TCP contd.
(connection release, flow control)

CSE 461, Spring 2021

Ratul Mahajan

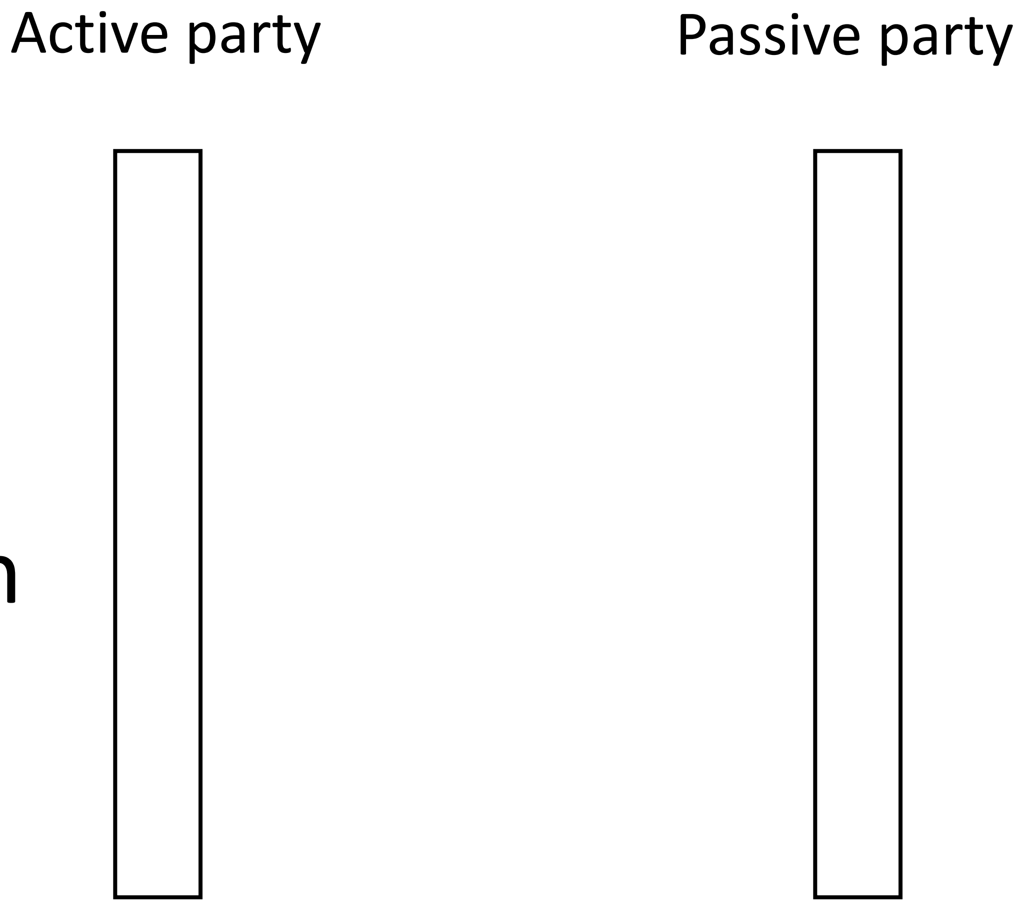
Connection Release

- Orderly release by both parties when done
  - Delivers all pending data and "hangs up"
  - Cleans up state in sender and receiver
- Key problem is to provide reliability while releasing
  - TCP uses a "symmetric" close in which both sides shutdown independently

TCP Connection Release

- Two steps:
  - Active sends FIN(x), passive ACKs
  - Passive sends FIN(y), active ACKs
  - FINs are retransmitted if lost

- Each FIN/ACK closes one direction of data transfer



TCP Connection Release (2)

- Two steps:
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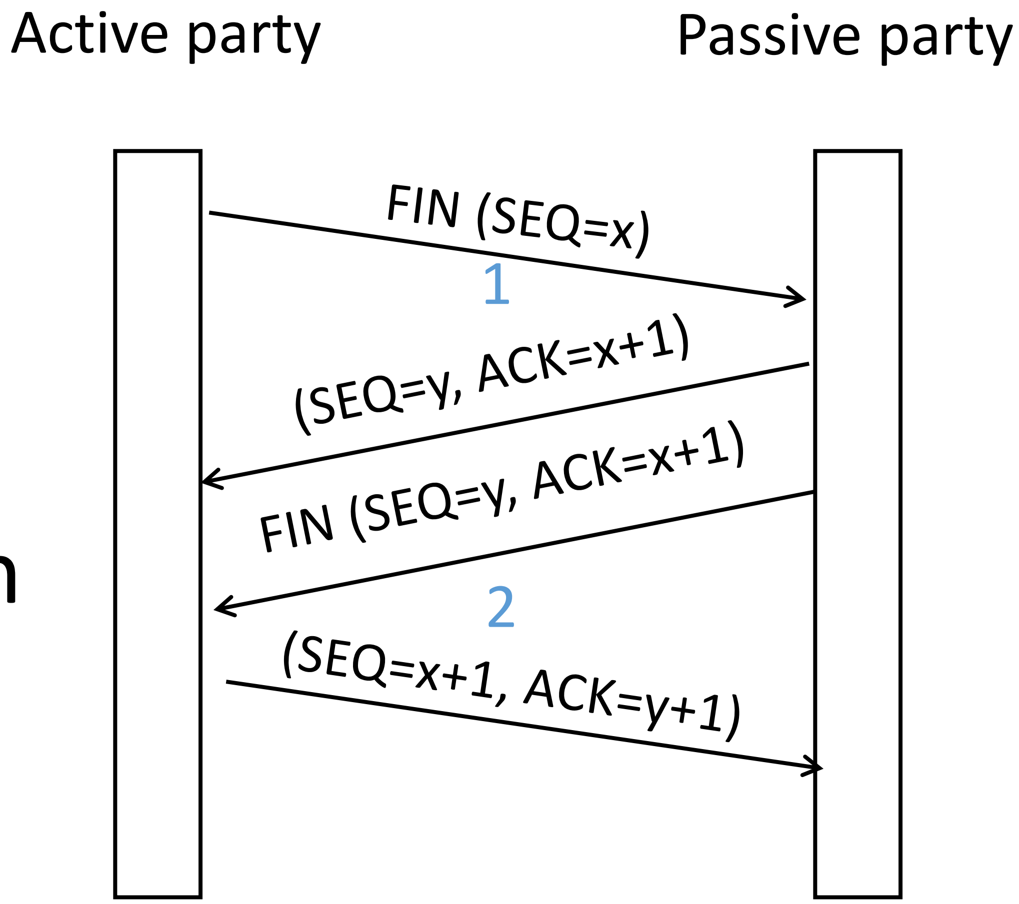
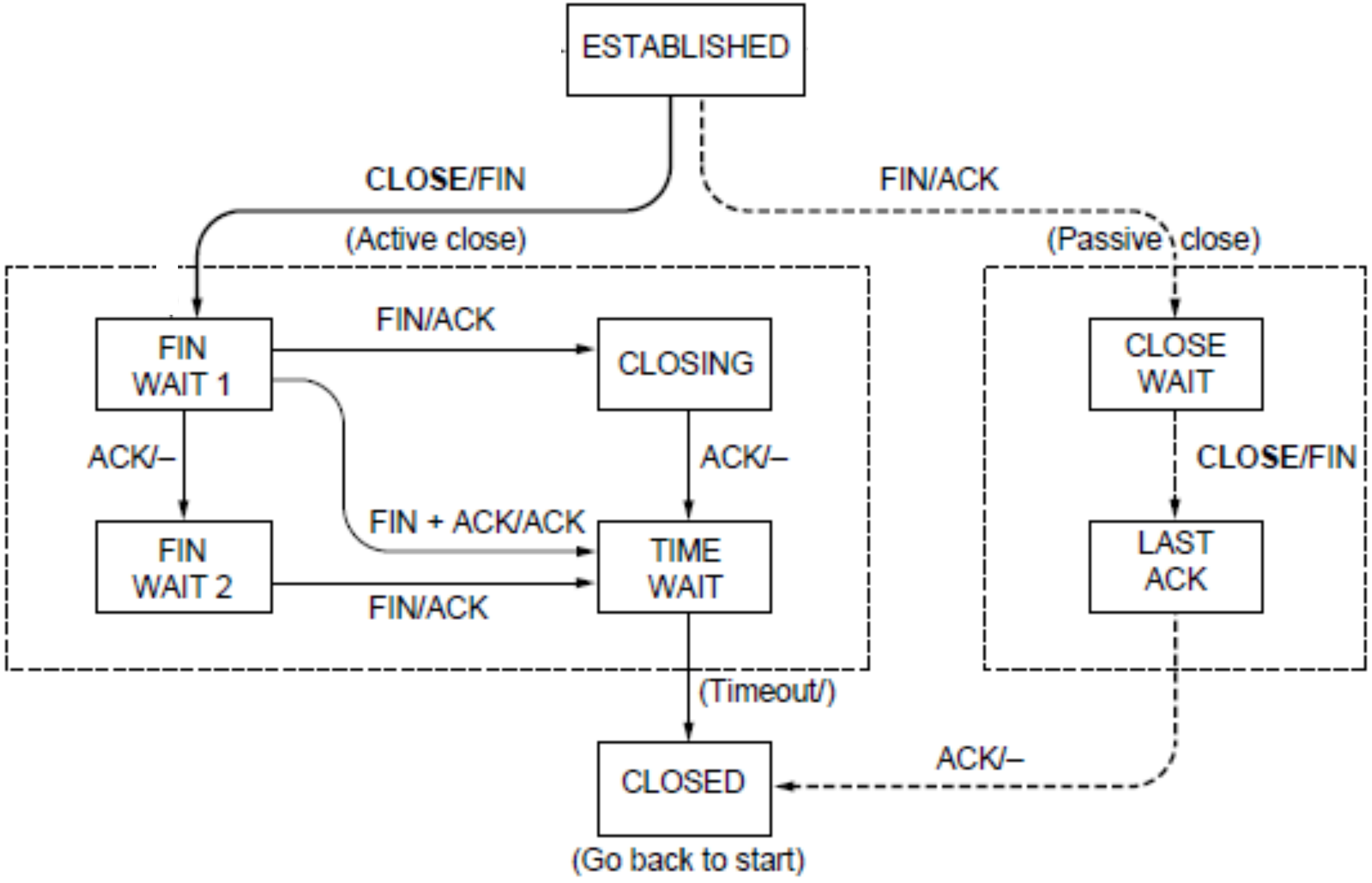


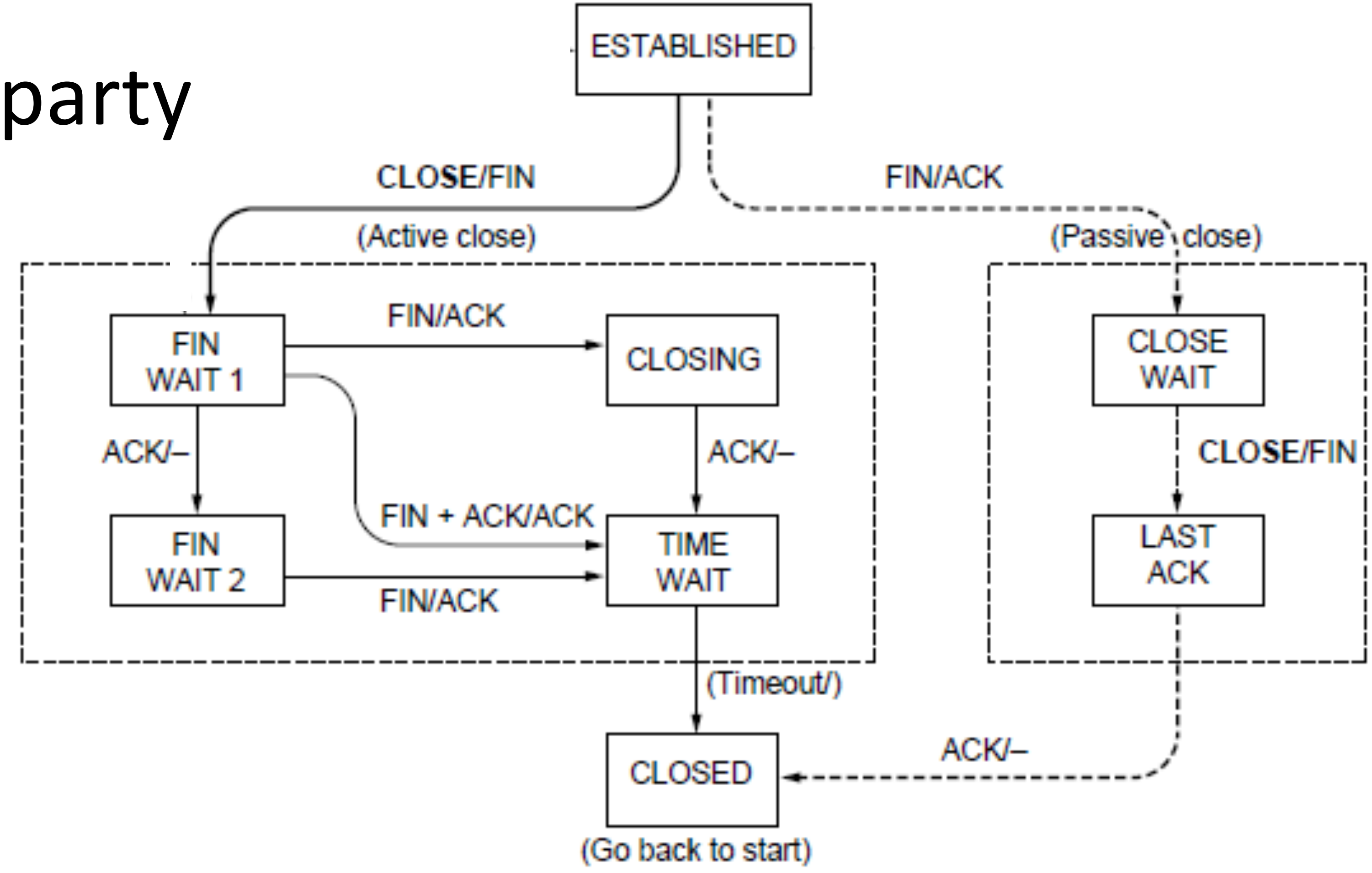
TCP Connection State Machine

Both parties run instances of this state machine



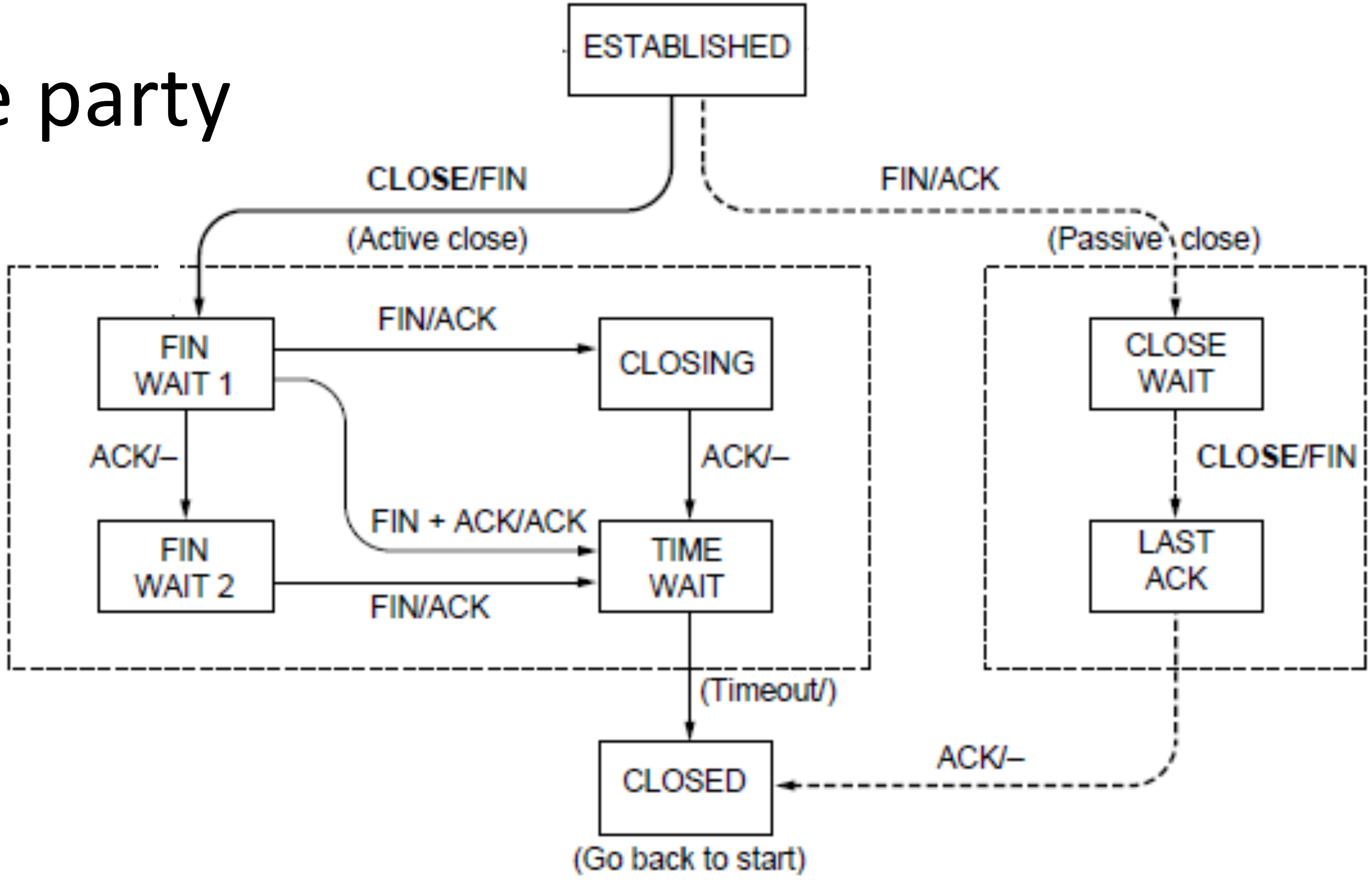
TCP Release

- Follow the active party



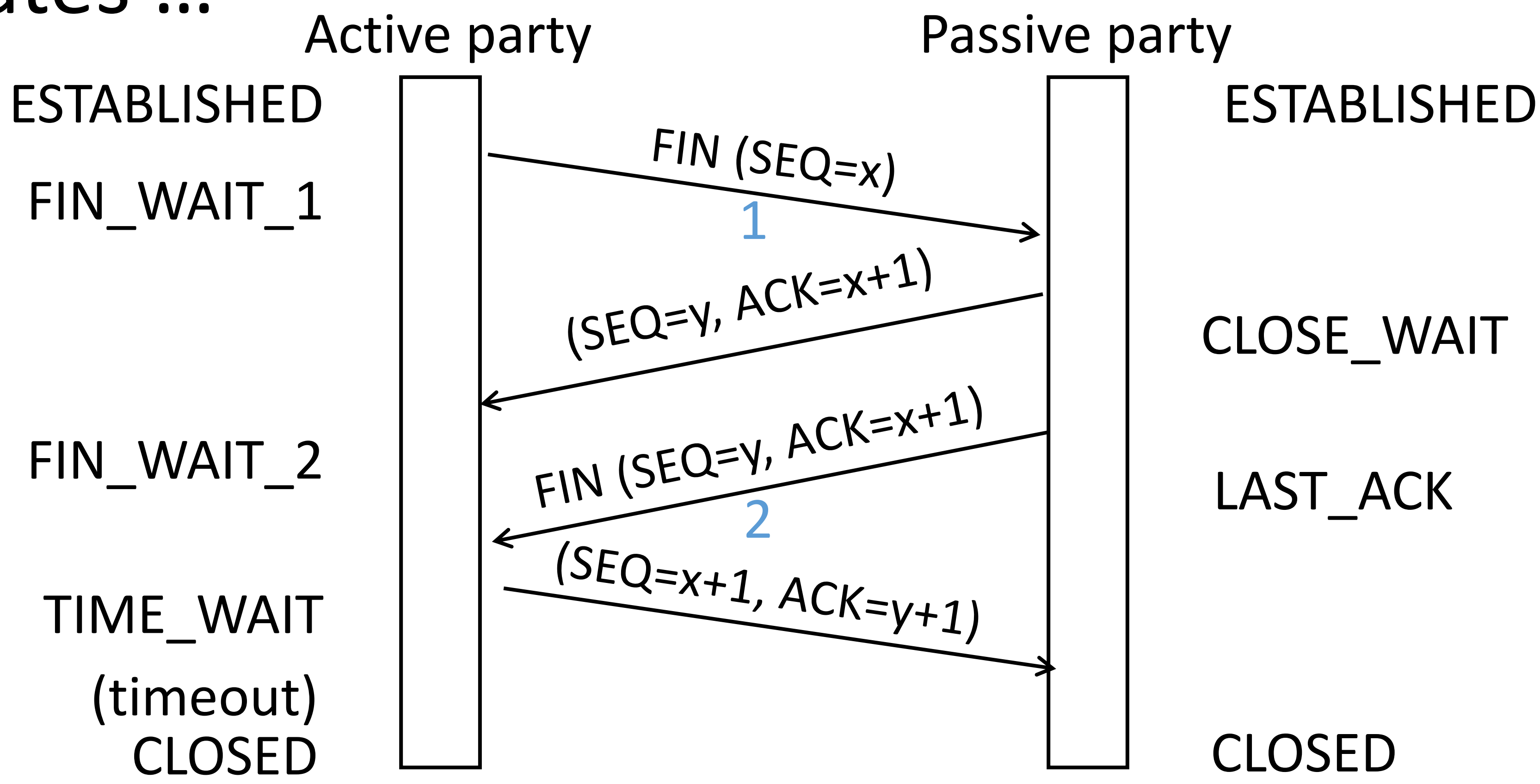
TCP Release (2)

- Follow the passive party



TCP Release (3)

- Again, with states …



TIME_WAIT State

- Wait a long time after sending all segments and before completing the close
  - Two times the maximum segment lifetime of 60 seconds
- Why?

TIME_WAIT State

- Wait a long time after sending all segments and before completing the close
  - Two times the maximum segment lifetime of 60 seconds
- Why?
  - ACK might have been lost, in which case FIN will be resent for an orderly close
  - Could otherwise interfere with a subsequent connection

Flow Control

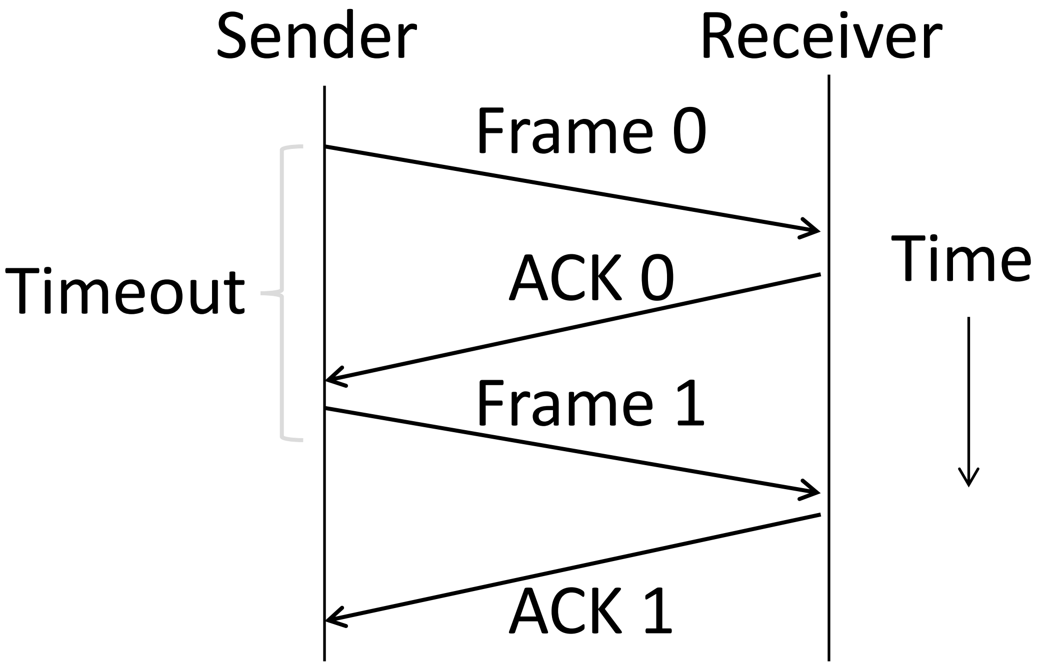
Flow control goal

Match transmission speed to reception capacity

- Otherwise data will be lost

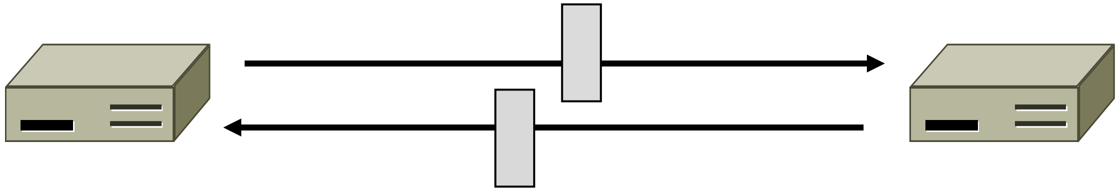
ARQ: Automatic repeat query

- ARQ with one message at a time is Stop-and-Wait



Limitation of Stop-and-Wait

- It allows only a single message to be outstanding from the sender:
  - Fine for LAN (only one frame fits in network anyhow)
  - Not efficient for network paths with longer delays

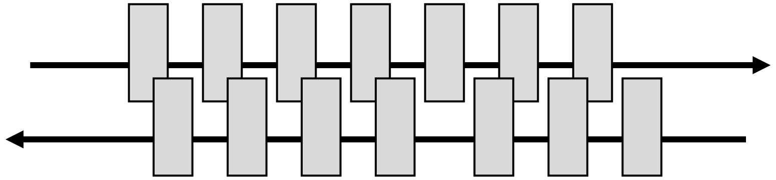


Limitation of Stop-and-Wait (2)

- Example: B=1 Mbps, D = 50 ms
  - RTT (Round Trip Time) = 2D = 100 ms
  - How many packets/sec?
    - 10
  - Usage efficiency if packets are 10kb?
    - $(10{,}000 \times 10) / (1 \times 10^6) = 10\%$
  - What is the efficiency if B=10 Mbps?
    - 1%

Sliding Window

- Generalization of stop-and-wait
  - Allows W packets to be outstanding
  - Can send W packets per RTT (=2D)



  - <u>Pipelining</u> improves performance
  - Need W=2BD to fill network path

Sliding Window (2)

What W will use the network capacity with 10kb packets?

- Ex: B=1 Mbps, D = 50 ms
  - $2BD = 2 \times 10^6 \times 50/1000 = 100$ Kb
  - W = 100 kb/10 = 10 packets

- Ex: What if B=10 Mbps?
  - W = 100 packets

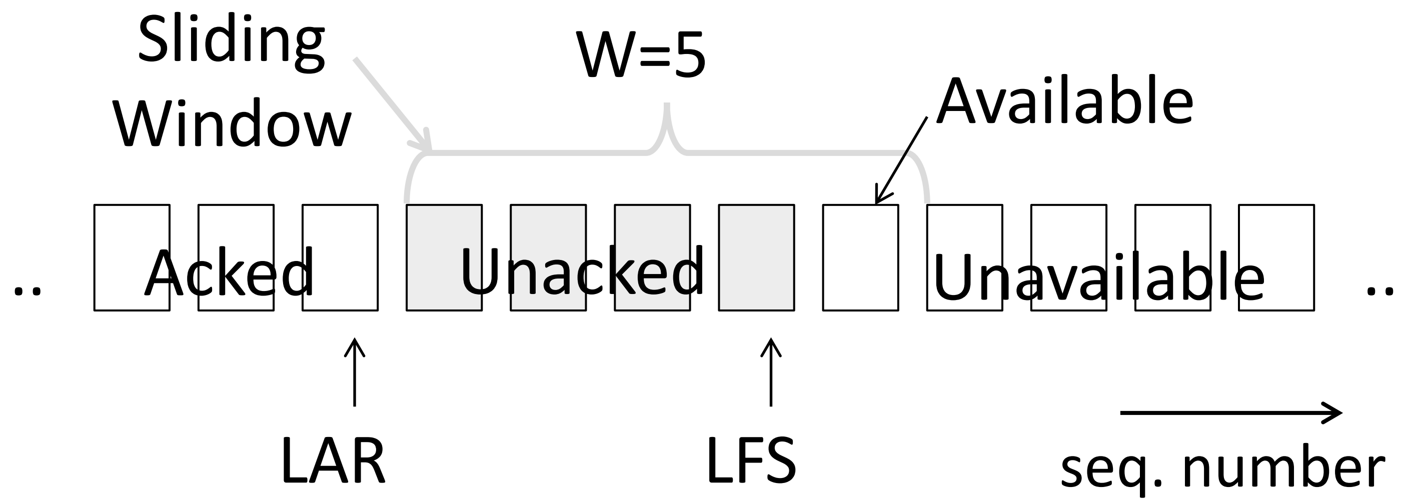
Sliding Window Protocol

- Many variations, depending on how buffers, acknowledgements, and retransmissions are handled

- Go-Back-N
  - Simplest version, can be inefficient
- Selective Repeat
  - More complex, better performance

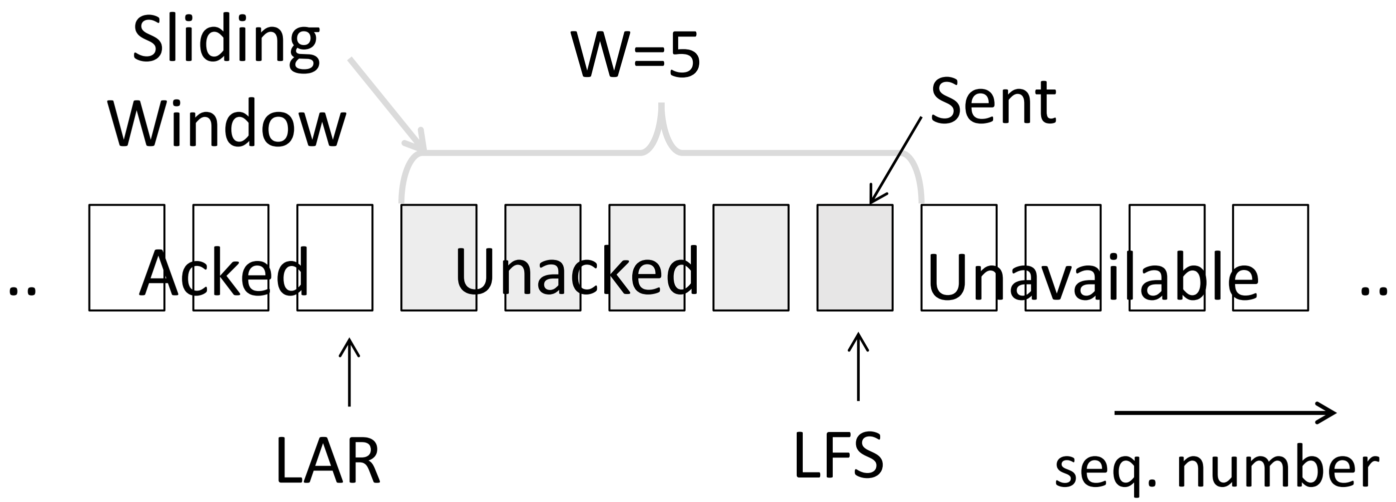
Sender Sliding Window

- Sender buffers up to W segments until they are acknowledged
  - LFS=LAST FRAME SENT, LAR=LAST ACK REC'D
  - Sends while LFS – LAR ≤ W



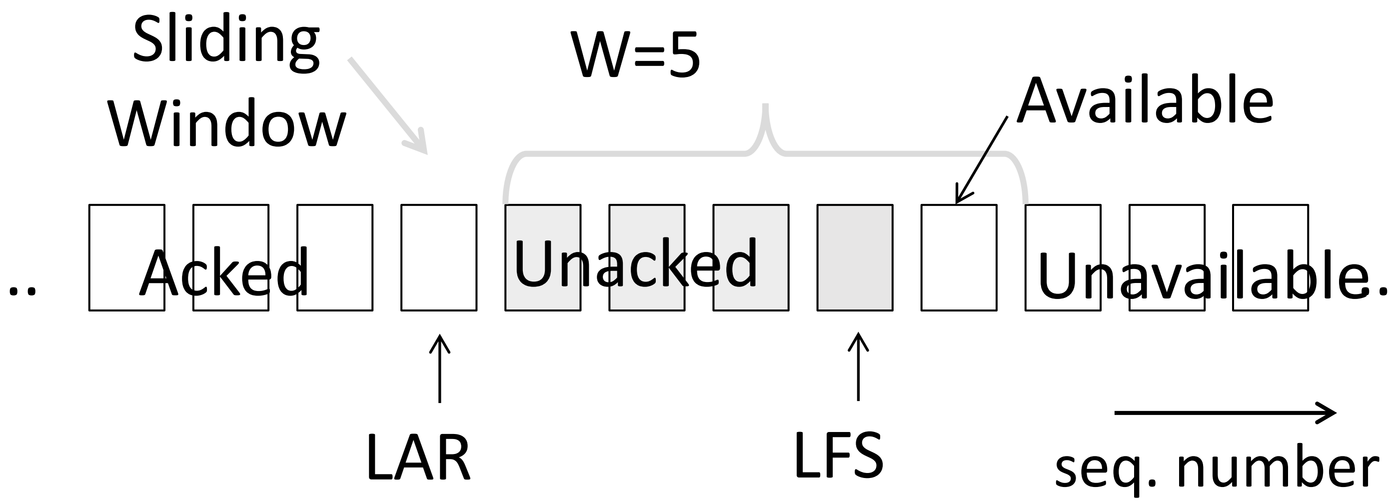
Sender Sliding Window (2)

- Transport accepts another segment of data from the Application ...
  - Transport sends it (LFS–LAR → 5)



Sender Sliding Window (3)

- Next higher ACK arrives from peer…
  - Window advances, buffer is freed
  - LFS–LAR → 4 (can send one more)



Receiver Sliding Window – Go-Back-N

- Receiver keeps only a single packet buffer for the next segment
  - State variable, LAS = LAST ACK SENT
- On receive:
  - If seq. number is LAS+1, accept and pass it to app, update LAS, send ACK
  - Otherwise discard (as out of order)

Receiver Sliding Window – Selective Repeat

- Receiver passes data to app in order, and buffers out-of-order segments to reduce retransmissions
- ACK conveys highest in-order segment, plus hints about out-of-order segments
  - Ex: I got everything up to 42 (LAS), and got 44, 45
- TCP uses a selective repeat design; we'll see the details later

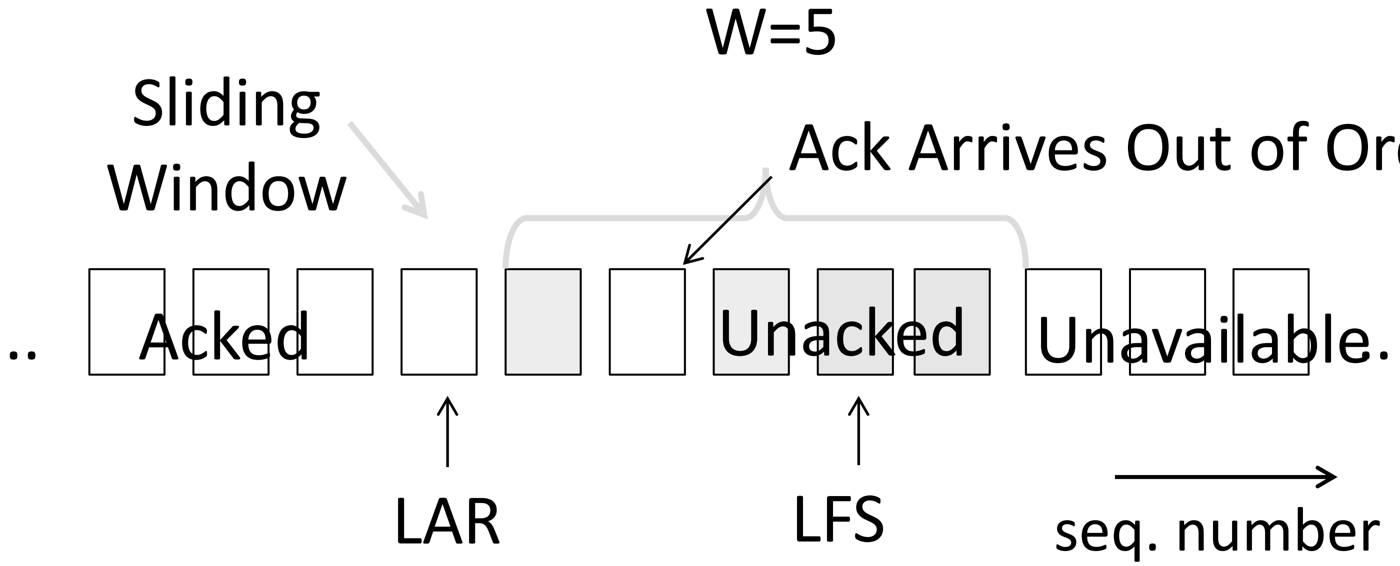
Receiver Sliding Window – Selective Repeat (2)

- Buffers W segments, keeps state variable LAS = LAST ACK SENT

- On receive:
  - Buffer segments [LAS+1, LAS+W]
  - Send app in-order segments from LAS+1, and update LAS
  - Send ACK for LAS regardless

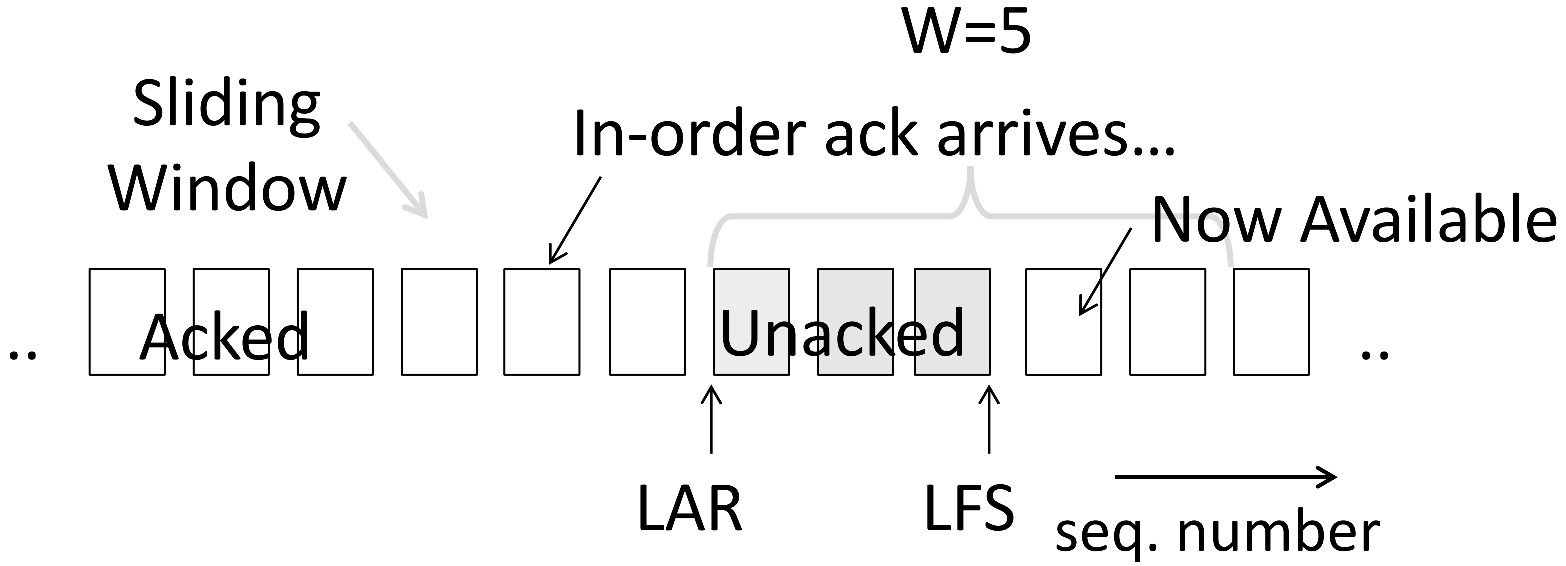
Sender Sliding Window – Selective Repeat

- Keep normal sliding window
- If out-of-order ACK arrives
  - Send LAR+1 again!



Sender Sliding Window – Selective Repeat (2)

- Keep normal sliding window
- If in-order ACK arrives
  - Move window and LAR, send more messages



Sliding Window – Retransmissions

- Go-Back-N uses a single timer to detect losses
  - On timeout, resends buffered packets starting at LAR+1
- Selective Repeat uses a timer per unacked segment to detect losses
  - On timeout for segment, resend it
  - Hope to resend fewer segments

Sequence Numbers

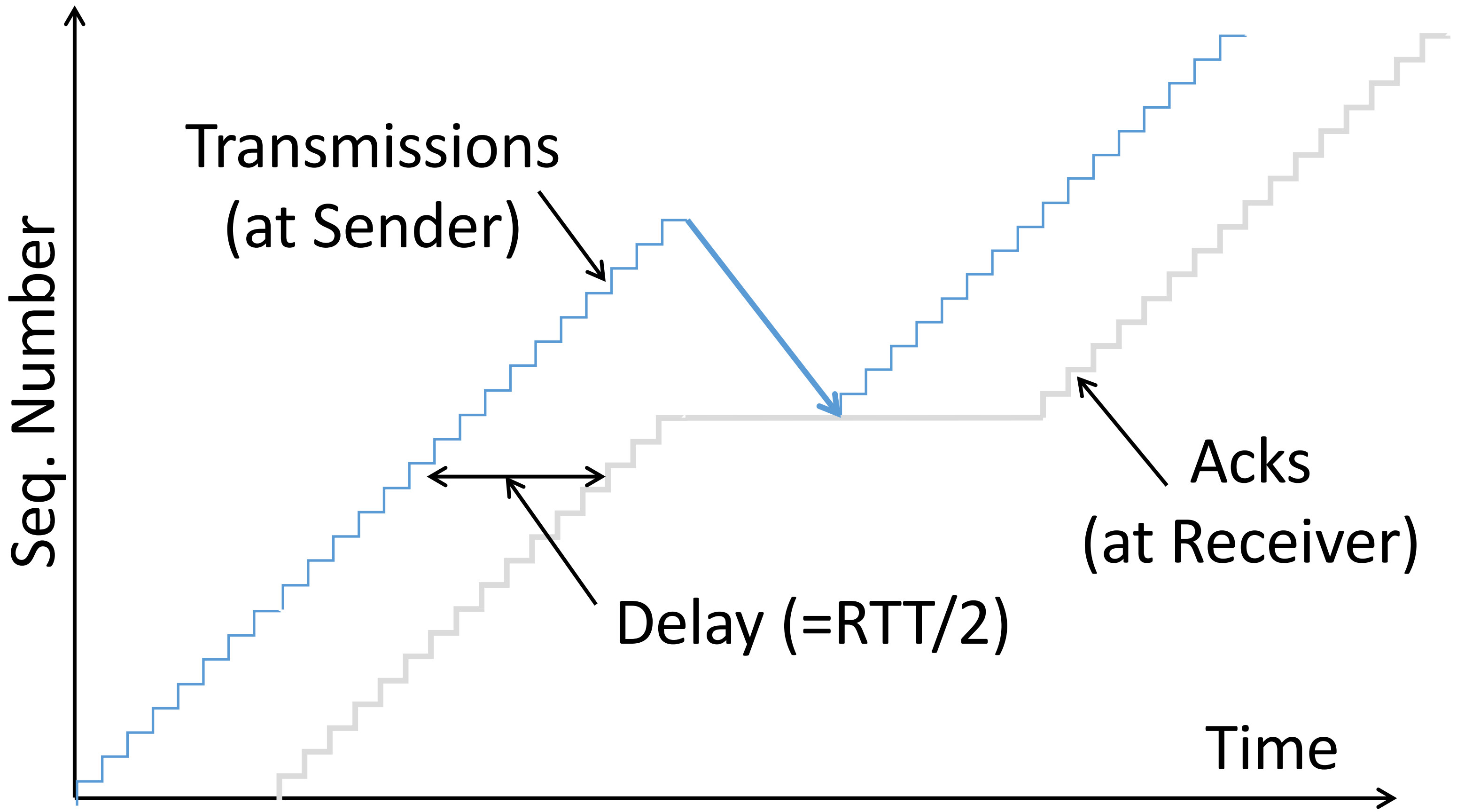
Need more than 0/1 for Stop-and-Wait … but how many?

- For Selective Repeat: 2W seq numbers
  - W for packets, plus W for earlier acks
- For Go-Back-N: W+1 sequence numbers

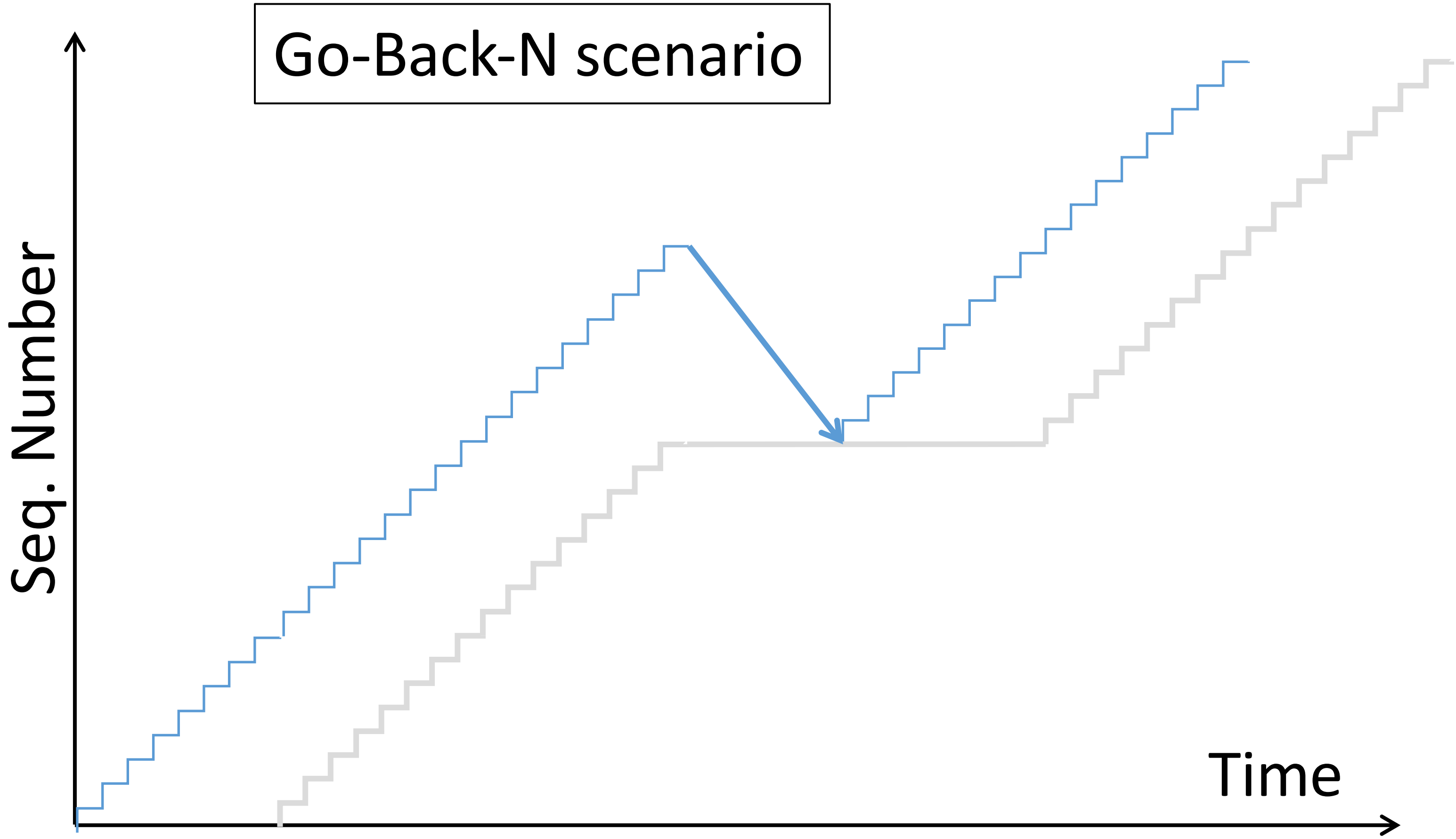
Typically implement seq. number with an N-bit counter that wraps around at 2^N—1

- E.g., N=8:   …, 253, 254, 255, 0, 1, 2, 3, …

Sequence Time Plot



Sequence Time Plot (2)



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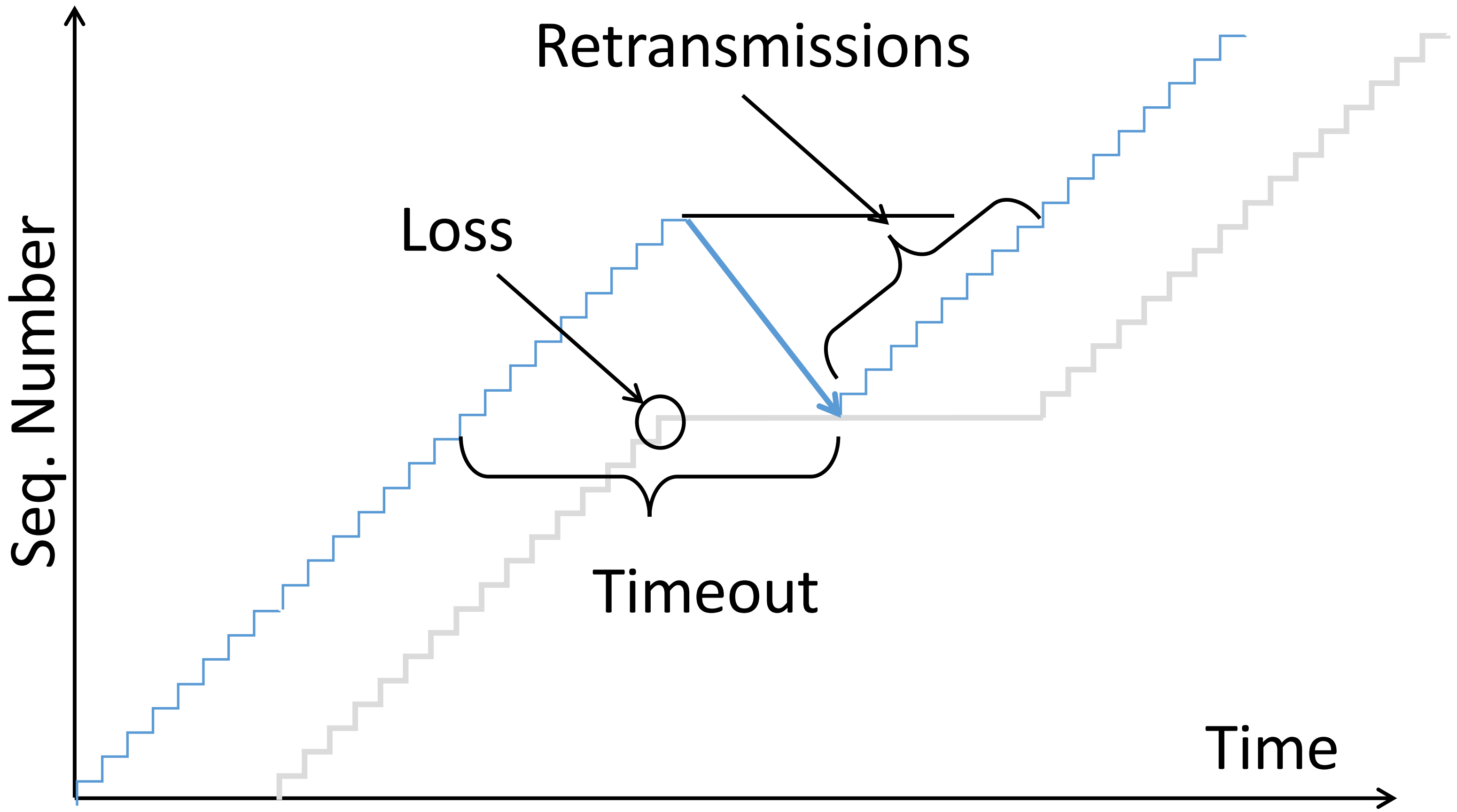


TCP recap

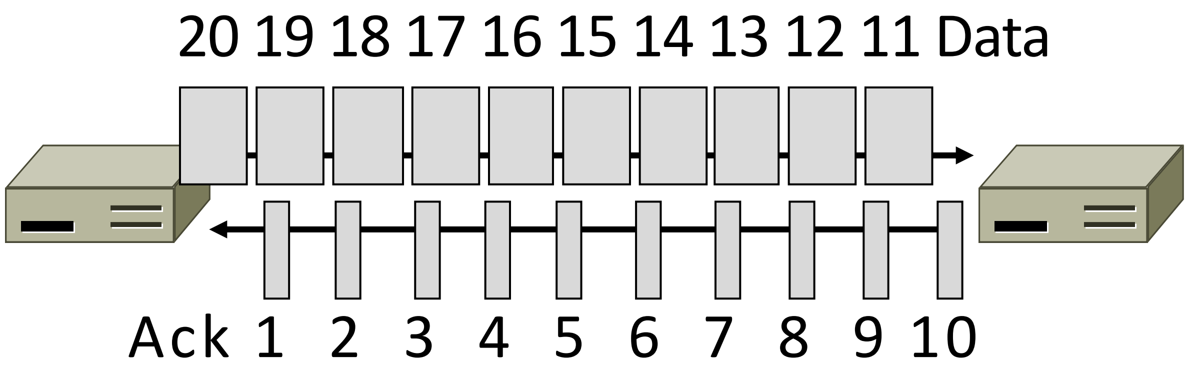
Three phases

1. Connection setup
2. Data transfer
    - Flow control – don’t overwhelm the receiver
        - ARQ – one outstanding packet
        - Go-back-N, selective repeat -- sliding window of W packets
        - **Tuning flow control (ack clocking, RTT estimation)**
    - **Congestion control**
3. Connection release

ACK Clocking

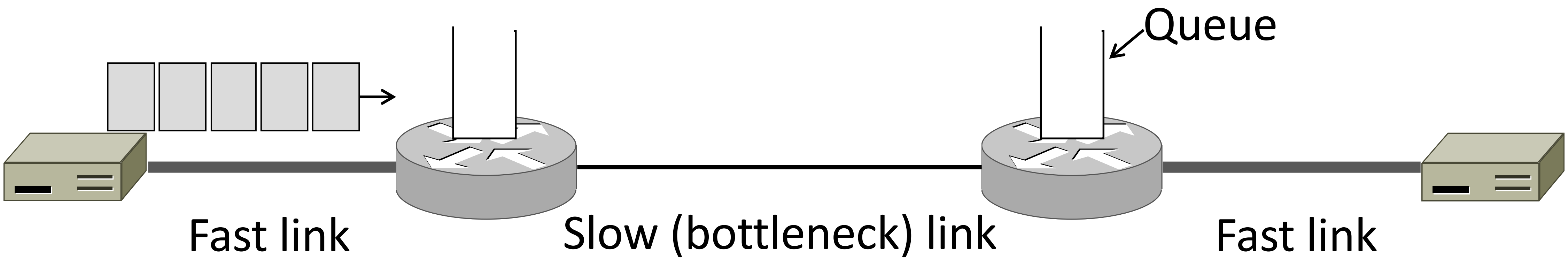
Sliding Window ACK Clock

- Typically, the sender does not know B or D
- Each new ACK advances the sliding window and lets a new segment enter the network
  - ACKs "clock" data segments



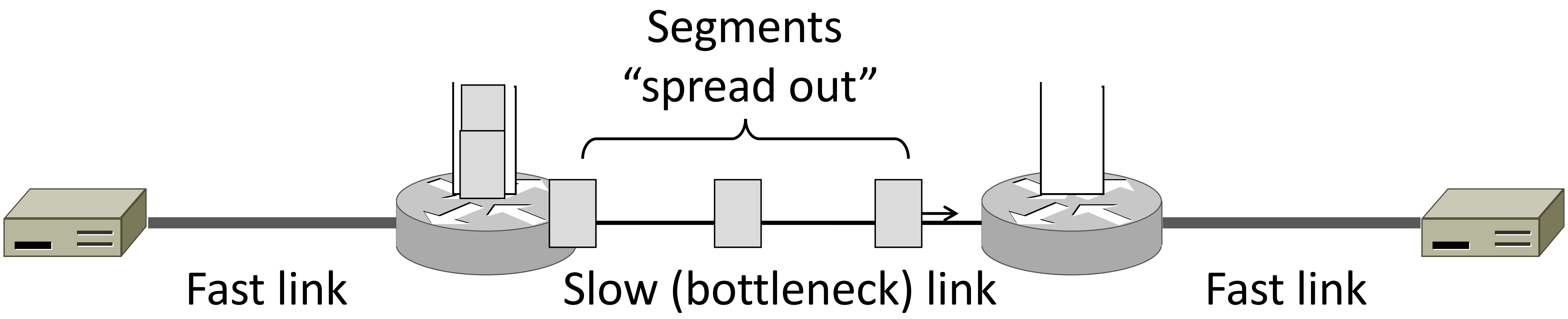
Benefit of ACK Clocking

- Consider what happens when sender injects a burst of segments into the network



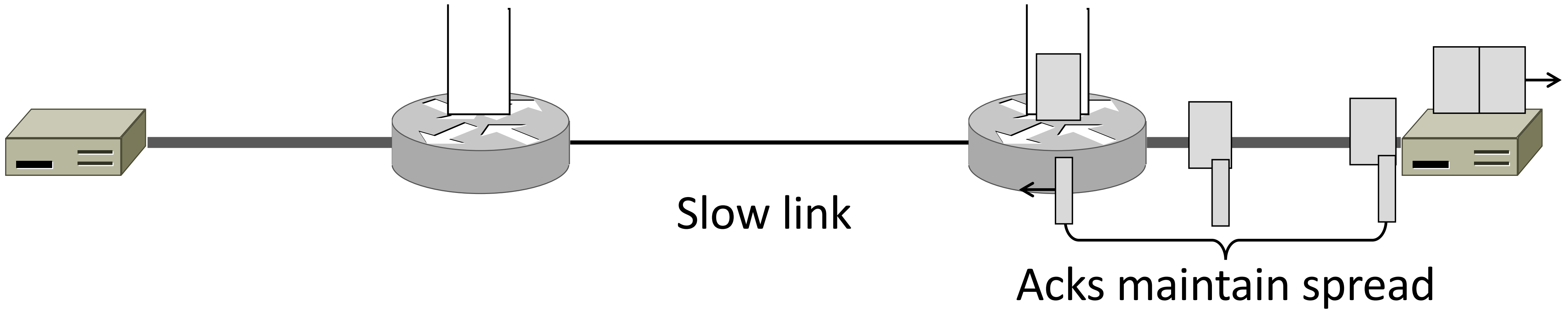
Benefit of ACK Clocking (2)

- Segments are buffered and spread out on slow link



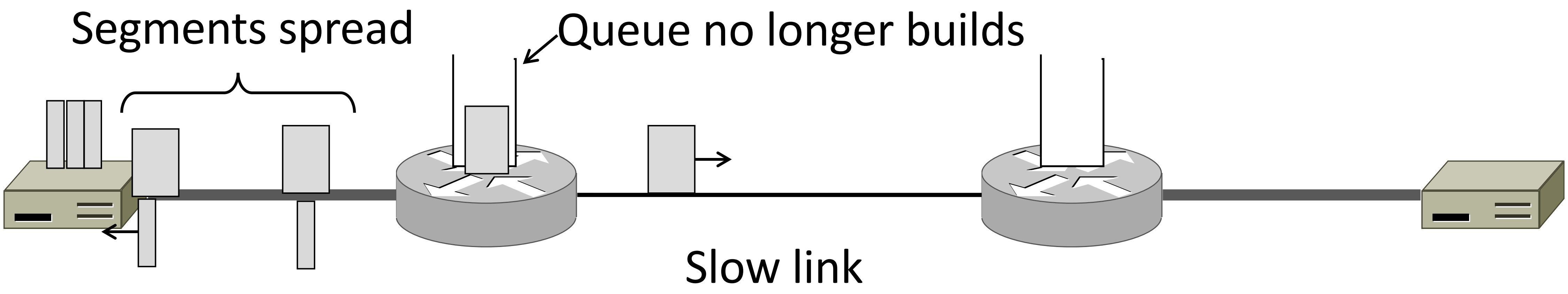
Benefit of ACK Clocking (3)

- ACKs maintain the spread back to the original sender



Benefit of ACK Clocking (4)

- Sender clocks new segments with the spread
  - Now sending at the bottleneck link without queuing!



Benefit of ACK Clocking (4)

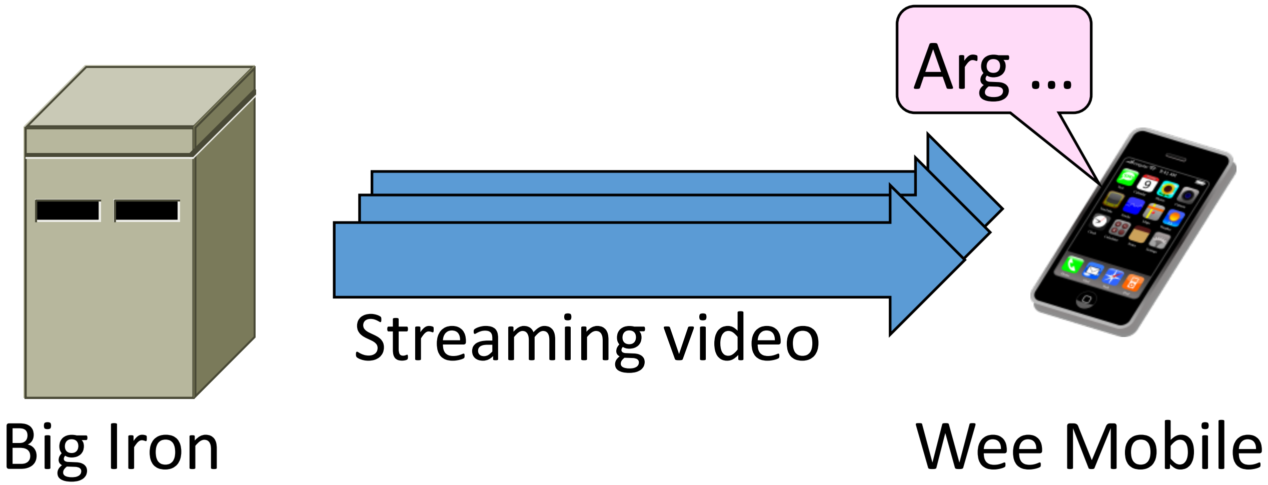
- Helps run with low levels of loss and delay!
- The network smooths out the burst of data segments
- ACK clock transfers this smooth timing back to sender
- Subsequent data segments are not sent in bursts so do not queue up in the network

TCP Uses ACK Clocking

- TCP uses a sliding window because of the value of ACK clocking
- Sliding window controls how many segments are inside the network
- TCP only sends small bursts of segments to let the network keep the traffic smooth

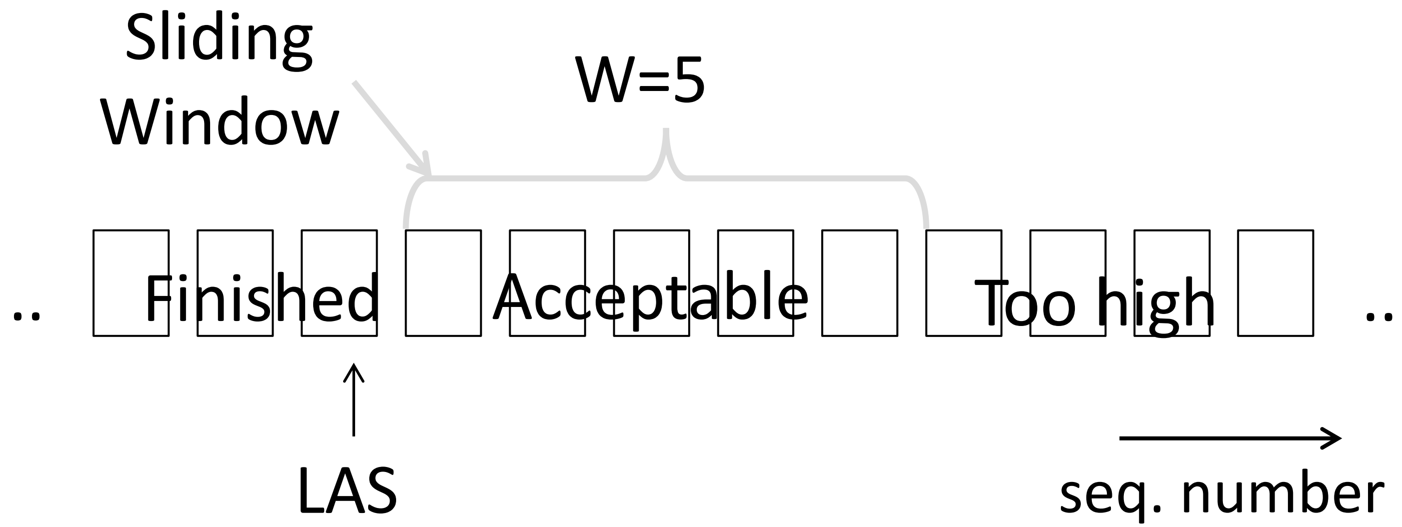
Problem

- Sliding window has pipelining to keep network busy
  - What if the receiver is overloaded?



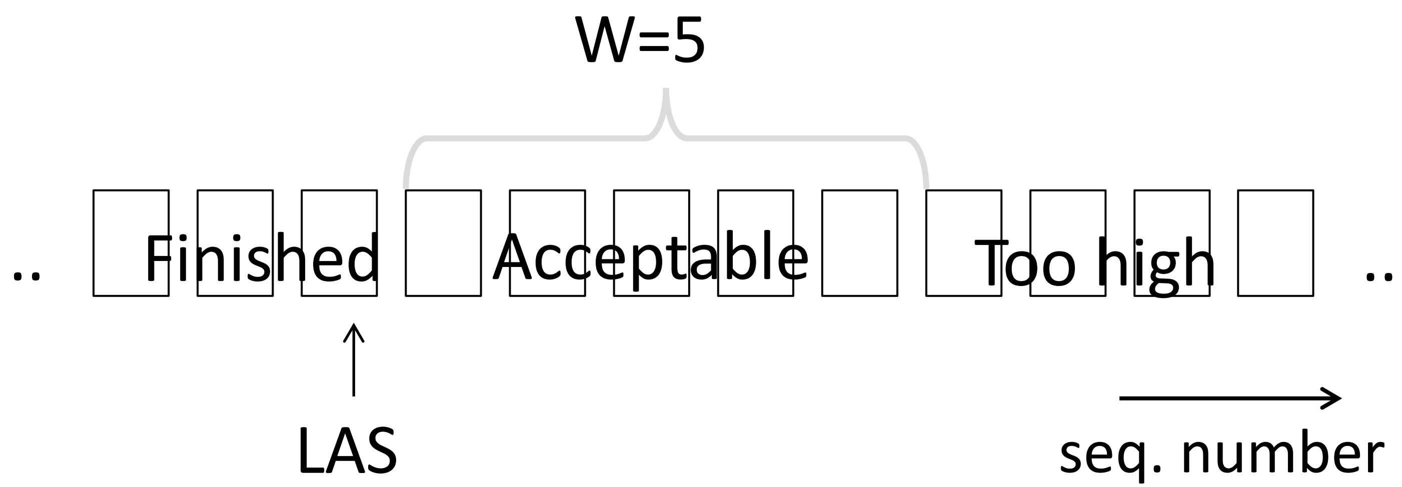
Receiver Sliding Window

- Consider receiver with W buffers
  - LAS=LAST ACK SENT
  - app pulls in-order data from buffer with recv() call



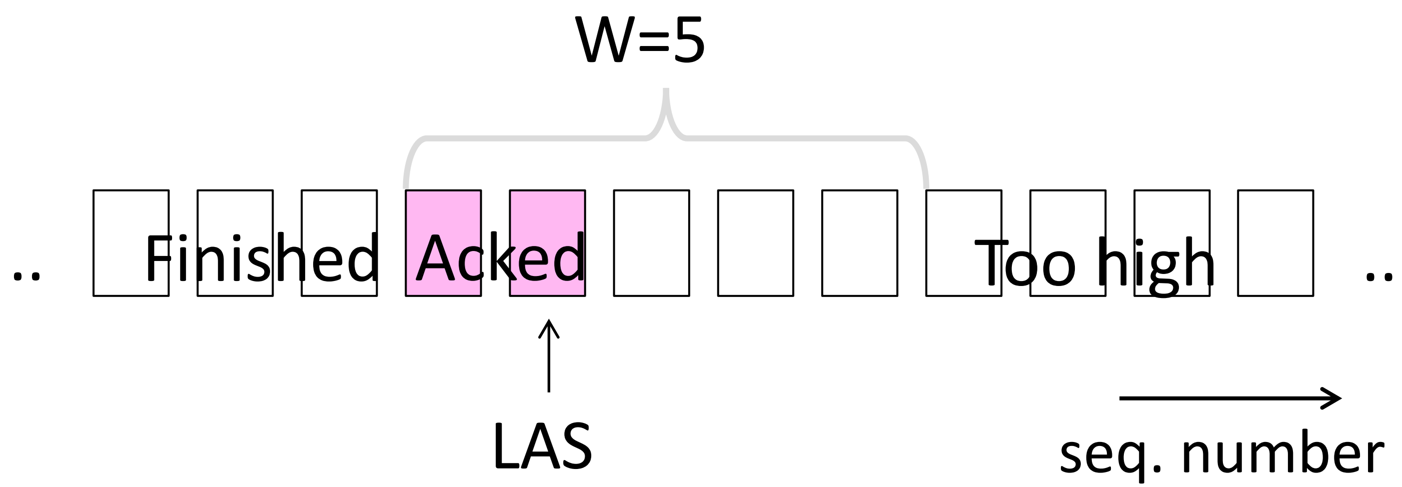
Receiver Sliding Window (2)

- Suppose the next two segments arrive but app does not call recv()



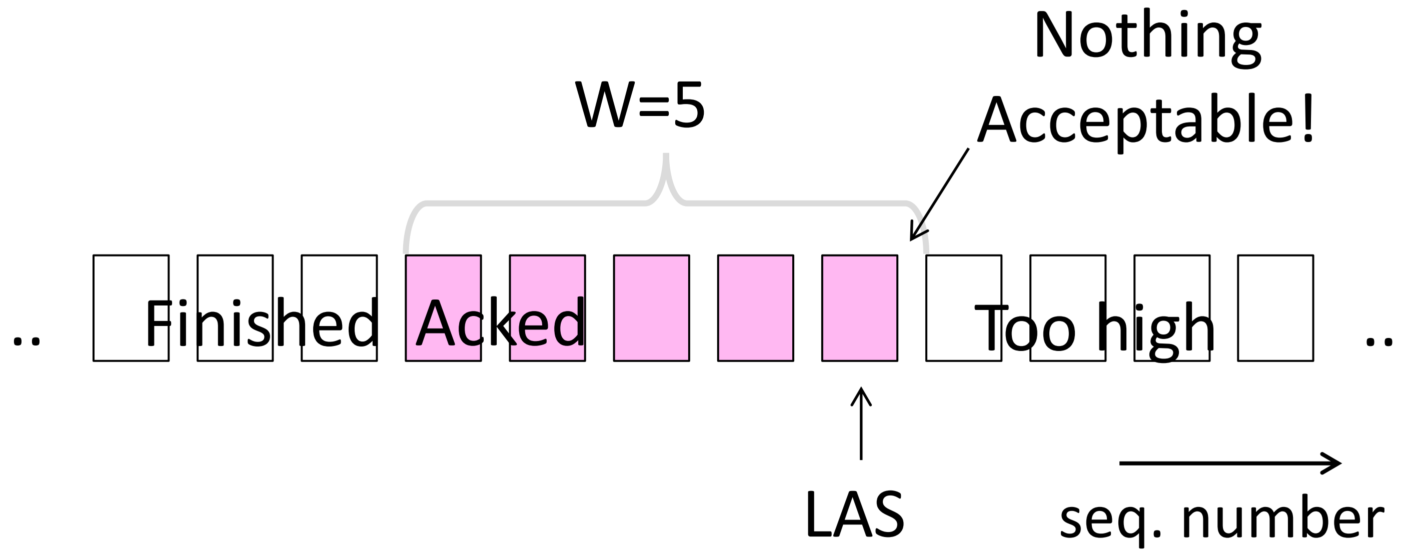
Receiver Sliding Window (3)

- Suppose the next two segments arrive but app does not call recv()
  - LAS rises, but we can't slide window!



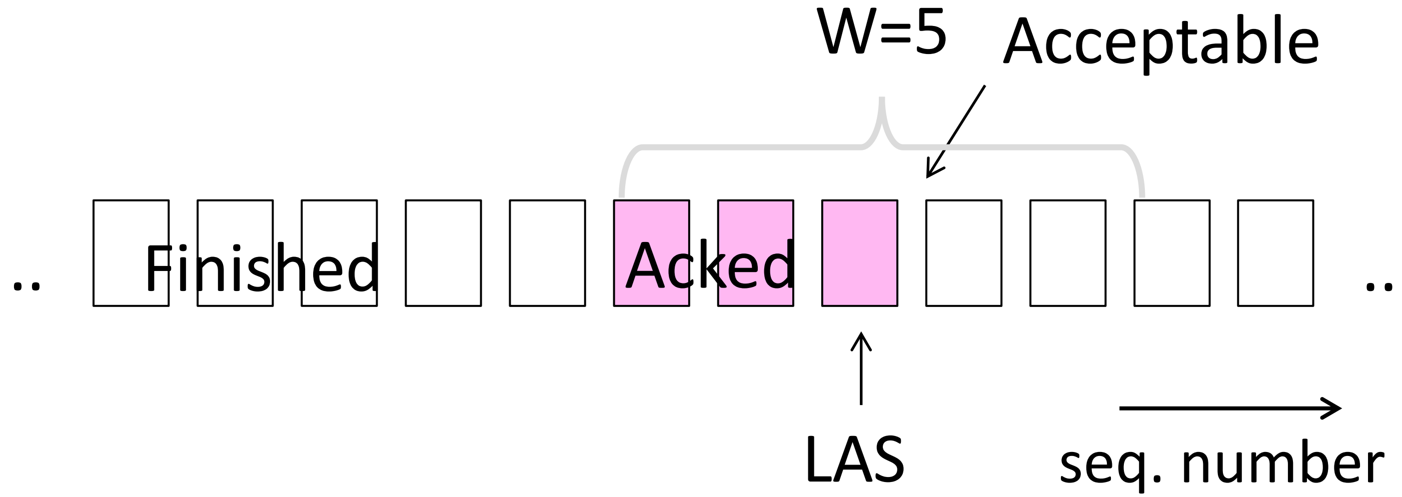
Receiver Sliding Window (4)

- Further segments arrive (in order) we fill buffer
  - Must drop segments until app recvs!



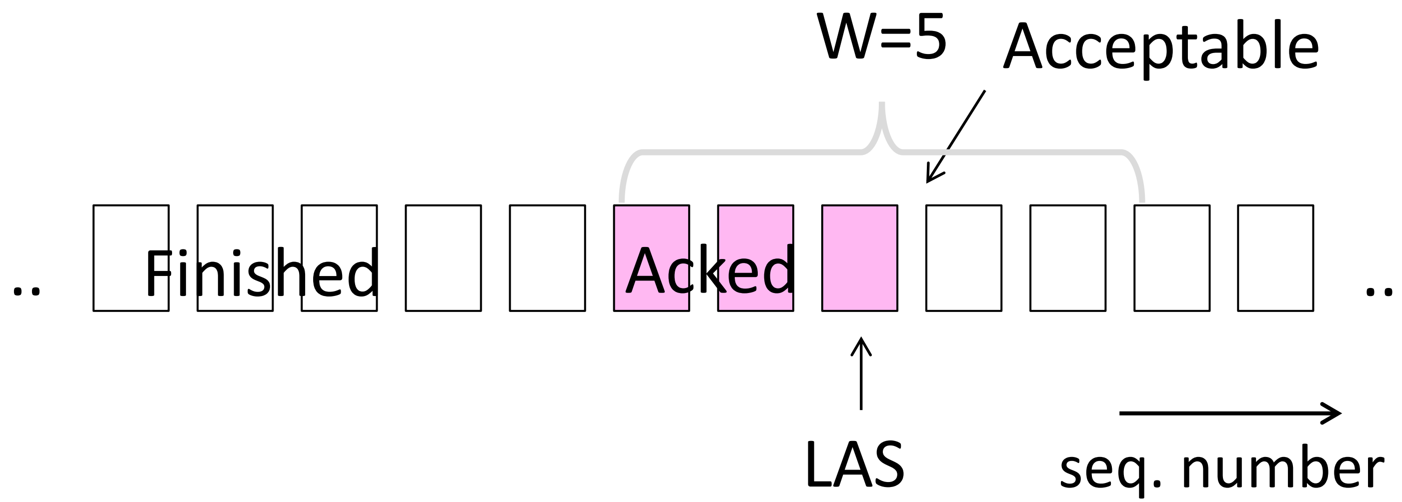
Receiver Sliding Window (5)

- App recv() takes two segments
  - Window slides (phew)



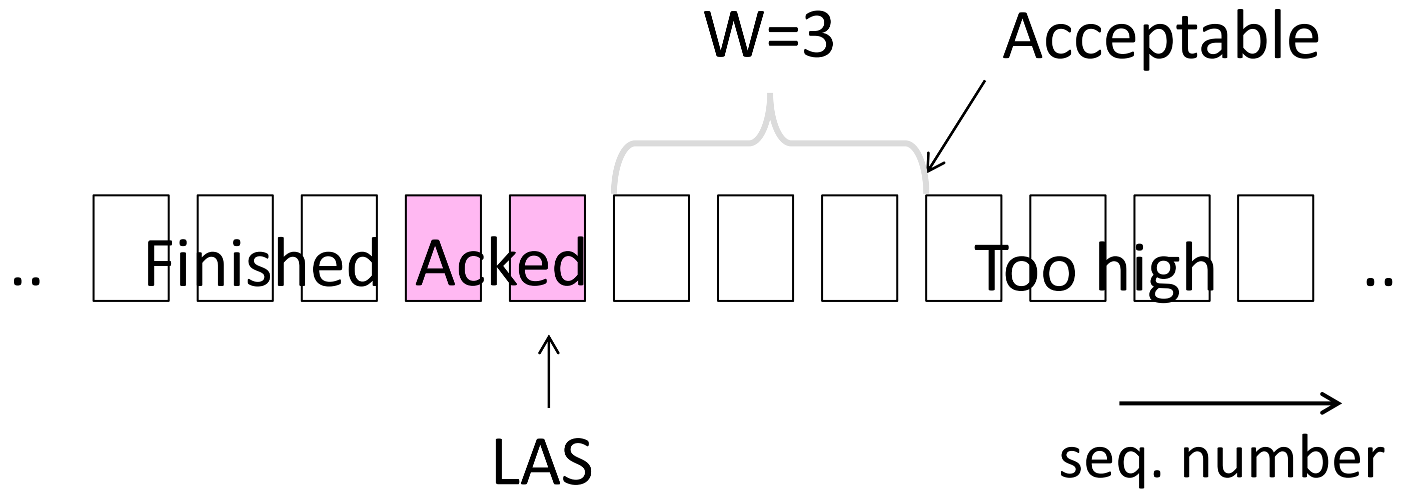
Flow Control

- Avoid loss at receiver by telling sender the available buffer space
  - WIN=#Acceptable, not W (from LAS)



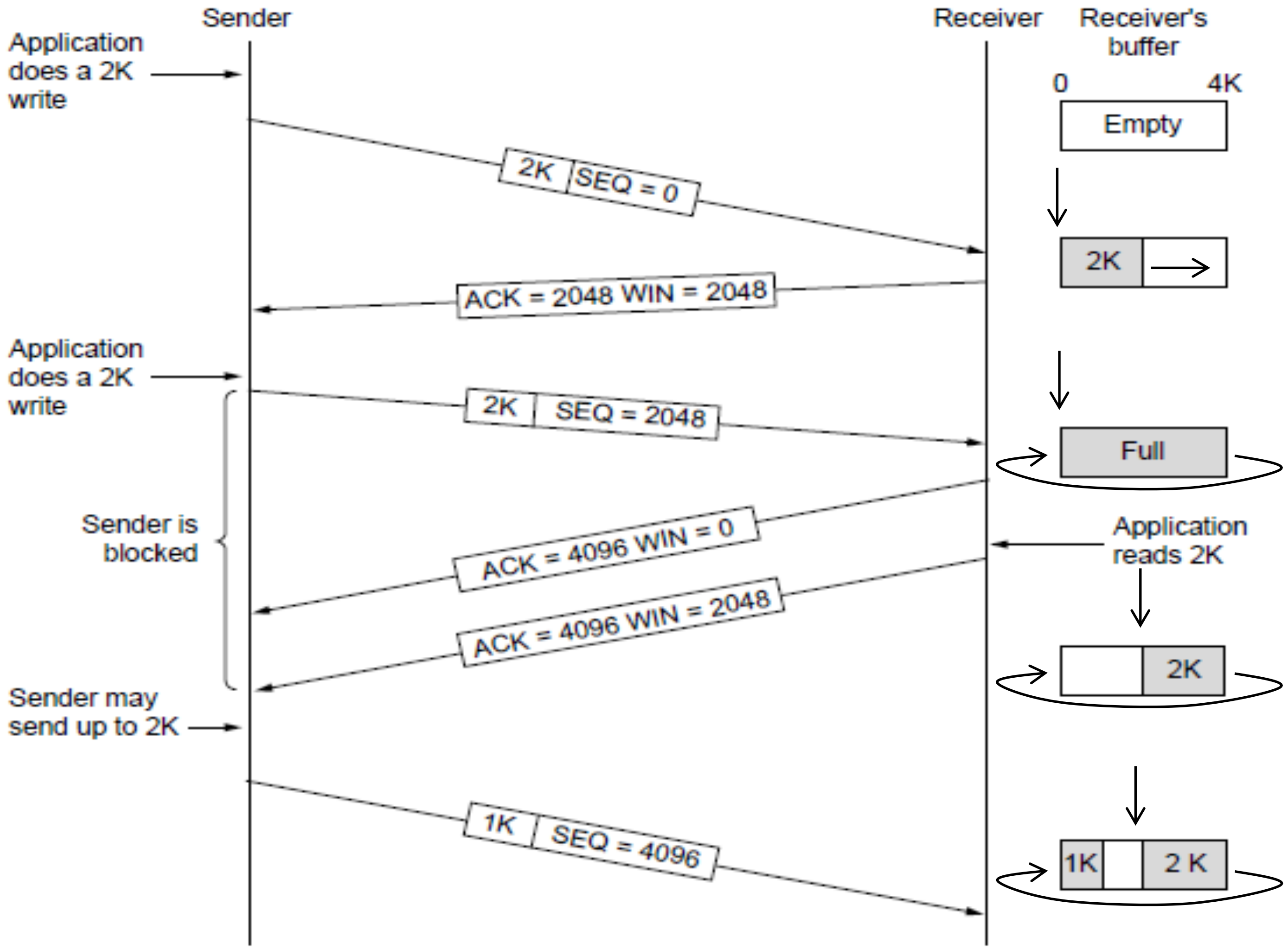
Flow Control (2)

- Sender uses lower of the sliding window and flow control window (WIN) as the effective window size



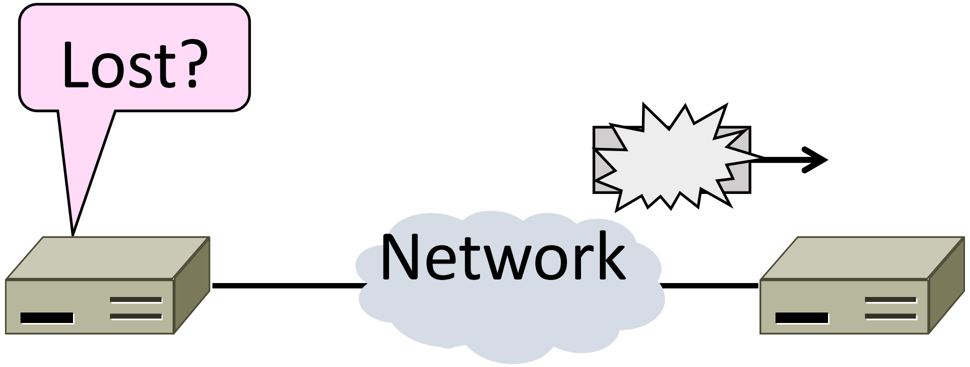
Flow Control (3)

- TCP-style example
  - SEQ/ACK sliding window
  - Flow control with WIN
  - SEQ + length < ACK+WIN
  - 4KB buffer at receiver
  - Circular buffer of bytes



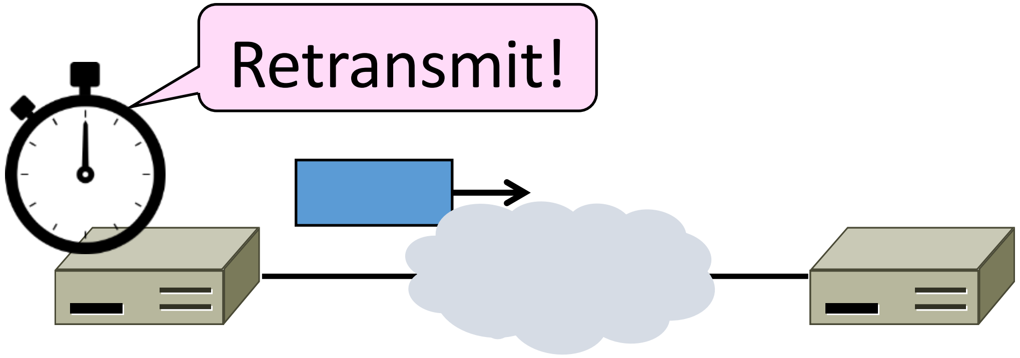
Topic

- How to set the timeout for sending a retransmission
  - Adapting to the network path



Retransmissions

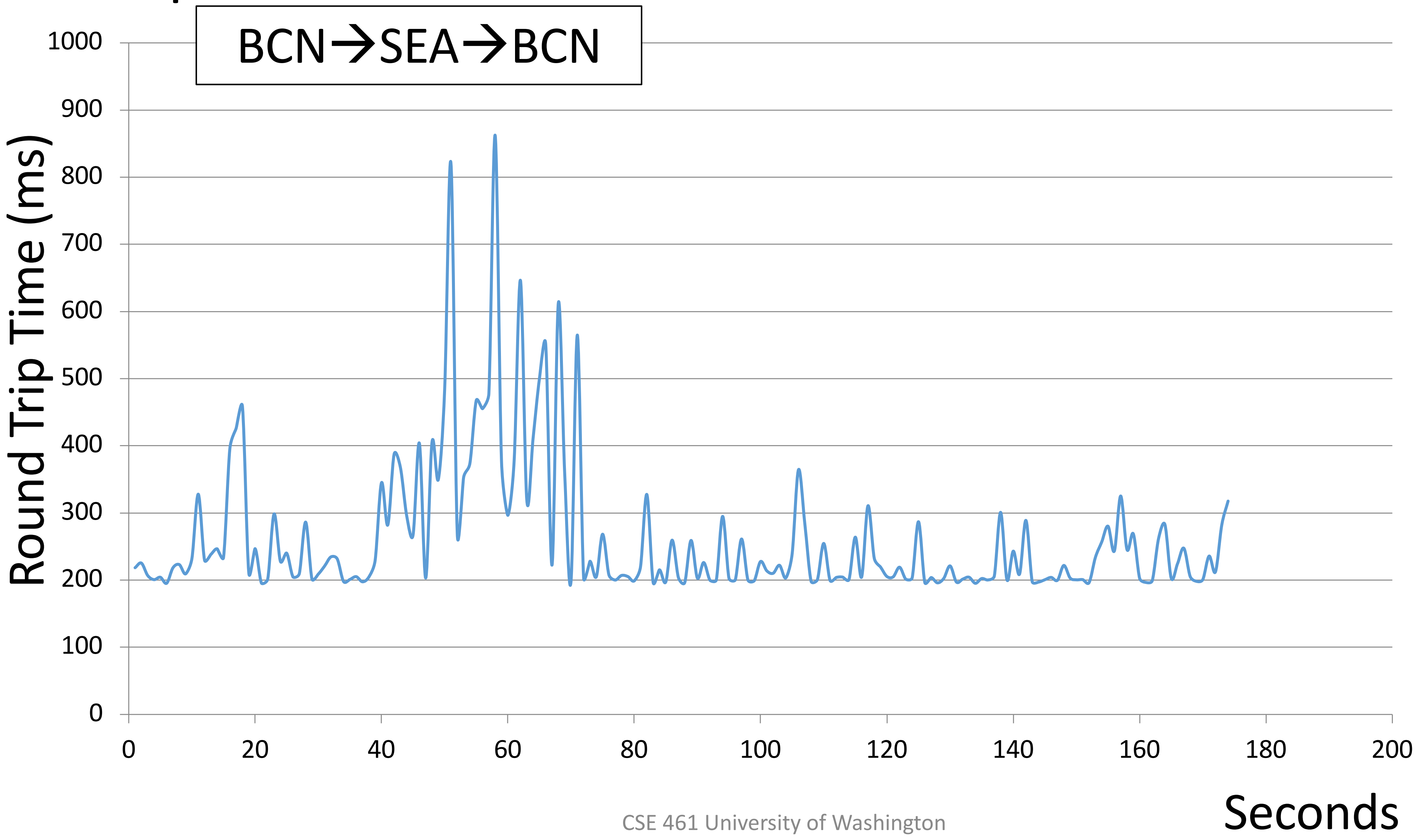
- With sliding window, detecting loss with <u>timeout</u>
  - Set timer when a segment is sent
  - Cancel timer when ack is received
  - If timer fires, <u>retransmit</u> data as lost



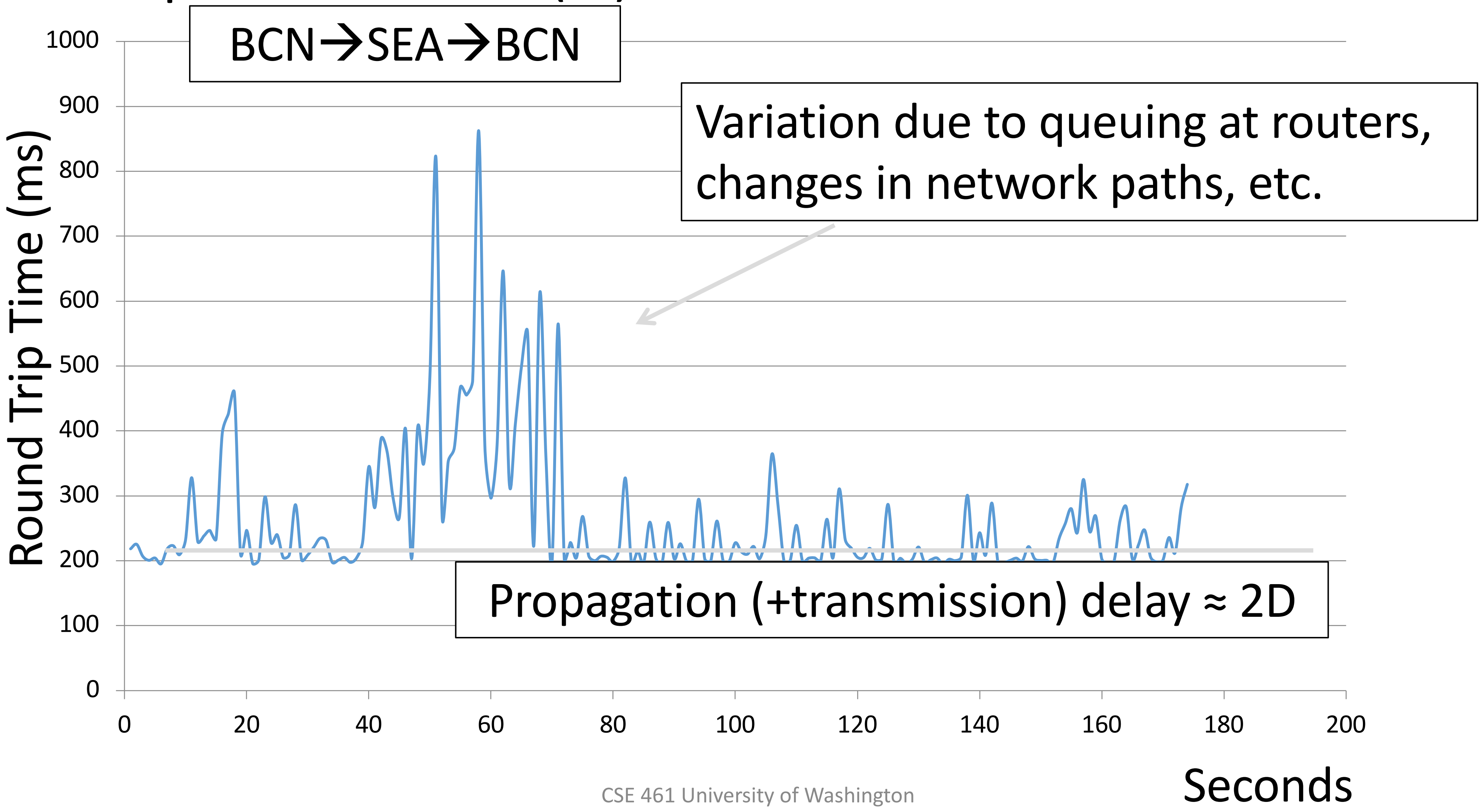
Timeout Problem

- Timeout should be "just right"
  - Too long → inefficient network capacity use
  - Too short → spurious resends waste network capacity
- But what is "just right"?
  - Easy to set on a LAN (Link)
    - Short, fixed, predictable RTT
  - Hard on the Internet (Transport)
    - Wide range, variable RTT

Example of RTTs



Example of RTTs (2)



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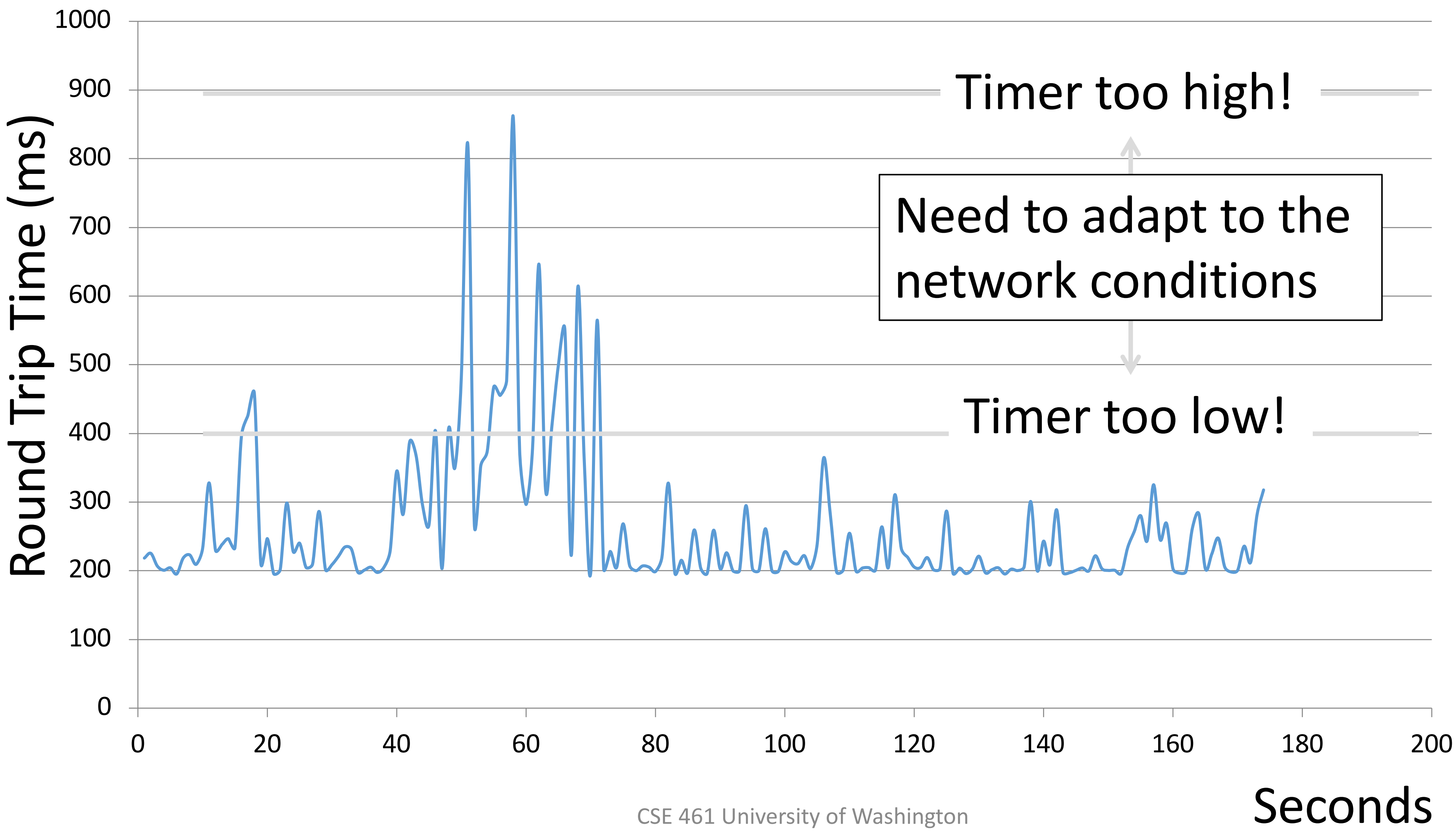
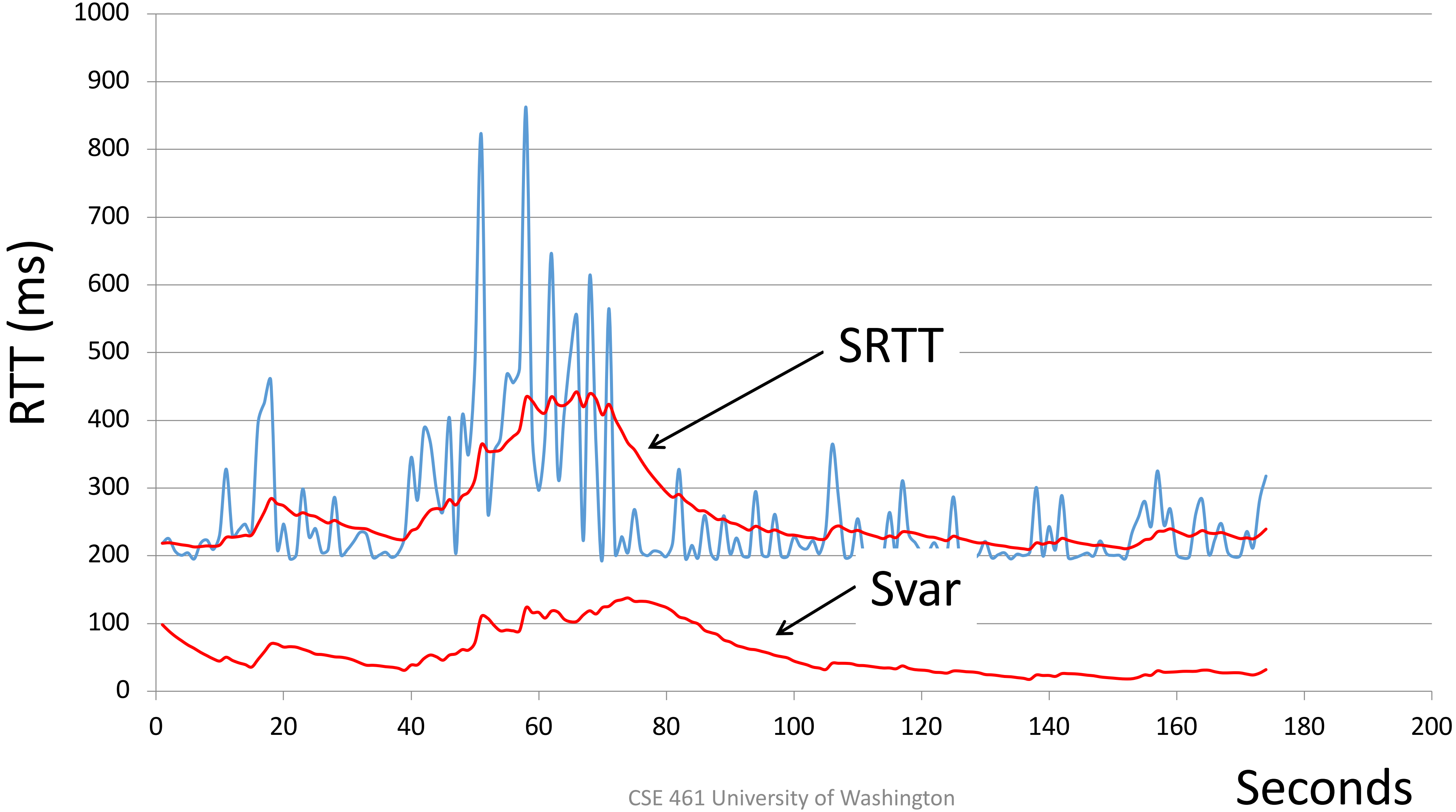


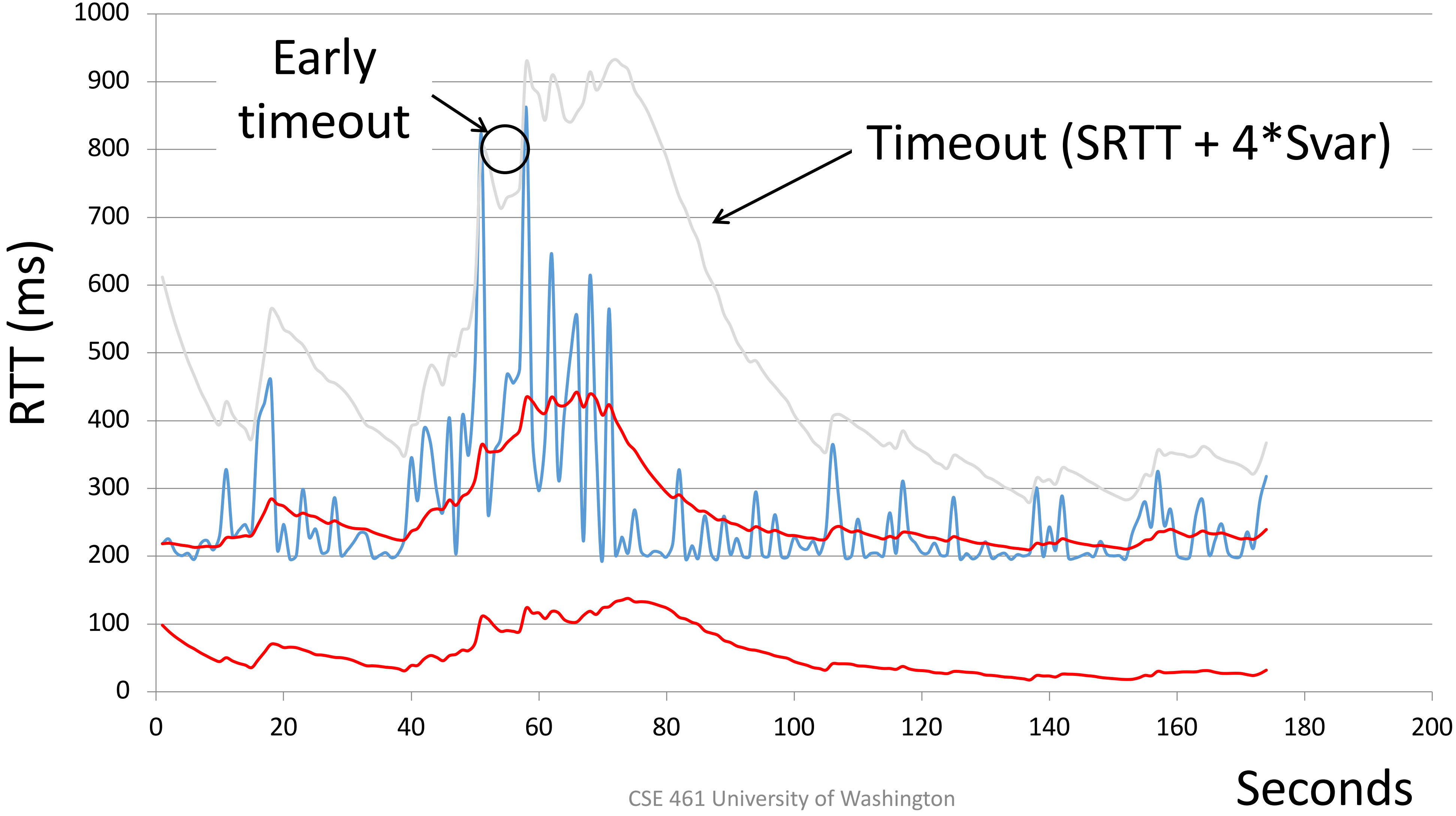
Adaptive Timeout

- Smoothed estimates of the RTT (1) and variance in RTT (2)
  - Update estimates with a moving average
  1. $SRTT_{N+1} = 0.9*SRTT_N + 0.1*RTT_{N+1}$
  2. $Svar_{N+1} = 0.9*Svar_N + 0.1*|RTT_{N+1} - SRTT_{N+1}|$
- Set timeout to a multiple of estimates
  - To estimate the upper RTT in practice
  - TCP $Timeout_N = SRTT_N + 4*Svar_N$

Example of Adaptive Timeout



Example of Adaptive Timeout (2)



Adaptive Timeout (2)

- Simple to compute, does a good job of tracking actual RTT
  - Little "headroom" to lower
  - Yet very few early timeouts

- Turns out to be important for good performance and robustness