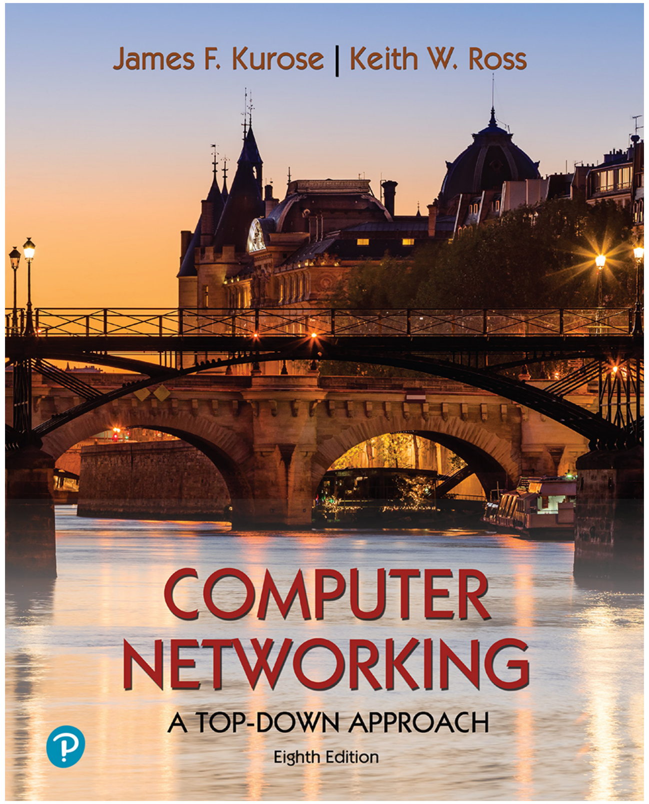
Midterm Exam Problems



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 1: roadmap

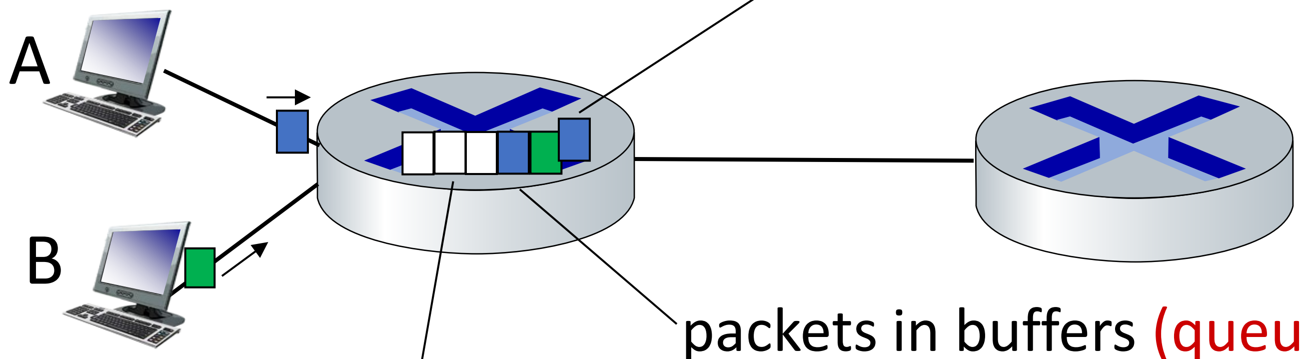
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models

IMPORTANT

How do packet delay and loss occur?

- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up

packet being transmitted (transmission delay)

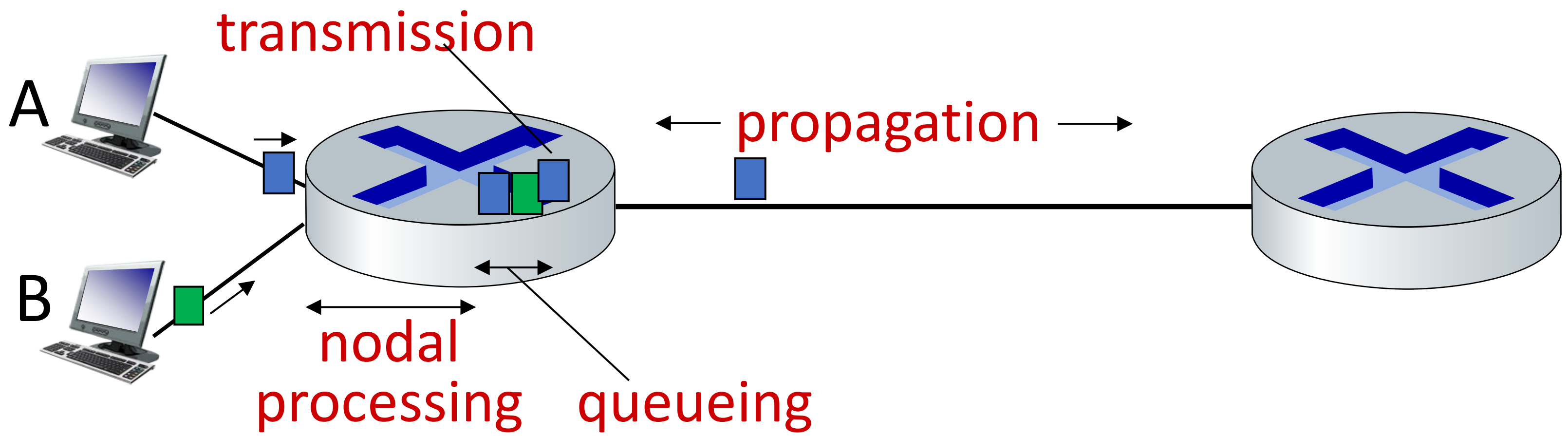


packets in buffers (queueing delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers

IMPORTANT

Packet delay: four sources



$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

d_{proc}: nodal processing

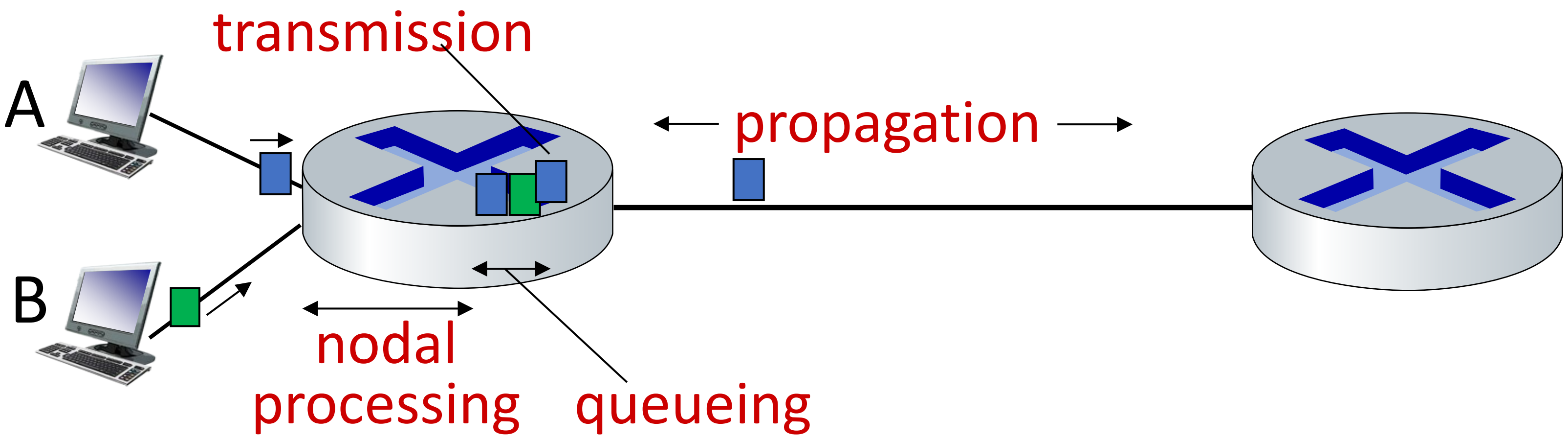
- check bit errors
- determine output link
- typically < microsecs

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

IMPORTANT

Packet delay: four sources



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

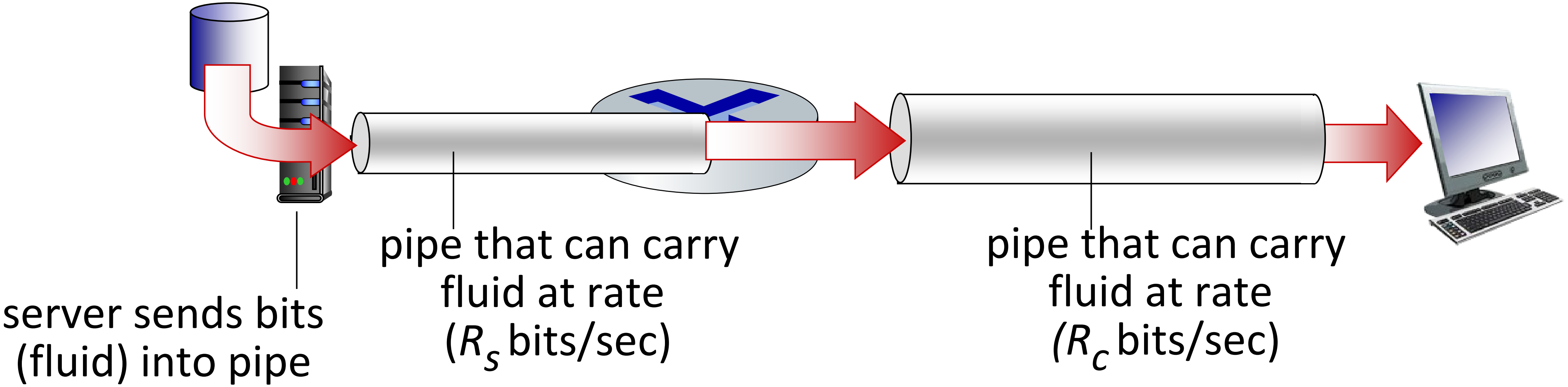
- d: length of physical link
- s: propagation speed (~2×10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop}
very different

IMPORTANT

Throughput

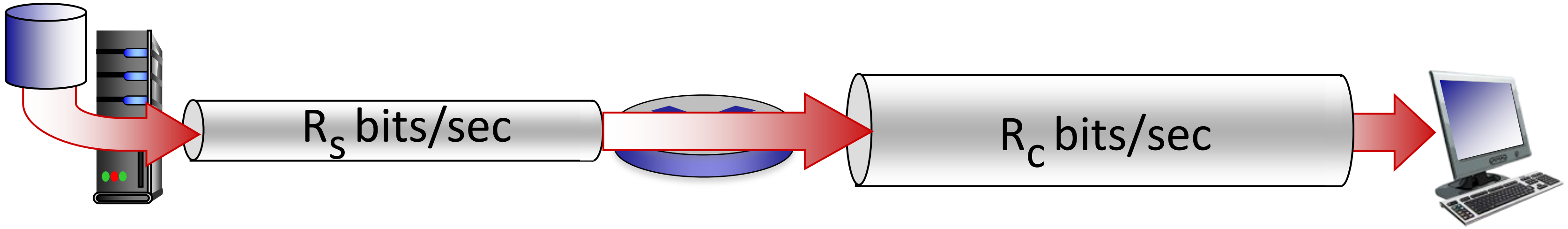
- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



IMPORTANT

Throughput

$R_s < R_c$ What is average end-end throughput?



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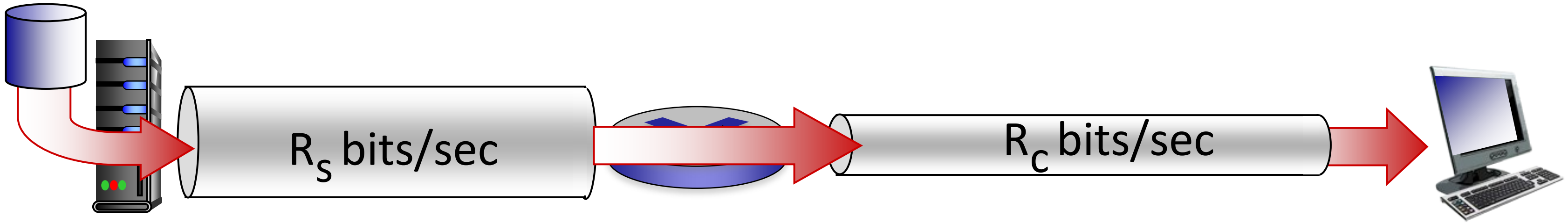
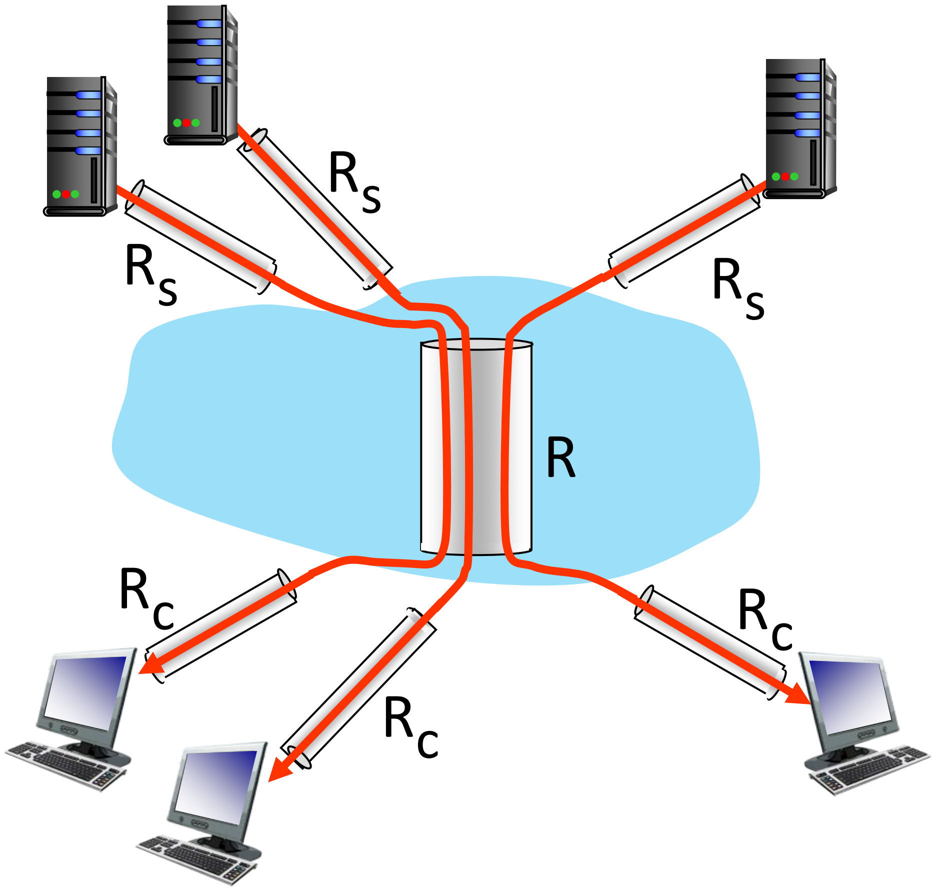


bottleneck link

link on end-end path that constrains end-end throughput

IMPORTANT

Throughput: network scenario

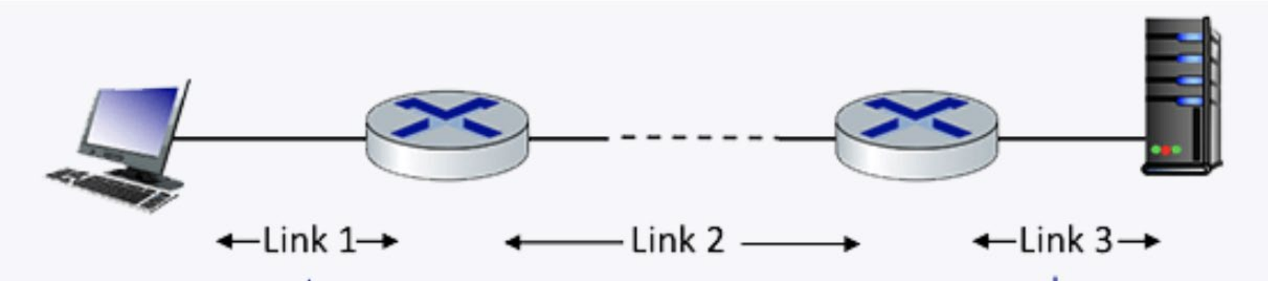


10 connections (fairly) share backbone bottleneck link *R* bits/sec

- per-connection end-end throughput: $min(R_c,R_s,R/10)$
- in practice: R_c or R_s is often bottleneck
- Link utilization: used bandwidth/available bandwidth. For the three links:
  - $min(R_c,R_s,R/10)/R_s$
  - $min(R_c,R_s,R/10)/(R/10)$
  - $min(R_c,R_s,R/10)/R_c$

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/

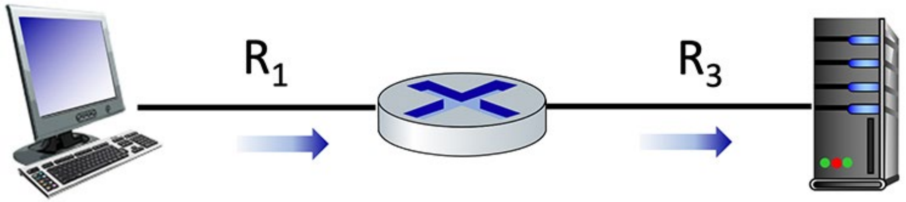
Midterm Question 1.4-01a



- 1.4-01a. Performance: Delay. Consider the network shown in the figure below, with three links, each with a transmission rate of 1 Mbps, and a propagation delay of 1 msec per link. Assume the length of a packet is 1000 bits.
- What is the end-end delay of a packet from when it first begins transmission on link 1, until is it received in full by the server at the end of link 3. You can assume that queueing delays and packet processing delays are zero, but make sure you include packet transmission time delay on all links. Assume store-and forward packet transmission.

- Each link has transmission delay 1000 bits/1 Mbps = 1ms. So each link has total delay of transmission + propagation = 1+1=2 ms.
- For the three links, the total delay = 2 + 2 + 2 = 6 ms. `

Midterm Question 1.4-01b

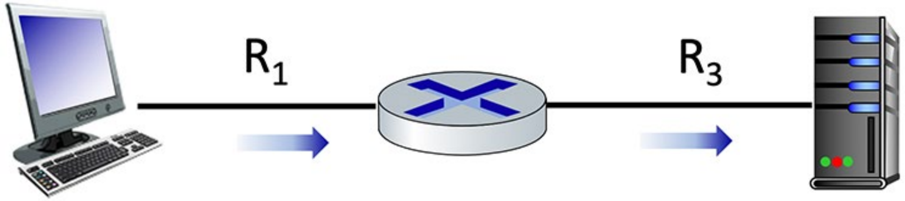


- Maximum end-end throughput. Consider the scenario shown below, with a single source client sending to a server over two links of capacities R1=100 Mbps and R3=10 Mbps.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for the client-to-server pair, assuming that the client is trying to send at its maximum rate?

- min (R1, R3) = min (100, 10) = 10 Mpbs.

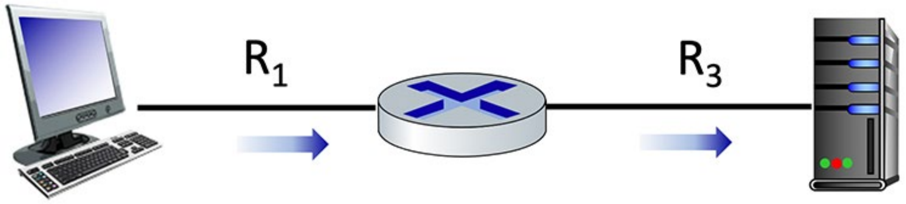
Midterm Question 1.4-01c

- Performance: Maximum end-end throughput. Consider the scenario shown below, with a single source client sending to a server over two links of capacities R1=10 Mbps and R3=100 Mbps.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for the client-to-server pair, assuming that the client is trying to send at its maximum rate?



- min (R1, R3) = min (10, 100) = 10 Mpbs.

Midterm Question 1.4-01c

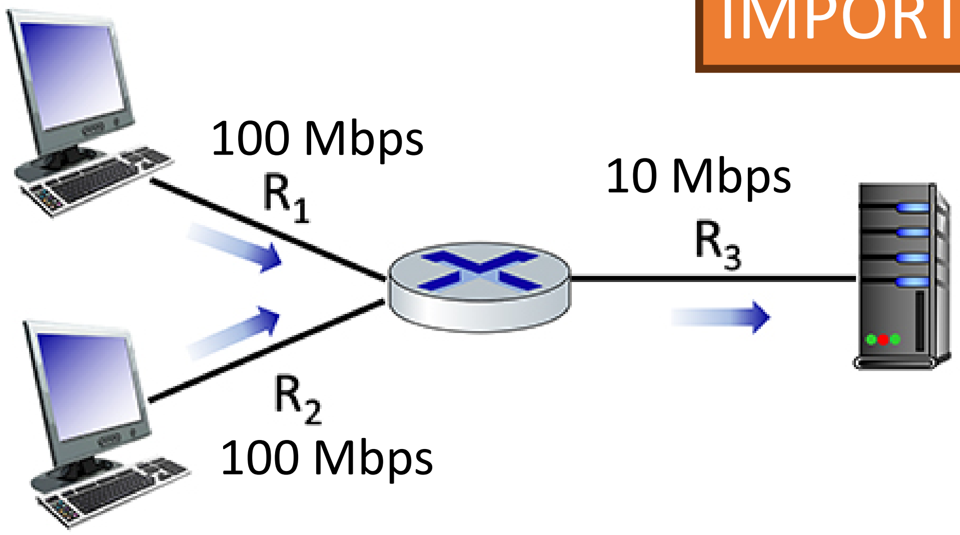


- Performance: Maximum end-end throughput. Consider the scenario shown below, with a single source client sending to a server over two links of capacities R1=10 Mbps and R3=100 Mbps.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for the client-to-server pair, assuming that the client is trying to send at its maximum rate?

- min (R1, R3) = min (10, 100) = 10 Mpbs.

IMPORTANT

Midterm Question 1.4-01d

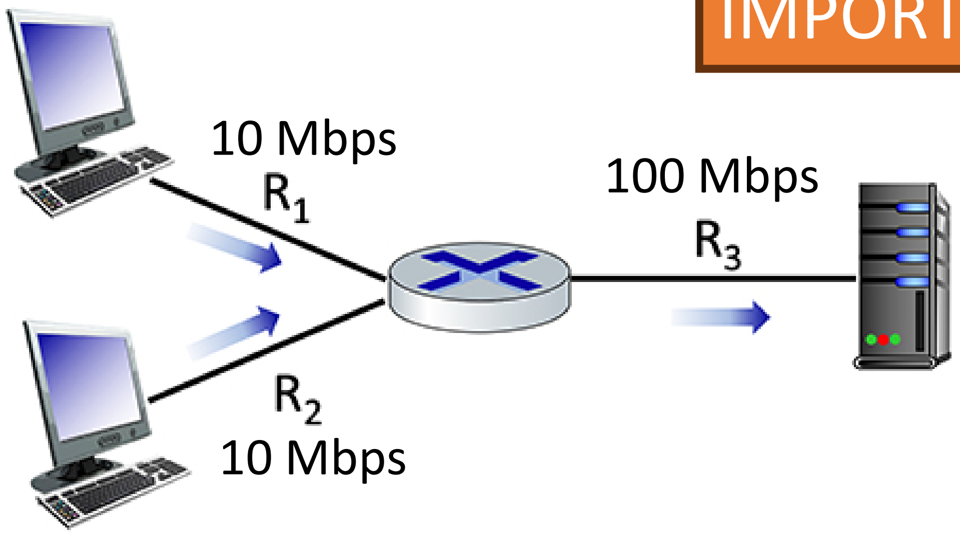


- 1.4-01e. Performance: Maximum end-end throughput. Consider the scenario shown below, with two clients sending to a server. The links attached to clients each have a capacity of R1= R2 = 100 Mbps. The link from the router to the server has a capacity of and R3 = 10 Mbps, which is shared evenly between the two sources when they are each sending at their maximum rate.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for each client-to-server pair, assuming that the client is trying to send at its maximum rate?

- The maximum achievable end-end throughput is min (R1, R3/2) = min (R2, R3/2) = min (100, 10/2) = 5 Mbps.
- The shared 100 Mbps link is fairly shared among two end-to-end connections (R1, R3) and (R2, R3), hence each end-to-end connection gets 10/2=5 Mbps.

IMPORTANT

Midterm Question 1.4-01e

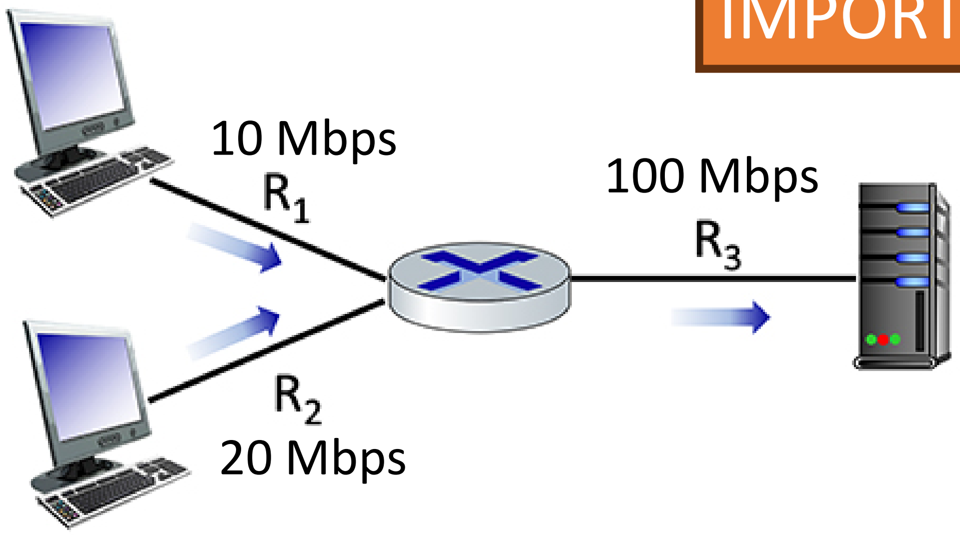


- 1.4-01e. Performance: Maximum end-end throughput. Consider the scenario shown below, with two clients sending to a server. The links attached to clients each have a capacity of R1= R2 = 10 Mbps. The link from the router to the server has a capacity of and R3 = 100 Mbps, which is shared evenly between the two sources when they are each sending at their maximum rate.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for each client-to-server pair, assuming that the client is trying to send at its maximum rate?

- The maximum achievable end-end throughput is min (R1, R3/2) = min (R2, R3/2) = min (10, 100/2) = 10 Mbps.
- The shared 100 Mbps link is fairly shared among two end-to-end connections (R1, R3) and (R2, R3), hence each end-to-end connection gets 100/2=50 Mbps.
- Note that min (R1, R2, R3/2) is incorrect, since R1 and R2 are on deferent end-to-end connections.
- Remember that parallel links should never be put into the min() formula, only sequential links forming the same end-to-end connection should be in the same min() formula.

IMPORTANT

Midterm Question 1.4-01e variation



- 1.4-01e. Performance: Maximum end-end throughput. Consider the scenario shown below, with two clients sending to a server. The links attached to clients each have a capacity of R1 = 10 Mbps, R2 = 20 Mbps. The link from the router to the server has a capacity of and R3 = 100 Mbps, which is shared evenly between the two sources when they are each sending at their maximum rate.
- What is the maximum achievable end-end throughput (in Mbps, give an integer value) for each client-to-server pair, assuming that the client is trying to send at its maximum rate?

- For client on top, the maximum achievable end-end throughput is min (R1, R3/2) = min (10, 100/2) = 10 Mbps.
- For client on bottom, the maximum achievable end-end throughput is min (R1, R3/2) = min (20, 100/2) = 20 Mbps.
- The shared 100 Mbps link is fairly shared among two end-to-end connections (R1, R3) and (R2, R3), hence each end-to-end connection gets 100/2=50 Mbps.

Midterm Question 1.4-02a

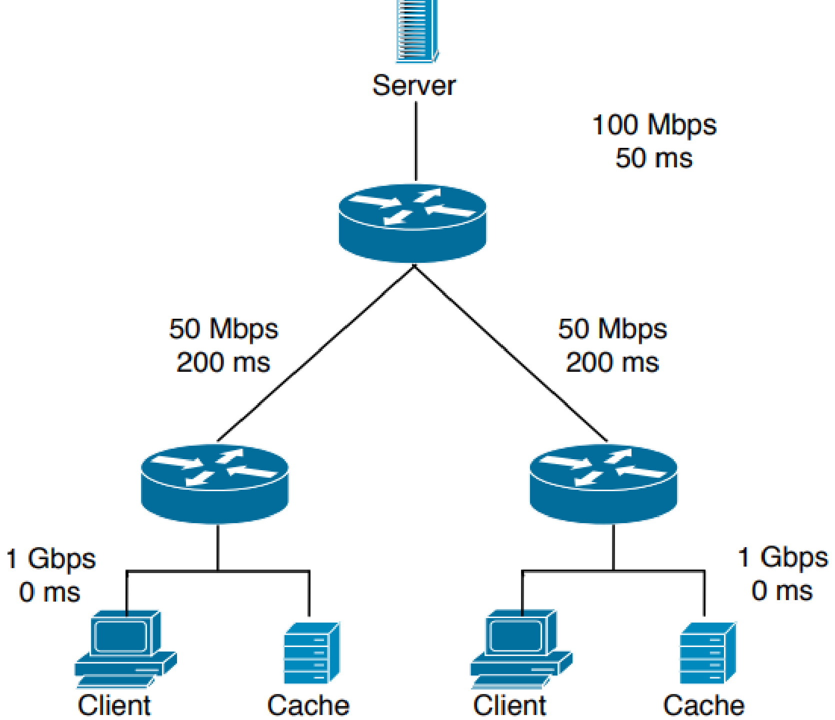


Figure 1

- Consider the scenario shown in Figure 1 in which a server is connected to a router by a 100Mbps link with a 50ms propagation delay. Initially this router is also connected to two routers, each over a 50Mbps link with a 200ms propagation delay. A 1Gbps link connects a host and a cache (if present) to each of these routers and we assume that this link has 0 propagation delay. All packets in the network are 20,000 bits long.
- What is the end-to-end delay (in msec) from when a packet is transmitted by the server to when it is received by the client? In this case, we assume there are no caches, there's no queuing delay at the routers, and the packet processing delays at routers and nodes are all 0.

- ANS: If all packets are 20,000 bits long it takes 200 usec to send the packet over the 100Mbps link, 400 usec to send over the 50Mbps link, and 20 usec to send over the 1Gbps link.
- Sum of the three-link transmission is 620 usec. Thus, the total end-to-end delay is 250 ms + 620 usec = 250.62 msec.

Midterm Question 1.4-02b

- Here we assume that client hosts send requests for files directly to the server (caches are not used or off in this case). What is the maximum rate at which the server can deliver data to a single client if we assume no other clients are making requests?

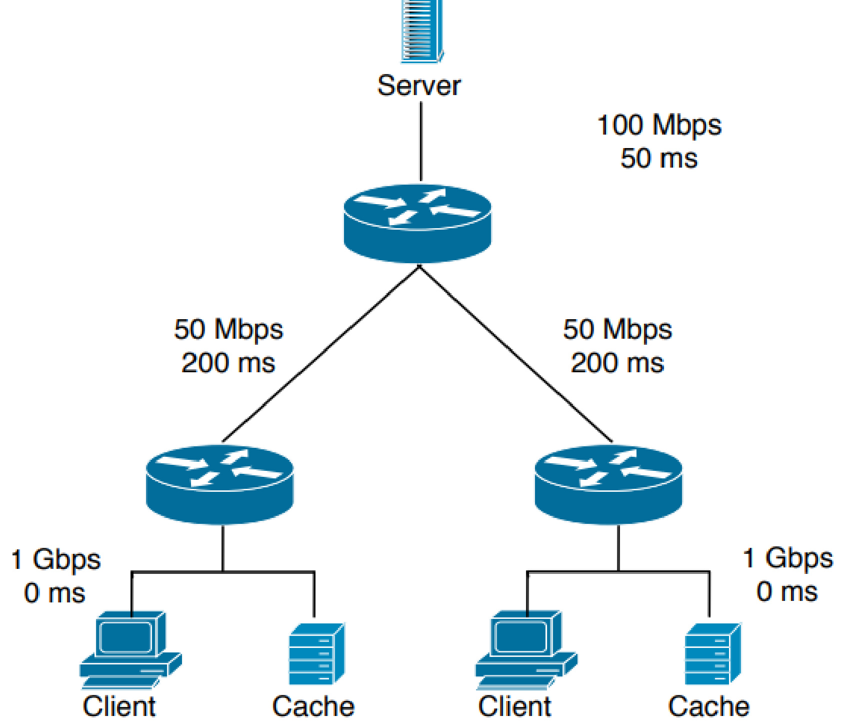


Figure 1

- Server can send at the max of the bottleneck link bandwidth min(100/2 Mbps, 50 Mbps, 1 Gbps) = 50 Mbps, since the top link is shared and the other two links are separate for each client and not shared.
- Suppose we had 10 clients on the bottom, then the bottleneck link bandwidth min(100/10 Mbps, 50 Mbps, 1 Gbps) = 10 Mbps.

Midterm Question 1.4-02c

- Again we assume only one active client but in this case the caches are on and behave like HTTP caches. A client's HTTP GET is always first directed to its local cache. 60% of the requests can be satisfied by the local cache. What is the average rate at which the client can receive data in this case?

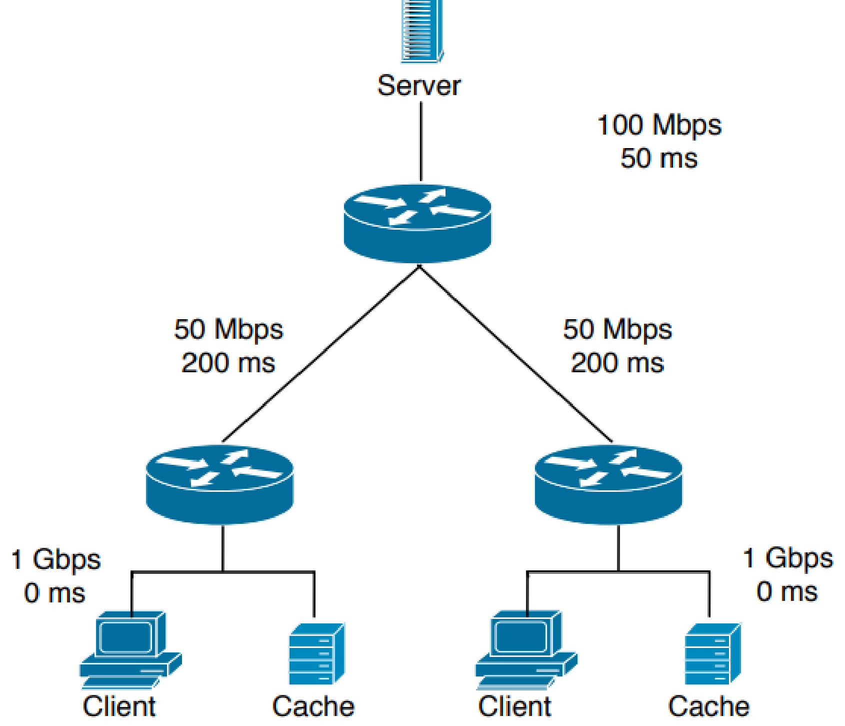


Figure 1

- 60% of the requests can be satisfied by the local cache, with bandwidth of 1 Gbps = 1000 Mpbs.
- 40% of the requests go to the remote server, with bandwidth of min (100 Mbps, 50 Mbps, 1Gbps) = 50 Mpbs.
  - Since we assume only one active client, we do not have 100/2 as the first term.
- The average rate at which the client can receive data is .4*50+.6*1000=620 Mbps

Midterm Question 1.4-02d

- Now clients in both LANs are active and the both caches are on. 60% of the requests can be satisfied by the local caches. What is the average rate at which each client can receive data?

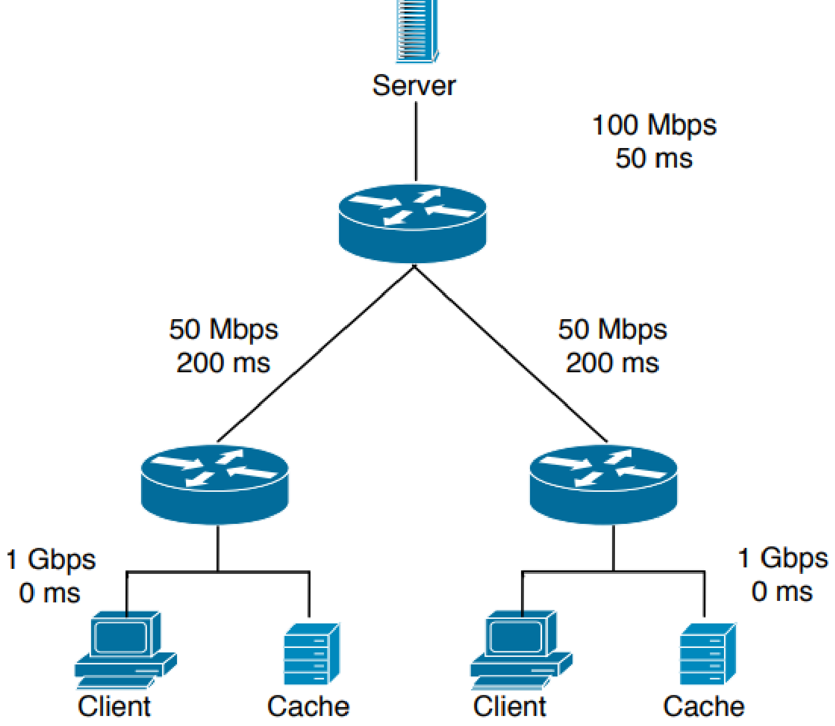


Figure 1

- 60% of the requests can be satisfied by the local cache, with bandwidth of 1 Gbps = 1000 Mpbs.
- 40% of the requests go to the remote server, with bandwidth of min (100/2 Mbps, 50 Mbps, 1Gbps) = 50 Mpbs.
  - Since we both clients are active, we have 100/2 as the first term.
- The average rate at which the client can receive data is .4*50+.6*1000=620 Mbps

Network layer: “data plane” roadmap

- Network layer: overview
  - data plane
  - control plane
- What’s inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized Forwarding, SDN
  - Match+action
  - OpenFlow: match+action in action
- Middleboxes

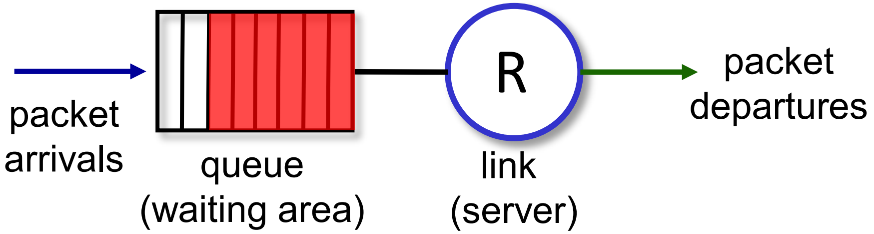
IMPORTANT

Packet Scheduling: FCFS

packet scheduling: deciding which packet to send next on link

- first come, first served
- priority
- round robin
- weighted fair queueing

Abstraction: queue



FCFS: packets transmitted in order of arrival to output port

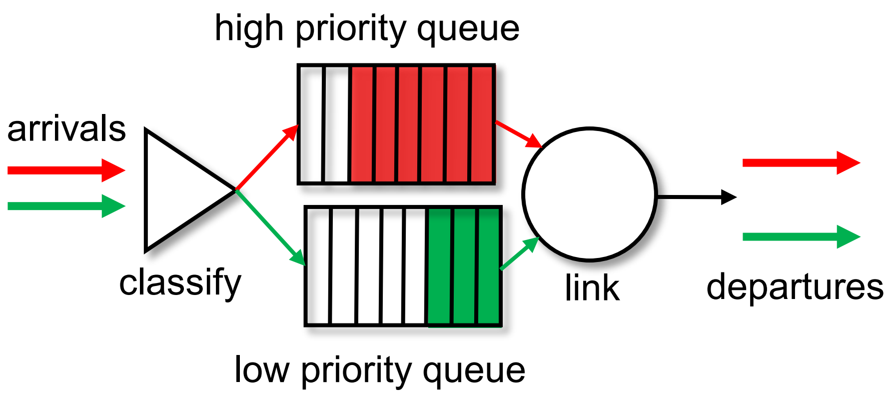
- also known as: First-in-first-out (FIFO)
- real world examples?

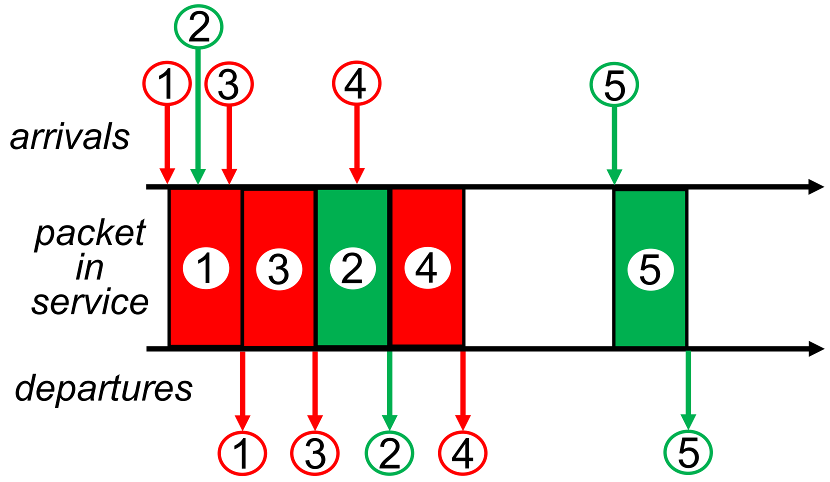
IMPORTANT

Scheduling policies: priority

Priority scheduling:

- arriving traffic classified, queued by class
  - any header fields can be used for classification
- send packet from highest priority queue that has buffered packets
  - FCFS within priority class



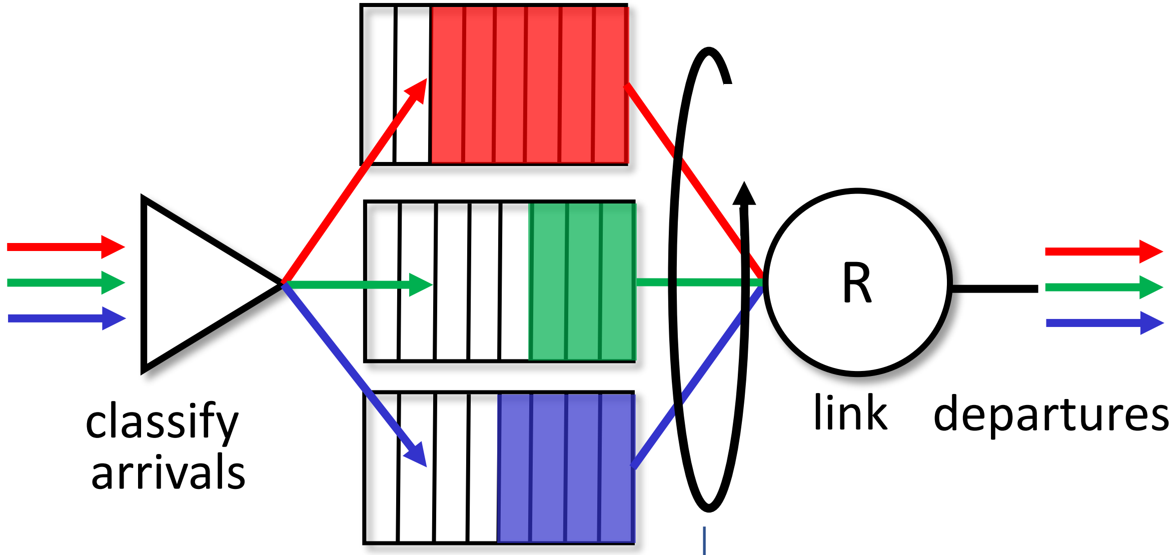


IMPORTANT

Scheduling policies: round robin

Round Robin (RR) scheduling:

- arriving traffic classified, queued by class
  - any header fields can be used for classification
- server cyclically, repeatedly scans class queues, sending one complete packet from each class (if available) in turn



IMPORTANT

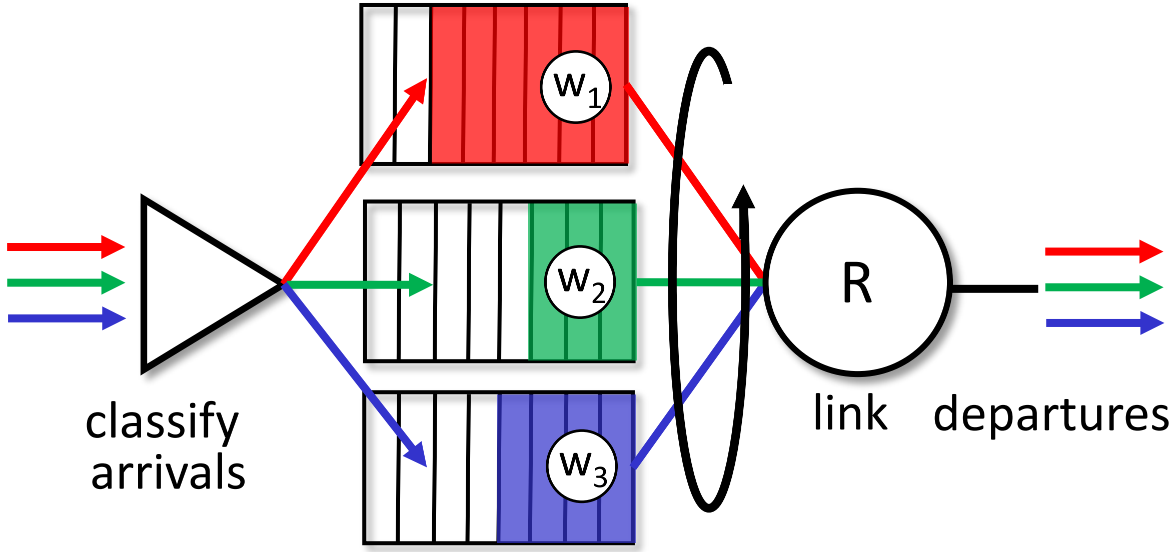
Scheduling policies: weighted fair queueing

Weighted Fair Queuing (WFQ):

- generalized Round Robin
- each class, i, has weight, w_i, and gets weighted amount of service in each cycle:

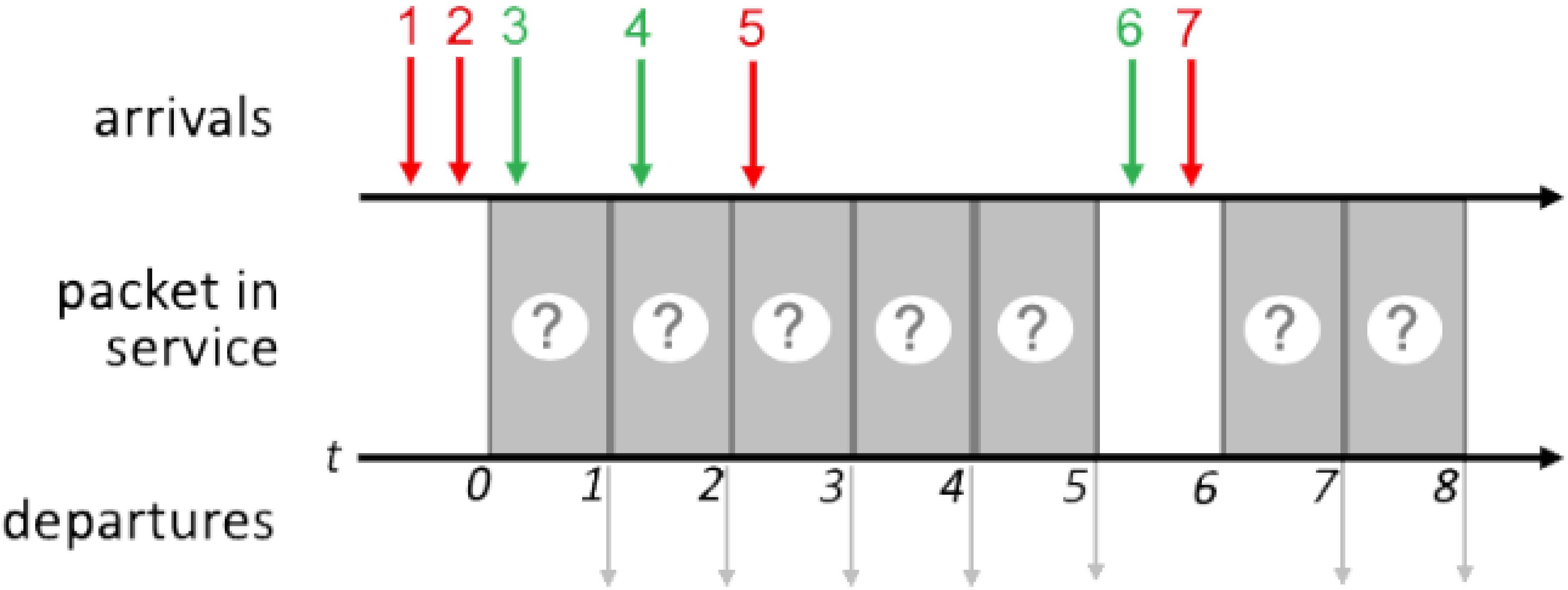
$$\frac{w_i}{\Sigma_j w_j}$$

- minimum bandwidth guarantee (per-traffic-class)



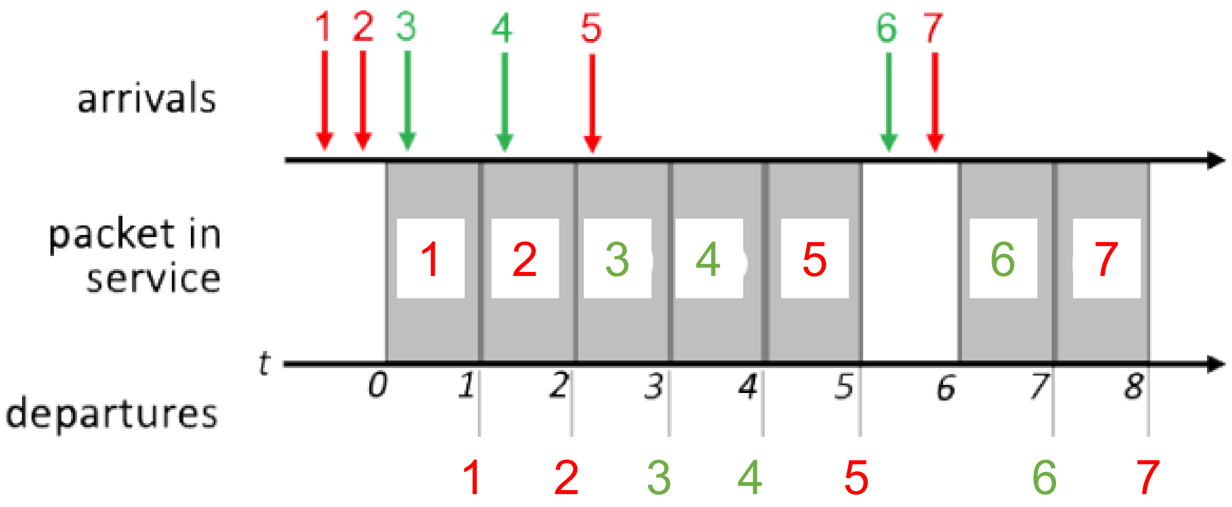
IMPORTANT

Quiz 1 4.2-7



IMPORTANT

Quiz 1 4.2-7a FCFS Scheduling

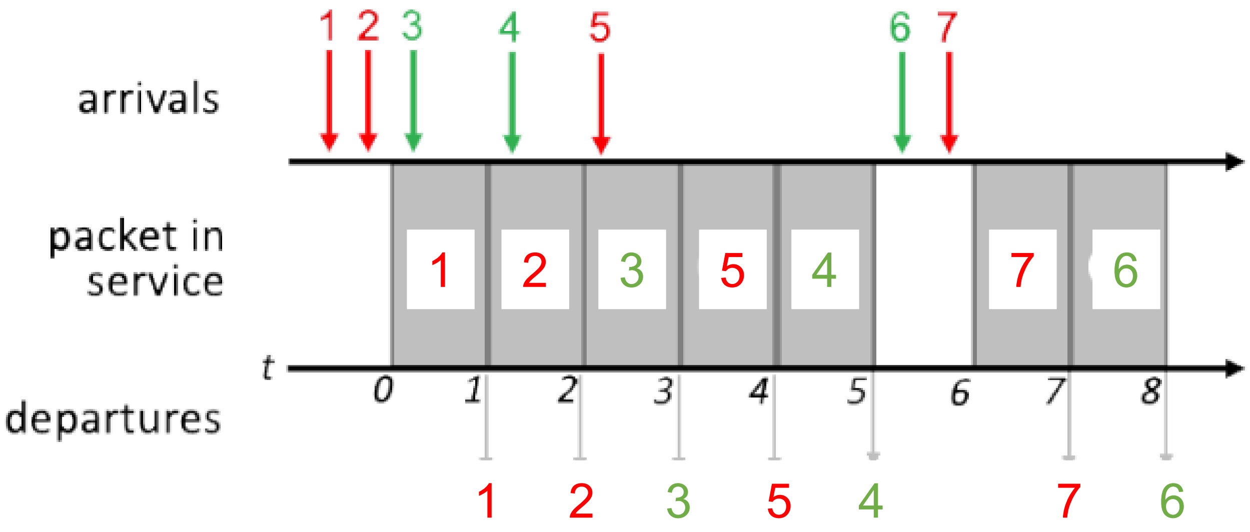


1 2 3 4 5 6 7

- Transmit order the same as packet arrival order of 1 2 3 4 5 6 7

IMPORTANT

Quiz 1 4.2-7b Priority Scheduling

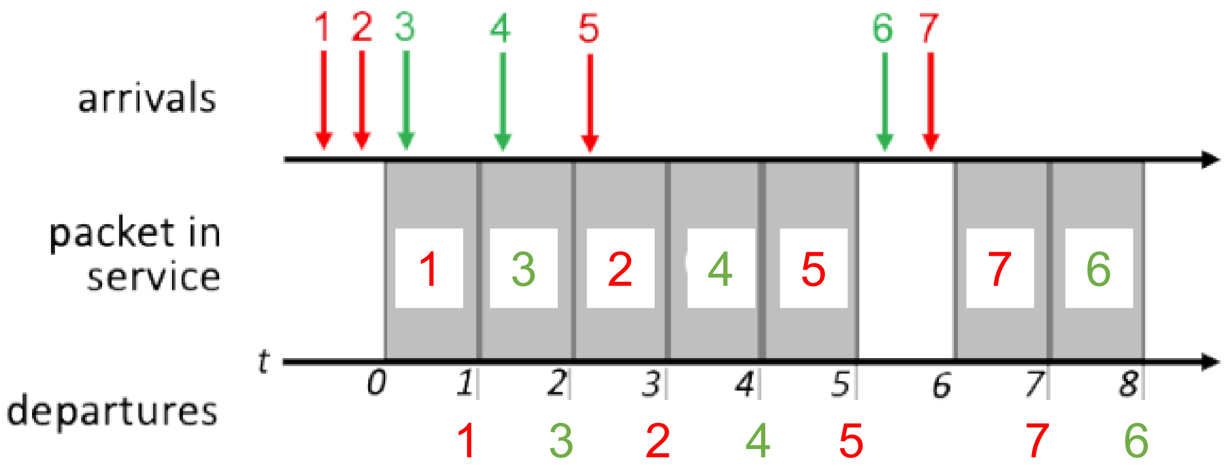


1 2 3 5 4 7 6

- Time 0: 1, 2 in queue, transmit 1
  - FCFS within same priority
- Time 1: 2, 3 in queue, transmit 2
- Time 2: 3, 4 in queue, transmit 3
  - FCFS within same priority
- Time 3: 4, 5 in queue, transmit 5
- Time 4: 4 in queue, transmit 4
- Time 6: 6, 7 in queue, transmit 7
- Time 7: 6 in queue, transmit 6

Quiz 1 4.2-7c Round Robin Scheduling

IMPORTANT



1 3 2 4 5 7 6

- Assume a round-robin scheduling cy red packets. i.e., (red, green) in each round.
- Time 0: 1, 2 in queue, transmit 1
  - 1st round of (red, green)
- Time 1: 2, 3 in queue, transmit 3
  - 1st round of (red, green)
- Time 2: 2. 4 in queue, transmit 2
  - 2nd round of (red, green)
- Time 3: 4, 5 in queue, transmit 4
  - 2nd round of (red, green)
- Time 4: 5 in queue, transmit 5
  - 3RD round of (red, green). Since there is no green packet ready, this round is (red, null)
- Time 6: 6, 7 in queue, transmit 7
  - 4th round of (red, green)
- Time 7: 6 in queue, transmit 6
  - 4th round of (red, green)
- Summary:
- Times 0-1: 1st round: (1, 3)
- Times 2-3: 2nd round: (2, 4)
- Time 4: 3rd round: (5, null)
  - No green packets ready
- Times 6-7: 4th round: (7, 6)