

Question Number etc. in left margin

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Q1a)

$$U = \frac{\text{transmission time}}{N_2 [\text{time line engaged}]}$$

$$N_2 = \sum_{i=1}^{\infty} i P^{i-1} (1-P) = \frac{1}{1-P}, \quad P = \text{probability that a slot frame is in error}$$

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

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

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

$$U = 1 - P$$

Q1b)

$N = N_2$ of stations

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

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

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

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

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

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Q2a)

GEO: Geostationary earth orbit:

- have a distance of almost 36,000 km to Earth
- Examps: TV, radio broadcast, weather satellites, backbone for telephone network
- few (~3) satellites are enough for a complete coverage of almost any spot on earth
- do not need handover

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 non handover

LEO:

- use altitudes of 500 - 1,500 km
- 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
- short life time
- Require special mechanism for handover

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Q₂b) 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

- Inter-satellite handover: If a user leaves the footprint of a satellite or if the satellite moves away, a handover to the next satellite takes place.

Inter satellite handover can also take place between satellites if they support ISBs.

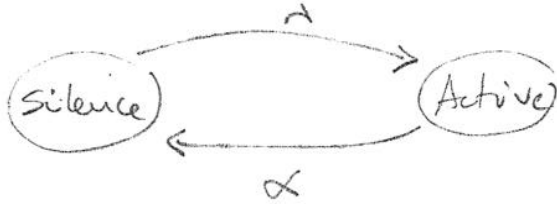
- Gateway handover: While the mobile user and satellite might still have good contact, the satellite might move away from the current gateway. The satellite has to connect to another gateway

- 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

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Q2b)
i)

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

steady state probability being active = $\frac{\lambda}{\lambda + \alpha}$

ii)

N -multiplexed independent sources:

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

$$p = \frac{\lambda}{\lambda + \alpha}$$

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

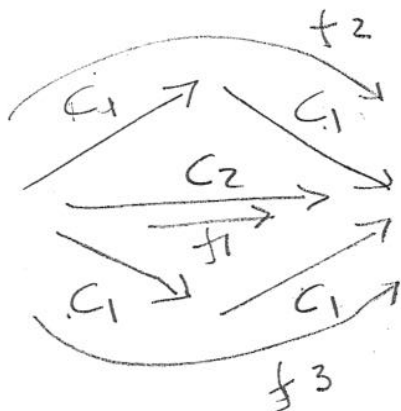
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Q3a)



$$f_1 + f_2 + f_3 = 10$$

$$f_2 = f_3$$

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

$$\frac{C_2}{(C_2 - f_1)^2} = \frac{2 \times C_1}{(C_1 - f_2)^2}$$

$$C_2 (C_1 - f_2)^2 = 2C_1 (C_2 - f_1)^2$$

$$\sqrt{C_2} (C_1 - f_2) = \sqrt{2C_1} (C_2 - f_1)$$

$$\begin{aligned} \sqrt{C_2} C_1 - \sqrt{C_2} f_2 &= \sqrt{2C_1} C_2 - \sqrt{2C_1} f_1 \\ &= \sqrt{2C_1} C_2 - \sqrt{2C_1} (10 - 2f_2) \end{aligned}$$

$$\sqrt{C_2} C_1 - \sqrt{2C_1} C_2 + \sqrt{2C_1} 10 = \sqrt{C_2} f_2 + \sqrt{2C_1} 2f_2$$

$$f_2 = \frac{\sqrt{C_2} C_1 + \sqrt{2C_1} (10 - C_2)}{\sqrt{C_2} + \sqrt{2C_1} 2}$$

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Subnetwork A $C_1 = 10, C_2 = 6$

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

$$f_1 = 2.561$$

$$D_A \sim 3.11$$

Subnetwork B $C_1 = 9, C_2 = 7$

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

$$f_1 = 3.43$$

$$D_B \sim 3.25$$

(23b)

Subnetwork A $C_2 \leftarrow C_2 + 1$

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

$$f_1 = 3.11$$

$$D_{A+\Delta A} \sim 2.896$$

Subnetwork B $C_2 \leftarrow C_2 + 1$

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

$$f_1 = 4$$

$$D_{B+\Delta B} \sim 3.00$$

$$\Rightarrow \text{Sub net } B$$

$$D_{TOT} = D_{A+\Delta A} + D_B$$

$$6.15 / 6.11$$

(min)

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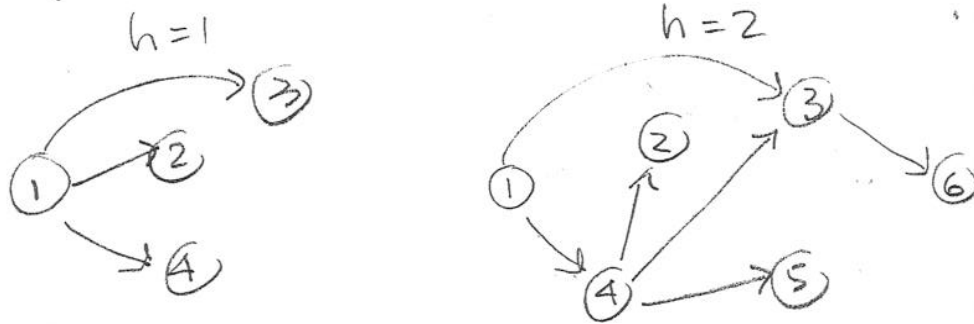
Q4a) i) Bellman Ford sh-pt:

- 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 $h = \text{solution } h+1$

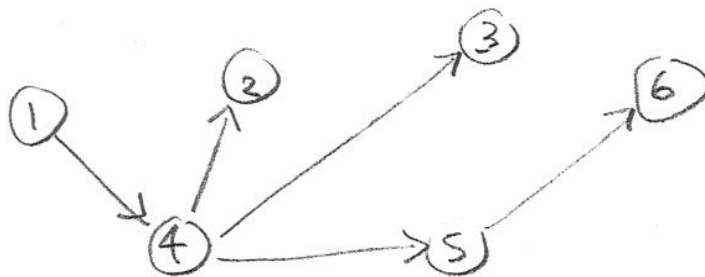
ii) Dijkstra sh-pt

- choose 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
- stop when all nodes are visited set P.

Q4b) i)



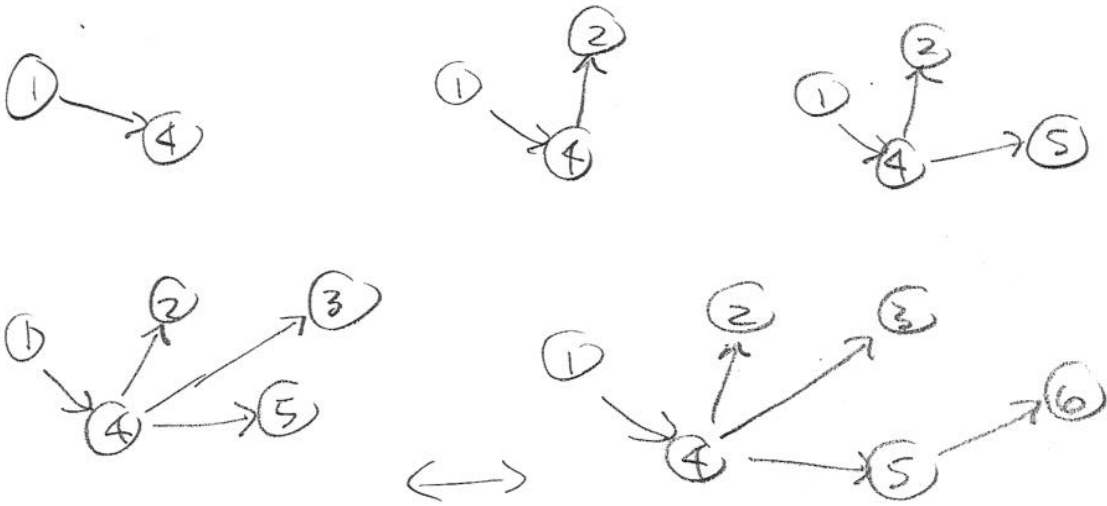
$h=3$



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Q4) i)



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Q-9) i) MPLS technology enables service providers to offer additional services for their customers, scale their current offerings, and exercise more control over their growing networks by using its traffic engineering capabilities. DiffServ uses its scalable differentiators to enable differentiated packet sizes to provide differentiated 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.

Q-10) Forward packets based on labels rather than next hop:

- 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
- how packets are assigned to a FEC does not impact the routers
- Packet payload are not examined by the forwarding router: 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
- MPLS is independent of layer 2 and layer 3 technologies hence allow interoperation of networks with different layer 2 and layer 3 protocols

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Q5b) $C^* = \min [G-f, G-s]$

$$G = f(R_p, h, u, u, x)$$

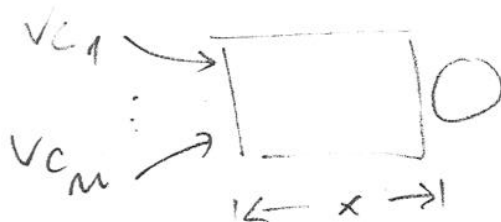
R_p = peak rate

h = mean burst length

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

x = capacity of the buffer

n = number of VC

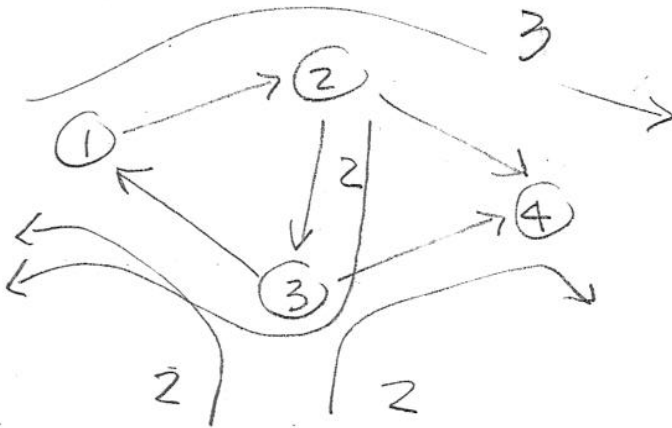


R_p, h, u - discussion in terms of source descriptors

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Q6a)



check optimal mi

$$N = \gamma \Gamma$$

$$\gamma = 9 [P(s)]$$

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

$$0.2040 < 0.3125$$

(sh pt)

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

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

$$N = 2.0236$$

Q6b)

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

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

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

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

$$z = \frac{+9.2 \pm \sqrt{(9.2)^2 - 4 \cdot 9}}{2} = \frac{9.2 \pm 6.979}{2}$$

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