IMPERIAL COLLEGE LONDON

EE3-17
EE9SO8

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2011

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

Corrected Copy Q 2

COMMUNICATION NETWORKS

Wednesday, 11 May 10:00 am

Time allowed: 3:00 hours

There are FIVE 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) : T-K. Kim

Special information for students

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

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

Where,

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

C_i = Transmission speed link i [bits/s]

μC_i = Service rate (link i) [packet/ s]

λ_i = Arrival rate (link i) [packet/ s]

2. Optimal Routing Problem (ORP)

$Min\ D(F)$ with respect to $F = \{ F_i \}$

where, $D(F) = \sum_{i=1}^{L} \frac{F_i}{C_i - F_i}$

and,

C_i = Capacity of link l_i.

F_i = Flow carried by link l_i.

The Questions

1.

a) Describe and discuss the advantages and disadvantages of the following wireless technologies: i) IEEE 802.11 (WiFi) and ii) IEEE 802.16 (WiMax)

[12]

b) Using Fig. 1.1, describe and explain the different TCP congestion control mechanisms known to you.

Discuss the differences between TCP Tahoe version and TCP Reno version.

[4]

c) For the sequence in Fig. 1.2. complete the sequence of the TCP flow control timing during a slow start phase. Define all parameters used in your time diagram.

[4]

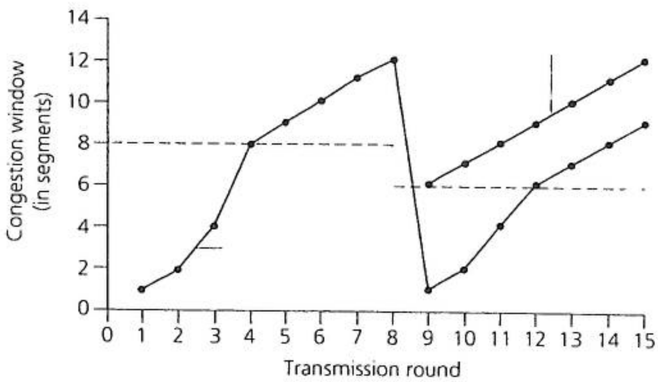

Figure 1.1.

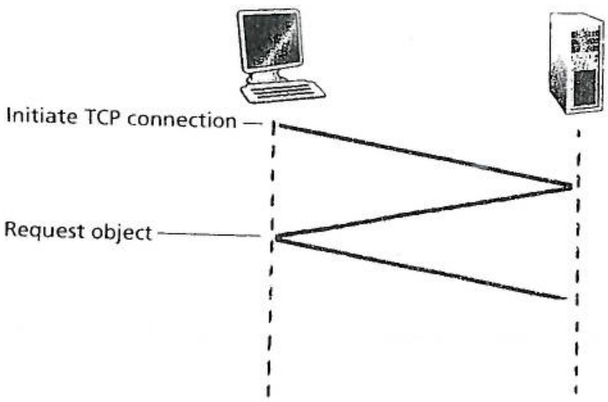

Figure 1.2.

2.

a) For the packet network in Fig. 2.1, assume that:

All external arrival streams are Poisson streams with arrival rate γ_{ij} [packets / s] given by the following table:

Demand Matrix [packets / s]		**Destination Node** j		
		1	**2**	~~2~~ 3
Origin Node i	**1**		0.35	0.25
	2	0.35		0.15
	3	0.25	0.15	

The transmission links are buffered by a large FIFO buffer,

Packet lengths are exponentially distributed with mean length 6 [Kbits],

Each channel operates at a rate 4 [Kbits / s],

Processing time at each node is negligible.

i) Obtain the mean number of packets in the network at equilibrium. [7]

ii) Obtain the mean average delay for the packet inside the network. [7]

b)

i) Explain why segmentation and reassembly are required when transporting IP packets across networks. [3]

ii) Describe in which context, and why encapsulation for IP packets is used. [3]

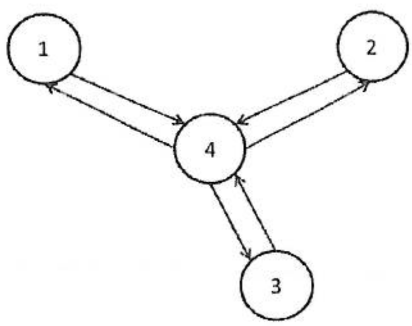

Figure 2.1.

3.

a)

i) Explain how a sliding window flow control mechanism would overcome the limitations imposed by the characteristics of the physical medium, on a stop and wait flow control mechanism.

[3]

ii) For a sliding window flow control mechanism, state the condition(s) under which the link utilisation is less than one (1).

[3]

iii) Derive the utilisation of the link if the condition in ii) is met.

[2]

b)

In the context of a combined optimal routing problem (ORP) and rate-based flow control mechanism, a penalty function $e_w(r_w)$ is introduced as an additional term in the underlying ORP. Where r_w is the input rate of a flow w.

An interesting class of function e_w is specified by the following formula for the first derivative.

$$\frac{\partial e_w(r_w)}{\partial r_w} = -\left(\frac{a_w}{r_w}\right)^{b_w}$$

Consider two different classes of flow w_1 and w_2 sharing the same path.

Assume that both classes of session are throttled (that is, the condition for active flow control is active in both flows).

i) Explain how the parameters a_w influence the allocation of flow rates between the two flows.

[6]

ii) Explain how the parameters b_w influence the allocation of flow rates between the two flows.

[6]

4.

Figure 4.1 represents a wireless network in which the active communication links are shown as lines between nodes.

Your objective is to find the path between node O and node D such that the energy consumed is minimum.

Use the following model for energy required to transmit $r_0 = Bt$ bits:

$$P(s_1, s_2) = [\alpha_1 + \alpha_2 d^n]Bt$$

Where

α_1 and α_2 = communication constants,

d = distance between two (s_1, s_2) adjacent nodes in meters,

n = signal propagation coefficient,

B = total link capacity between one hop neighbour,

t = total packet size in seconds.

Hint: you can use d^4 (i.e. $n = 4$) as a proxy for energy consumption.

i) Calculate the costs of each active link in the network of Fig. 4.1. [5]

ii) Obtain the shortest path between O and D using the Bellman-Ford or the Dijkstra algorithm. State clearly which algorithm you are using. [5]

iii) How are the path(s) lengths affected if a new node becomes active in the position highlighted by the dark node in Fig. 4.2. [5]

iv) Discuss the limitations in the above context if the minimum hop criterion is used to select the minimum path length. [5]

Question 4 continues next page

4. *Question 4 continues from previous page*

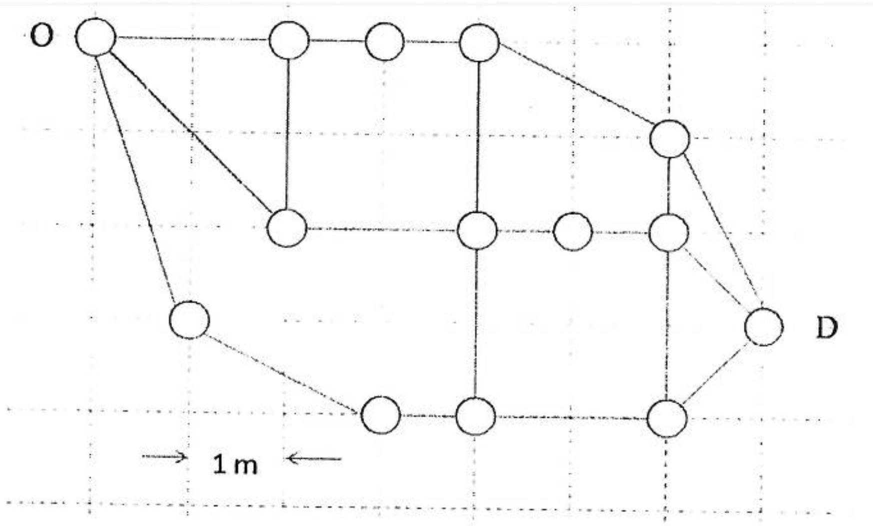

Figure 4.1

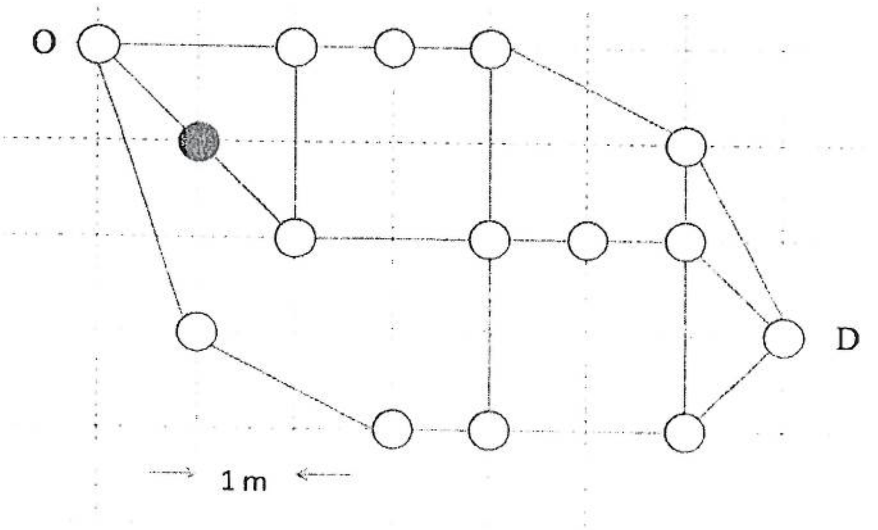

Figure 4.2

5.

a) For a network of M/M/1 queues:

Describe the underlying assumptions of a Jackson's network of queues,

Briefly state Jackson's network theorem,

Discuss why Jackson's network assumptions might or might not apply to small, medium and large scale networks.

[5]

b) Define and discuss the underlying characteristics of three (3) per hop behaviour (PHB) used by the IP DiffServ model.

[5]

c) Explain the principles behind queue management and packet scheduling.

[5]

d) PHB Assured Forwarding has its roots in random early detection (RED) queue management mechanisms. Explain the principles of RED mechanism and its RIO extension.

[5]

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Q1 a

Wimax (IEEE 802.16 family of standards) radio access technology aimed at providing broadband and long distance wireless data delivery
- Wimax supports QoS and multicasting

Wifi (IEEE 802.11 family of standards) radio access designed to provide in-building broadband coverage.
- Wifi does not guarantee QoS and not originally design to support high speed mobility

Wifi vs Wimax

Range: - Wifi local access approx few hundred mts
- Wimax expected to have a range of 50+ Km

Scalability:
- Wifi: for LAN applications users scale from one to tens with one subscriber for each CPE
- Wimax: designed to support from one to hundreds of CPEs.

Bit rate:
- Wifi: works at 2.5 bps/Hz (up to 54 Mbps in 20 MHz channel)
- Wimax: works at 5 bps/Hz (up to 100 Mbps in a 20 MHz channel)

QoS:
- Wifi does not guarantee any QoS but Wimax will provide several levels of QoS
- Wimax can bring the underlying Internet connection needed to service local Wifi nets
- Wifi does not provide ubiquitous broadband while Wimax does

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Q1 b) TCP congestion control mechanisms

- Additive-Increase, multiplicative-decrease :)
 i) increase slowly congestion window size after a positive acknowledment
 ii) halving the congestion window size after a loss event
 (in both cases the increment are in multiples of MSS = maximum segment size)

- Slow start:
 At the onset of congestion the congestion window size is initiated to 1 MSS. The sender then increases its rate exponentially by doubling the value of the congestion window size every RTT [s] (RTT = round trip time); until there is a loss event: at which time congestion window size is cut in half and then grow linearly.

- Congestion Avoidance algorithm
 Reaction to timeout events: slow start phase (starting with congestion window = 1 MSS) and then grows the congestion window exponentially until the congestion window reaches ~~half~~ the value before time out. Then it grows linearly

NOTE: threshold is set to one half of value of congestion window before loss event

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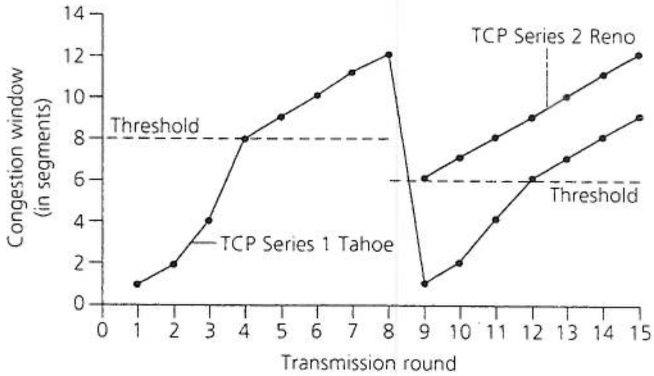

(use figure to further explain mechanism)

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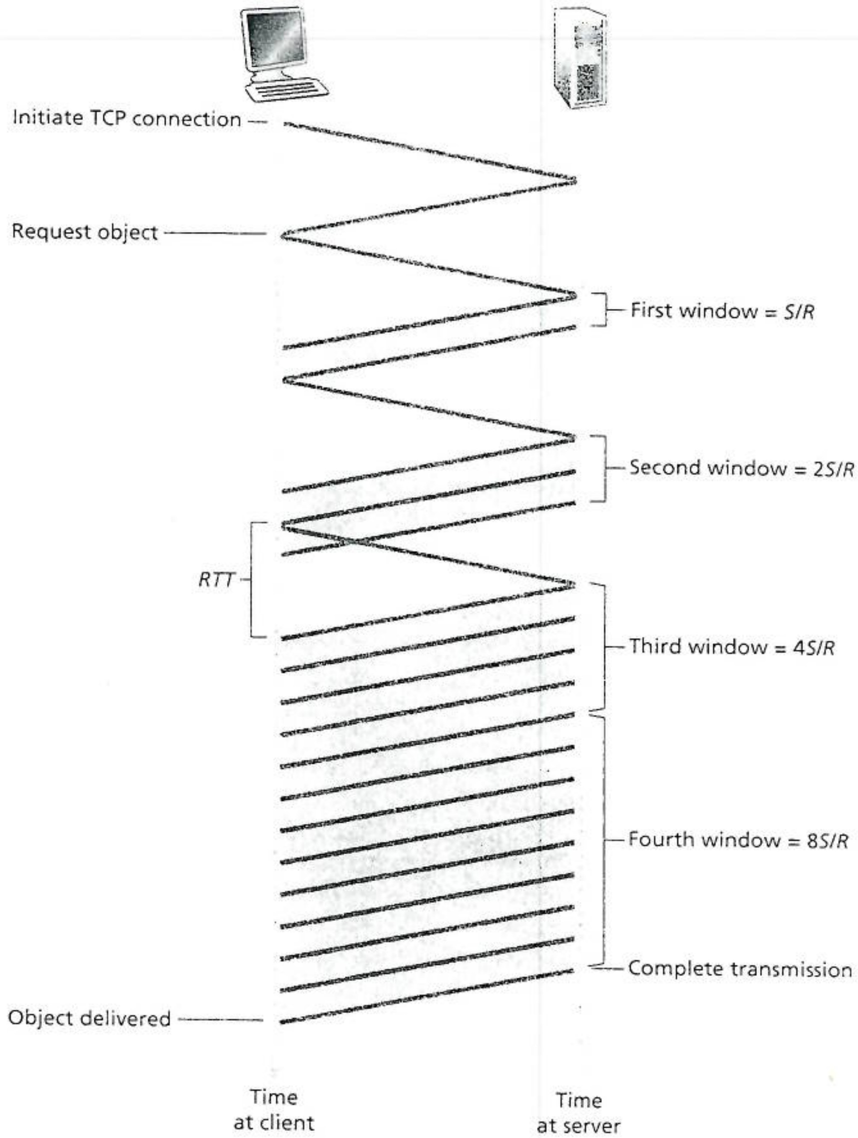

clearly introduce:

R = bottleneck link with transmission rate R bps

S = the maximum segment size is S bits

RTT = Round trip time

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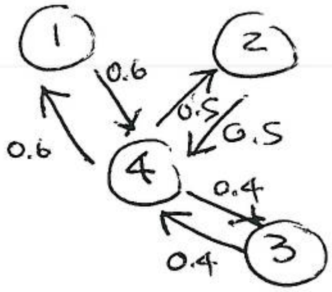
Q2

a)



$C_i = 4 \frac{\text{Kbits}}{s}$, $\frac{1}{\mu} = 6$ Kbits $\Big\}$ $\mu C_i = \frac{4}{6} \frac{\text{packets}}{s}$

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

$= \frac{\lambda_i / \mu C_i}{1 - \lambda_i / \mu C_i} = \frac{\rho_i}{1 - \rho_i}$

$\rho_1 = 0.6 \times \frac{6}{4} = 0.9$

$\rho_2 = 0.5 \times \frac{6}{4} = 0.75$

$\rho_3 = 0.4 \times \frac{6}{4} = 0.6$

$\Big\}$ $N = 2 \sum \frac{\rho_i}{1 - \rho_i}$

$= 27$ packets

$T = \frac{N}{\gamma}$ $\qquad \gamma =$ sumation of all traffic

$= 1.5$ packets/s

$T = 18$ s

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Q2 b) User data and fragmentation / Reassembly

- User data is fragmented by IP host into several pieces to fit in an IP packet's payload
- Each physical network usually imposes a certain packet-size limitation (eg. Ethernet MTU 1500 bytes, FDDI MTU 4464 bytes).

IP encapsulation is needed e.g. in the context of routing for mobile IP

- The home agent cannot directly send packets to the mobile host in a foreign network in a conventional way
- Needs a tunneling mechanism that provides two destination addresses:

  The destination of the other end of the tunnel (the foreign agent)

  The final destination (the mobile host)

  The IP packet is encapsulated with an outer IP header

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Q3 a) Stop and wait flow control utilisation of the media is $1/(1+2a)$ which means that if a (propagation delay) > 1 the link is underutilised

Sliding window

Sender

- Keeps a list of sequence number that are allowed to be sent
- Keeps frames in memory until acknowledge
- If buffer is full: stop transmitting

Receiver

- Keeps a window size with the number of frames sequence it is permitted
- Frames falling outside window are discarded

Sender host will receive acknowledge of frame 1 after all frames permitted by window size have been transmitted. For this case N (# of window frames in one window) is greater than 2a+1 (a = propagation delay and 1 = normalised transmission time).

If $N < 2a+1 \Rightarrow U = \dfrac{N}{2a+1}$

For the case that utilisation is equal to 1 we have the condition $N > 2a+1$ (window big enough to receive first acknowledge before all frames have been transmitted).

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Q3 b)

Two different classes of flow w_1 & w_2 sharing the same path ($P_{w_1} = P_{w_2}$) the optimality condition is given by

$$x_p^* > 0 \Rightarrow d_p^* \le d_{p'}^* \quad \forall p' \in P_w \text{ and } d_p^* \le -e_w'(R_w^*)$$

$$R_w^* < \tilde{R}_w \Rightarrow -e_w'(R_w^*) \le d_p^* \quad \forall p \in P_w$$

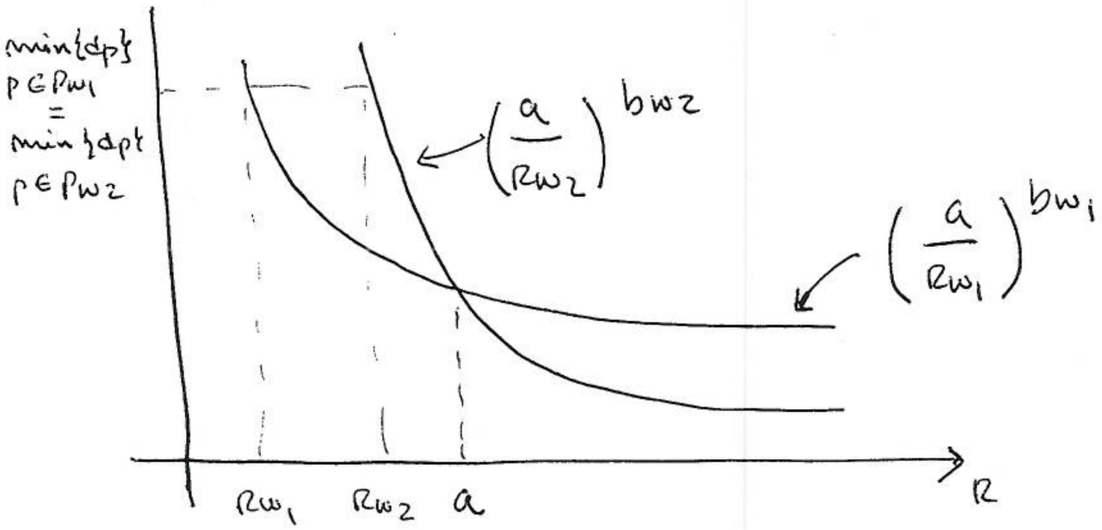
$$e_{w_1}' = -\left(\frac{a_{w_1}}{R_{w_1}}\right)^{b_{w_1}} \qquad e_{w_2}' = -\left(\frac{a_{w_2}}{R_{w_2}}\right)^{b_{w_2}}$$

① if $b_{w_1} = b_{w_2}$

$$-\frac{a_{w_1}}{R_{w_1}} = -\frac{a_{w_2}}{R_{w_2}} \Rightarrow \frac{R_{w_2}^*}{R_{w_1}^*} = \frac{a_{w_2}}{a_{w_1}}$$

a_w - influence the optimal, relative input rate of the session class w

② if $a_{w_1} = a_{w_2}$ and $b_{w_1} < b_{w_2}$ (b_{w_1} low priority)



b_w - influence the relative priority of the session class w under heavy load condition

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Q4

i)

ii)

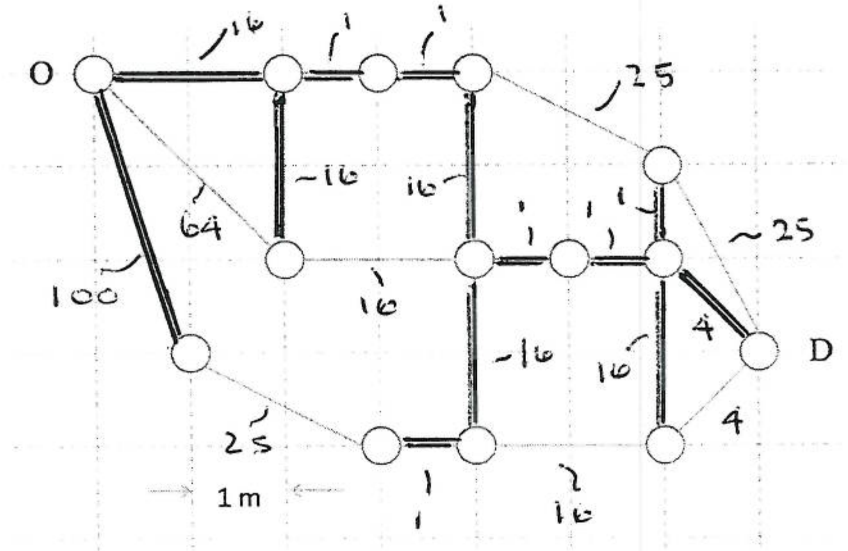

Figure 4.1

$\ell = d^4$

iii)

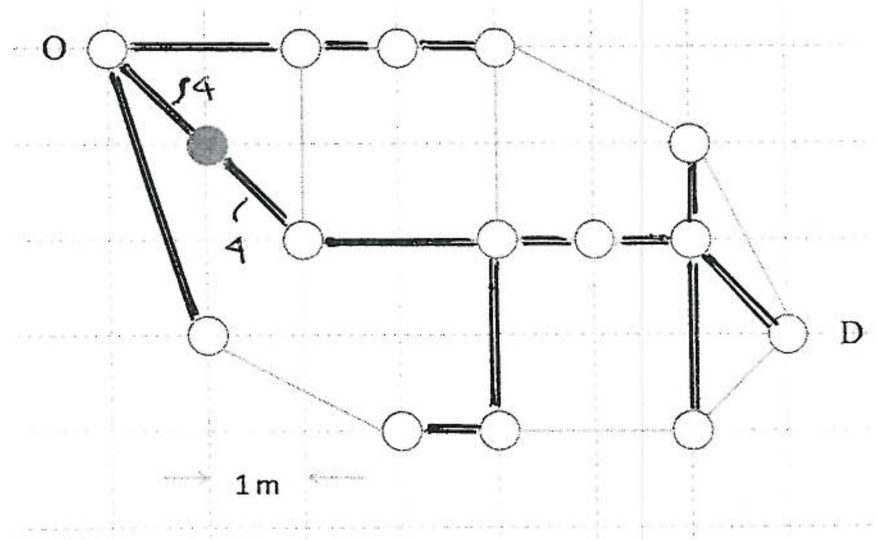

Figure 4.2

iv) discussion on limitation of shortest path algorithms with alternative link lengths.

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Q5

Assumptions

a) - Network of queues consisting of n nodes (or l links) each having an independent exponential service time distribution.

- Customers (packets) arriving from outside the system to any one node is a Poisson stream

- once a customer (packet) is served it goes to another node with a fixed probability or leave the system

Jackson's Networks

- For such network of queues each node (link) behaves as a system of independent M/M/1 queues with input Poisson streams determined by the i) Partition, ii) merging and iii) Tandem of Poisson streams.

Discussion

The underlying discussion should point at the fact that the bigger the network (in size and number of incoming Poisson streams) the more likely it is that queues will behave as a system of independent queues

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Q5 b) Individual router's behaviour are called PHB's (per hop behaviour)

- Expedite Forwarding PHB
  - low-loss, low-latency, low-jitter, assured bandwidth, end to end service
- Assured Forwarding PHB
  - Delivers aggregate traffic with high assurance as long as the traffic does not exceed the traffic profile
  - Not intended for low-latency, low-jitter
- Default PHB
  - Best effort treatment

Q5 c) Queue management Tasks

- Move packets to appropriate queue
- Remove packets from a queue on request from packet scheduler
- Drop and/or remark packets if queue is full or approaching saturation (examples RED with I/O (RIO))

Packet scheduling tasks

- Decides which packet to send next and per flow bandwidth guarantee
- There is no mechanism to control queue size

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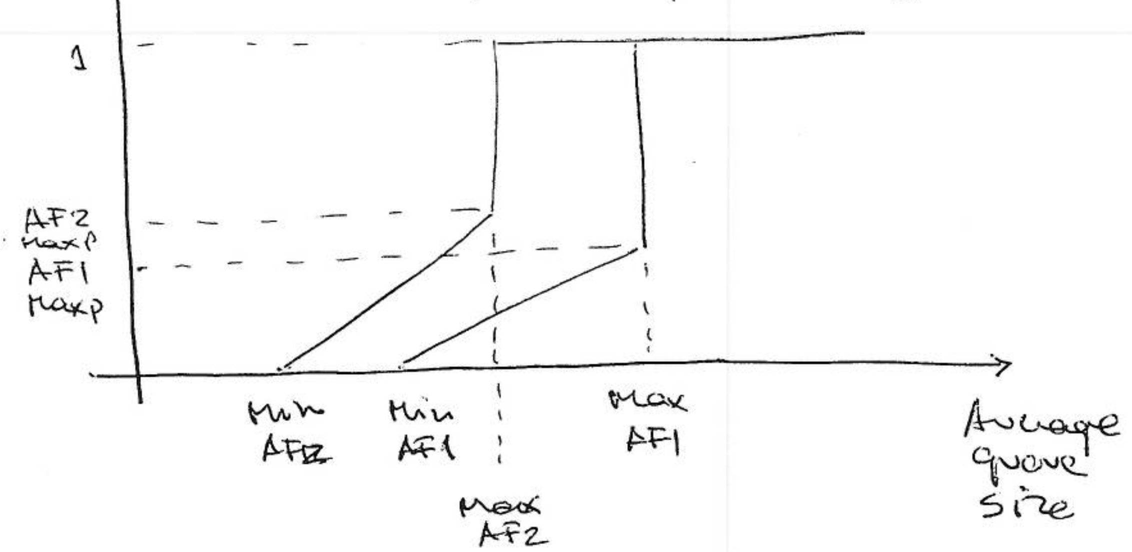
Q5 d)

Weighted Random Early Detection



AF2 marked packets are dropped more aggressively than AF1 packets. Two classes of traffic two drop probability curves

RED with in/out

RIO scheme assumes edge routers marking packets conforming to SLA

- conforming packets = "in" profile
- Non conforming packets = "out" profile

Packets out of profile dropped first if a router suffers congestion

Different set of parameters used for in/out packets (min, max threshold and p)

$$\text{Av Queue length} = (1-w)\,\text{AvQueue length}_{t-1} + w\,\text{Qlength}_t$$