss an alternative flow control mechanisms to the one investigated in parts ~~a) & b)~~ such that the potentially efficiency ***U*** is improved. [5]
b) & c).

2.

a) Briefly describe the operation of the three different TCP congestion control mechanisms listed below:

- additive increase / multiplicative decrease,
- slow start, and
- reaction to time out events.

[6]

b) Consider the following parameters:

- W = window size in segments,
- S = maximum segment size in bits,
- R = transmission rate of link,
- RTT = round trip time, and
- O = size of the object.

i) Show that latency for a TCP control congestion mechanism when $WS/R > RTT + S/R$ is given by:

$2RTT + O/R$

Clearly explain all the steps in your derivation.

[4]

ii) Show that latency for a TCP control congestion mechanism when $WS/R < RTT + S/R$ is given by:

$2RTT + O/R + (k-1)[S/R + RTT - WS/R]$

Define parameter k in the above expression.

Clearly explain all the steps in your derivation.

[4]

c) Consider an IP based network, for example, the Internet.

i) You are asked to transport short real-time messages periodically. Which transport layer protocol will you choose and why?

[3]

ii) You are asked to transfer long files containing, for example, Bank transactions that need to be received with no errors. Which transport layer protocol will you choose and why?

[3]

3.

a) Consider the packet network represented in Fig. 3.1. and the following observations:

- all offered traffic ($\gamma_{14}, \gamma_{24}, \gamma_{34}$) form a Poisson stream,

- the destination of all traffic is node 4,

- the packet arrival rate is $\gamma_{ij} = 10$ [*packets/s*],

- any flow arriving at a node that has two outgoing links is split up randomly (30%, 70%) using the rule shown in Fig. 3.2.,

- the mean length of a packet is $1/\mu = 100$ [*bits*].

- the capacity of each link is 10 [*Kbps*].

Furthermore, assume that the only relevant incurred delays are the one associated with the speed of transmission of each link and its corresponding buffer spaces.

Obtain the outstanding number of packets in the networks.

[6]

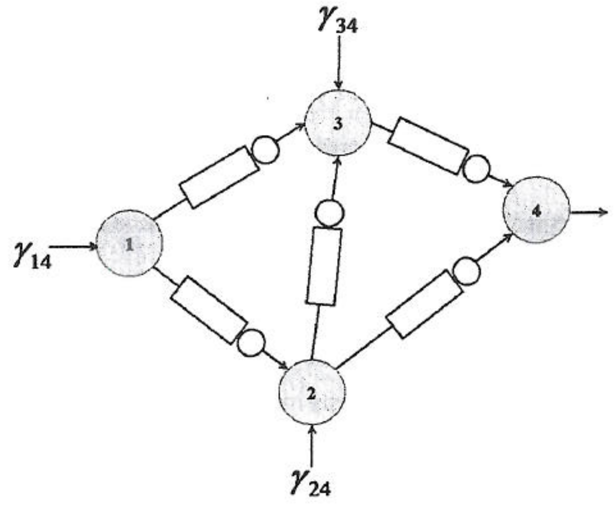

Figure 3.1.

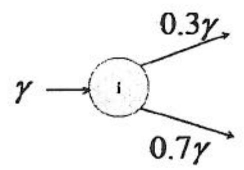

Figure 3.2.

QUESTION 3 Part b) : Next page

3.

b) Consider the network represented in Fig. 3.3. You are asked to assign capacities to all links in the network C(1,2), C(2,3) and C(1,3) from only two set of available capacities:

- maximum two (2) available capacity CA = 10 [*Kbps*], and
- maximum two (2) available capacity CB = 20 [*Kbps*]

Considering the following information:

- the traffic demand between node 1 and node 3 is R(1,3) = 15 [*Kbps*], and
- link C(1,2) and C(2,3) are constrained to have the same capacity.

Your goal is to assign capacities to the links in Fig. 3.3 such that the mean network delay is minimised. Explain clearly the reason for your choice and any supporting derivation and calculation.

[9]

b) 10:40

c) For the solution obtained in part ~~a)~~ calculate the capacity of link C(1,3) such that all traffic is carried by link C(1,3). Explain clearly all the steps in your derivations.

[5]

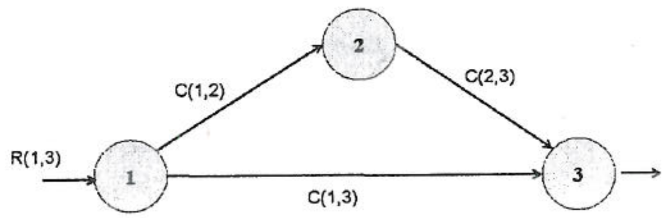

Figure 3.3.

4.

a) Consider the network in Fig. 4.1. with only one Origin-Destination flow (γ_{15}) to which the Optimal Routing Problem (ORP) is to be applied.

i) State the *Optimality Conditions* for the ORP.

[2]

ii) Using the fist derivative length criterion as the cost of carrying a marginal flow on a path, identify step by step the shortest path using Dijkstra algorithm, when the network is not carrying traffic.

[5]

iii) Using the minimum hop criteria to choose a path, identify step by step the shortest path using Bellman-Ford algorithm.

[3]

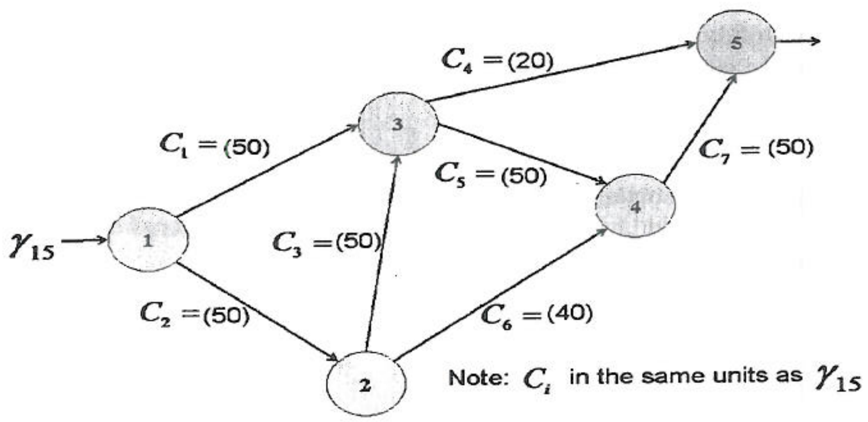

Figure 4.1.

b)

Explain how could you combine ORP and end to end flow control, by adjusting both the routing variables and the Origin-destination input rate, r_w, in such a way that the cost function does not allow for the input rate becoming too small.

[10]

5.

a) You are given the task of designing, deploying and operating an IP based packet network, that should offer a limited number of quality of service (QoS) levels to end-users.

You are told that the packet network is an IP based network and is expected to grow quite rapidly in terms of number of end-users.

If you are given the choice of deploying the DiffServ or the InServ service models: which model will you choose and why?

[5]

b) Assume that you are in charge of an IP based network which is one of several interconnected Autonomous Systems (AS).

You are asked to implement inter-domain routing protocol which should support the implementation of restrictions on the carried traffic offered by adjacent AS.

Discuss the characteristics of a suitable inter-domain routing protocol.

[5]

c)

i) Briefly highlights the key underlying processes of a data communications network management.

[2]

ii) Describe briefly at least two generic network management responsibilities.

[2]

iii) Describe briefly three generic performance management reports that you consider the most important ones. Explain the reasons of your choice and explain how you will use each one of your selected reports.

[6]

6.

a) For the network in Fig. 6.1. it is required to send R(1,4) [*Kbps*] from Node **1** to Node **4** using only one route. Assume the following data:

Link i	C(i)	$e(i)$ = probability of failure link i
	[*Kbps*]	
1	3	0.20
2	2	0.10
3	50	0.01
4	2	0.20
5	4	0.40

- Path availability = $\text{PA}(L) = \prod_{k \in path\ L} (1-e(k))$, where $e(k)$ is the probability of failure of link k.
- Path length = $\text{PL}(L) = \sum_{k \in path\ L} \frac{1}{C(k)(1-e(k))}$, where $C(k)(1-e(k))$ is an adjusted normalised capacity which considers the fact that there is a probability of link failure.

i) Identify the path with highest availability. [3]

ii) Identify the shortest path using PL(L) as definition of path length [3]

iii) Discuss the merits of paths found in part i) and part ii). [4]

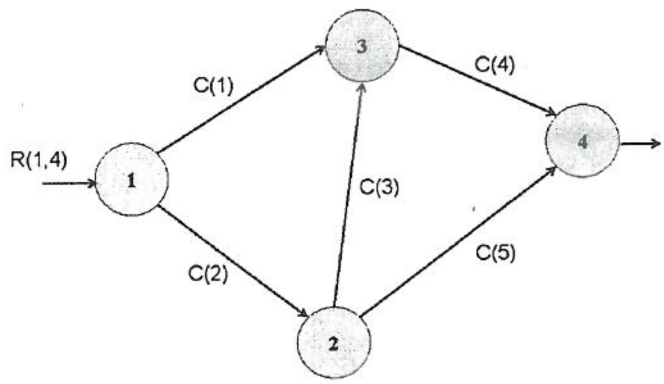

Figure 6.1.

QUESTION 6 Part b) : Next page

6.

b) Consider the network in Fig. 6.2. which represents a wireless ad-hoc network.

Define interference as the number of neighbours that can overhear a transmission (i.e. within radio range).

Assume that each node can calculate locally its possible interference.

Sender **S1** wants to send a packet to receiver **R1** and simultaneously Sender **S2** wants to send a packet to receiver **R2**.

i) Identify the minimum hop paths (**S1 → R1** & **S2 → R2**). [2]

ii) Identify the least interference routes (LIR). (**S1 → R1** & **S2 → R2**) [4]

iii) Discuss the merits of paths found in part i) and part ii). [4]

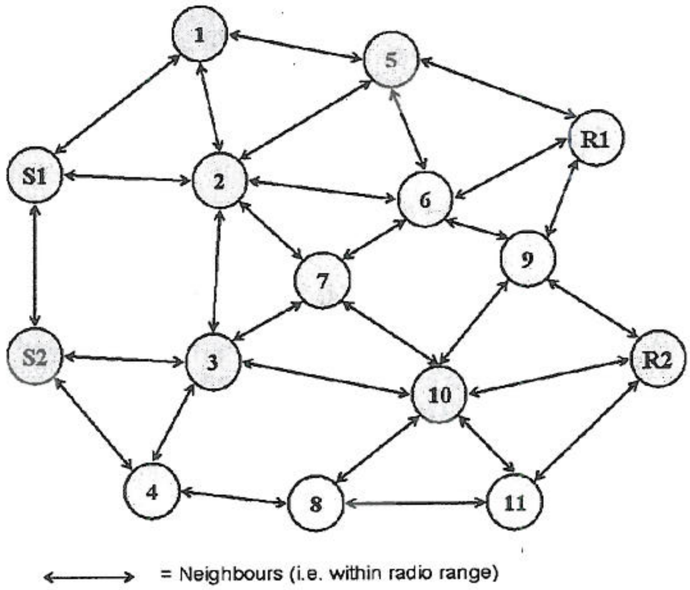

Figure 6.2.

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Q1.
Students are required to understand the limitation of communication media imposed on a point to point protocol and perform calculations.

Q2.
Part a) extension of class discussion. Part b) the window flow control has been discussed during class but students should show with the help of the correct time diagram the corresponding latencies. Part c) students need to understand the services limitations and choose correct transport protocol.

Q3.
Part a) new problem. Calculate mean network delay applying Little's theorem. Part b) new problem. Apply the definition of mean network delay and optimal routing problem to minimise congestion. Part c) new problem. Apply the underlying concept of marginal cost and constraint on flow in an optimal routing problem.

Q4.
Part a) new problem. Apply two different algorithms to solve the shortest path problem and give conditions of marginal cost. Part b) the student need to understand the limitations of the ORP statement if flow control need to be considered.

Q5.
Part a) students need to understand the underlying characteristics of two different IP service models and argue for the election of one of them. Part b) Students need to understand what characteristics a border gate routing protocol should possess in order to support e.g. policy based routing. Part c) extension of class discussion.

Q6.
Part a) new problem. Part b) new problem. In both part a) and part b) students need to understand limitation of shortest path algorithms known to them and argue the benefit of alternative ways of finding optimal routes.

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COMMUNICATION NETWORKS 2010

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Q1 a) stop and wait flow control

T_F = time to send one frame and receive ack.

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

Assuming processing time is relative neglible and acknowledge time (frame) is very small

$T_F \sim 2t_{prop} + t_{frame}$

t_{prop} = propagation time from S_1 to S_2

t_{frame} = time to transmit a frame.

$$U \sim \frac{t_{frame}}{2t_{prop} + t_{frame}} = \frac{1}{1 + 2a}$$

$$a = \frac{t_{prop}}{t_{frame}}$$

4

b) Transmission time $= 424 / 155.52 \times 10^6 = 2.7 \times 10^{-6}$ s

Propagation time $= 10^6 / 2 \times 10^8 = 0.5 \times 10^{-2}$ s

$$a = \frac{0.5 \times 10^{-2}}{2.7 \times 10^{-6}} = 1850$$

$$U = \frac{1}{1850 \times 2 + 1} = \frac{1}{3701} = 0.00027$$

2

Q1 c)

Transmission time $= 1000 / 10 \times 10^{6} = 1 \times 10^{-4}$ s

Propagation time $= 1000 / 2 \times 10^{8} = 5 \times 10^{-6}$ s

$$a = \frac{5 \times 10^{-6}}{10^{-4}} = 5 \times 10^{-2} = 0.05$$

$$U = \frac{1}{0.05 \times 2 + 1} = 0.9$$

2

d)

$$a = \frac{\text{propagation time}}{\text{Transmission time}} \qquad U = \frac{1}{1 + 2a}$$

$$a = \frac{d/V}{L/V} = \frac{R\,d}{V\,L}$$

d = distance of link

V = velocity of propagation

L = length frame in e.g. bits

R = data rate

For a fixed-length frame, 'a' is proportional to the data rate times the length of the medium

a can be interpreted as the 'length of the medium' in eq. bits $\left[R \times \frac{d}{V}\right]$ compared to the frame length L

The relation between the physical characteristics of the link and frame length is very relevant

5

Q1 e) If $U = \frac{1}{1+2a}$

then the aim would be to reduce the magnitude of 'a' or,
to allow more than only one outstanding frame on the media 2

f) An alternative flow control mechanism that allows more than one outstanding frame in the sliding-window flow control. It allows 'W' frames on the media without requiring acknowledgment

If we implement this mechanism

i) if $W \geq 2a+1$ $U = 1$ 5

ii) if $W < 2a+1$ $U = W/(2a+1)$

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Q2 a) The basic idea behind TCP congestion control is for the sender to reduce its sending rate when a loss (segment) event occurs.

i) multiplicative decrease: halving the current value of congestion window (maximum number of outstanding segments) after a loss event
Additive increase: TCP sender increases congestion window by one maximum segment size every round trip time 2

ii) slow start: during the initial phase, the TCP senders begins by transmitting at a slow rate but increases its sending rate exponentially

iii) Reaction to time out events: 2
- Introduce threshold. TCP sender enters the slow start phase after a time out event. While in slow start, it increases the value of congestion window exponentially fast until the congestion window reaches threshold. When congestion window reaches threshold, TCP enters the congestion avoidance phase, during which congestion window ramps up linearly. 2

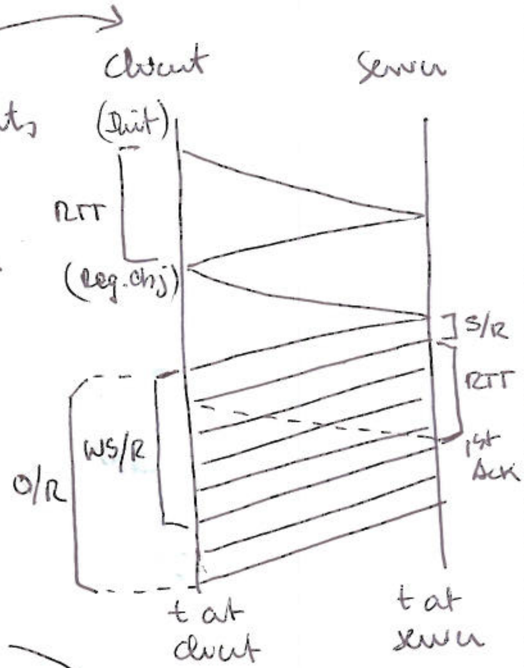
Q2 b) i) Latency: time from when the client initiates a TCP connection until the time at which the client receives the requested object in its entirety.

Q6. b) ii)

Case $WS/R > RTT + S/R$

W = window size in segments
S = Max. segment size in bits
R = transmission rate of link
RTT = Round trip time
O = size of object

Hence
$$\text{Latency} = 2RTT + O/R$$



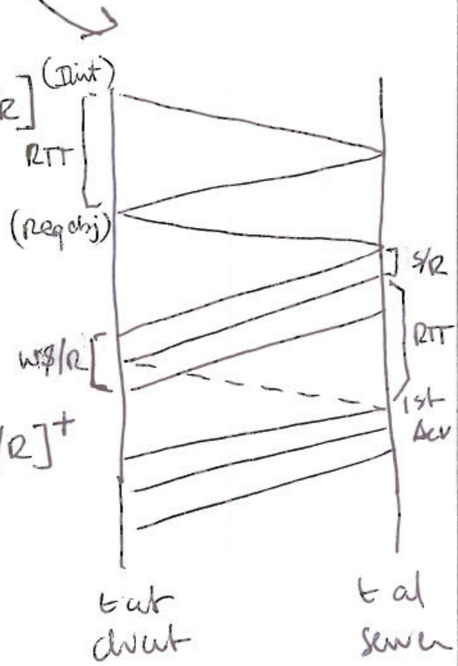
4

Case $WS/R < RTT + S/R$

Latency =
$$2RTT + O/R + (K-1)[S/R + RTT - WS/R]$$
(K = nr of windows of data that covers the object)

Combining the two above

Latency =
$$2RTT + O/R + (K-1)[S/R + RTT - WS/R]^+$$



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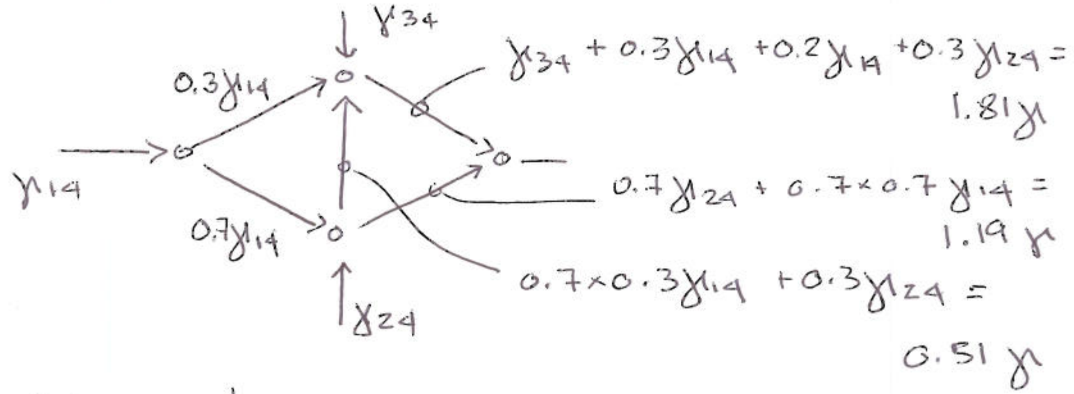
Q3 b)

i) For this case UDP transport layer protocol will be suitable.
UDP is an unreliable connectionless transport layer protocol. It is a simple extension to IP that provides amongst others error checking of data. There is no flow control mechanism. Since the sensor data is Received periodically what is needed is fast delivery. If data is lost or corrupted the receiver can either use previous data as estimates or wait for next arrivals. 3

ii) For this case TCP transport layer protocol will be suitable
TCP is a connection oriented data service at the transport layer.
TCP provides full duplex reliable delivery of data. It also provides recovery mechanism from out-of order packets, duplicate packets, lost packets & corrupt packets. 3
Provides flow control mechanism

Q3a)



$$t_i = \frac{1}{\mu C_i - \lambda_i} \qquad \mu C_i = 100 \text{ [packets/s]}$$

$$t_1 = \frac{1}{100-3} \quad t_2 = \frac{1}{100-7} \quad t_3 = \frac{1}{100-5.1} \quad t_4 = \frac{1}{100-18.1}$$

$$t_5 = \frac{1}{100-11.9}$$ 3

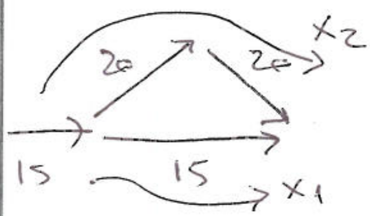
Using Little's theorem at the network level and at each link (queue):

$N = \gamma T$ $\quad$ N = time average of packet in the network
γ = time average arrival rate
T = time average of packet delay

and at each queue i = $q_i = \lambda_i t_i$ we have that the number of outstanding packet in the network is

$$N = \gamma T = \sum \lambda_i t_i = \frac{3}{100-3} + \frac{7}{100-7} + \frac{5.1}{100-5.1} + \frac{18.1}{100-18.1} + \frac{11.9}{100-11.9}$$ 3

Q_3 a)



$x_1 + x_2 = 15$

$x_1 = 15 - x_2$

$$\frac{c_1}{(c_1-x_1)^2} = \frac{c_2}{(c_2-x_2)^2} + \frac{c_3}{(c_3-x_3)}$$ (optimal allocation of traffic)

$$\frac{15}{(15-x_1)^2} = \frac{40}{(20-x_2)^2}$$

$$15(20-x_2)^2 = 40(15-x_1)^2$$

$$\sqrt{15}(20-x_2) = \sqrt{40}(15-x_1)$$

$$\sqrt{15}\cdot 20 - \sqrt{15}\cdot x_2 = \sqrt{40}\cdot 15 - \sqrt{40}x_1$$

$$77.45 - \sqrt{15}x_2 = 94.86 - \sqrt{40}\cdot 15 + \sqrt{40}x_2$$

$$77.45 = (\sqrt{40}+\sqrt{15})x_2$$

$$77.45 = (6.32+3.87)x_2$$

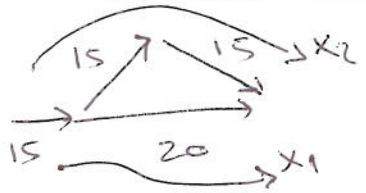
$$x_2 = 7.41$$

$$x_1 = 7.59$$

$$D_2 \sim \frac{x_1}{c_1-x_1} + \frac{x_2}{c_2-x_2} + \frac{x_3}{c_3-x_3} = \frac{7.59}{15-7.59} + \frac{2\cdot 7.41}{20-7.41}$$

$$= 2.198$$ 3

Q3 (a)



$x_1 + x_2 = 15$

$x_1 = 15 - x_2$

$$\frac{c_1}{(c_1-x_1)^2} = \frac{c_2}{(c_2-x_2)^2} + \frac{c_3}{(c_3-x_3)}$$ (optimal allocation of traffic)

$$\frac{20}{(20-x_1)^2} = \frac{30}{(15-x_2)^2}$$

$$2(15-x_2)^2 = 3(20-x_1)^2$$

$$\sqrt{2}(15-x_2) = \sqrt{3}(20-x_1)$$

$$\sqrt{2}\cdot 15 - \sqrt{2}x_2 = \sqrt{3}\cdot 20 - \sqrt{3}x_1$$

$$21.21 - \sqrt{2}x_2 = 34.64 - \sqrt{3}(15-x_2)$$

$$\sqrt{3}(15-x_2) - \sqrt{2}(x_2) = 13.43$$

$$\sqrt{3}\cdot 15 - \sqrt{3}x_2 - \sqrt{2}x_2 = 13.43$$

$$25.98 - 13.43 = (\sqrt{3} + \sqrt{2})x_2$$

$$= (1.73 + 1.41)x_2$$

$$12.55 = 3.14 x_2$$

$$x_2 = 3.99$$

$$x_1 = 11.01$$

$$D_1 \sim \frac{x_1}{c_1-x_1} + \frac{x_2}{c_2-x_2} + \frac{x_3}{c_3-x_3} = \frac{11.01}{20-11.01} + \frac{2\cdot 3.99}{15-3.99} = 1.99$$ 3

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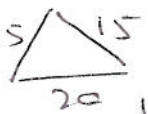
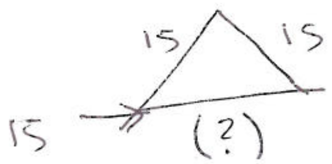
Compare D_1 and D_2. Since D_1 is lower than D_2 choose configuration 

. Note that D_1 is proportional to outstanding number of packets in the network. 3

Q b) In this case we have to impose the following condition: $x_2 = c$ and then solve the CRP.



$$\frac{c_1}{(c_1-x_1)^2} = \frac{15}{(15-x_2)^2} + \frac{15}{(15-x_2)^2}$$

$$\frac{c_1}{(c_1-15)^2} = \frac{1}{15} + \frac{1}{15}$$

$$\frac{15}{2} c_1 = (c_1-15)^2 = c_1^2 - 30c_1 + (15)^2$$

$$7.5 c_1 = c_1^2 - 30 c_1 + 225$$

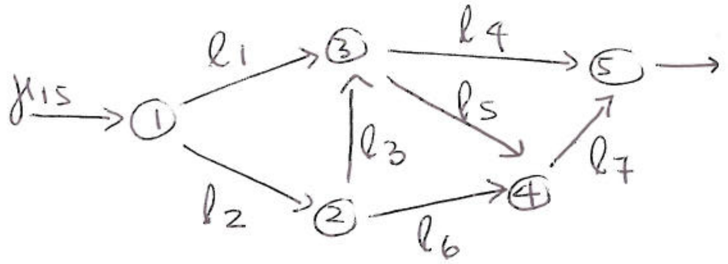
$$c_1^2 - 37.5 c_1 + 225 = 0$$

$$c_1 = \frac{37.5 \pm \sqrt{(37.5)^2 - 4 \cdot 225}}{2} = \begin{cases} 7.5 \\ 30.0 \end{cases}$$

$c_1 = 30$ will carry all the traffic (15). 5

Question labels in left margin | Marks allocations in right margin

Q4 a)



All possible paths

Path 1 $= l_1 + l_4$ Path 2 $= l_1 + l_5 + l_7$

Path 3 $= l_2 + l_3 + l_4$ Path 4 $= l_2 + l_3 + l_5 + l_7$

Path 5 $= l_2 + l_6 + l_7$

i) For the ORP the marginal cost of transporting flows should be equal - if flow is to be split up. Marginal cost of transporting x_i in a link with capacity c_i $= \dfrac{c_i}{(c_i - x_i)^2}$ (= first derivative length)

therefore need to identify and evaluate all paths from 1 → 5

length path 1 $= \dfrac{50}{(50-x_1)^2} + \dfrac{20}{(20-x_4)^2}$

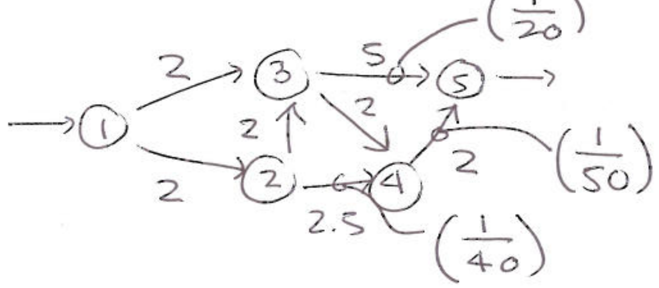
Length path 2 $= \dfrac{50}{(50-x_1)^2} + \dfrac{50}{(50-x_5)^2} + \dfrac{50}{(50-x_7)^2}$

Length path 3 $= \dfrac{50}{(50-x_2)^2} + \dfrac{50}{(50-x_3)^2} + \dfrac{20}{(20-x_4)^2}$

Length path 4 $= \dfrac{50}{(50-x_2)^2} + \dfrac{50}{(50-x_3)^2} + \dfrac{50}{(50-x_5)^2} + \dfrac{50}{(50-x_7)^2}$

Length path 5 $= \dfrac{50}{(50-x_2)^2} + \dfrac{40}{(40-x_6)^2} + \dfrac{50}{(50-x_7)^2}$ 2

Q4 a) ii) In this case $x = 0$ for all links then the cost of each link is: 1



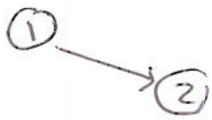
$2 = \frac{1}{50} (\times 10^2)$

Dijkstra.

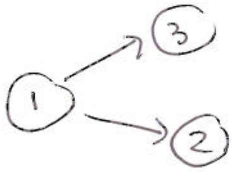
$M = \{1\}$

$M = \{1,3\}$

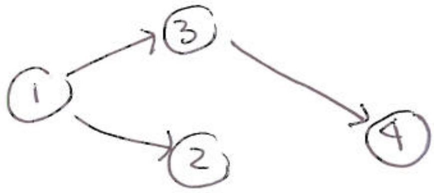
(OR) $M = \{1,2\}$



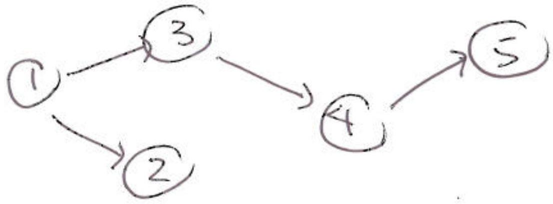
$M = \{1,2,3\}$



$M = \{1,2,3,4\}$



$M = \{1,2,3,4,5\}$



5

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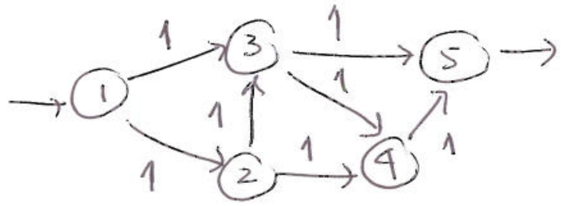
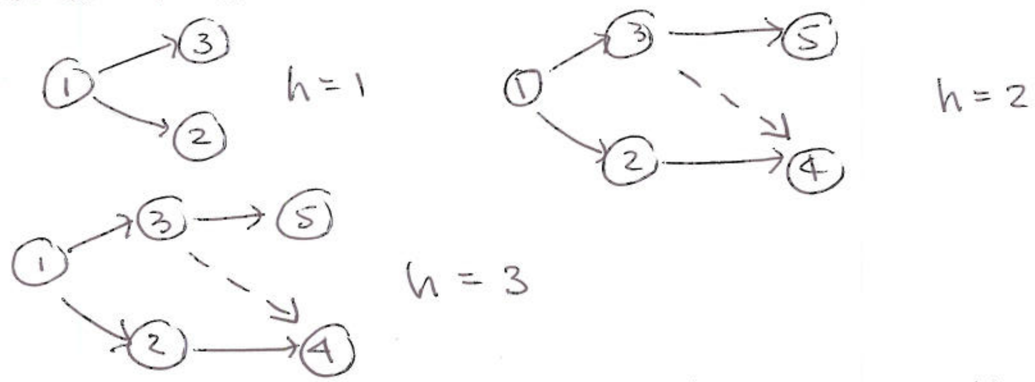
Q4(a)(iii) For the minhop the cost of each link is =1.



Bellman-Ford



3

The criterion of minimum first derivative length assigns flows to paths that will minimise the marginal increase of outstanding packets in the network.

Note: outstanding number of packets and Average network delay are directly related via Little's theorem

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Q8 b)

The aim of combining optimal routing problem is to allow for high throughput but at the same time keep the network delay at a reasonable level. In this case we would need to minimise $D = \sum \frac{F}{C-F}$ in respect to $\{F\}$ (flow allocation in the network) as well as $\{R_w\}$ (the offered traffic to the network)

If this is required the optimal solution is the trivial one $F=0$, $R_w = 0$. Hence the need for a penalty function that does not allow for R_w to tend to zero. 4

A suitable penalty function will have the shape

$$e_w(R_w) = \frac{a_w}{R_w}$$

The effect is that a part of the flow that is offered will not have access to the network

$\bar{R}_w \to \xrightarrow{R_w}$, $\downarrow y_w$ therefore the problem now is:

$$\min \sum \frac{F}{C-F} + \sum e_w(R_w)$$

If we define $E_w(y_w) = e_w(\bar{R}_w - y_w) = e_w(R_w)$

Then the additional terms (penalties) may be viewed as a "delay" function for an imaginary overflow link $\left(E_w(y_w) = \frac{a_w}{\bar{R}_w - y_w} \right)$

The same solution framework used to solve the ORP applies. 6

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Q5 a) DiffServ should be the clear candidate
IntServ model requires to keep flow-specific states for each flow. The amount of state information increases proportionally with the number of flows (Routers may need huge storage spaces and demand processing power)
IntServ model also needs to implement the RSVP protocol, admission control, packet classification and sophisticated packet scheduling algorithms.
All of the above highlights the scalability and complexity issues associated with IntServ 5

Q6 b) An inter-domain routing algorithm should provide mechanism for address aggregation as well as policy-based rules.
The algorithm should keep a global view of the IP network and their information bases.
The algorithm should exchange reachability information with other Inter-domain routes.
One such type of algorithm is the BGPv4 defacto Internet algorithm. 5

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Q5 a) i) Key underlying processes are:

- operating
- monitoring
- controlling

the network to ensure sustainability of the business and provides value to its users. Also the implication of planning, desing and organisation could be included. 2

ii) Describe any two of the following

- day to day operations
- Support network users (define network users)
- Ensures network operating reliability
- HW & SW acquisition
- Management of technical staff
- Network budget
- strategy for evolution, Specify new services 2

...

iii) Describe and explain use of any three of the following

- periodic usage, numbering error of equipment
- Network availability, service availability
- Network maintenance policies
- Fault diagnosis
- Response time to failure
- Peak volume statistics 3
- Trend analysis and recurrent patterns.

All of the above are mainly aim at. quality of service assurance 3

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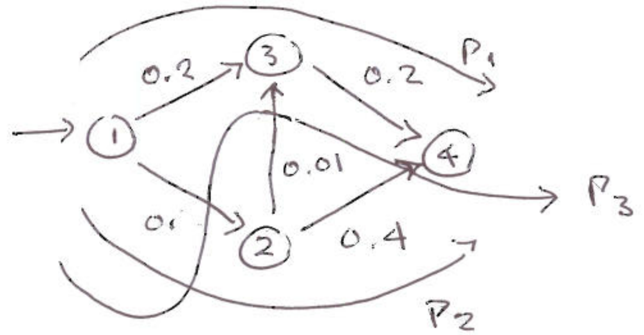
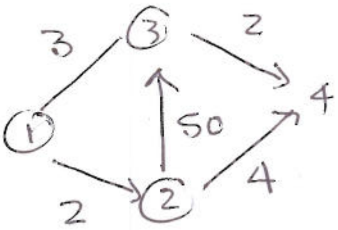
Q6 a)





i) Using reliability figures:

$PA(1) = 0.8 \cdot 0.8 = 0.64$ (*)

$PA(2) = 0.8 \cdot 0.6 = 0.48$

$PA(3) = 0.8 \cdot 0.99 \cdot 0.8 = 0.6336$ 3

ii) using Adjusted normalised capacity

$$PL(1) = \frac{1}{3(1-0.2)} + \frac{1}{2(1-0.2)} = 0.41\bar{6} + 0.625 = 1.041$$

$$PL(2) = \frac{1}{2(1-0.1)} + \frac{1}{4(1-0.4)} = 0.5\bar{5} + 0.41\bar{6} = 0.9722 \ (*)$$

$$PL(3) = \frac{1}{2(1-0.1)} + \frac{1}{50(1-0.01)} + \frac{1}{2(1-0.2)} = 0.5\bar{5} + 0.0202 + 0.625$$ 3

iii) The discussion should be centred in two key aspects

- Reliability figures on its own (part i)) do not give us a clear picture of the capacity of the network to deliver
- In contrast part ii) considers also the the fact that the path with highest potential to complete transfer of R(1,4) and this is given by a combined performance (c) / Reliability (1-c) figure 4
- Further comments a highly reliable link (c(3)) in a non critical path has very little effect in both i) & ii)

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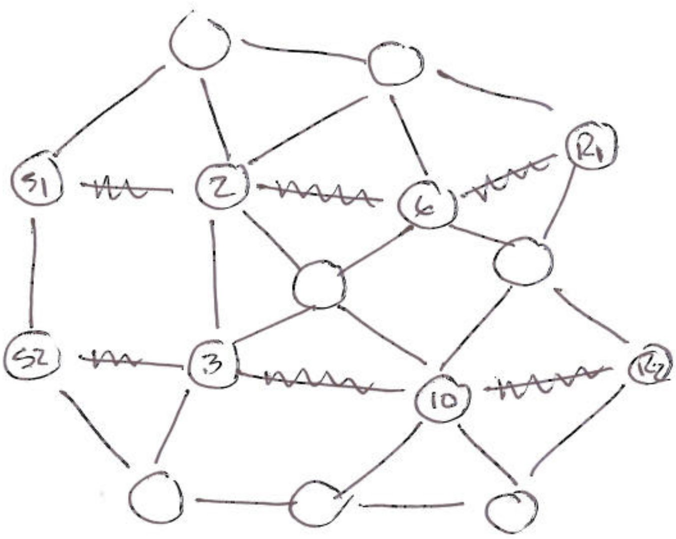
Q6 (i)

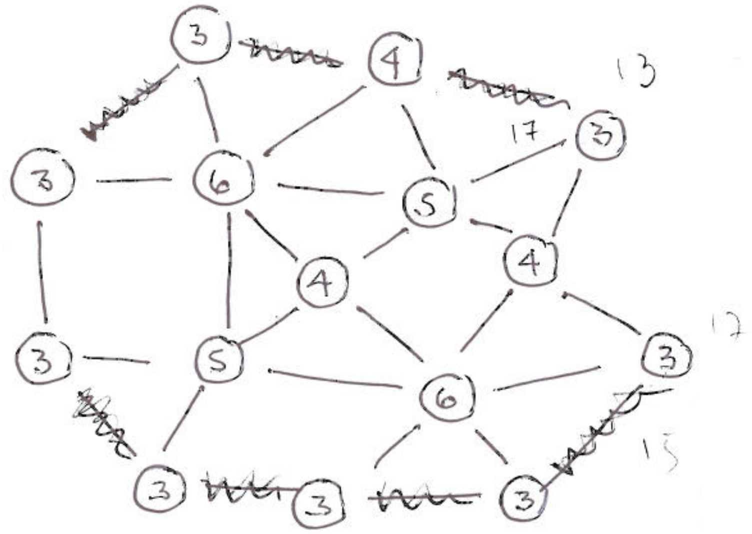
i)



$S_1 \to R_1$: $S_1, 2, 6, R_1$ (Any algorithm is allowed) 2

$S_2 \to R_2$: $S_2, 3, 10, R_2$ (Any algorithm is allowed)

ii)



◯ = value inside circle is Interference seen by the node

Q6 b) ii) Using LIR

$S_1 \rightarrow R_1$: S1, 1, 5, R1

$S_2 \rightarrow R_2$: S2, 4, 8, 11, R2 4

iii) The discussion here should focus on:

- The implication on a wireless environment of two transmission taking place simultaneously: interference
- Many well know algorithm just use number of hops but in this case it is highlighted that this would not be the best choice
- Note that $S_2 \rightarrow R_2$ choose a route with more nodes and links but the level of interference has been minimised. 4