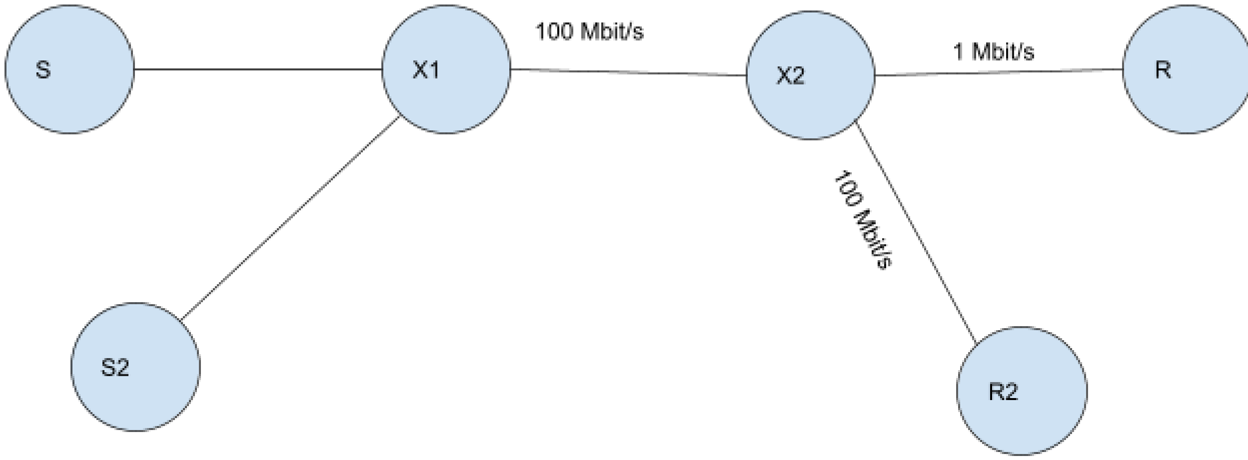
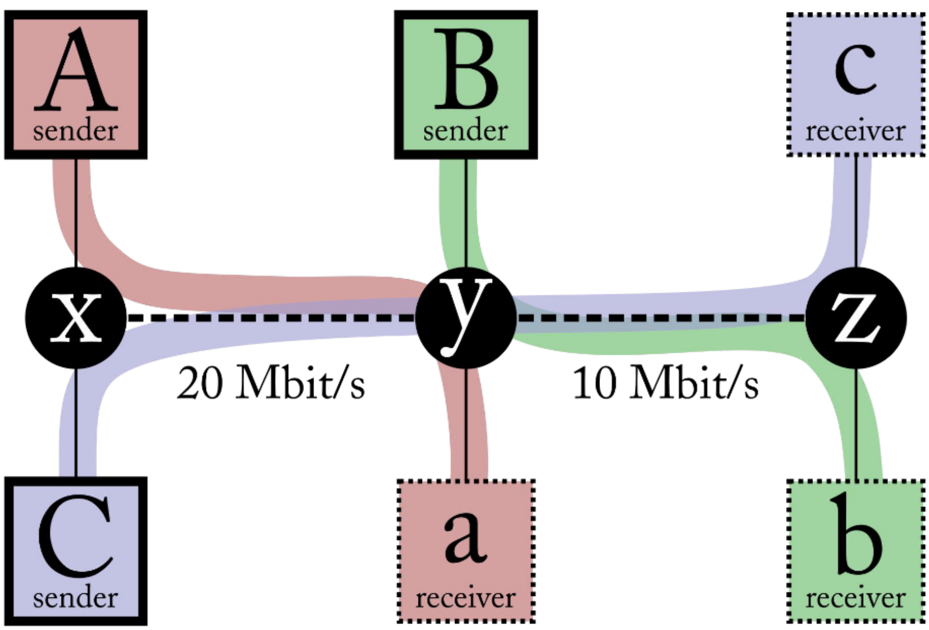
Last week: packet switching
This week: congestion control
Congestion control is resource management: assigning limited resources of link rate to flows

- TCP: flow-controlled bidirectional byte stream
    - The speed is regulated by link_rate at the beginning. The steady state is limited by min(link_rate, how fast the reader is draining the byte stream (window_size)).
- Single-flow, single-hop model
  S(ender) —--------- X(router) —---------- R(receiver) with r = 1 Gbit/s and propagation delay = 1 second
    - The sender sends a datagram, still waiting for the corresponding ackno, where could the datagram be (in the sender's mind):
        - Propagating on the link
        - Waiting at the router queue (bottleneck queue)
        - Could have been received by the receiver, but ackno still on the way back
        - Or the datagram or the ackno is lost/dropped
    - Outstanding segments from the sender's perspective: [ackno, ackno + window_size)
    - Window_size: cap on the number of "outstanding" bytes
        - "Outstanding" means sent, not acked or judged lost
    - Q: what if the window size is really small?
      A: throughput $\frac{1\,byte}{2 * propogation\ delay} = 0.5\ byte/s\ (if\ propogation\ delay\ = 1\ s)$
      (RTT = 2*propogation delay)
    - Q: what if the window size is gigantic?
      A: maximum throughput: 1 Gbit/s and the router may run out of memory or huge queueing delay.
      We call this **congestion.**
- Congestion is bad
    - Congestion collapse (in the 1980s): receivers were advertising large window_size and forced the router to drop lots of packet
    - Or some flows send too much, others are starved. There is an issue for fairness.
- Useful work should increase as demand increases. It's okay if the derivative is less than 1, but it should not be the case that the derivative is negative.
    - Single-flow, single-hop model would not have a collapse, since the throughput stays at 1 Gbit/s even if many packets are dropped
    - The "collapse" issue:



- If there is only 1 flow: S2 → R2, throughput would be 100 Mbit/s
- If there is two flows: S → R and S2 → R2, throughput would be ~51 Mbit/s if S sends at 100 Mbit/s (COLLAPSE)
- If there is two flows: S → R and S2 → R2, S sends at 1 Mbit/s and S2 sends at 99 Mbit/s. Throughput would be 100 Mbit/s
- The “fairness” issue:



- A -> a, B -> b, C -> c, total

A -> a	B -> b	C -> c	total	
15,	5,	5,	25	max-min fair
20,	10,	0,	30	max utilization/efficiency
16,	6,	4,	26	proportionately fair
0,	0,	~~20~~10,	10	congestion collapse

- The objective: maximizing a utility function: $max_{\{x_r\} \in S} \sum_r U_r(x_r)$ and $U(x) = \frac{x^{1-\alpha}}{1-\alpha}$
    - $\alpha = 0$, max utilization
    - $\alpha \to 1$, proportional fairness

        - $\alpha = 2$, min-potential-delay fairness
        - $\alpha \rightarrow \inf$, max-min fairness
    - Other objectivesL
        - Minimize flow completion time (of average download)
        - Minimize page load time (with many download flows)
        - Maximize “power” (= throughput / delay)
- Algorithms to prevent collapse are called “**congestion control**”
    - What is the right window size?
    - How should flows learn the window size?