1 True or False

1. On a fast cross-continental link ($\approx$ 100Gbps), *propagation delay* usually dominates *end-to-end packet delay* (Most messages are smaller than 100MB).

2. On the same cross-continental link ($\approx$ 100Gbps), when transferring a 100GB file, *propagation delay* still dominates end-to-end file delivery.

3. On-demand circuit-switching is adopted by the Internet.

4. The aggregate (i.e., sum) of peaks is usually much larger than peak of aggregates in terms of bandwidth usage.

5. Bursty traffic (i.e., when packet arrivals are not evenly spaced in time) always leads to queuing delays.

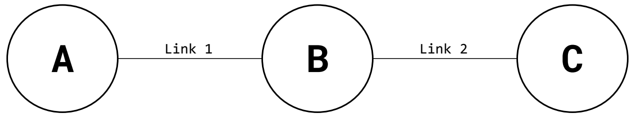
6. Layering in the network stack is an example of the end-to-end principle.

7. We implement all the same layers in both the host and routers.

8. Layers 4 and 7 are used for forwarding in switches / routers.

2 End-to-End Delay

Consider the diagram on the next page. Link 1 has length L_1 m (where m stands for meters) and allows packets to be propagated at speed $S_1 \frac{\text{m}}{\text{sec}}$, while Link 2 has length L_2 m but it only allows packets to be propagated at speed $S_2 \frac{\text{m}}{\text{sec}}$ (because two links are made of different materials). Link 1 has transmission rate $T_1 \frac{\text{bits}}{\text{sec}}$ and Link 2 has transmission rate $T_2 \frac{\text{bits}}{\text{sec}}$.



Assuming nodes can send and receive bits at full rate and ignoring processing delay, consider the following scenarios:

1. How long would it take to send a packet of 500 Bytes from Node A to Node B given $T_1 = 10000$, $L_1 = 100000$, and $S_1 = 2.5 \cdot 10^8$?

2. Compute RTT (round trip time) for a packet of B Bytes sent from Node A to Node C (packet gets transmitted back from Node C immediately after Node C receives it).

3. At time 0, Node A sends packet P_1 with D_1 Bytes and then it sends another packet P_2 with D_2 Bytes immediately after it pushes all bits of P_1 onto Link 1. When will Node C receive the last bit of P_2?

4. Find the variable relations that need to be satisfied in order to have no queuing delays for part (c).

3 Statistical Multi-What?

Consider three flows (F_1, F_2, F_3) sending packets over a single link. The sending pattern of each flow is described by how many packets it sends within each one-second interval; the table below shows these numbers for the first ten intervals. A perfectly smooth (i.e., non-bursty) flow would send the same number of packets in each interval, but our three flows are very bursty, with highly varying numbers of packets in each interval:

Time (s)	1	2	3	4	5	6	7	8	9	10
F_1	1	8	3	15	2	1	1	34	3	4
F_2	6	2	5	5	7	40	21	3	34	5
F_3	45	34	15	5	7	9	21	5	3	34

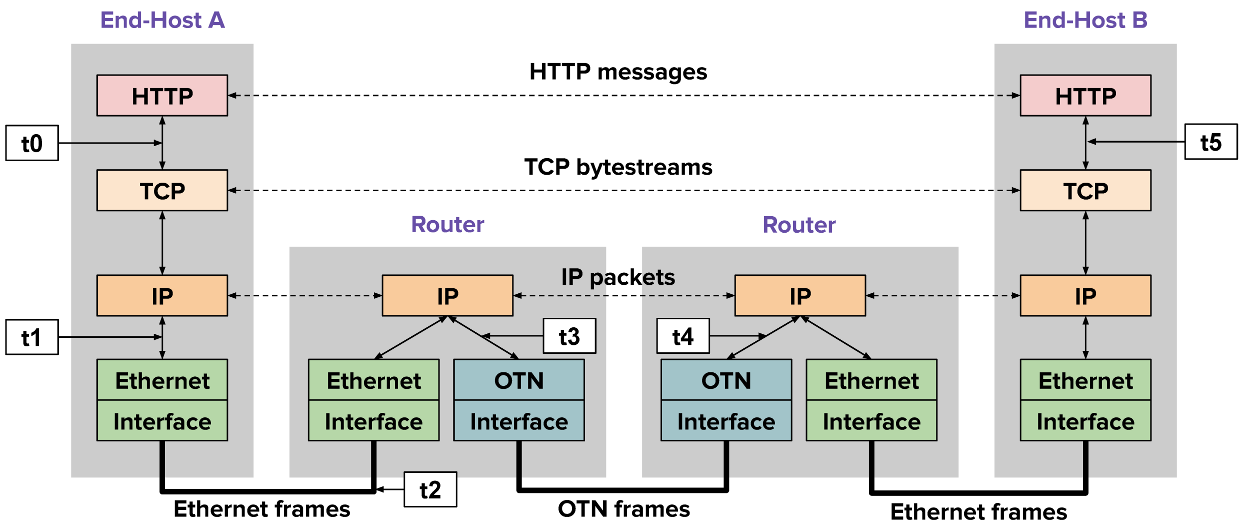
1. What is the peak rate of F_1? F_2? F_3? What is the sum of the peak rates?

2. Now consider all packets to be in the same aggregate flow. What is the peak rate of this aggregate flow?

3. Which is higher - the sum of the peaks, or the peak of the aggregate?

4 Protocol Diagram

Refer to the figure below, which is similar to the one from Lecture 3. In this example, Host A sends one packet to host B at time t = 0. In this question, we explore how the packet header changes as the packet traverses different layers and protocols of the network. At each time step, fill in the empty blocks to describe which headers are attached to the payload. The packet headers are provided at time t = 2 for reference.



Time = t0					Payload
Time = t1					Payload
Time = t2	L1/L2	L3	L4	L7	Payload
Time = t3					Payload
Time = t4					Payload
Time = t5					Payload