Q1 a) $U = \dfrac{\text{transmission time}}{N_R\,[\text{time line engaged}]}$

$N_R = \sum_{i=1}^{\infty} i P^{i-1}(1-P) = \dfrac{1}{1-P}$, P = probability that a single frame is in error 2

i) $N = 2 < 1+2a = 3$

$U = \dfrac{N(1-P)}{1+2a}$ 4

ii) $N = 4 > 1+2a = 3$

$U = 1-P$ 4

Q1 b) N = No. of stations

P = probability that a station transmit during an available time slot 2

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

A = probability that exactly one station attempts transmission in a slot 4

Probability that a successful transmission will take j attempts is given by 4

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

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

Q2 a) GEO: geostationary earth orbit:
- have a distance of almost 36,000 Km to Earth
- Examples: TV, radio broadcast, weather satellites, backbone for telephone network
- few (~3) satellite are enough for a complete coverage of almost any spot on earth
- do not need handover 1

MEO:
- operate at a distance of about 5,000-12,000 Km
- only require a dozen of satellites
- Satellites move slowly relative to the Earth's rotation
- requires some handover

LEO:
- use altitudes of 500-1,500 Km 2
- circulate at lower orbit hence a much shorter period.
- try to ensure high elevation for every spot on earth to provide a high quality communication link
- Each satellite will be seen from Earth around 10 minutes
- need 50-200 or more satellites to cover Earth.
- Complex system 2
- Short life time
- Require special mechanism for handover

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Q2 b) For MEOs and LEOs

- Intra-satellite handover: A user might move from one spot beam of a satellite to another spot beam of the same satellite 1

- Inter-satellite handover: If a user leaves the foot print of a satellite or if the satellite moves away, a handover to the next satellite takes place. 1
Inter satellite handover can also take place between satellites if they support ISLs.

- Gateway handover: while the mobile user and satellite might still have good contact, the satellite might move away from the current gateway. The satellite has to connect to another gateway 1

- Inter-system handover: typically, satellite systems are used in remote areas if no other network is available. As soon as traditional cellular networks are available, users might switch to this type usually because it is cheaper and offer lower latency 1

4

Q2 b) i)

$$\begin{tikzcd} \text{Silence} \arrow[r, bend left, "\lambda"] & \text{Active} \arrow[l, bend left, "\alpha"] \end{tikzcd}$$

$$Q = \begin{bmatrix} -\lambda & \lambda \\ \alpha & -\alpha \end{bmatrix} \qquad \pi = \left[\frac{\alpha}{\lambda+\alpha}, \frac{\lambda}{\lambda+\alpha} \right]$$

Steady state probability being active $= \dfrac{\lambda}{\lambda+\alpha}$ 3

ii) N-multiplexed independent sources:

$$\pi_i = \binom{N}{i} p^i (1-p)^{N-i}$$

$$p = \frac{\lambda}{\lambda+\alpha} \qquad 1-p = \frac{\alpha}{\lambda+\alpha}$$ 7

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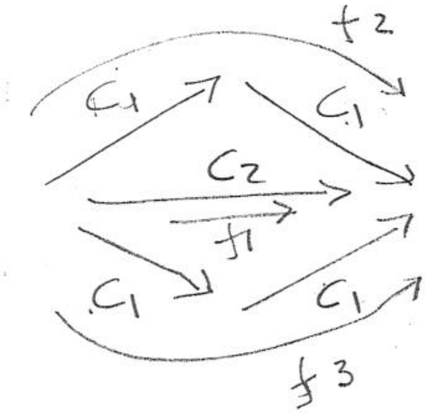
Q3a)



$f_1 + f_2 + f_3 = 10$

$f_2 = f_3$

$f_1 = 10 - 2f_2 = 10 - 2f_3$ 3

$$\frac{c_2}{(c_2 - f_1)^2} = \frac{2 \times c_1}{(c_1 - f_2)^2}$$

$$c_2 (c_1 - f_2)^2 = 2c_1 (c_2 - f_1)^2$$

$$\sqrt{c_2}\,(c_1 - f_2) = \sqrt{2c_1}\,(c_2 - f_1)$$

$$\sqrt{c_2}\,c_1 - \sqrt{c_2}\,f_2 = \sqrt{2c_1}\,c_2 - \sqrt{2c_1}\,f_1$$

$$= \sqrt{2c_1}\,c_2 - \sqrt{2c_1}\,(10 - 2f_2)$$

$$\sqrt{c_2}\,c_1 - \sqrt{2c_1}\,c_2 + \sqrt{2c_1}\,10 = \sqrt{c_2}\,f_2 + \sqrt{2c_1}\,2f_2$$

$$f_2 = \frac{\sqrt{c_2}\,c_1 + \sqrt{2c_1}\,(10 - c_2)}{\sqrt{c_2} + \sqrt{2c_1}\,2}$$ 3

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subnetwork A $c_1 = 10$, $c_2 = 6$

$$f_2 = \frac{\sqrt{6}\,10 + 4\sqrt{20}}{\sqrt{6} + 2\sqrt{20}} = 3.7195$$

$f_1 = 2.561$ $D_A \sim 3.11$ 2

subnetwork B $c_1 = 9$, $c_2 = 7$

$$f_2 = \frac{\sqrt{7}\,9 + 3\sqrt{18}}{\sqrt{7} + 2\sqrt{18}} = 3.28$$

$D_B \sim 3.25$

$f_1 = 3.43$ 2

(Q3b) Subnetwork A $c_2 \leftarrow c_2 + 1$

$$f_2 = \frac{\sqrt{7}\,10 + \sqrt{20}\,3}{\sqrt{7} + \sqrt{20}\,2} = 3.44$$

$f_1 = 3.11$ $D_{A+\Delta A} \sim 2.896$ 5

Subnetwork B $c_2 \leftarrow c_2 + 1$

$$f_2 = \frac{\sqrt{8}\,9 + 2\sqrt{18}}{\sqrt{8} + 2\sqrt{18}} = 3$$

$f_1 = 4$ $D_{B+\Delta B} \sim 3.00$ 5

$\Rightarrow$ sub net B $D_{TOT} = D_{A+\Delta B} + D_A$

(min)

6.15 | 6.11

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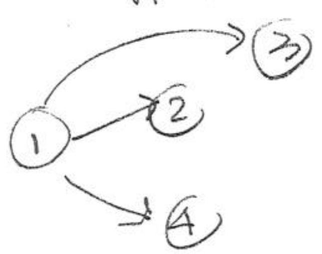
Q4a) i) Bellman Ford sh-pt:
- Find the shortest path to the rest of the nodes in the network using at most 1 (one) link
- Find the shortest path to the rest of the nodes in the network using at most 2 (two) links

...
- stop when solution h = solution h+1 5

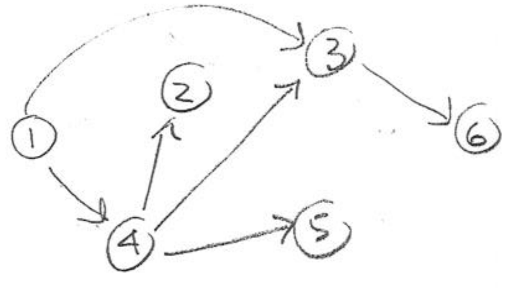
ii) Dijkstra sh-pt
- chose always the closest node to the origin node and added into a set P
- The idea is to develop the paths in order of increasing path length 5

...
- stop when all nodes are inside set P.

Q4b) i) h=1

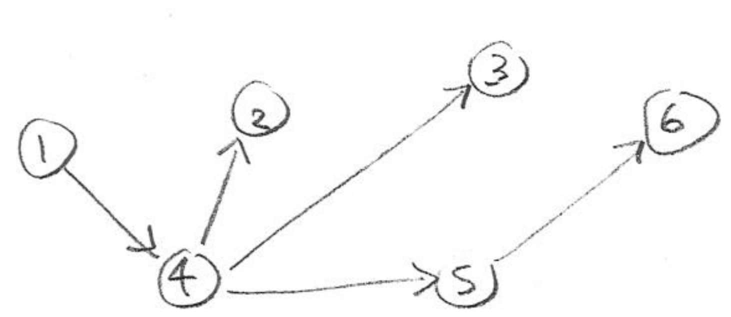


h=2



5

h=3



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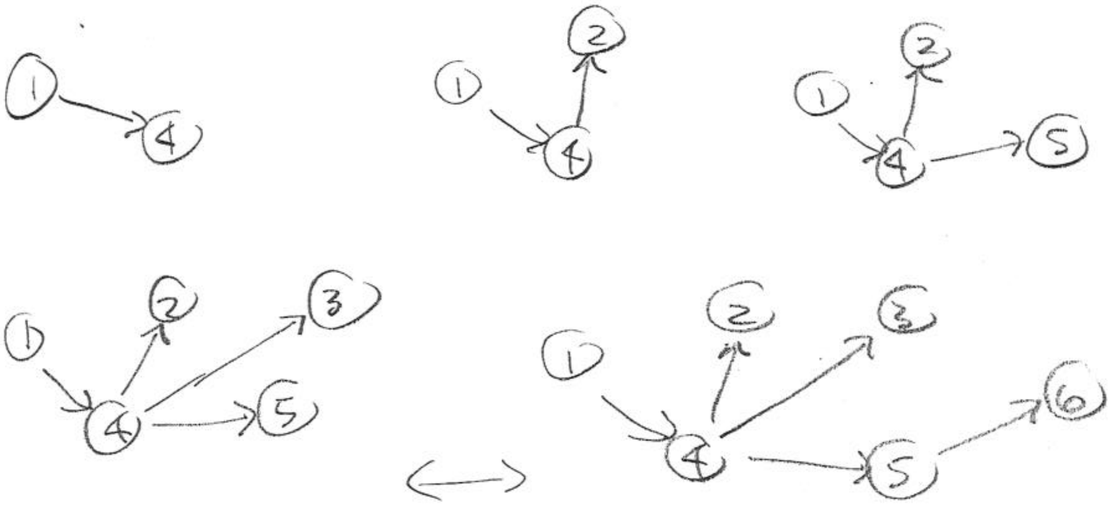
Q4) ii)



5

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Q5 a) i) MPLS technology enables service providers to offer additional services for their customers, scale their current offering, and exercise more control over their growing networks by using its traffic engineering capabilities. DiffServ using its scalable differentiation enables differentiated queuing schemes to provide differential QoS.
MPLS is a switching technology used to get packets from one place to another through a series of hops while DiffServ governs what happens to the packet at each hop. 6

Q5 ii) Forward packets based on labels rather than routing:
- The assignment of a packet to a Forwarding Equivalent Class (FEC) is done just once as the packet enters the network
- packets can be assigned a priority level 4
- How packets are assigned to a FEC does not impact the routers
- Packet payloads are not examined by the forwarding routers: allowing traffic encryption and transport of multiple protocols
- In MPLS a packet can be forced to follow an explicit route. This could be done to e.g. support traffic Engineering 3
- MPLS is independent of Layer 2 and Layer 3 technologies hence allows integration of networks with different layer 2 and layer 3 protocols

Q5(b) $C^* = \min\,[G_{-f}, G_{-s}]$

$G_- = f(R_p, b, n, u, x)$

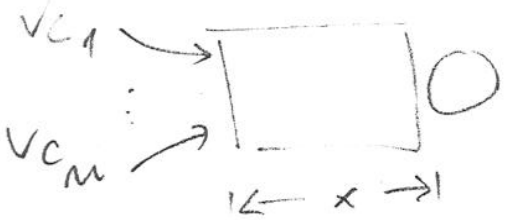
R_p = peak rate

b = mean burst length

u = utilisation (fraction of time in the "on" state) 4

x = capacity of the buffer

n = number of VC



R_p, b, u — discussion in term of source descriptors 3

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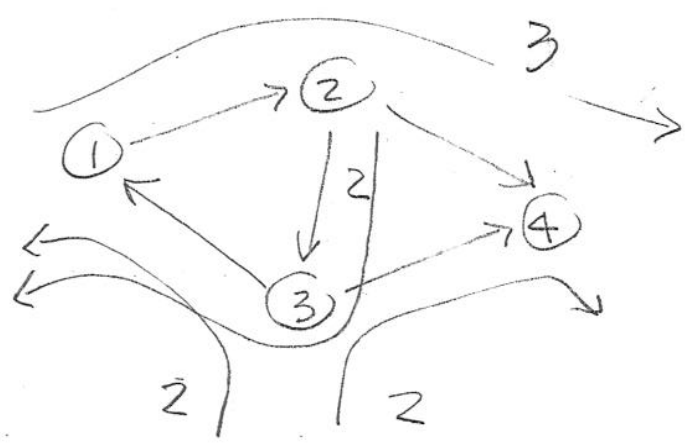
Q6a)



5

check optimal min

$N = \gamma T$

$$\frac{10}{(10-3)^2} \Leftrightarrow \frac{2\cdot 10}{(10-2)^2}$$

$\gamma = q[P(s)]$

0.2040 < 0.3125
(sh pt)

$$D = \frac{3\times 2}{10-3} + \frac{2\times 2}{10-2} + \frac{4}{10-4}$$ 5

$$D = \frac{4}{\cancel{7}} + \frac{4}{8} + \frac{4}{6} =$$

$N = 2.0236$

5

Q6b)

$$\frac{2\cdot 10}{(10-2)^2} = \frac{z}{(z-3)^2}$$

$$20(z-3)^2 = z\,(8)^2$$

$$(z-3)^2 - z\,\frac{64}{20} = 0$$

$$z^2 - 9.2z + 9 = 0$$

$$z = \frac{+9.2 \pm \sqrt{(9.2)^2 - 4\cdot 9}}{2} = \frac{9.2 \pm 6.974}{2}$$ 5

$$z_1^* = 8.087 \qquad z_2 = 1.685$$