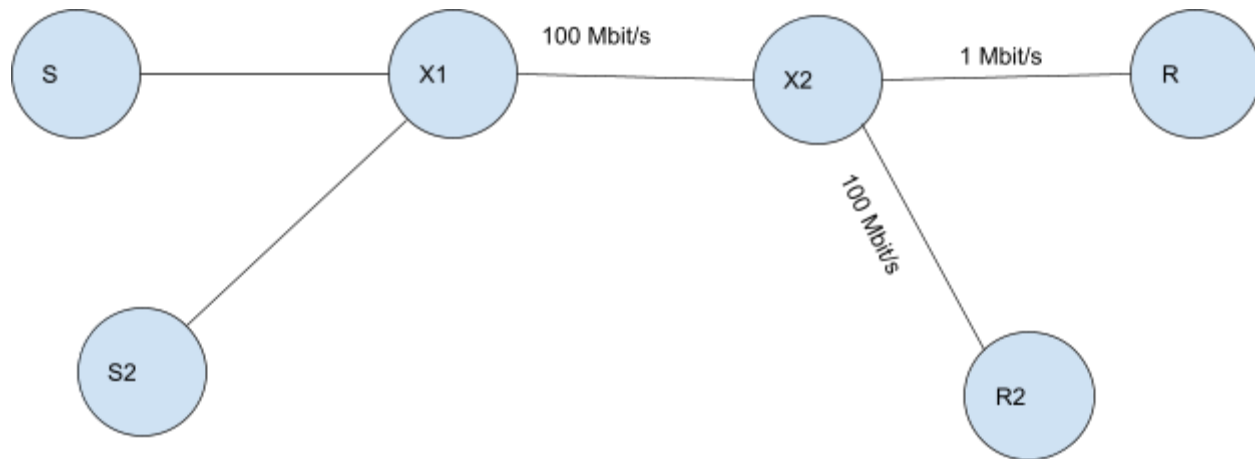


Last time: packet switching

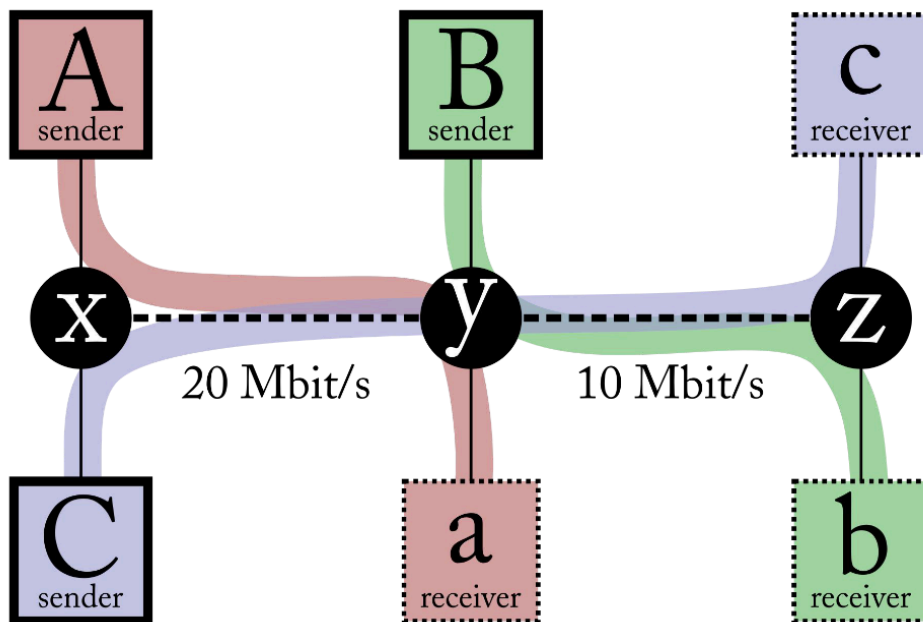
Now: congestion control

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 $\min(\text{link_rate}, \text{how fast the reader is draining the byte stream (window_size)})$.
- Single-flow, single-hop model
S(sender) ----- X(router) ----- R(receiver) with $r = 1 \text{ Gbit/s}$ 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 $\frac{1 \text{ byte}}{2 * \text{propagation delay}} = 0.5 \text{ byte/s}$ (if propagation delay = 1 s)
(RTT = 2*propagation 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:



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



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- A → a, B → b, C → c, total

15,	5,	5,	25
20,	10,	0,	30
16,	6,	4,	26
0,	0,	20	10,

max-min fair
 max utilization/efficiency
 proportionately fair
 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
 - $\alpha \rightarrow 1$, proportional fairness

- $\alpha = 2$, min-potential-delay fairness
 - $\alpha \rightarrow \infty$, max-min fairness
- Other objectives
 - 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?