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Q1 a) i)

$f(i) = 1 + (i-1)K$

from the sliding window protocol

when $W > 2a+1$ an upper bound to the number of outstanding frames is $2a+1$

when $W < 2a+1$ an upper bound to the number of outstanding frames is W

Therefore

$K \sim 2a+1$ if $W > 2a+1$

$K \sim W$ if $W < 2a+1$ [5]

ii)

$$N_R = \sum f(i)\, P^{i-1}(1-P)$$

$$N_R = (1-K)\sum_{i=1}^{\infty} P^{i-1}(1-P) + K\sum_{i=1}^{\infty} i\,P^{i-1}(1-P)$$

$$= 1-K+\frac{K}{1-P} = \frac{1-P+KP}{1-P}$$

$$U\Big|_{W>2a+1} = \frac{1-P}{1+2aP}$$

$$U\Big|_{W<2a+1} = \frac{W(1-P)}{(1+2a)(1-P+WP)}$$

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Q4 ii) i)

MANETS

- Do not rely on fixed backbone infrastructure support.
- Dynamically changing topologies
- Mobile devices might have short battery lifetime and limited computing power
- Easy to deploy 2

Technical Issues

- Power consumption management
- security threats
- wireless data rates
- scalability (memory, bandwidth, processing power) 2

Routing

- Dynamic topology (high probability of link failure)
- every device is a potential router
- no centralised routing 2

Deployment examples

- opportunistic inter-personal communications
- Disaster relief remote environments 1
- Alternative to expensive fixed infrastructure

ii) Intelligent vehicle

- Collision avoidance 3
- Driver assistance
- Collision notification

expand any specific application from above

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Q2a i) $\min T_1 = \sum x_i l_i(x_i)$

This optimisation problem minimises the total or equivalently the average delay experienced over all paths

$$T_1 = \frac{x_1^2}{3} * x_1 + 2x_2^2 * x_2 \qquad x_1 + x_2 = 1$$

$$\frac{3x_1^2}{3} = 6x_2^2 \qquad \text{opt condition}$$

$$x_1 = \sqrt{6}\, x_2 \qquad x_1 + x_2 = 1$$

ii) $\min T_2 = \sum \int l_i(x_i)$

In this case each source choose minimum delay end-to-end path. That is all path with nonzero flow have the same delay. There is no regard as to the delay of the other path on the system

$$\frac{x_1^2}{3} = 2x_2^2$$

$$x_1^2 = 6x_2^2$$

$$x_1 = \sqrt{6} x_2 \qquad x_1 + x_2 = 1$$

$x_1^* = 0.7101$
$x_2^* = 0.2898$

iii) discussion

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Q2b) P1: marking of packets allow routers to distinguish among packets from different traffic classes
- classification allow routers to treat different classes accordingly
- A service level agreement is necessary 2

P2: provide a degree of protection among traffic flows 0.5
- A policing mechanism needs to be in place 2

P3: While providing isolation among flows it is desirable to use resources as efficiently as possible 0.5
- Flows allow to use another flow's unused bandwidth 2

P4: As sufficient resources will not be always available, before accepting a new call flows declare their QoS requirements 0.5
- Call admission process is needed: network may deny service if it cannot meet needs. 2

0.5

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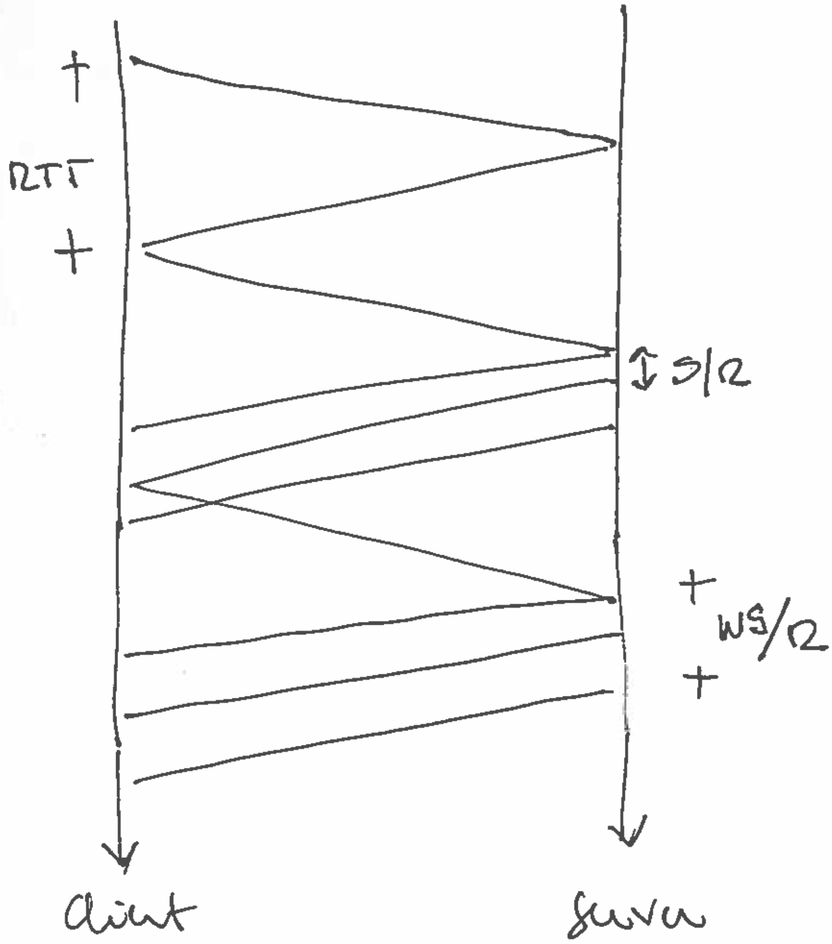
Q3 a) i) The TCP congestion control algorithm has three major components:
- Additive-increase, multiplicative decrease
- Slow start
- Reaction to time out events

+ Discussion and highlight of implementation issues 4

ii) For the case $WS/R < RTT + S/R$



$$\text{Latency} = 2RTT + O/R + (K-1)\left[\frac{S}{R} + RTT - \frac{WS}{R}\right]$$ 4

$K = O/WS$ 2

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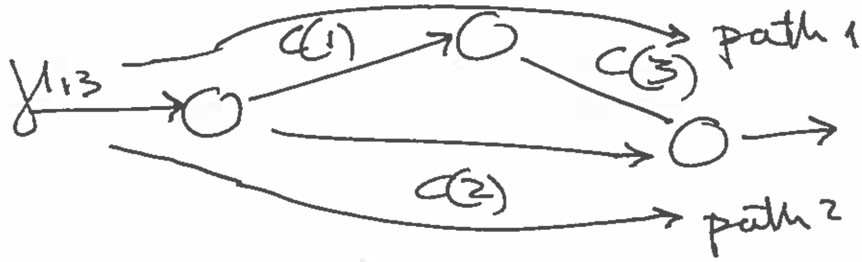
Q3b)



i) All traffic is carried by path 2. Optimality condition:

$$\frac{c_1}{(c_1-\phi)^2} + \frac{c_3}{(c_3-\phi)^2} = \frac{c_2}{(c_2-\gamma)^2}$$

$$\frac{1}{c_1} + \frac{1}{c_3} = \frac{c_2}{(c_2-\gamma)^2} = R$$

$$c_3 + c_1 = R c_1 c_3$$

$$c_1 - R c_1 c_3 = -c_3$$

$$c_1(1 - R c_3) = -c_3 \longrightarrow \boxed{\frac{c_3}{Rc_3-1} = c_1}$$

$$\boxed{Rc_3 - 1 > 0}$$ 5

ii) $c_2 = 2\gamma \qquad c_3 = 2c_2 = 4\gamma$

$$c_1 = \frac{4\gamma}{\frac{8\gamma^2}{(2\gamma-\gamma)^2} - 1} = \frac{4\gamma}{8-1} = \frac{4}{7}\gamma$$ 5

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Q4 a) i) This Index is independent of the shared resource. The Index always lies between 0 and 1. For example if the Index is 0.1 means that is unfair to 90% of the users.

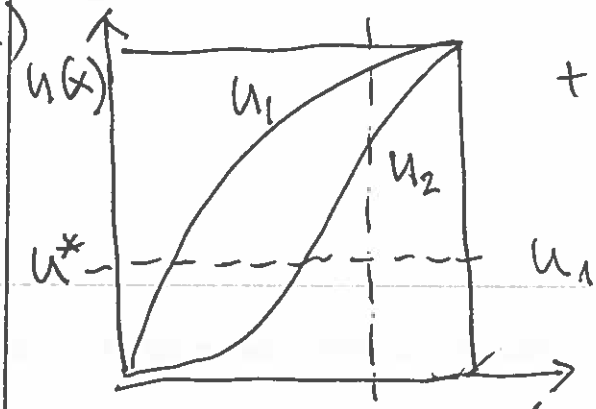
worst case $\frac{1}{n}$ best case 1

$\frac{k}{n}$ when k users equally share the resources and the other n-k users receive zero allocation. 3

ii) Max-min fairness:

Max-min fairness has been achieved if the allocation is feasible and an attempt to increase the allocation of flow will decrease the allocation of some other flow with an equal or smaller allocation.

- The allocation is done in infinitesimal increments to all flows until one is satisfied then among the remainder of the flows and so on until all flows are satisfied or the bandwidth is exhausted. 3

iii) 

+ Discussion 3

$u_1 = u_2$ (utility max-min fair)

$x_1 = x_2$ (bandwidth max-min fair) 3

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3(b) i) Edge Router:

- Per flow (aggregate) traffic management
- Mark packets as in-profile and out-profile

profile: pre-negotiated rate r and bucket size b (in the context of a token bucket mechanism).

Use of marking:

- class based marking
- Intra-class marking 4

ii) Core router:

- Per class traffic management
- Queuing and scheduling based on marking at the edge
- Preference given to in-profile over out-of-profile packets.
- Individual router's behaviour are referred as per-hop behaviour (PHB)
- PHB result in a different measurable forwarding performance behaviour
- PHB does not specify what mechanism to use to ensure required PHB.
- Example of PHB:

  Expedite forwarding
  Assured forwarding
  Best effort 4