Before Today: Datagrams, User Datagrams, Reliable byte streams on top of unreliable service abstraction

Today: Packet Switching

Logistics:

- Come to the lab
- Help each other out both in the lab and on Ed
- Extra credits will be given in upcoming checkpoints for new test cases

How does end point drop a "postcard" to its destination?

- Circuit-switched networks (e.g. telephones)
  - Each telephone is connected to a center office
  - And a staff worked in the office would connect the wires upon customers' request
  - If the person you want to call does not belong to the same office as you, there are circuits between main offices
  - Any phone call has a real direct electrical circuit
  - BUT: setting up and tearing down circuit is expensive, it works for telephone calls, but would not make sense if you only want to send a short piece of data
- Packet Switching
  - The time it takes for the first bit to be received **Propagation Delay:**

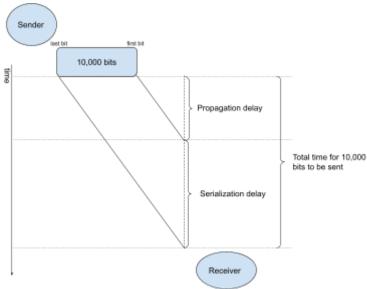
$$t_1 = \frac{l}{c}$$
 (I = distance, c = light speed in that medium) (seconds)

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$$c = 2 \times 10^8 \, m/s$$
 in cable

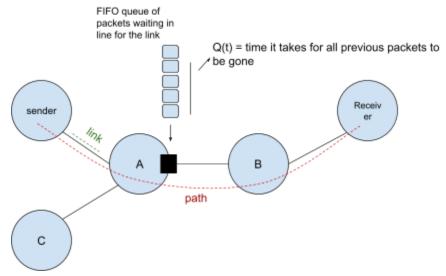
- The time it takes for the whole packet to be received after the first bit is received

— Serialization (packetization) delay: 
$$t_p = \frac{\text{size of packet}}{\text{link rate (bits per second)}} = \frac{p}{r}$$

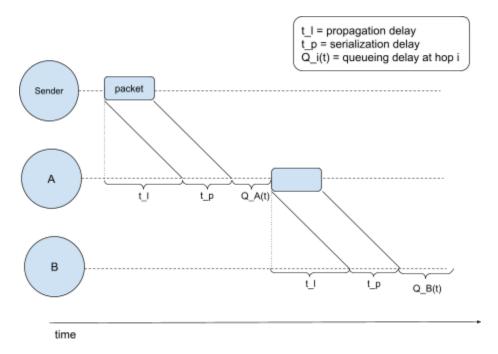
- Total time to send a packet across a link:  $t = t_p + t_l = \frac{p}{r} + \frac{l}{c}$ 



- The path between sender and receiver consists of multiple links



- Each hop on the link receives the whole packet before sending it out, and therefore each hop would have propagation delay + serialization delay
- And there is **Queueing delay** if the link is busy (a packet needs to wait in line at the FIFO queue).
- Time until packet begins transmission on a link Queueing delay:
  - $Q(t) = \sum serialization delay of any packet before this packet in the queue$



- End-to-end delay:  $\sum\limits_{i \, \in \{hops\}} \, \left(t_p^{} \, + \, t_l^{} \, + \, Q_i^{}(t)\right)$