1. In Figure 1: (a) What is C's initial distance vector? (b) What is the distance vector after it receives a vector from A? (c) What is its vector when it receives a vector from B? (d) If C uses split horizon with poison reverse, what is the distance vector that B then receives from C? [4 marks]

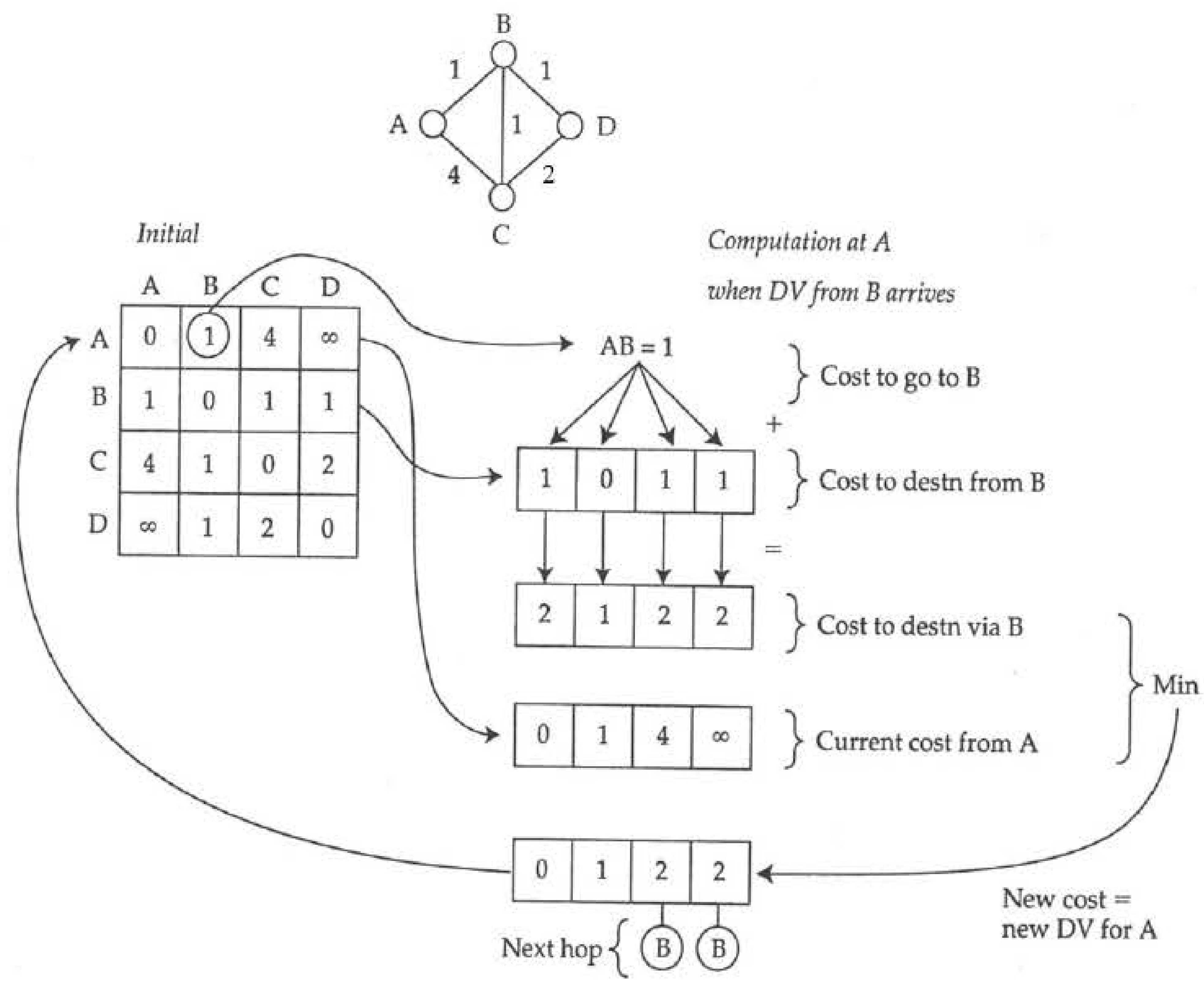


Figure 1

2. Consider the network shown in Figure 2. The numbers associated with each link represent link costs. Use Dijkstra's algorithm to compute the shortest paths between Node 3 and each of the other nodes. If there is a tie, ***break it in favor of leftmost column***. Let [8 marks]

- $D(v)$: cost of the least-cost path from source to destination $v$.
- $P(v)$: previous node (neighbour of $v$) along the current least-cost path
- $N$: $v$ is in $N$ if the least-cost path from source to $v$ is known.

| N | D(1),P(1) | D(2),P(2) | D(4),P(4) | D(5),P(5) | D(6),P(6) |
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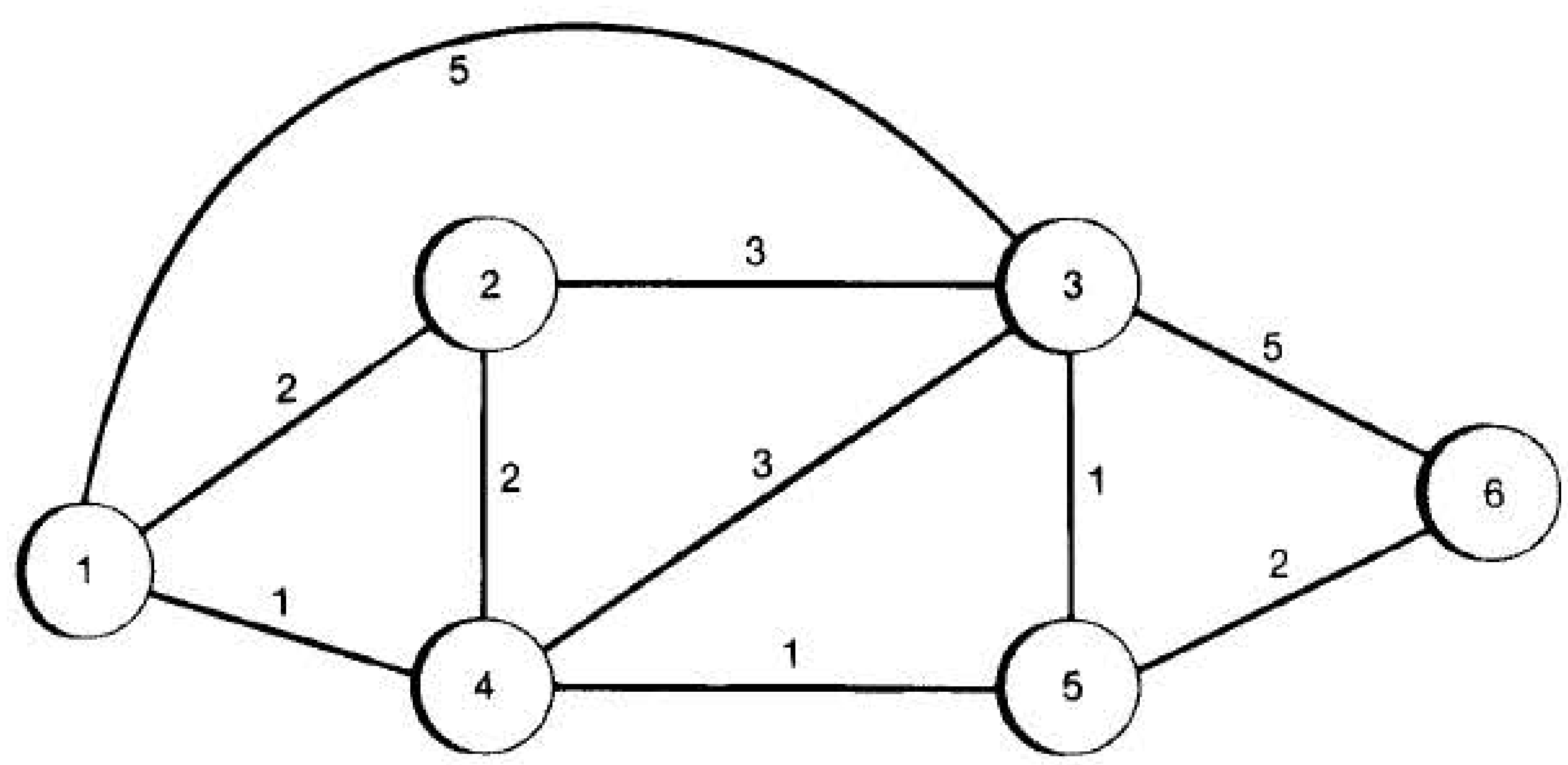
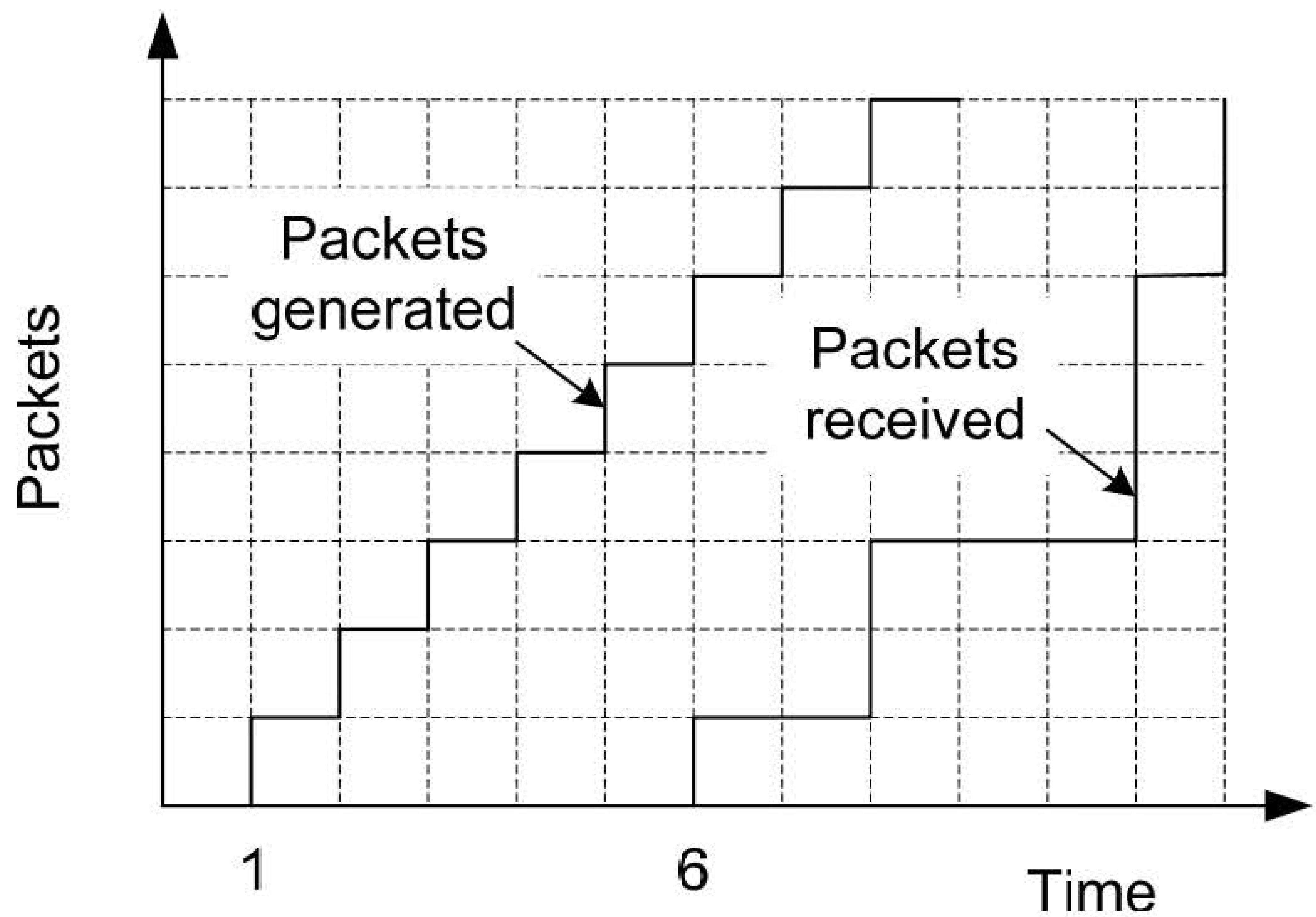



Figure 2

3. Consider the figure below. A sender begins sending packetized audio periodically at $t$=1. The first packet arrives at the receiver at $t$ = 6. [4 marks]

a) If audio playout begins at $t$ = 5, which of the first eight packet sent will *not* arrive in time for playout?
b) If audio playout begins at $t$ = 6, which of the first eight packets sent will not arrive in time for playout?
c) If audio playout begins at $t$ = 7, which of the first eight packets sent will not arrive in time for playout?
d) What is the minimum playout delay at the receiver that results in all of the first eight packets arriving in time for their playout?



4. Please use the TCP EA-RTT estimator, which is given by

$$\text{EA-RTT}(K + 1) = \alpha \times \text{EA-RTT}(K) + (1 - \alpha) \times \text{RTT}(K + 1),$$

to obtain the estimated round-trip time RTT for the following cases. Please list out all the calculation steps. [6 marks]

a) Choose $\alpha = 0.90$ and EA-RTT(0) = 1 second and assume the measured RTT values are RTT(n) = n second where n = 1,2,… and no packet loss. What is EA-RTT(4)?

b) Now let $\alpha = 0.25$ and EA-RTT(0) = 4 second and assume the measured RTT values are RTT(n) = n+3 second and no packet loss. What is EA-RTT(4)?

5. Consider Figure Q. 5, in which there is an institutional network connected to the Internet. Suppose that the average object size is 800,000 bits and that the average request rate from the institution's browsers to the origin servers is 90 requests per minute. Also suppose that the amount of time it takes from when the router on the Internet side of the access link forwards an HTTP request until it receives the response is twice of one-trip time, with each one-trip time equal to two seconds on average. Model the total average response time as the sum of the average access delay (that is, the delay from the Internet router to the institution router) and the average Internet delay. For the average access delay, use $T/(1-TB)$, where $T$ is the average time required to send an object over the access link and $B$ is the arrival rate of objects to the access link. [15 marks]

i. Find the total average response time. [3 marks]

ii. Now suppose a cache is installed in the institutional LAN. Suppose that the hit rate is 0.4. Find the total average response time. [3 marks]

iii. Now suppose a cache is installed in the router on the Internet side of the access link instead. Suppose that the hit rate is 0.4. Find the total average response time. [3 marks]

iv. What is the total average response time if we upgrade the access link to the speed of 5 Mbps instead of installing a cache? If the speed of the access link can be further increased, what is the minimum possible value for the total average response time? [3 marks]

v. What is the result of i. if we consider the delay caused by the LAN (Hint: use the formula for calculating the access delay)? [3 marks]

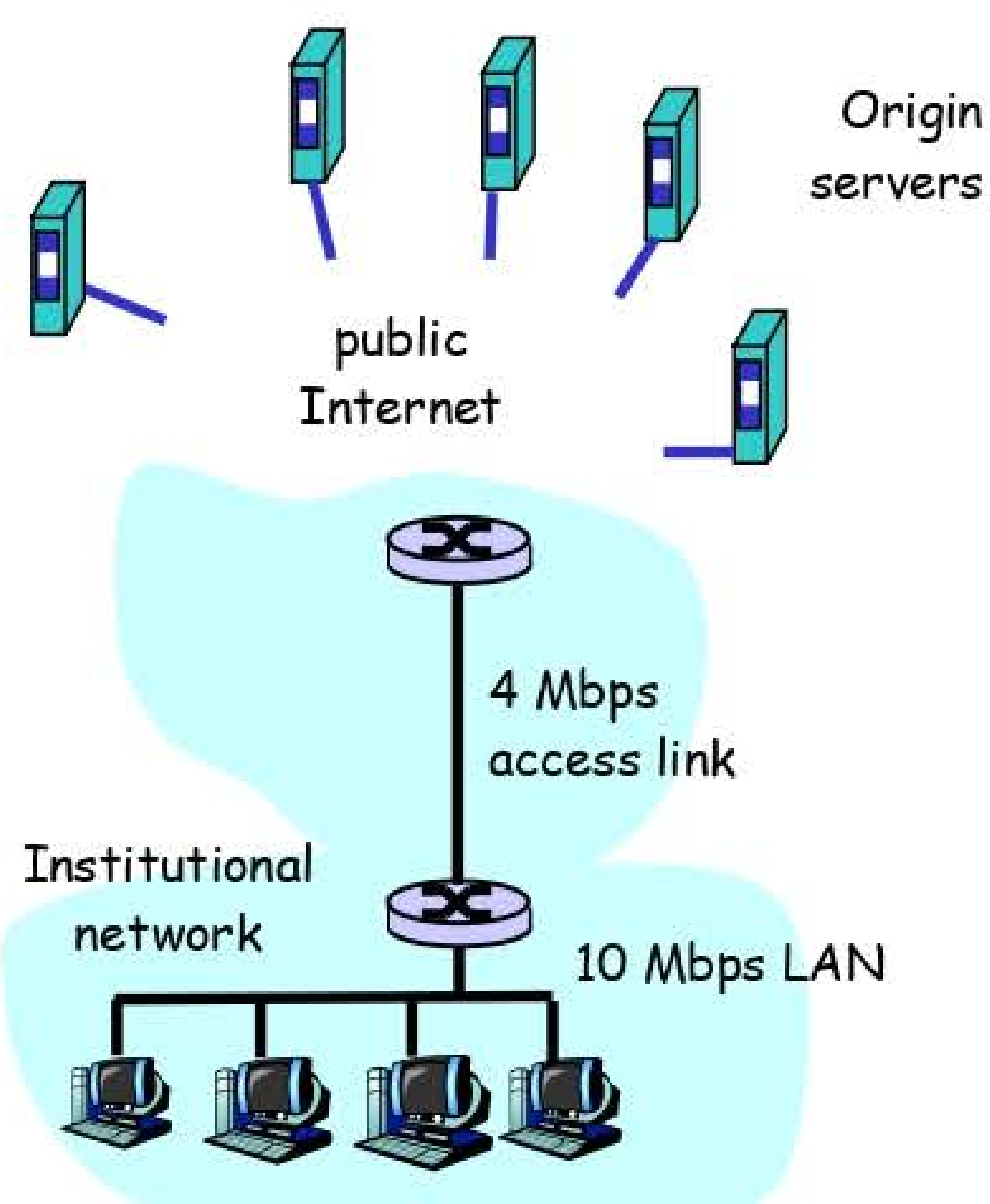



Figure Q.5

6. In this problem we consider the delay introduced by the TCP slow-start phase. Consider a client and a Web server directly connected by one link of rate $R$. Suppose the client wants to retrieve an object whose size is exactly equal to $8S$, where the maximum segment size (MSS) is $S/2$. Denote the round-trip time between client and server as RTT (assume to be constant). Ignoring protocol headers, determine the time to retrieve the object (**excluding** TCP connection establishment) when $5\ S/R < 2RTT < 8\ S/R$.

[4 marks]

7. Consider Figure Q.7, which shows a leaky bucket policer being fed by a stream of packets. The token buffer can hold at most two tokens, and is initially full at $t = 0$. New tokens arrive at a rate of two tokens per slot. The output link speed is such that if two packets obtain tokens at the beginning of a time slot, they can both go to the output link in the same slot. The timing details of the system are as follows: [6 marks]

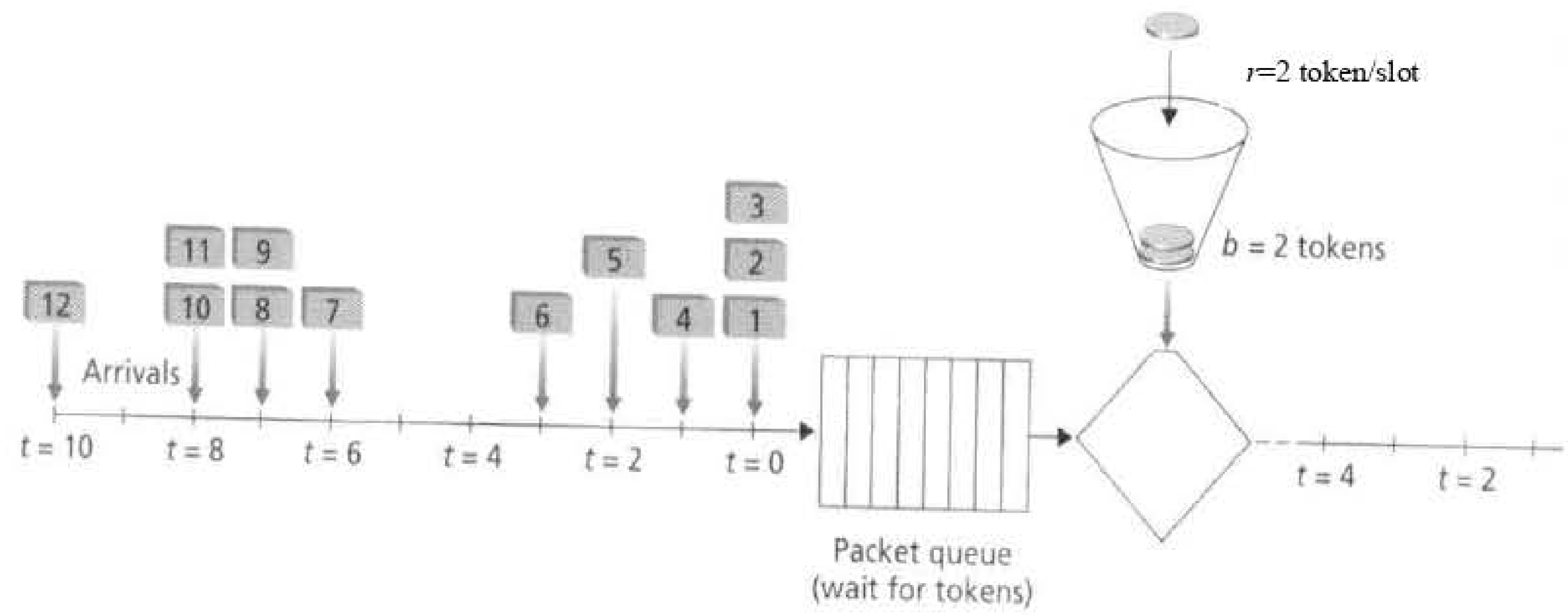



Figure Q.7

1) Packets (if any) arrive at the beginning of the slot. Thus in the figure, packets 1, 2 and 3 arrive in slot 0. If there are already packets in the queue, then the arriving packets join the end of the queue. Packets proceed towards the front of the queue in a FIFO manner.
2) After the arrivals have been added to the queue, if there are any queued packets, one or two of those packets (depending on the number of available tokens) will each remove a token from the token buffer and go to the output link during that slot. Thus, packets 1 and 2 each remove a token from the buffer (since there are initially two tokens) and go to the output link during slot 0.
3) One or two new tokens are added to the token buffer if it is not full until it is full, since the token generation rate is $r = 2$ token/slot.
4) Time then advances to the next time slot, and these steps are repeated.

Answer the following questions:

i. For each time slot, identify the packets that are in the queue and the number of tokens in the bucket, immediately after the arrivals have been processed (step 1 above) but before any of packets have passed through the queue and removed a token. Thus, for the $t = 0$ time-slot in the example above, packets 1, 2 and 3 are in the queue, and there are two tokens in the buffer.
ii. For each time slot indicate which packets appear on the output after the token(s) have been removed from the queue. Thus, for the $t = 0$ time-slot in the example above, packets 1 and 2 appear on the output link from the leaky buffer during slot 0 (the $t = 0$ time-slot).

8. Referring to the figure below, determine whether packets with sequence number 3, 4 and 6 are the first in the talkspurt and explain why. [3 marks]