CS 43: Computer Networks
TCP

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October 10, 2017

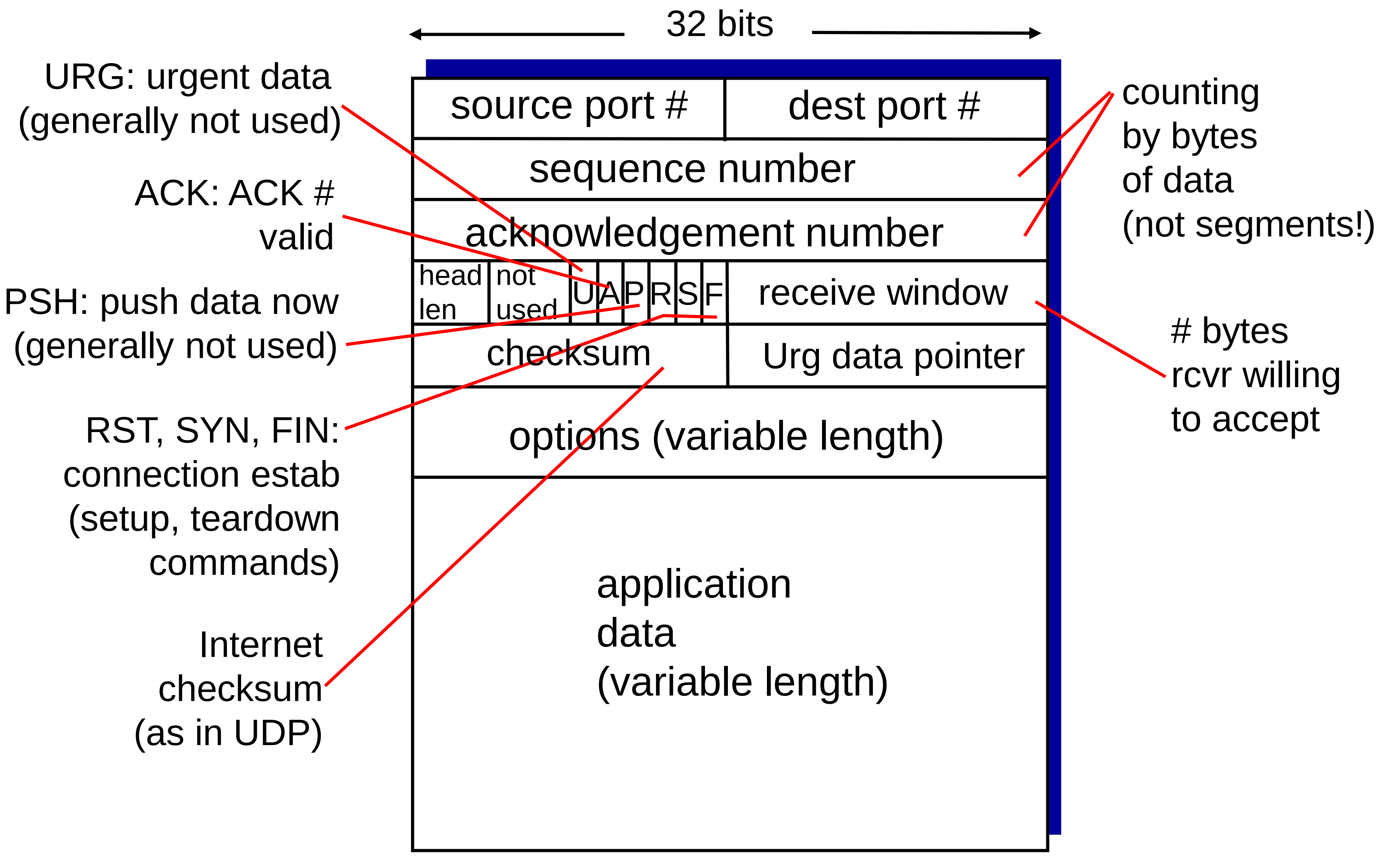
Practical Reliability Questions

- How do the sender and receiver keep track of outstanding pipelined segments?
- How many segments should be pipelined?
- How do we choose sequence numbers?
- What does connection establishment look like?
- How should we choose timeout values?

TCP Overview

- Point-to-point, full duplex
  - One pair of hosts
  - Messages in both directions
- Reliable, in-order byte stream
  - No discrete messages
- Connection-oriented
  - Handshaking (exchange of control messages) before data transmitted
- Pipelined
  - Many segments in flight
- Flow control
  - Don't send too fast for the receiver
- Congestion control
  - Don't send too fast for the network

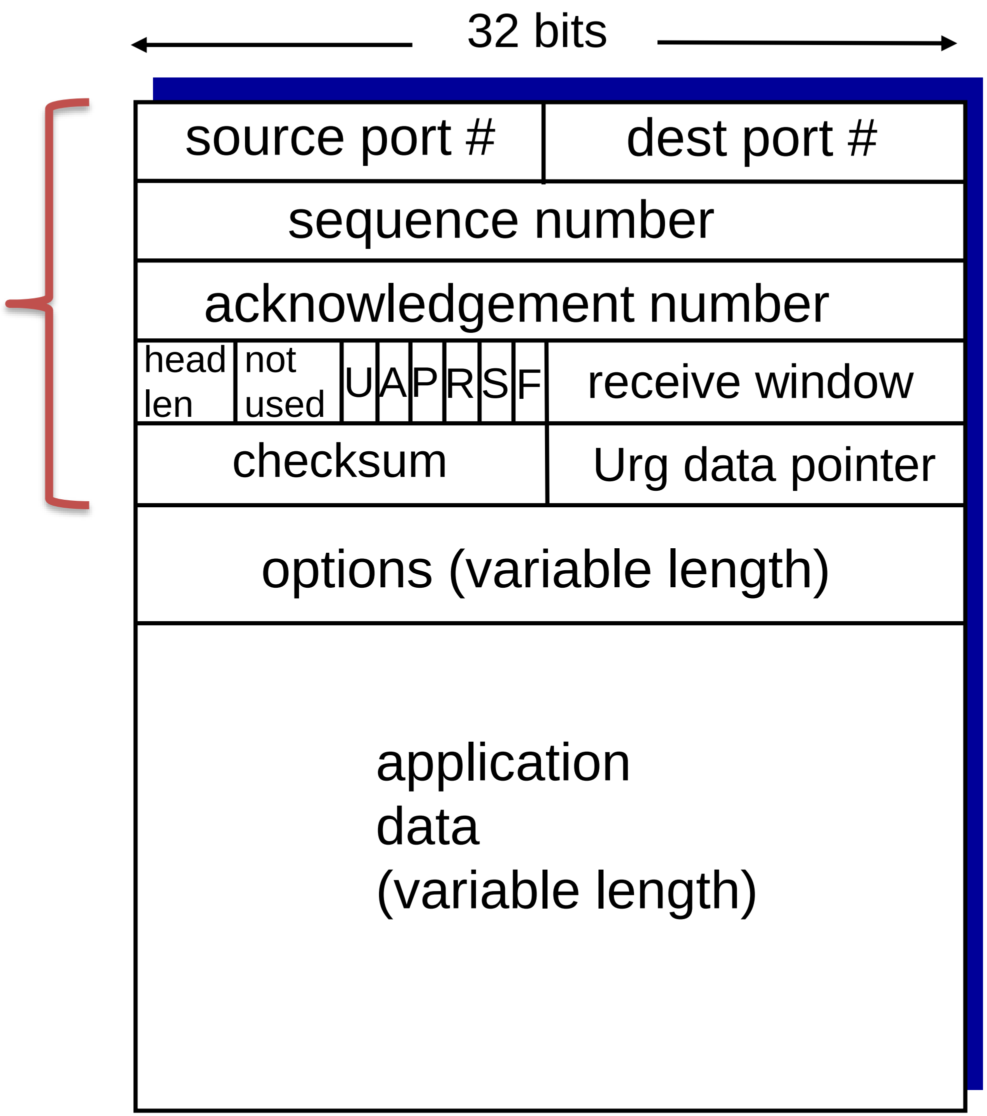
TCP Segments



TCP Segments

20 Bytes

(UDP was 8)



Practical Reliability Questions

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A connection…

1. Requires stored state at two hosts.
2. Requires stored state within the network.
3. Establishes a path between two hosts.

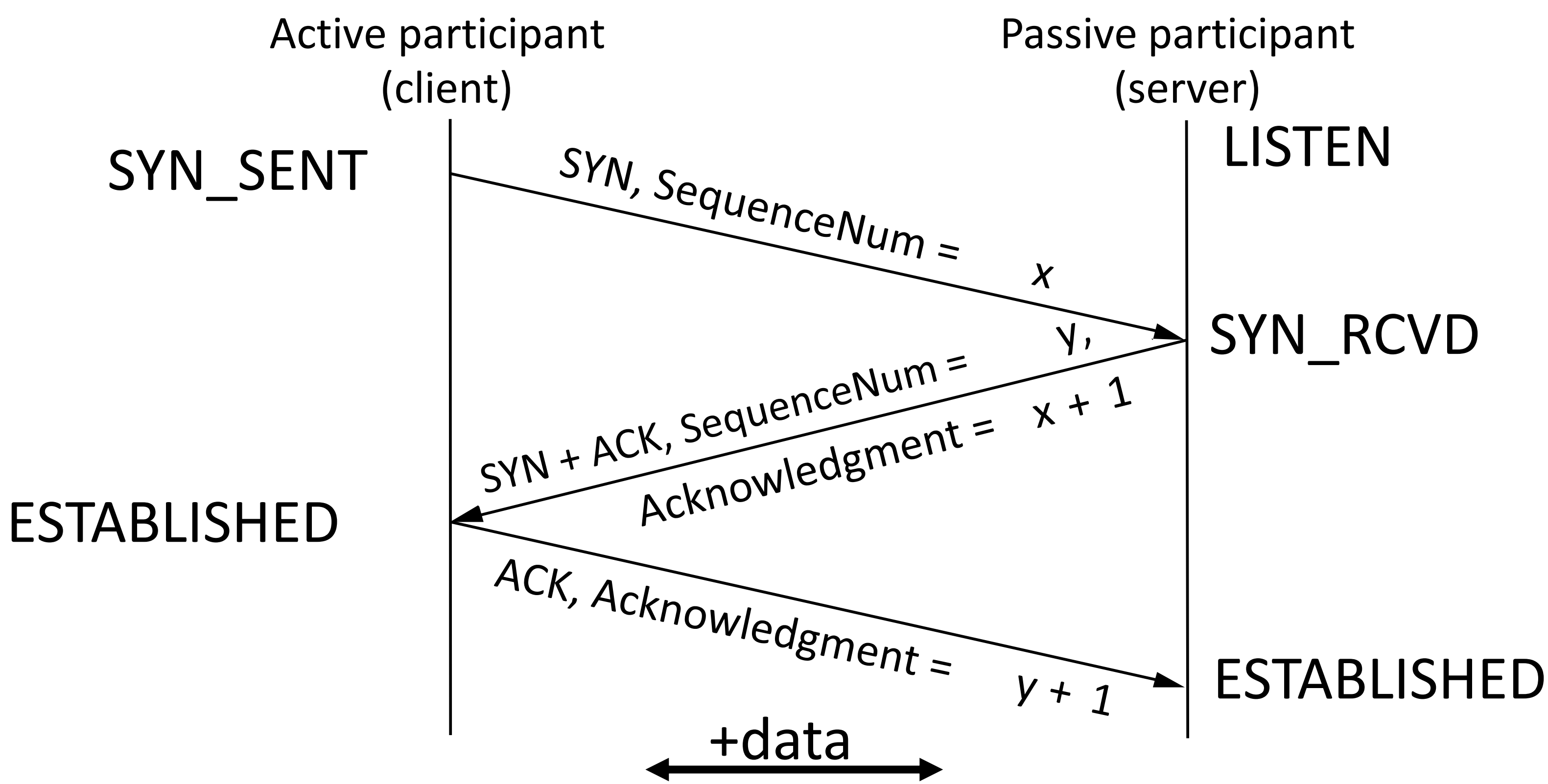
A. 1
B. 1 & 3
C. 1, 2 & 3
D. 2
E. 2 & 3

Connections

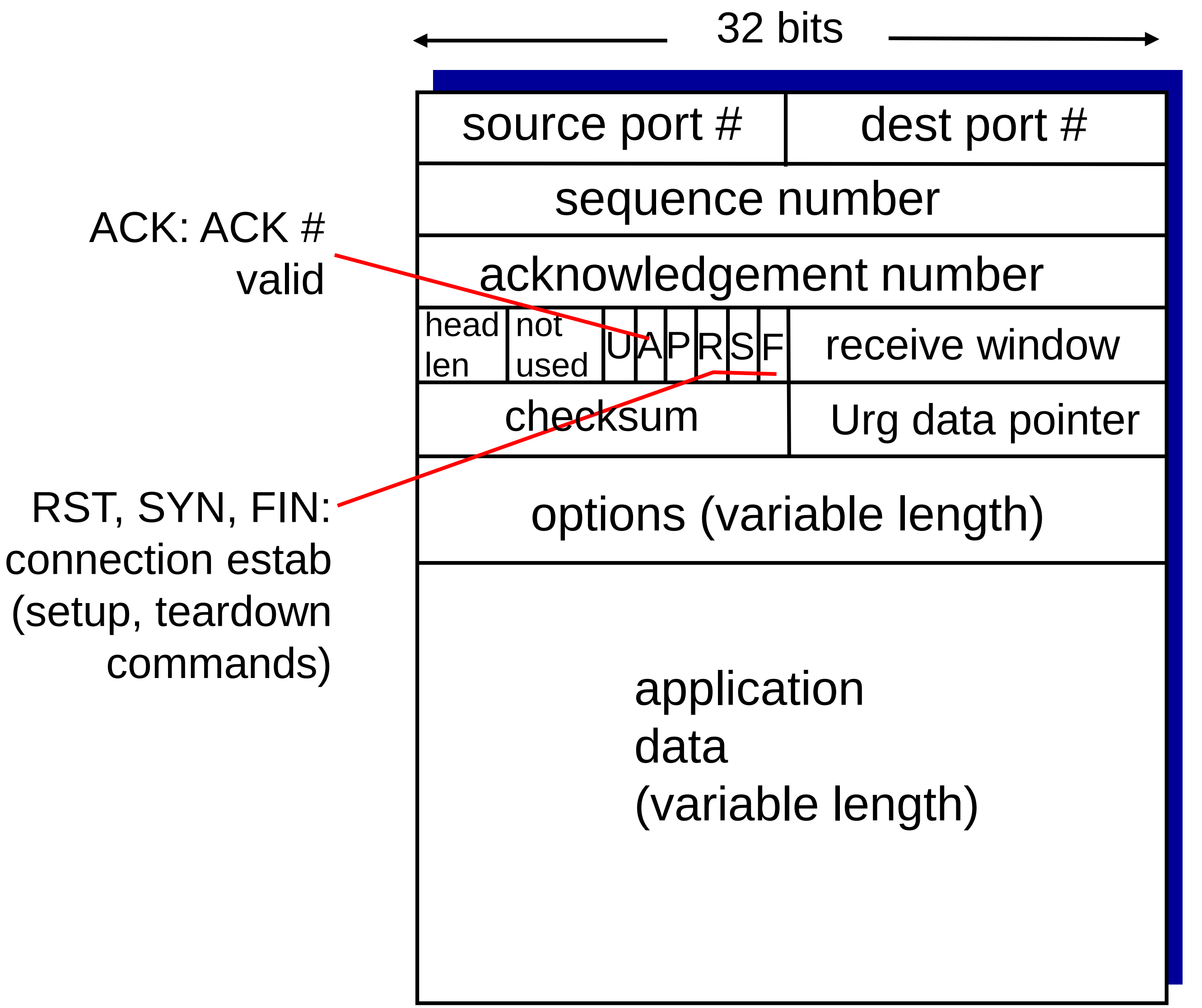
- In TCP, hosts must establish a connection prior to communicating.

- Opportunity to exchange initial protocol state.
  - Which sequence numbers to use.
  - What the maximum segment size should be.
  - Initial window sizes, etc. (several parameters)

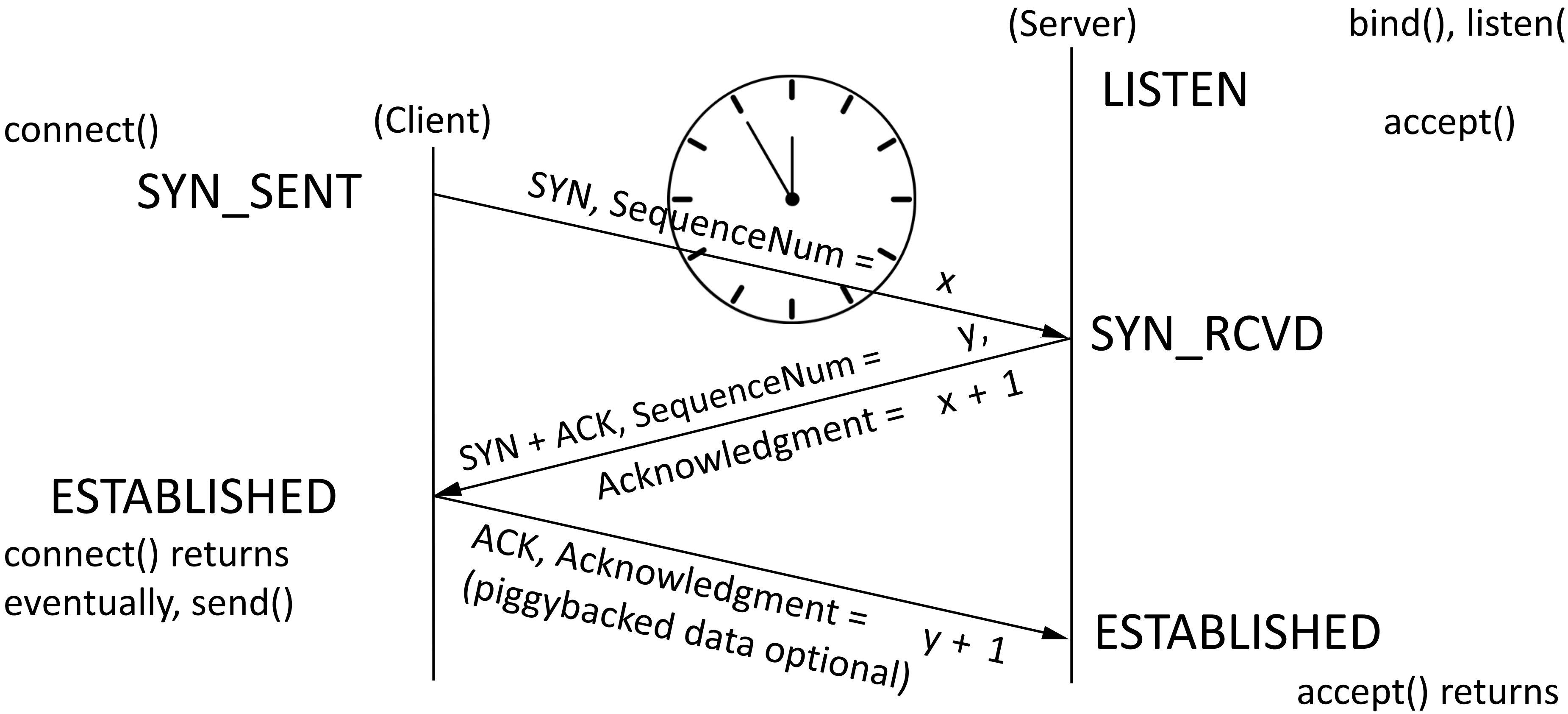
Connection Establishment (three-way handshake)



TCP Segments



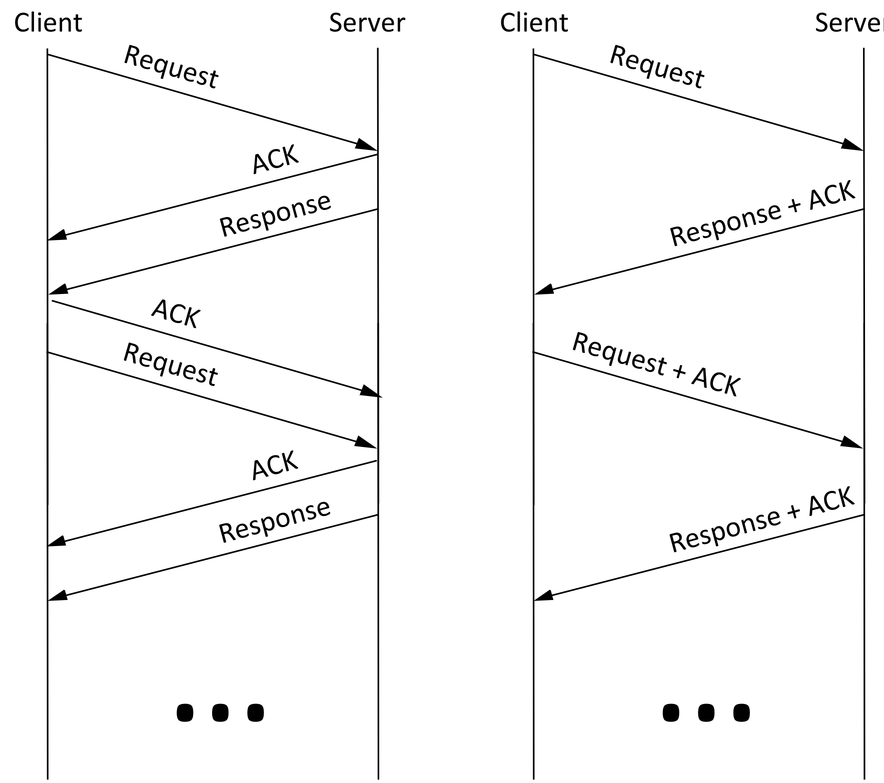
Connection Establishment (three-way handshake)



Both sides agree on connection.

Piggybacking

- So far, we've assumed distinct "sender" and "receiver" roles
- In reality, usually both sides of a connection send some data
  - request/response is a common pattern



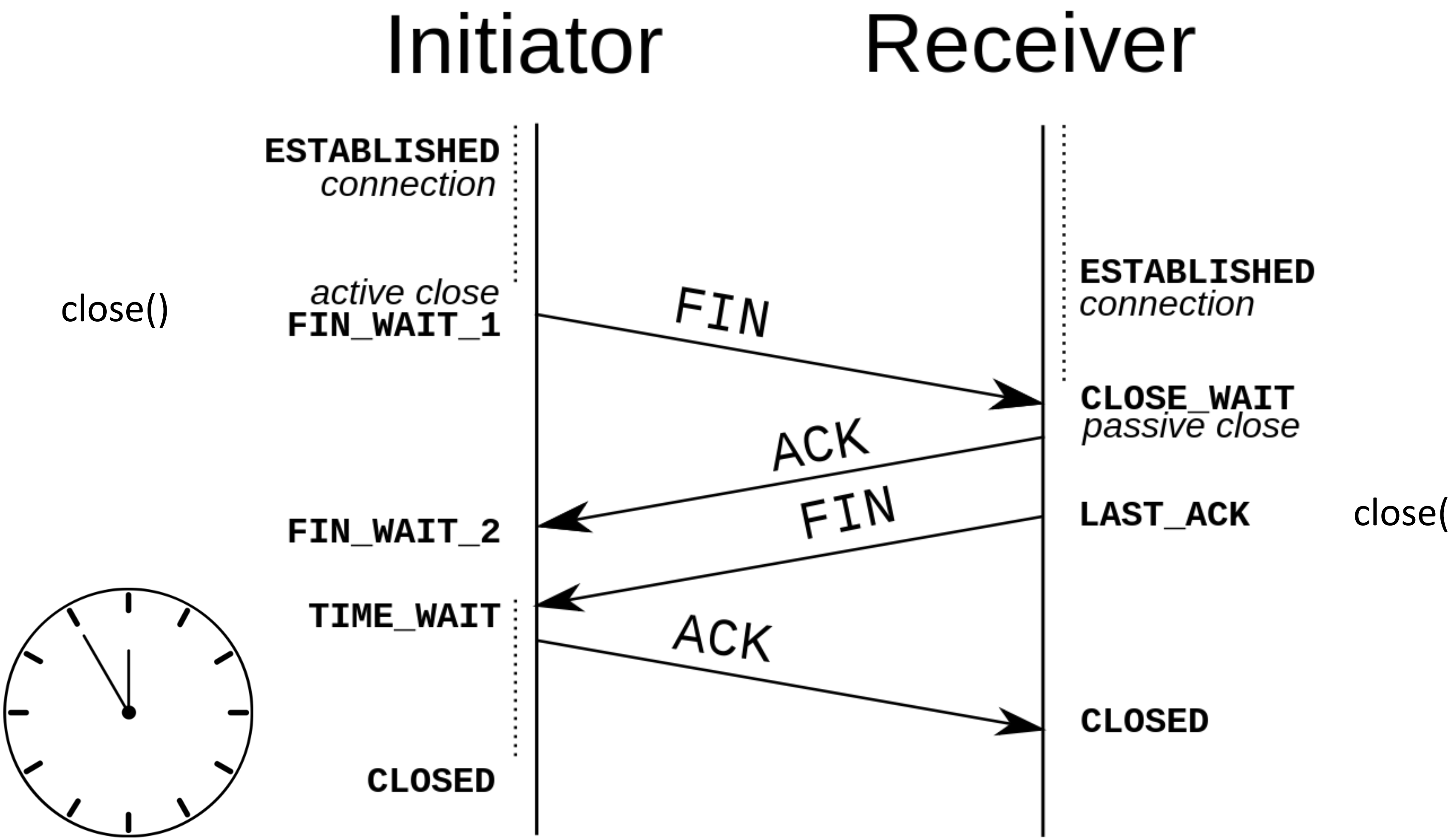
Without Piggybacking

With Piggybacking

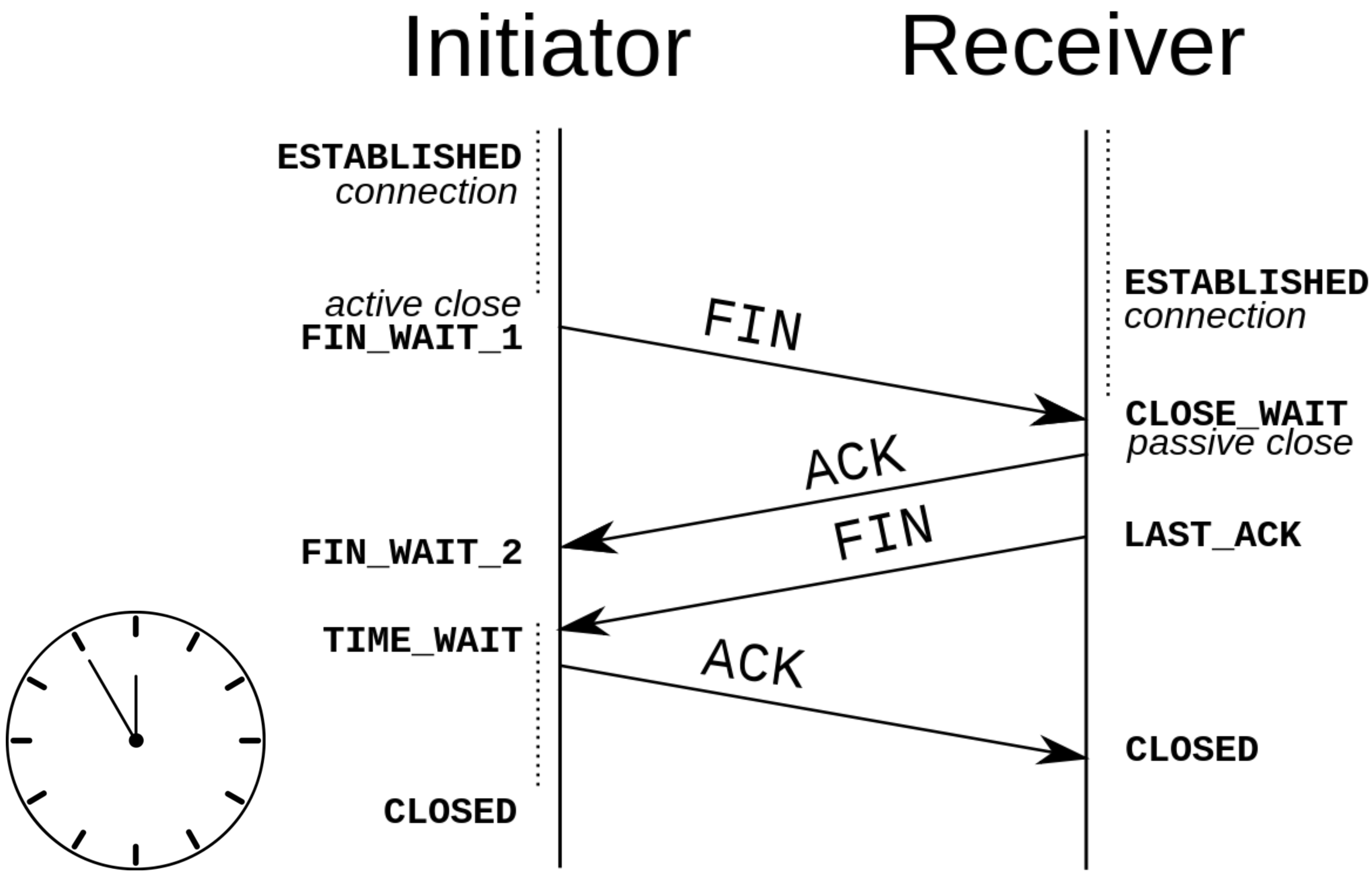
Connection Teardown

- Orderly release by sender and receiver when done
  - Delivers all pending data and “hangs up”
- Cleans up state in sender and receiver
- Each side may terminate independently

TCP Connection Teardown



Why does one side need to wait before transitioning to CLOSED state?



The TIME_WAIT State

- We wait 2*MSL (maximum segment lifetime) before completing the close. The MSL is arbitrary (usually 60 sec)
- ACK might have been lost and so FIN will be resent
  - Could interfere with a subsequent connection
- This is why we used SO_REUSEADDR socket option in lab 2
  - Says to skip this waiting step and immediately abort the connection

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How should we choose the initial sequence number?

What can go wrong with sequence numbers?
-How they're chosen?
-In the course of using them?

A. Start from zero

B. Start from one

C. Start from a random number

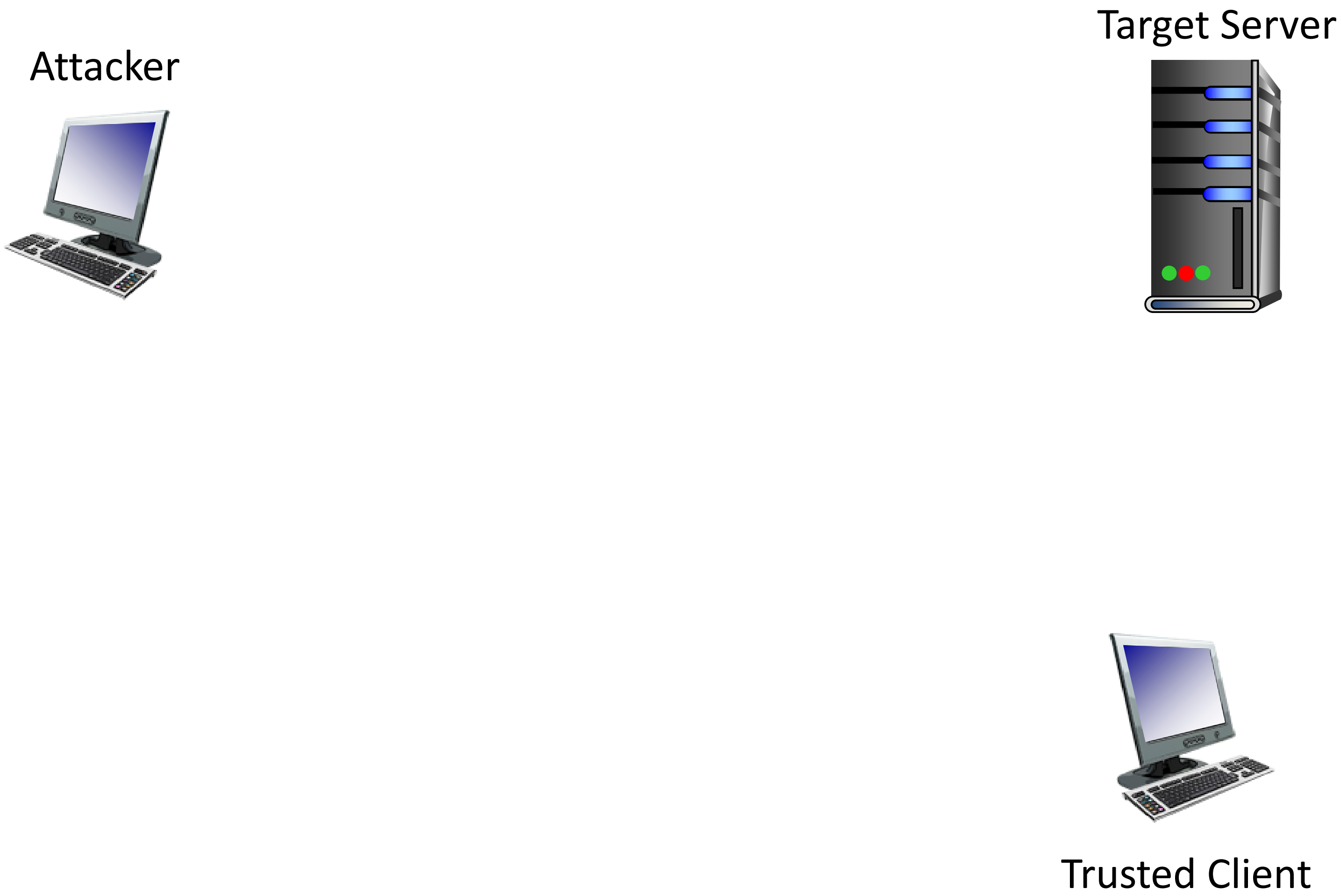
D. Start from some other value (such as…?)

Sequencing

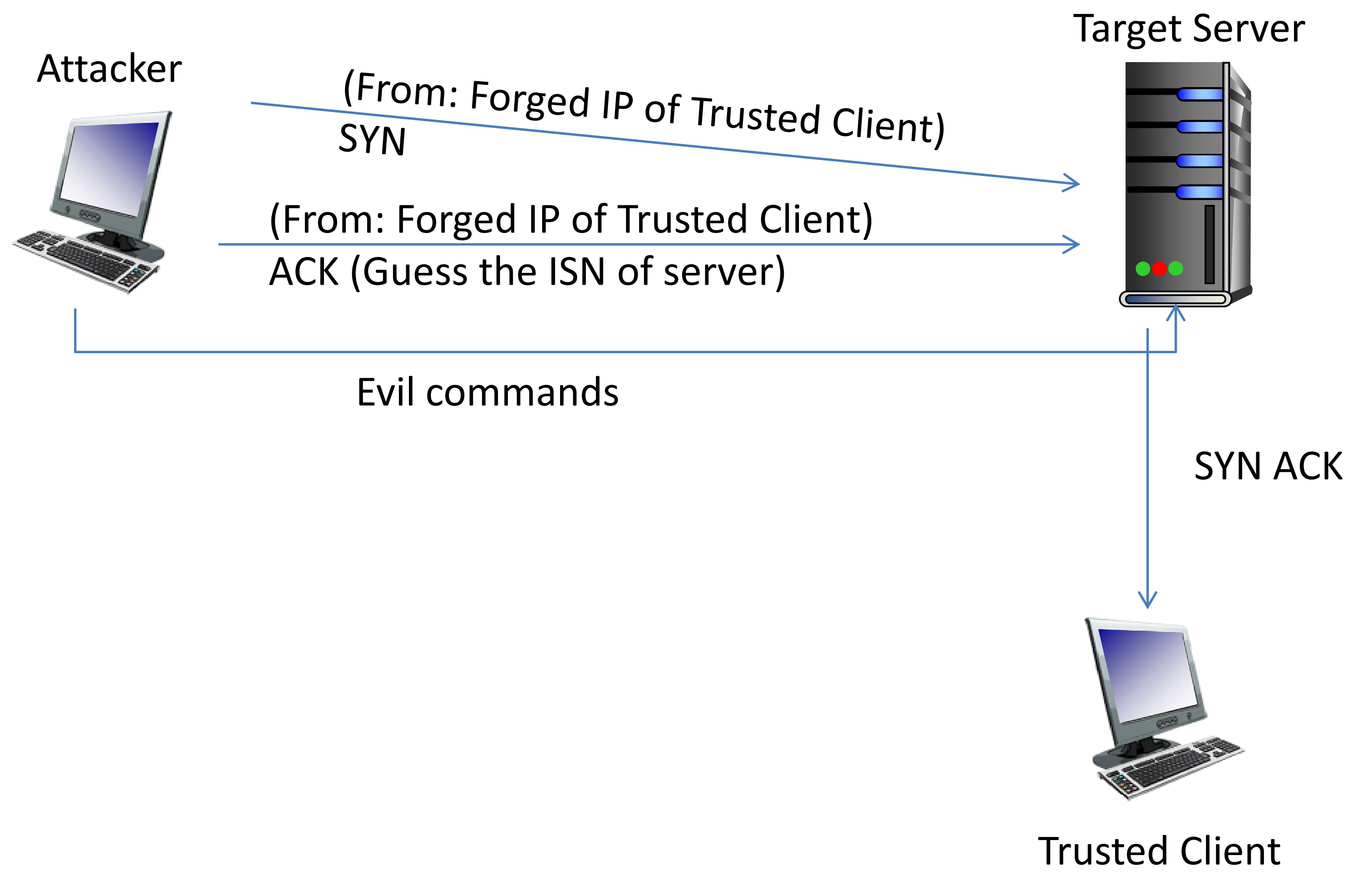
- Initial sequence numbers (ISN) chosen at random
  - Does not start at 0 or 1 (anymore).
  - Helps to prevent against forgery attacks.

- TCP sequences bytes rather than segments
  - Example: if we're sending 1500-byte segments
    - Randomly choose ISN (suppose we picked 1150)
    - First segment (sized 1500) would use number 1150
    - Next would use 2650

Sequence Prediction Attack (1996)



Sequence Prediction Attack (1996)



Practical Reliability Questions

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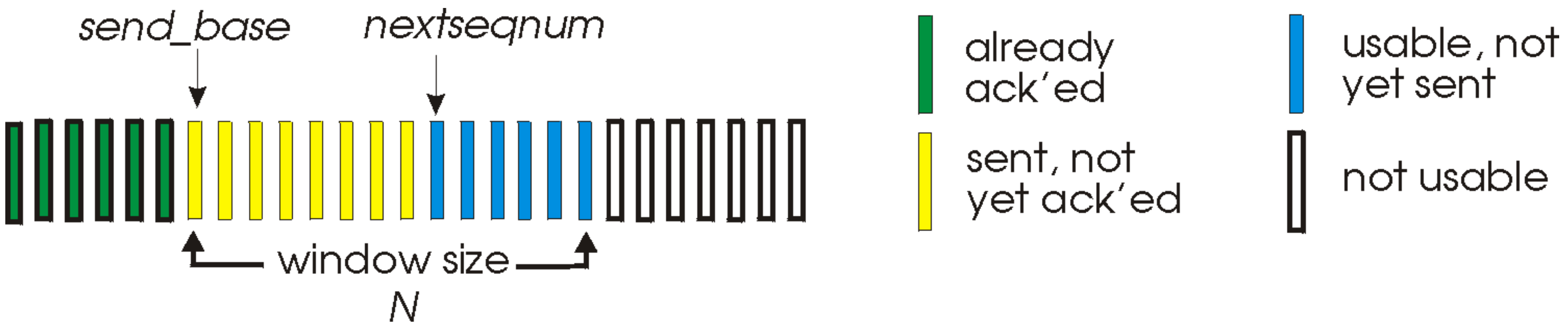
Windowing (Sliding Window)

- At the sender:
  - What's been ACKed
  - What's still outstanding
  - What to send next
- At the receiver:
  - Go-back-N
    - Highest sequence number received so far.
  - (Selective repeat)
    - Which sequence numbers received so far.
    - Buffered data.

Go-back-N

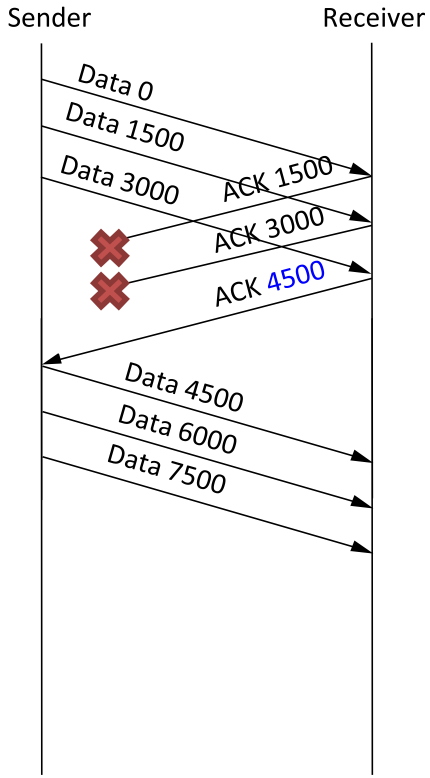
- At the sender:



- At the receiver:
  - Keep track of largest sequence number seen.
  - If it receives ANYTHING, sends back ACK for largest sequence number seen so far. (Cumulative ACK)

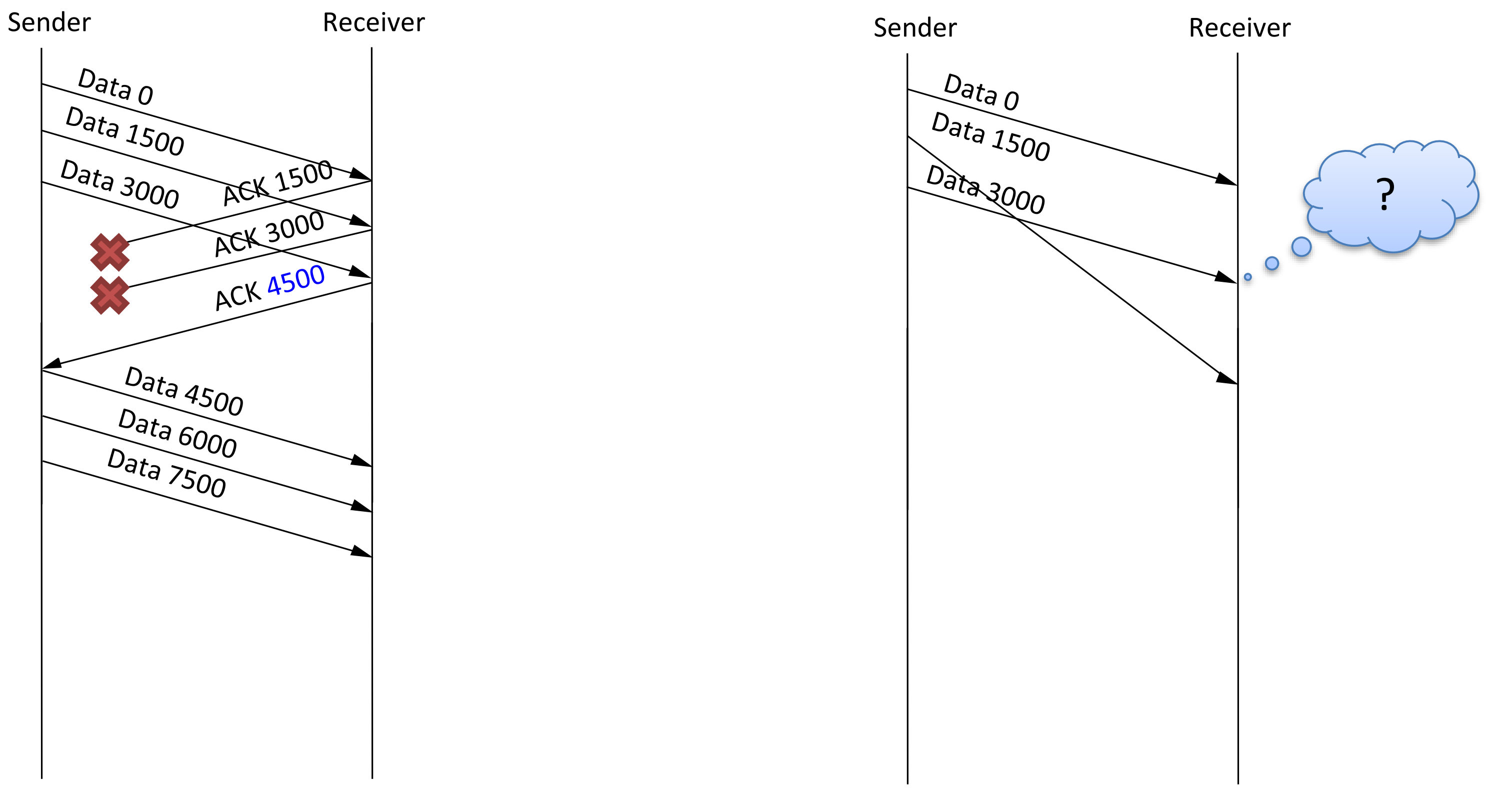
Cumulative Acknowledgements

- An ACK for sequence number N implies that all data prior to N has been received.



Cumulative Acknowledgements

- An ACK for sequence number N implies that all data prior to N has been received.



What should we do with an out-of-order segment at the receiver?

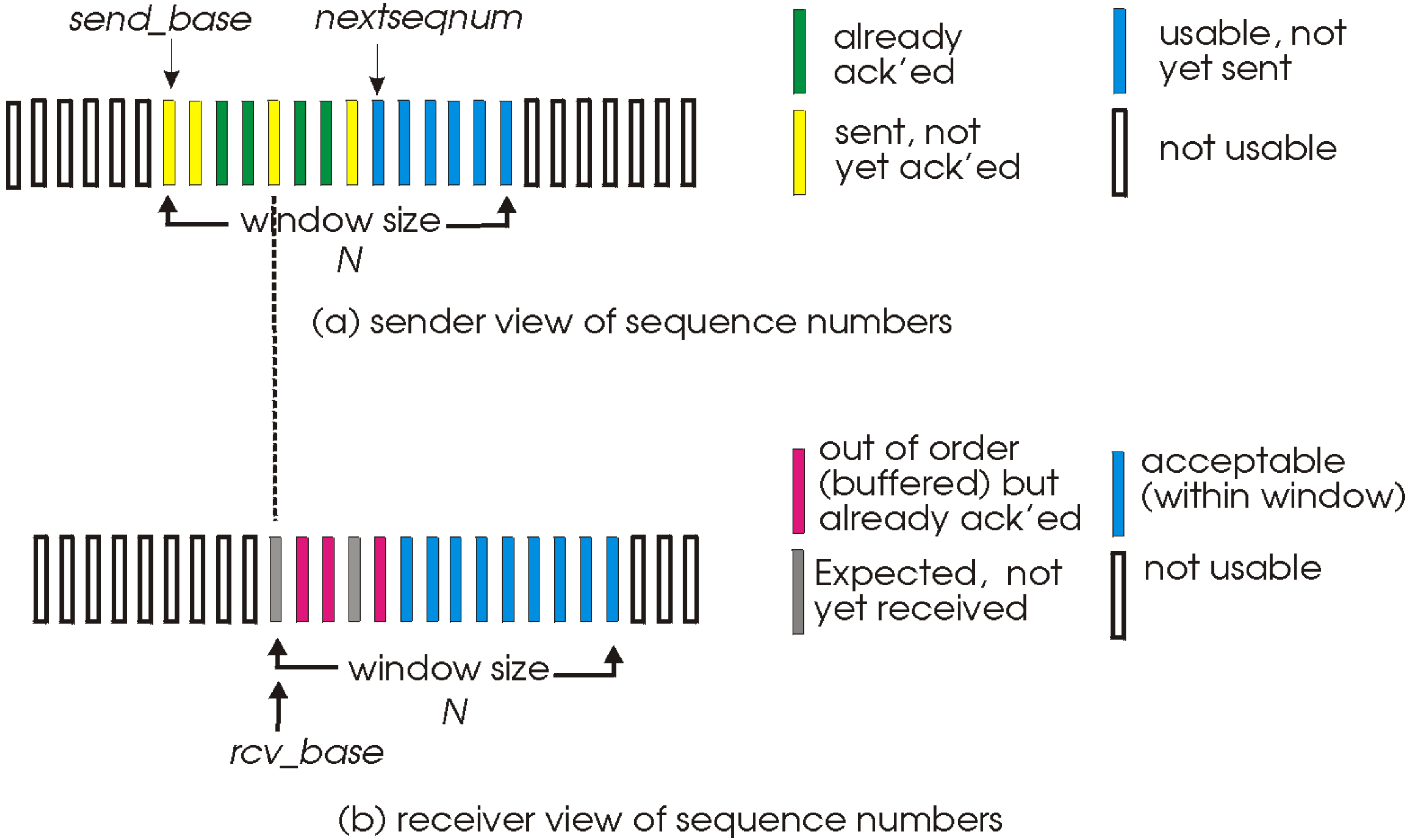
A. Drop it.

B. Save it and ACK it.

C. Save it, don’t ACK it.

D. Something else (explain).

Selective Repeat



If you were building a transport protocol, which would you use?

A. Go-back-N

B. Selective repeat

C. Something else (explain)

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Timeouts

- How long should we wait before timing out and retransmitting a segment?

- Too short: needless retransmissions
- Too long: slow reaction to losses

- Should be (a little bit) longer than the RTT

Estimating RTT

- Problem: RTT changes over time
  - Routers buffer packets in queues
  - Queue lengths vary
  - Receiver may have varying load
- Sender takes measurements
  - Use statistics to decide future timeouts for sends
  - Estimate RTT and variance
- Apply “smoothing” to account for changes

Estimating RTT

- For each segment that did not require a retransmit (ACK heard without a timeout)
  - Consider the time between segment sent and ACK received to be a sample of the current RTT
  - Use that, along with previous history, to update the current RTT estimate

- Exponentially Weighted Moving Average (EWMA)

EWMA

EstimatedRTT = (1 – a) * EstimatedRTT + a * SampleRTT

a is usually 1/8.

In other words, our current estimate is a blend of 7/8 of the previous estimate plus 1/8 of the new sample.

DevRTT = (1 – B) * DevRTT + B * | SampleRTT – EstimatedRTT |

B is usually 1/4

Example

- Suppose EstimateRTT = 64, Dev = 8

Latest sample: 120

New estimate = 7/8 * 64 + 1/8 * 120 = 56 + 15= 71

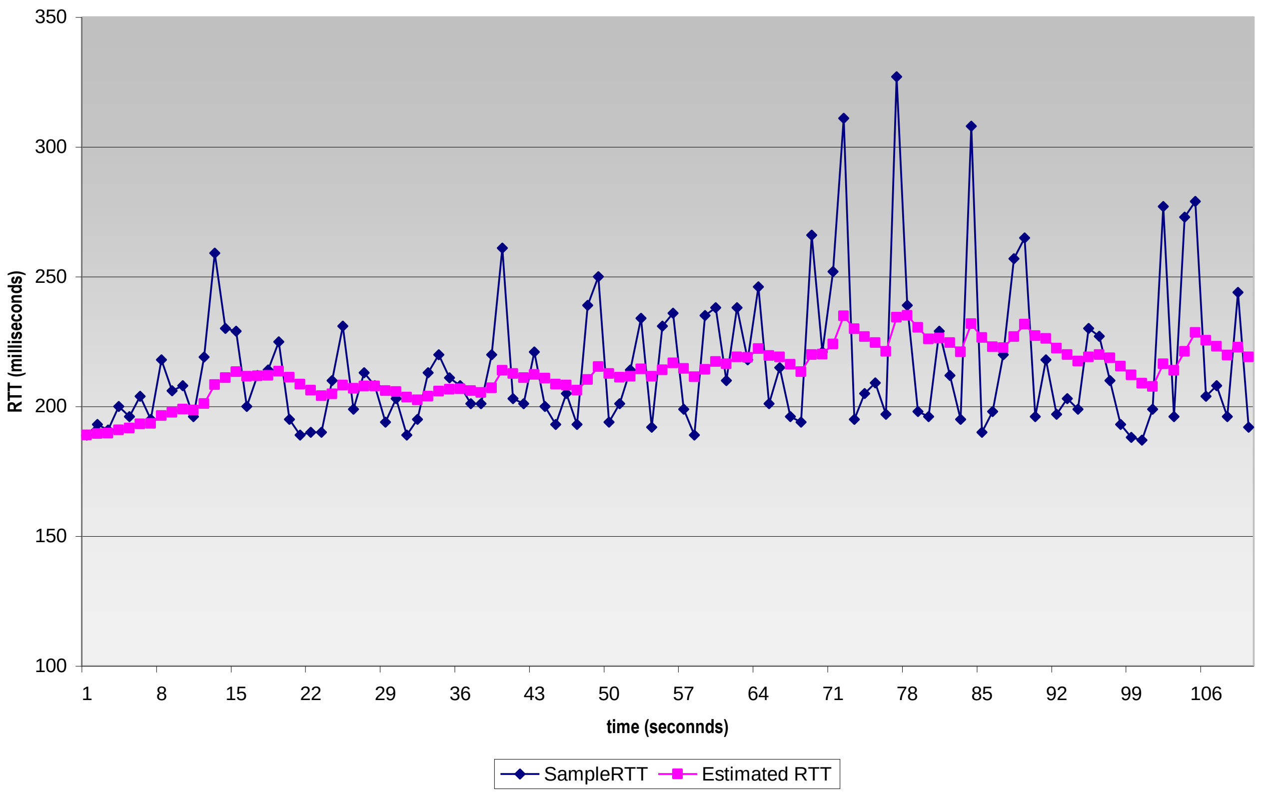
New dev = 3/4 * 8 + 1/4 * | 120 - 71 | = 6 + 12 = 18

- Another sample: 400

New estimate = 7/8 * 71 + 1/8 * 400 = 62 + 50 = 112

New dev = 3/4 * 18 + 1/4 * | 400 - 112 | = 13 + 72 = 85

Book Example (Smoothing)



TCP Timeout Value

```
TimeoutInterval = EstimatedRTT + 4*DevRTT
```

estimated RTT (↑ EstimatedRTT)

"safety margin" (↑ DevRTT)

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Next time…

- How do the sender and receiver keep track of outstanding pipelined segments?
- **How many segments should be pipelined?**
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- What does connection establishment look like?
- How should we choose timeout values?