Introduction to Computer Networks

TCP Congestion Control (I)

CS640

https://pages.cs.wisc.edu/~mgliu/CS640/S25/index.html

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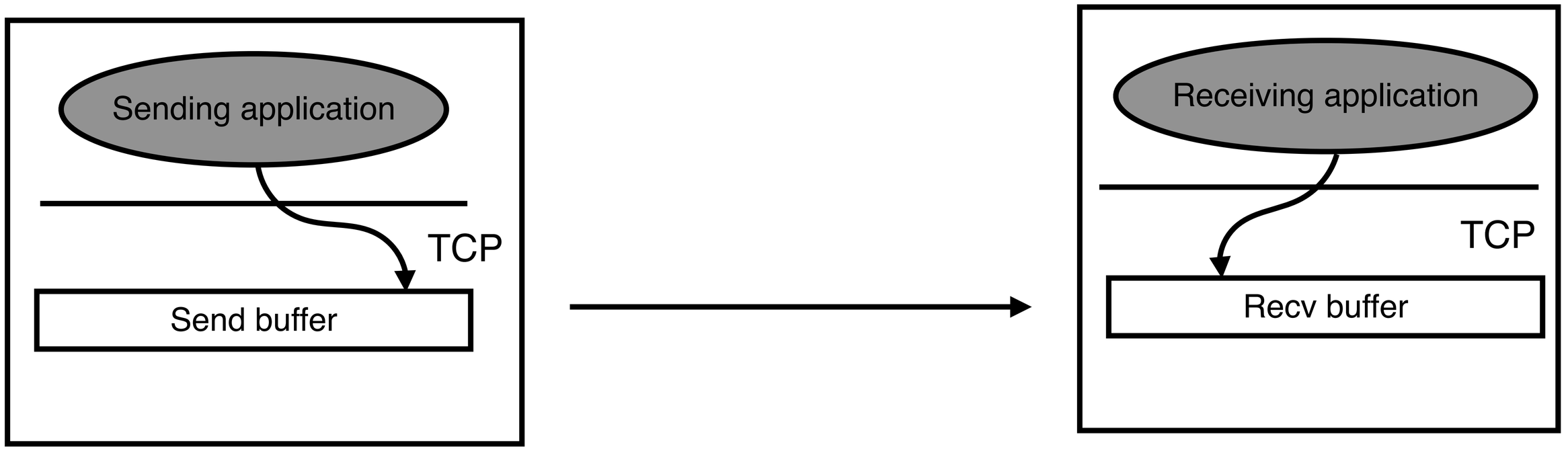
Outline

- Last
  - TCP Reliability Support (II)
- Today
  - TCP Congestion Control (I)
- Announcements
  - Lab 4 due date 05/01/2025 12:01PM

Recap: UDP Issues

- #1: Arbitrary communication
  - Senders and receivers can talk to each other in any ways
- #2: No reliability guarantee
  - Packets can be lost/duplicated/reordered during transmission
  - A checksum is not enough
- #3: No resource management
  - Each channel works as an exclusive network resource owner
  - No adaptive support for the physical networks and applications

Set Up the Context



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Effectively use the networking resources

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Effectively use the networking resources

- Utilization: each networking hardware is fully utilized
- Fairness: each networking hardware is equally shared

Challenges

- #1: Varying resource capacities
  - The underlying networking fabric and hardware are dynamic

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- #1: Varying resource capacities
  - The underlying networking fabric and hardware are dynamic

- #2: Unpredictable traffic
  - We don’t know how applications use the network and their requirements

The Key Idea

- The smart-sender dumb-receiver philosophy
  - The sender adjusts the sending window based on congestion signals
  - Congestion signal: an event telling network contention **might** happen

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- Congestion window = Sending window
  - Define the total amount of data the sender can push into the network without overwhelming it
  - AdvertiseWindow: the total amount of data the sender can send to the receiver without overwhelming it

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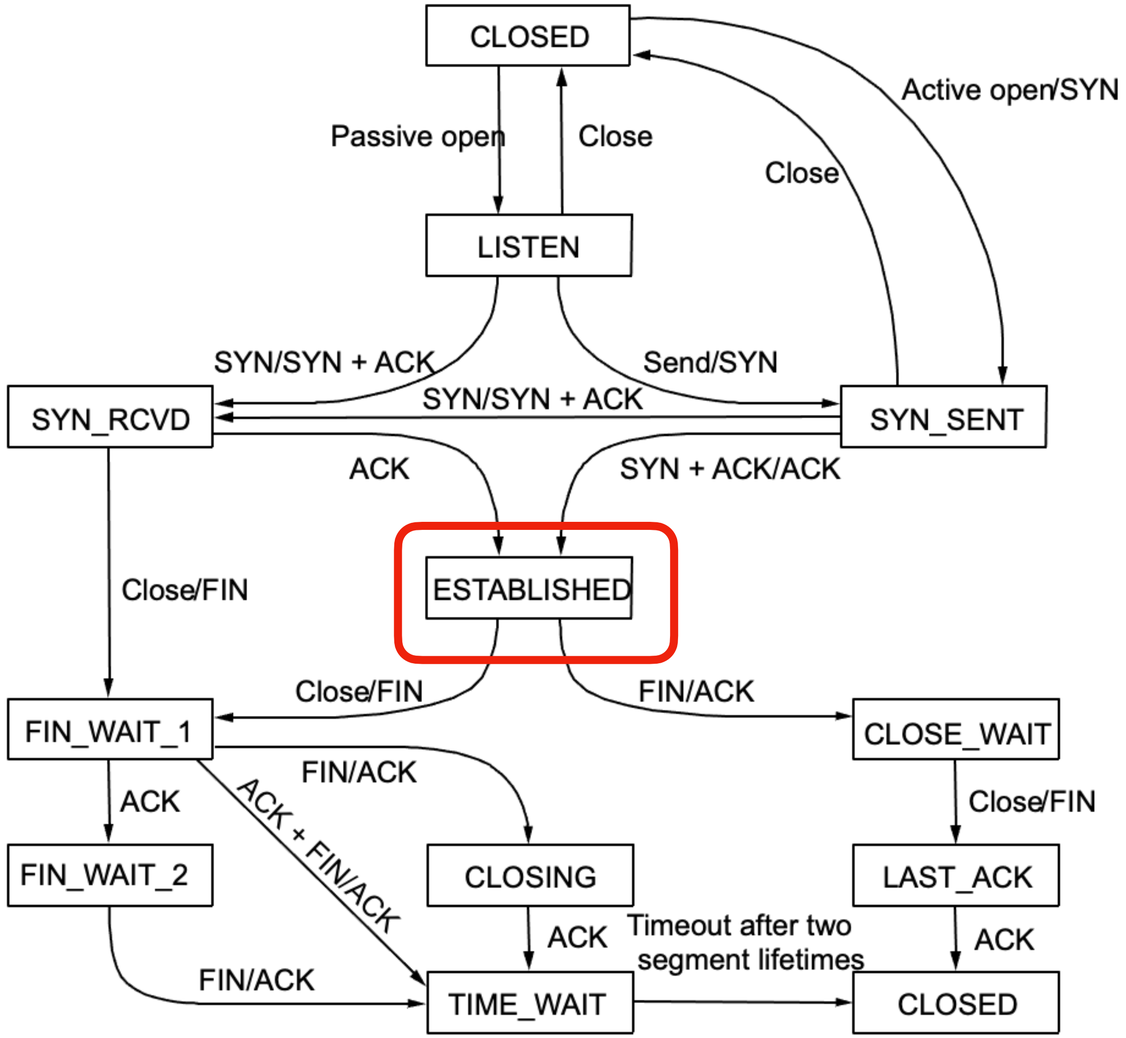
  - **EffectiveWindow=MIN(CongestionWindow, AdvertiseWindow)**

But how?

Let’s Start From the Begining



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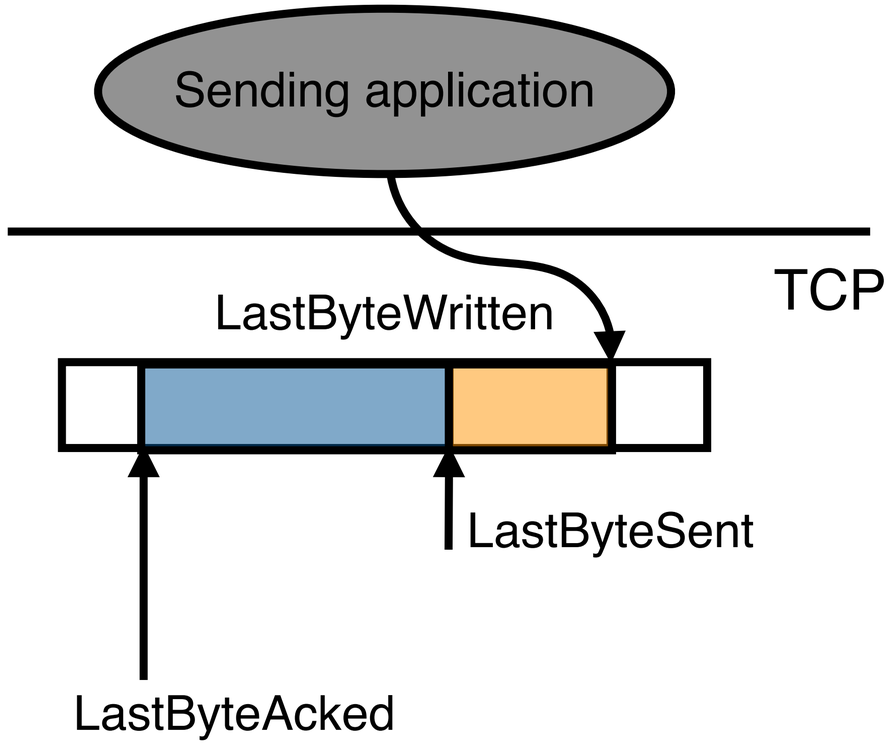
- Option #1: send AdvertisedWindow-sized data
  - Not overwhelming the receiver



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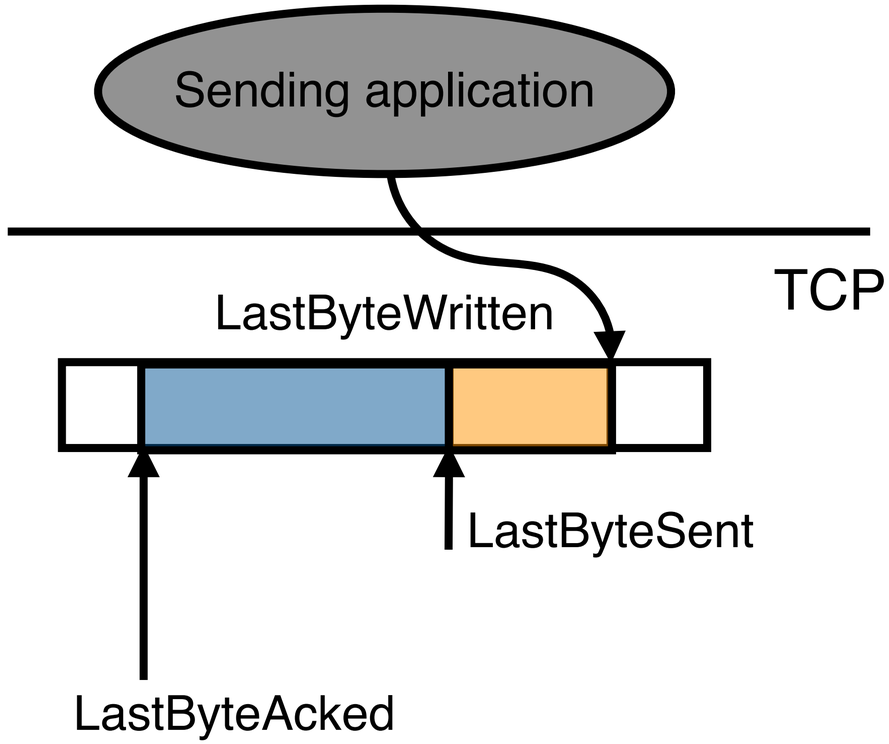
  - **But this might overwhelm the network!**



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- Option #2: send random-sized data, whose size is N
  - N is between 0 and AdveertisedWindow
  - Not overwhelming the receiver

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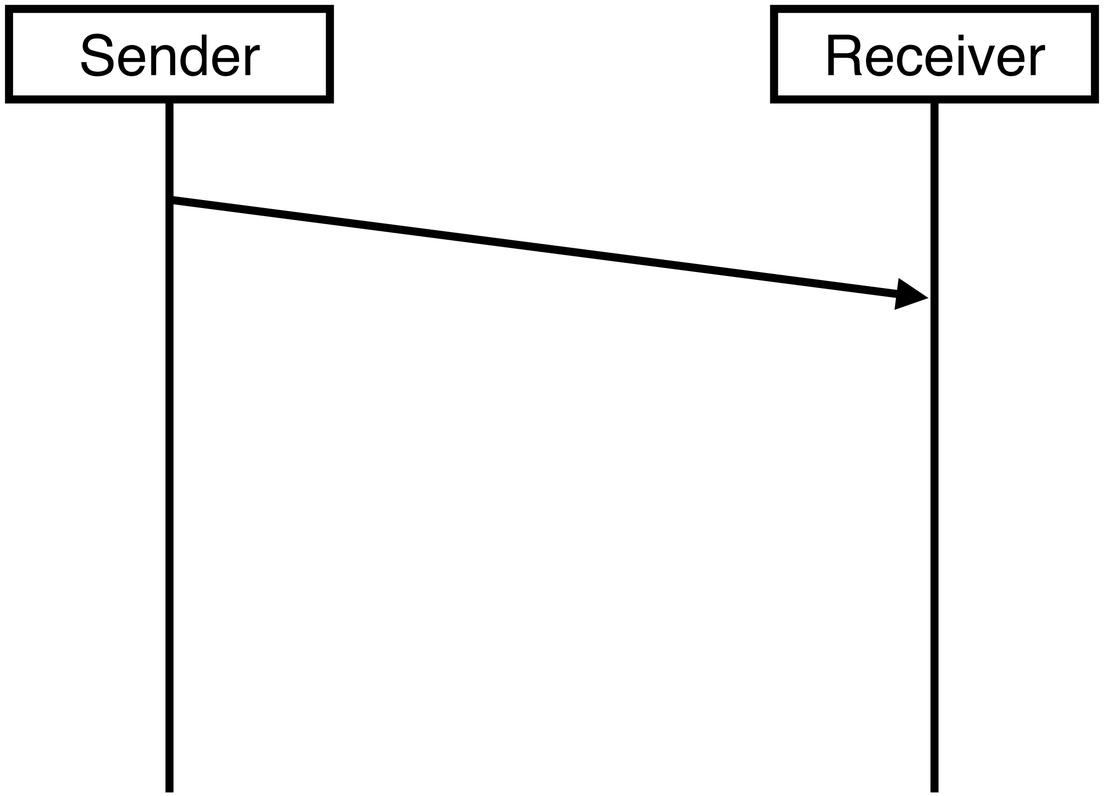
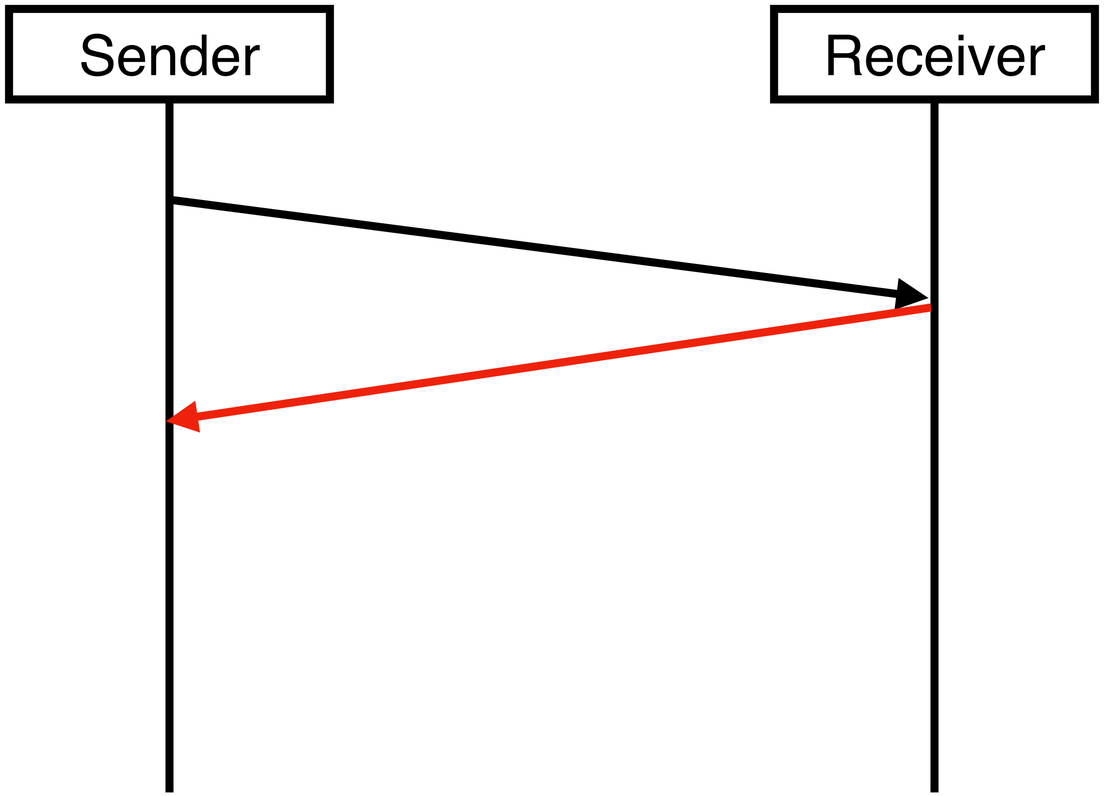
- **Option #3: just send 1 segment => TCP goes with it**
  - **A conservative approach but keeps the data pipe moving**

What happens next



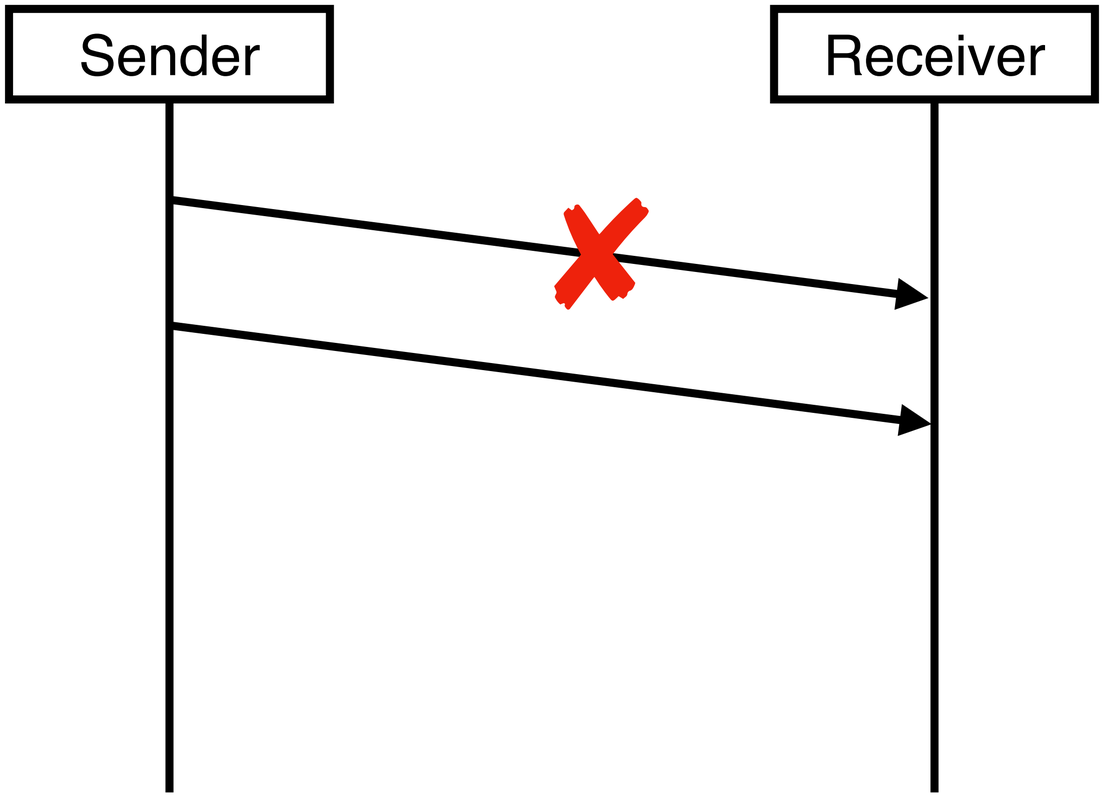
What happens next

- Case #1: the receiver receives the segment and returns an ACK
  - The ACK also carries the AvertisedWindow



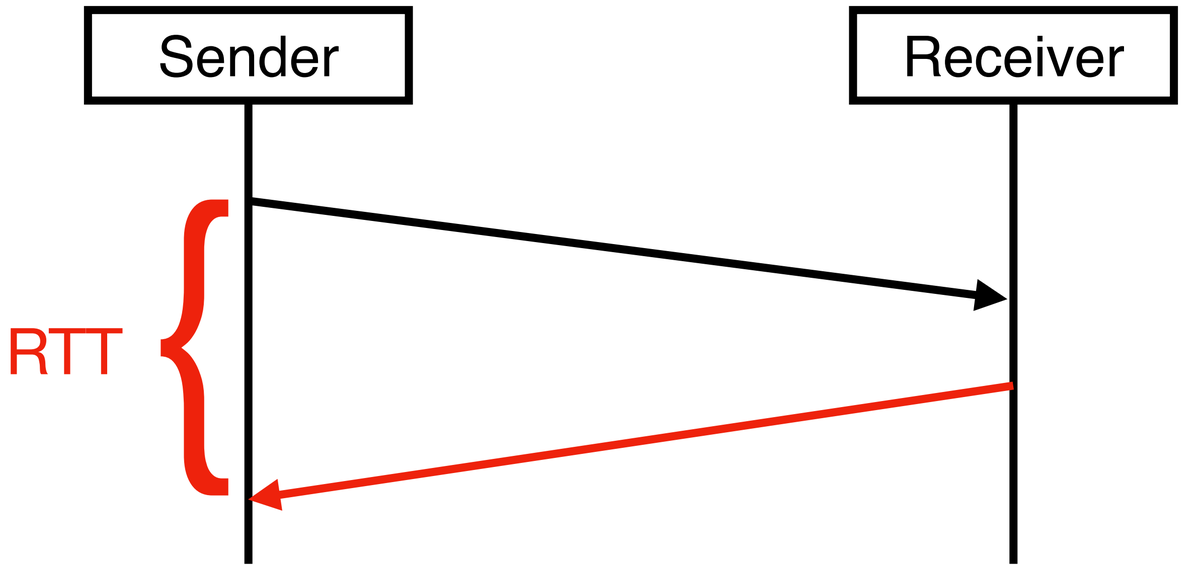
What happens next

- Case #2: the receiver receives nothing
  - The segment or its replied ACK is dropped, but we don’t know which one
  - A local timeout triggers and the sender sends it again



The 1st Round Summary

- Case 1: receive an ACK w/o timeout
  - Effective BW = Segment Size / RTT
  - Congestion Window > 1 segment
- Case 2: receive an ACK w/ timeout
  - Effective BW = Segment Size / Amplified RTT
  - Congestion Window = 1 segment



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  - Slow performance

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- Option #2: send random-sized data, whose size is N

The network bandwidth availability is still unknown!

- Option #3: send 1 segment
  - A conservative approach
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How much data to send next round

- Option #1: send AdvertisedWindow-sized data
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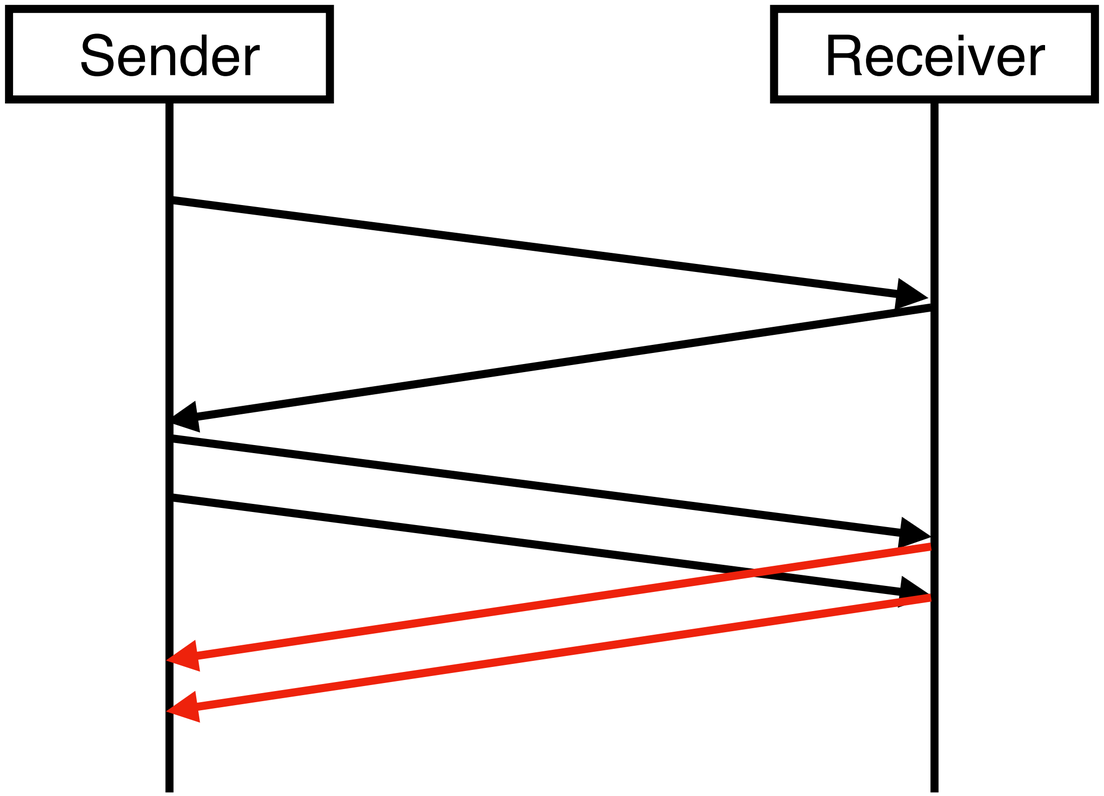
  - But this might overwhelm the network!

- Let's introduce some "probing" here
- Option #4: send 2 segments
  - Implication: The 1st round try with 1 segment succeeds. The network might be able to do more!

  - A conservative approach
  - Slow performance

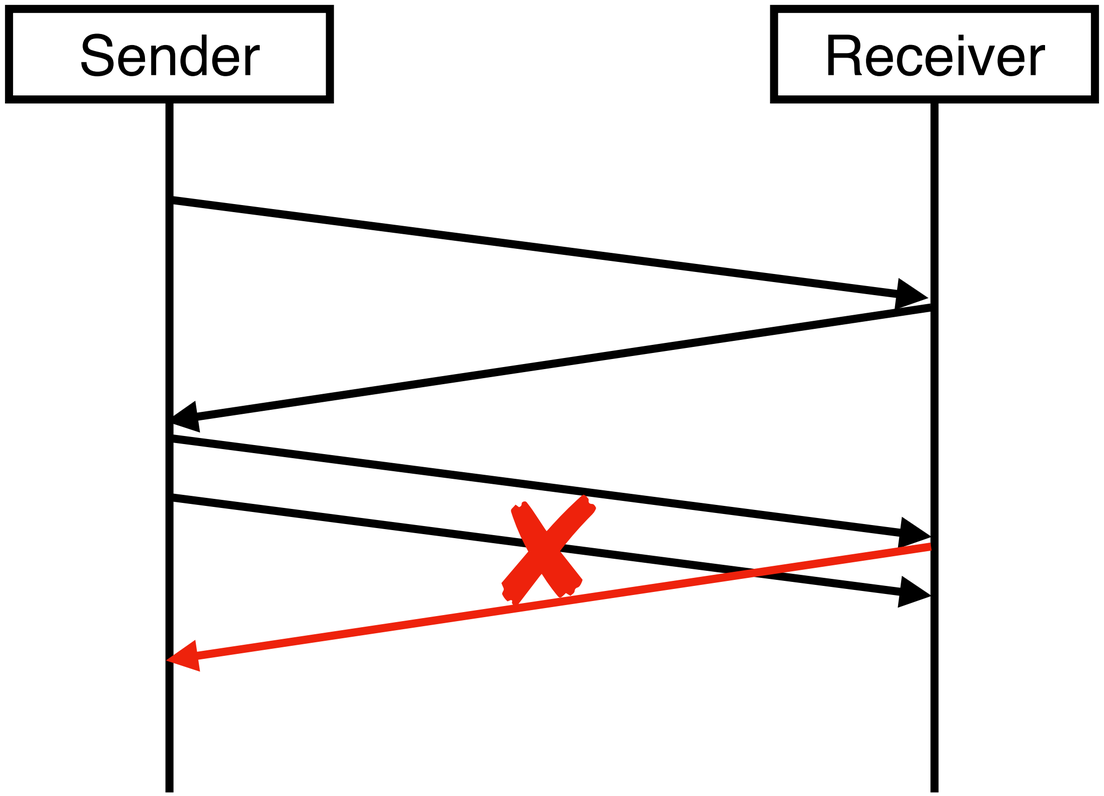
What happens next?

- Case #1: the receiver receives two segments and returns ACKs
  - The probing works!



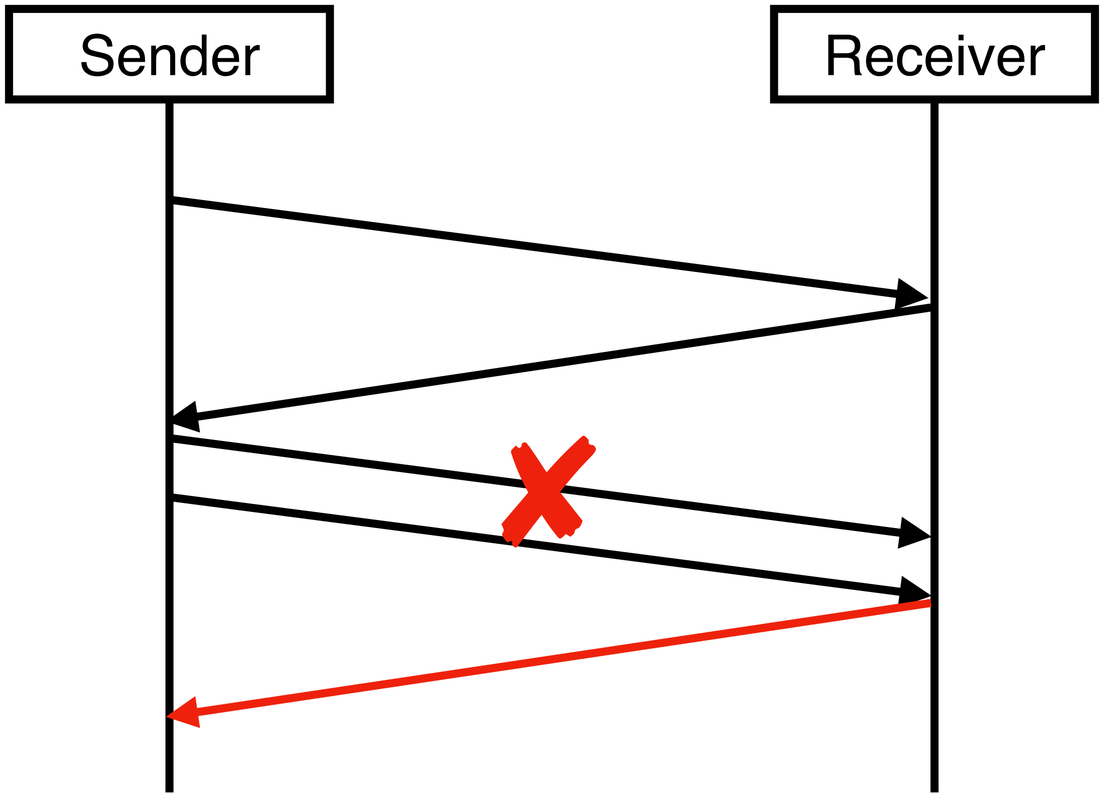
What happens next?

- Case #2: the receiver receives 1st segment and returns an ack
  - The timeout of the 2nd segment => retransmit until receiving an ACK



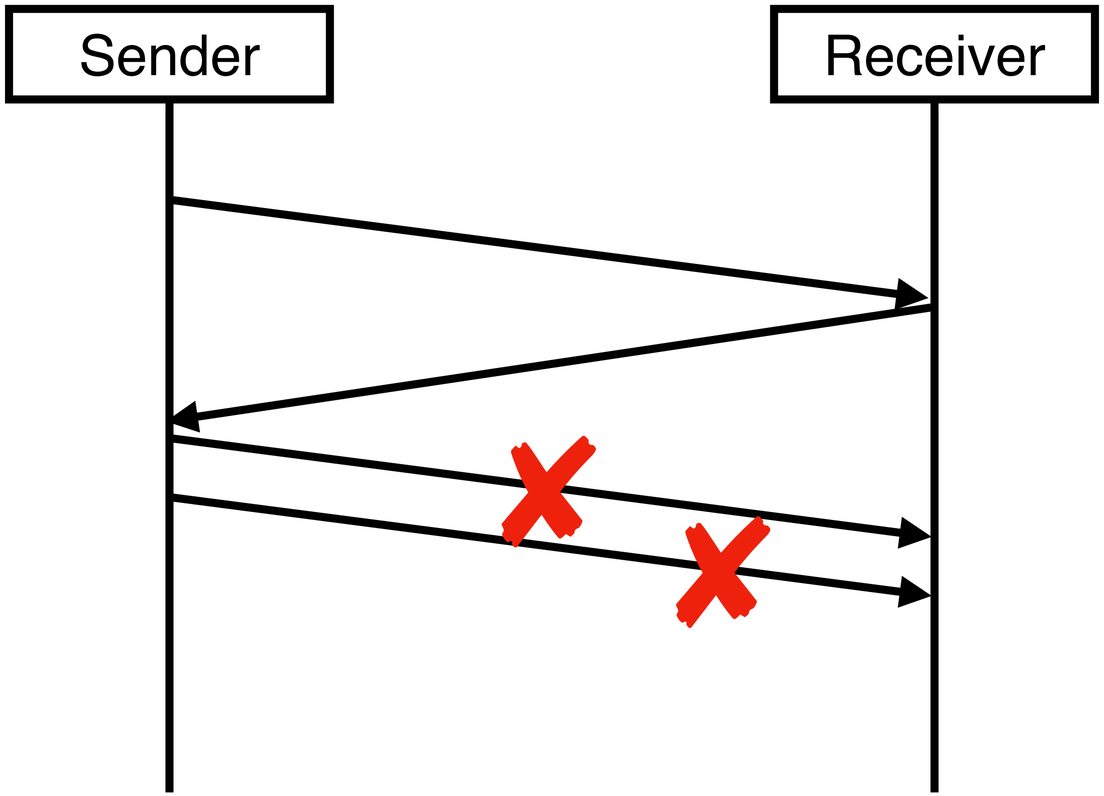
What happens next?

- Case #3: the receiver receives 2st segment and returns an ack
  - An out-of-order ACK => retransmit
  - Or a local timeout => retransmit



What happens next?

- Case #4: the receiver receives nothing
  - Local timeout triggers and retransmit



The 2nd Round Summary

- Case #1: the receiver receives 2 ACKs
  - Average BW = 3 segments / Time-to-send-3-segments
  - 2nd BW = 2 segments / Time-to-send-2-segments
  - Congestion Window > 2 segments

- Case #2: the receiver receives 1ACK (1st seg) w/ 2nd timeout
  - Average BW = 3 segments / Time-to-send-3-segments (amplified)
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  - Average BW = 3 segments / Time-to-send-3-segments (amplified)
  - 2nd BW = 2 segments / Time-to-send-2-segments (amplified)
  - **Congestion Window = 1 segment**

1 segment is the congestion window from the last round.

The 2nd Round Summary (con't)

- Case #3: the receiver receives 2 ACK (2nd seg) w/o 2nd timeout
  - An out-of-order ACK happens => an implicit signal on the contention
  - But out-of-order ACK is not as strong as a local timeout
  - Average BW = 3 segments / Time-to-send-3-segments (amplified)
  - 2nd BW = 2 segments / Time-to-send-2-segments (amplified)
  - Congestion Window = 1 segment

- Case #3': the receiver receives 1 ACK (2nd seg) w/ 2nd timeout
  - Average BW = 3 segments / Time-to-send-3-segments (amplified)
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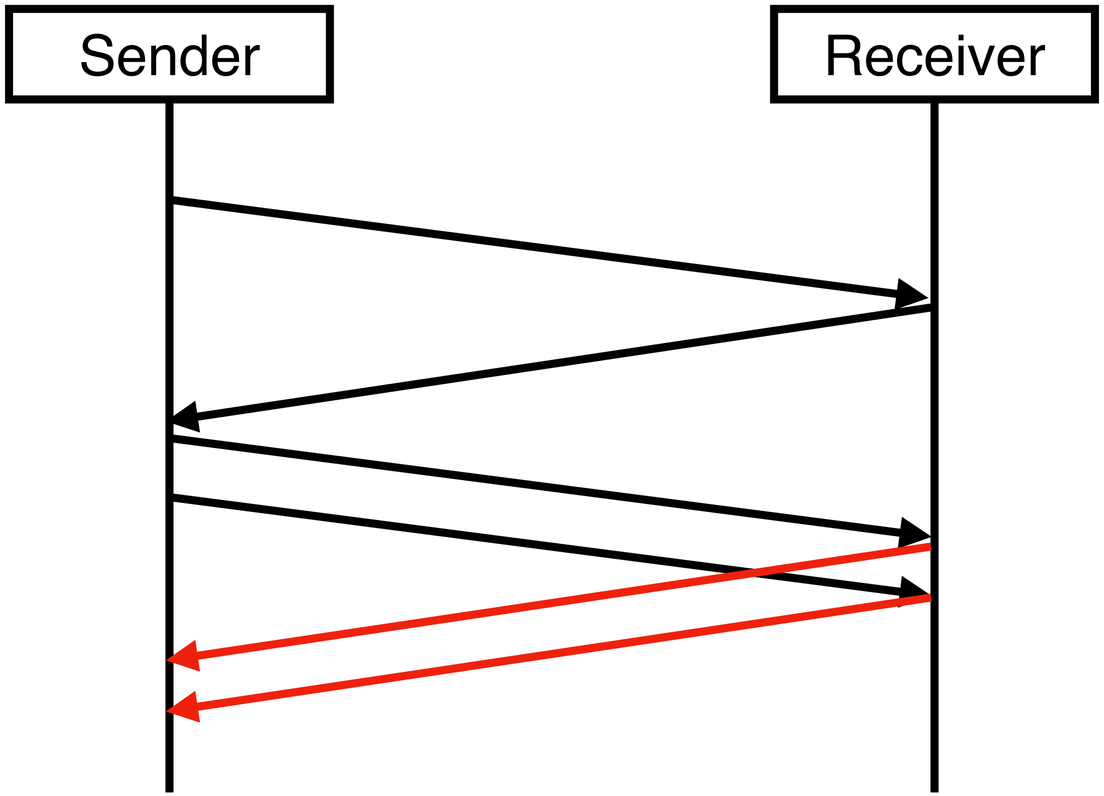
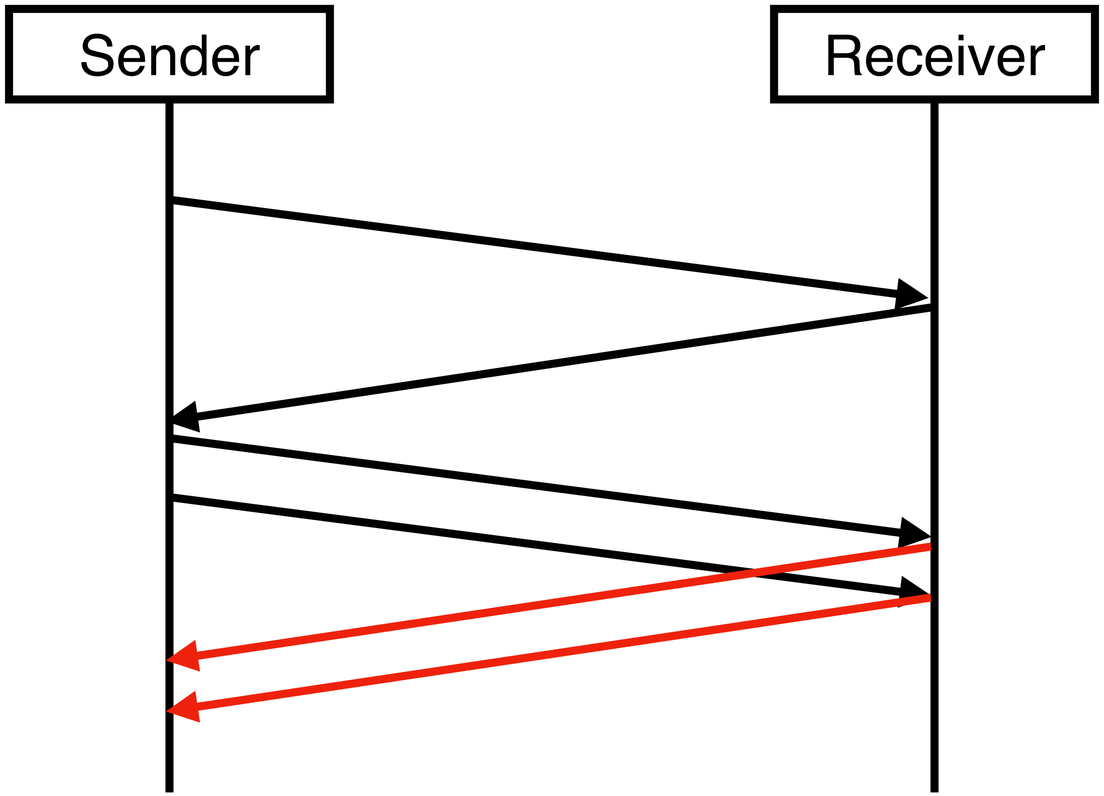


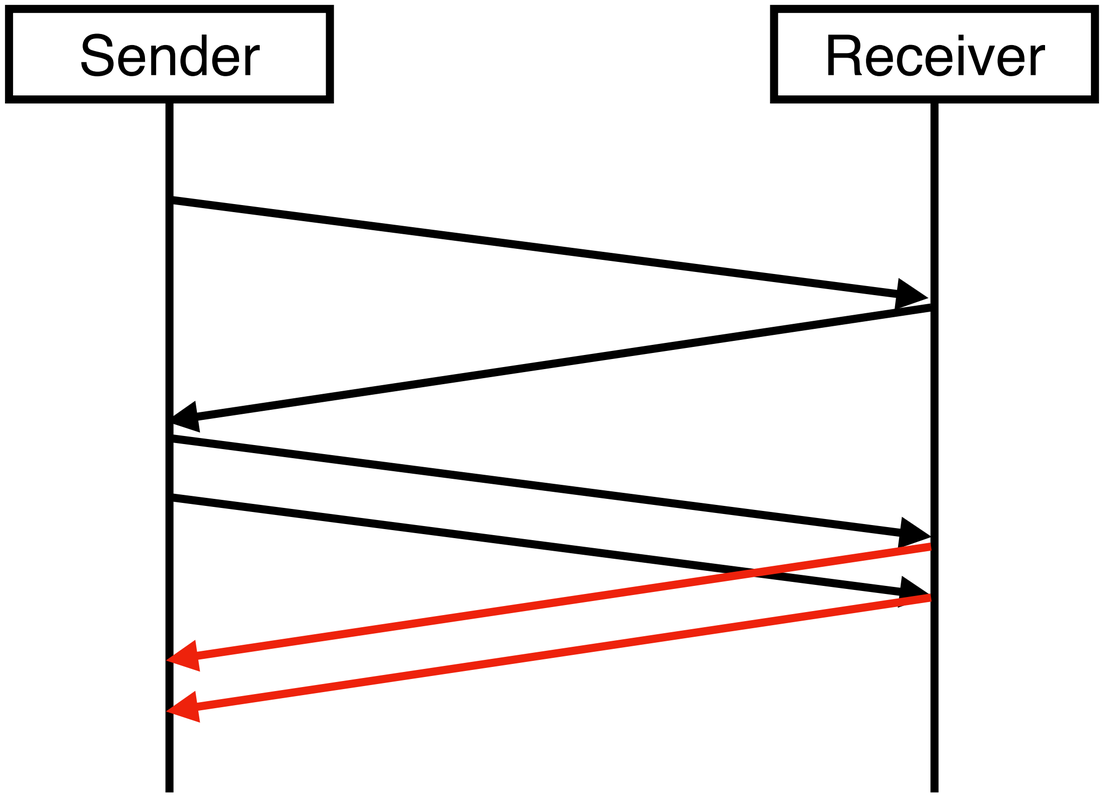
How much data to send next round?

- Keep probing if the last round succeeds
- Otherwise, just send 1 segment



How much data to send next round?

- Suppose we do a probing
  - Problem: how can we quickly find the maximum available capacity
  - Let’s do an exponential increase



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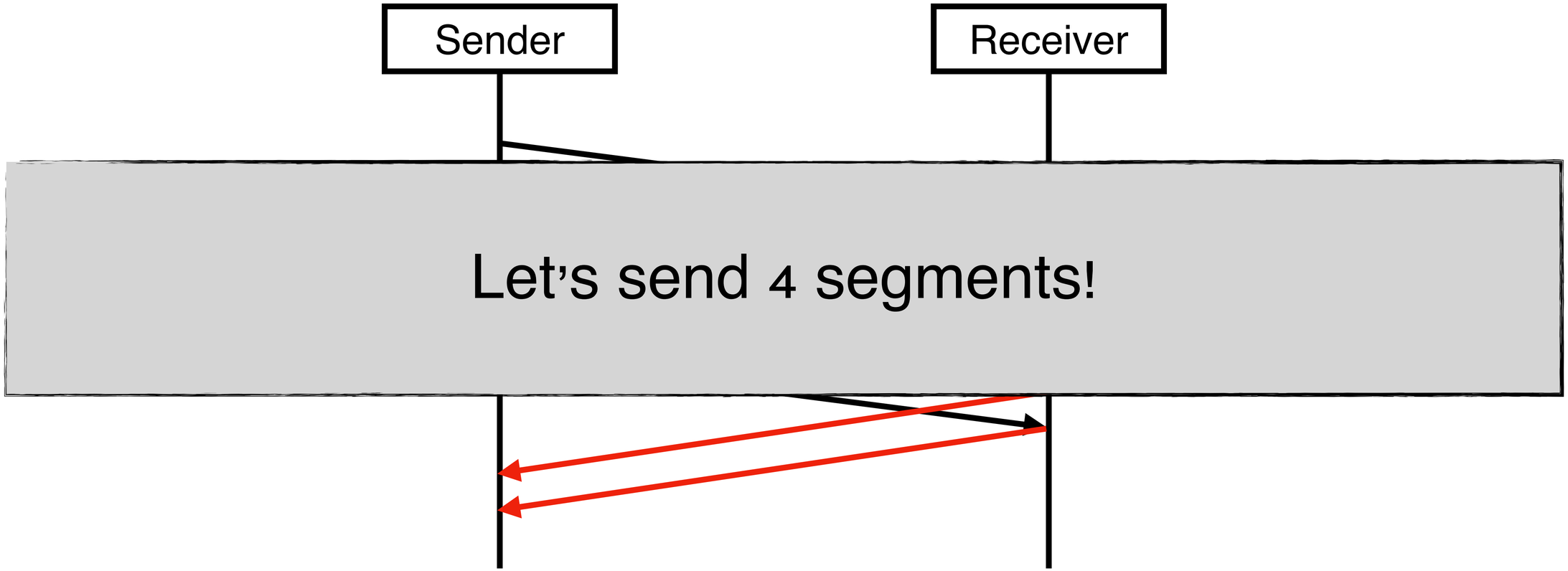

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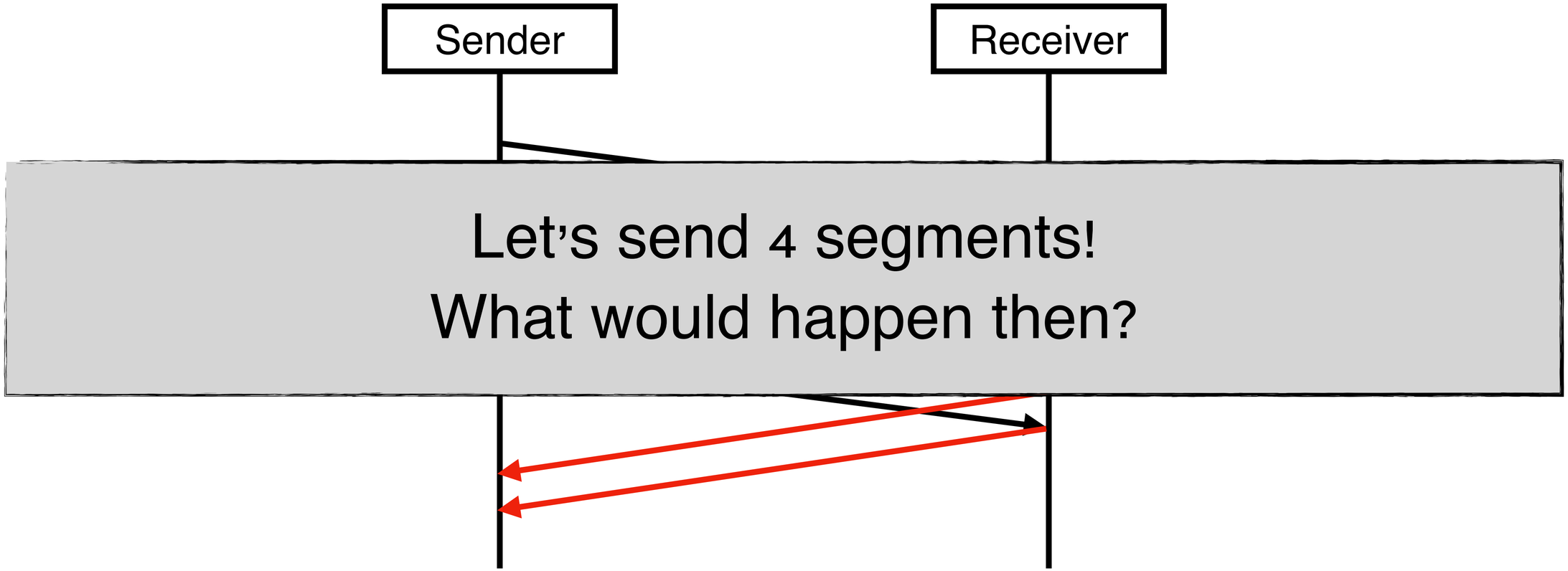
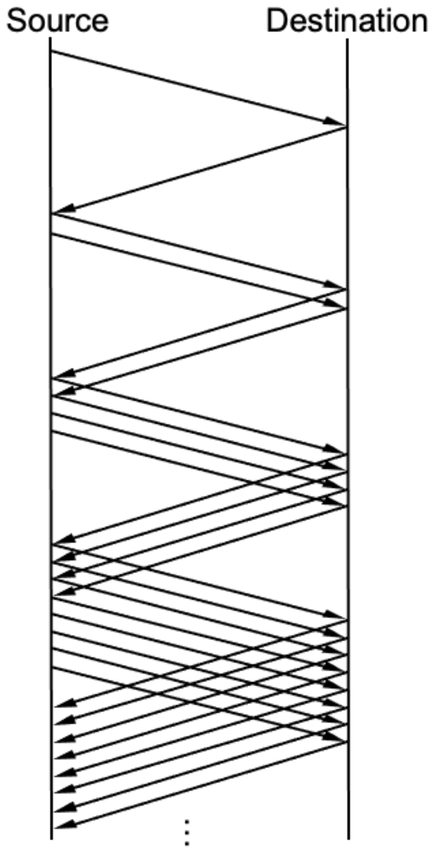


TCP Slow Start

- Determine the available networking capacity exponentially
  - At round i, probe the congestion window with 2^(i-1) segments



TCP Slow Start

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  - An indirect indicator of a congested network
  - Probing should stop

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  - Congestion window = congestion threshold
  - Congestion threshold = congestion window/2

The congestion threshold is continuously updated every round to capture the bandwidth availability.

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  - At round i, probe the congestion window with 2^(i-1) segments
- Congestion signal: out-of-order ACK
  - An indirect indicator of a congested network
  - Probing should stop
  - Congestion window = congestion threshold
  - Congestion threshold = congestion window/2
- Congestion signal: local time out
  - A strong indicator of a congested network
  - Probing should stop
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How does the transmission look like so far?

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Is this efficient?

Summary

- Today
  - TCP congestion control (I)

- Next lecture
  - TCP congestion control (II)