Computación en Internet I

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Agenda

1. **TCP**
   - Introduction
   - TCP segment structure
   - Reliable Data Transfer
   - TCP Flow control
   - TCP Connection management
   - Socket Programming with TCP
2. **Exercises**

Agenda del día

What is the TCP?

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- The Internet's transport-layer, connection-oriented, reliable transport protocol.

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What are its main characteristics?

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- The Internet's transport-layer, connection-oriented, reliable transport protocol.

What are its main characteristics?

- Point-to-Point.
  - One sender, one receiver.
- Reliable, in-order byte stream.
  - No message boundaries
- Full duplex data.
  - Bi-directional data flow in same connection.
  - MSS: maximum segment size.

What are its main characteristics?

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- Cumulative ACKs.
- Pipelining.
  - Sending multiple data units without waiting for an acknowledgment for the first frame sent.
  - TCP congestion and flow control set window size.
- Connection-oriented.
  - Handshaking (exchange of control messages) initializes sender, receiver state before data exchange.
- Flow controlled.
  - Sender will not overwhelm receiver

How does a TCP connection is established?

How does a TCP connection is established?

- A process running in one host wants to initiate a connection with another process in another host.
  - Client process - Server process.
- The client application process first informs the client transport layer that it wants to establish a connection to a process in the server.
- The client application process first informs the client transport layer that it wants to establish a connection
- A three-way handshake is performed.
  - The client first sends a special TCP segment.
  - The server responds with a second special TCP segment.
  - Finally the client responds again with a third special segment.
  - The first two segments carry no payload, that is, no application-layer data.
  - The third of these segments may carry a payload.

Then, how do two application processes exchange data?

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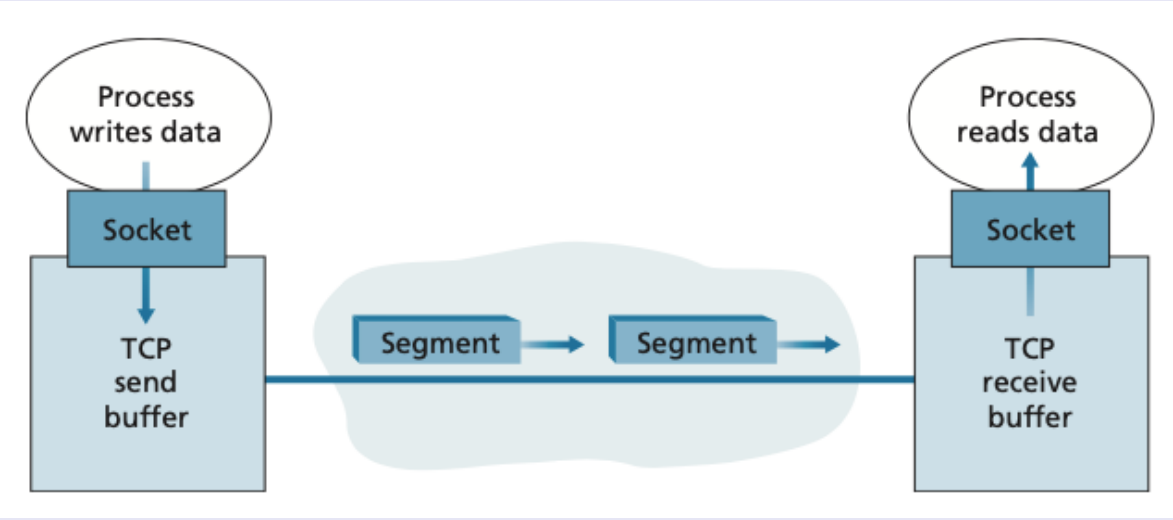

- TCP directs this data to the connection's send buffer.
- TCP will grab chunks of data from the send buffer and pass the data to the network layer.
  - Data is limited by the maximum segment size (MSS).
- TCP pairs each chunk of client data with a TCP header forming TCP segments.
- The segments are passed down to the network layer.
- There they are separately encapsulated within network-layer IP datagrams.
- The IP datagrams are then sent into the network.

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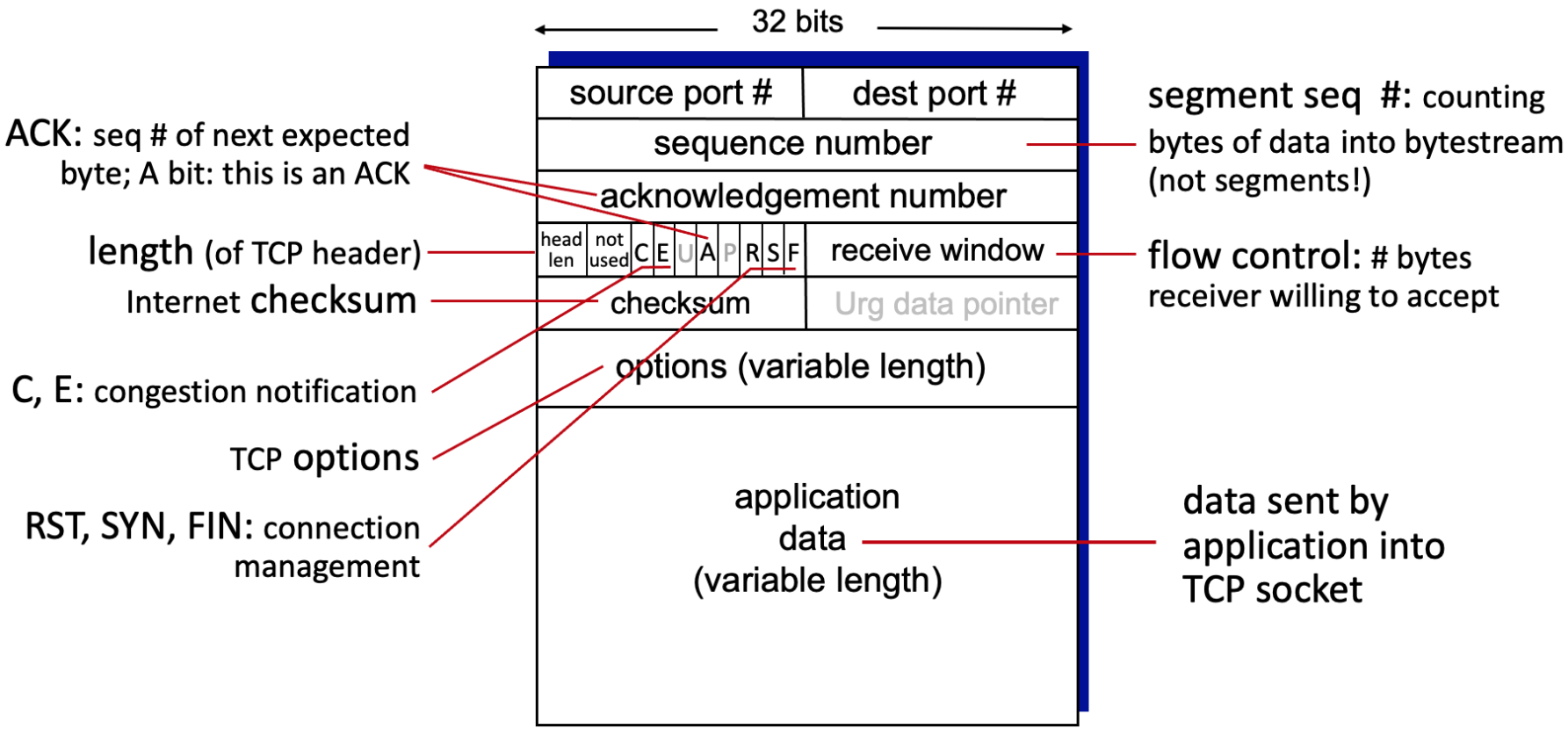

TCP segment structure

What is the purpose of TCP sequence numbers and ACKs?

TCP segment structure

What is the purpose of TCP sequence numbers and ACKs?

- They are a critical part of TCP's reliable data transfer service.
- Sequence numbers
  - Byte stream number of first byte in segment's data.
  - The host implicitly numbers each byte in the data stream.
  - Each sequence number is inserted in the sequence number field.
- Acknowledgements
  - Sequence number of next byte expected from other side.
  - Cumulative ACK.

TCP segment structure

How the are outgoing segments?

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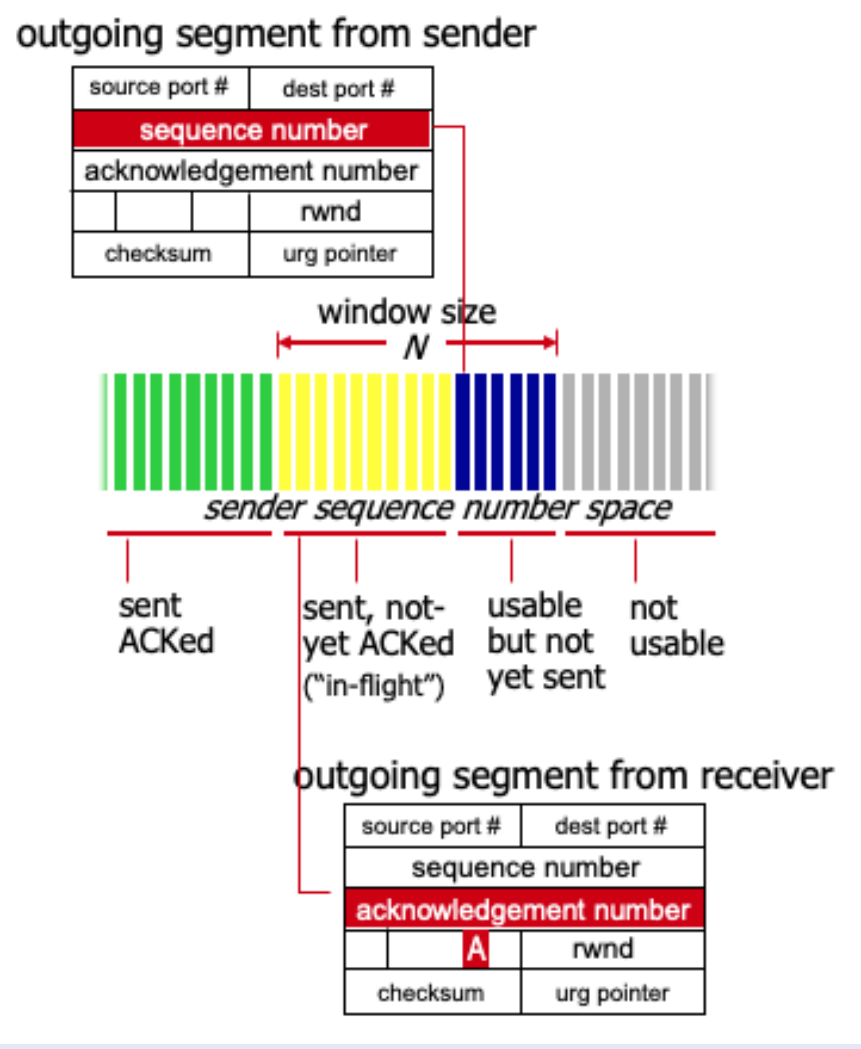

How about a Telnet example?

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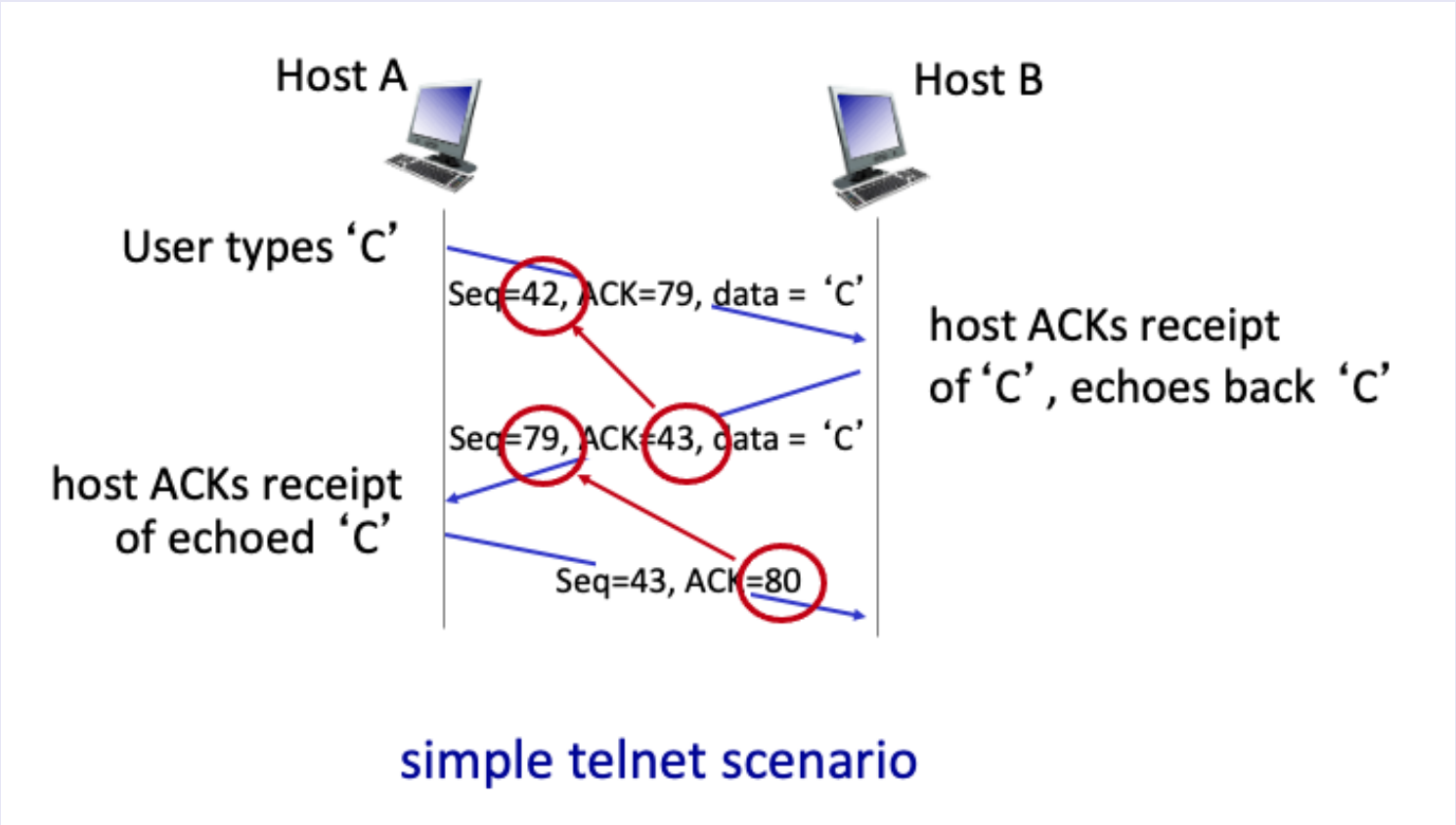

simple telnet scenario

TCP segment structure

How does TCP recover from lost segments?

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How to set a TCP timeout value?

- Longer than RTT (time from when a segment is sent until it is acknowledged).
- Too short: premature timeout, unnecessary retransmissions.
- Too long: slow reaction to segment loss.

TCP segment structure

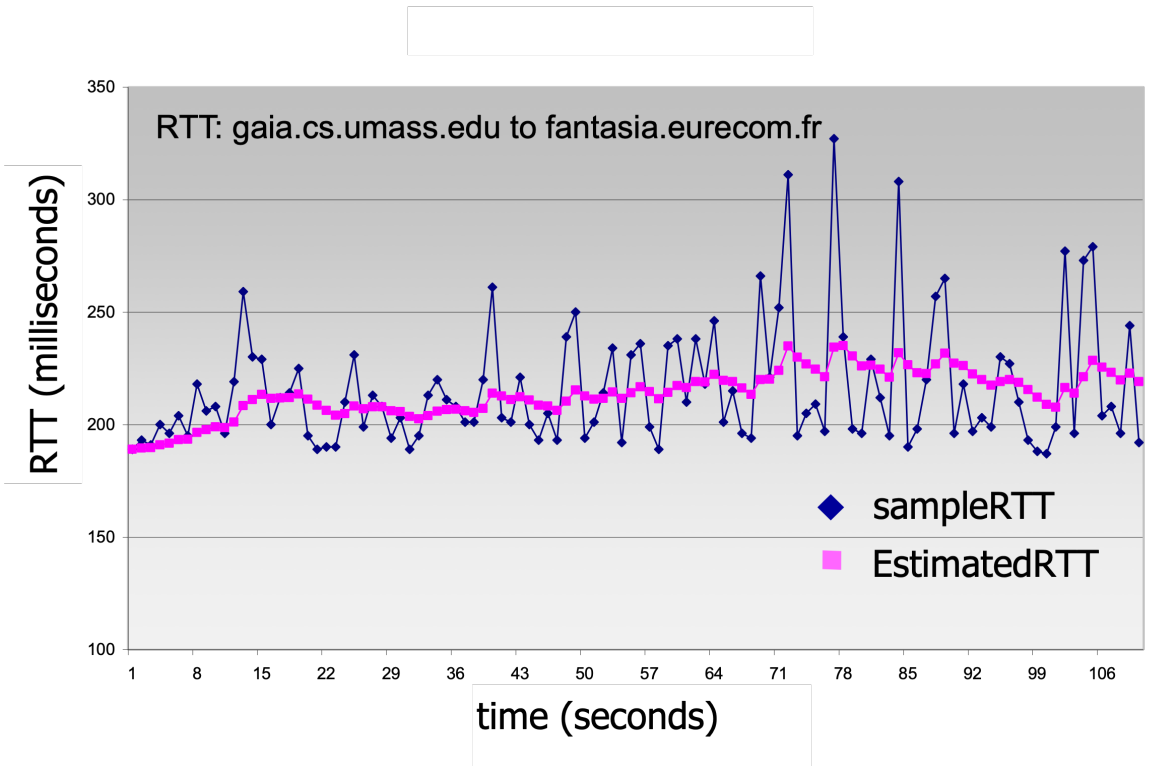
How to estimate RTT?

How to estimate RTT?

- SampleRTT: measured time from segment transmission until ACK receipt.
  - Ignore retrasmissions.
  - Only one SampleRTT measurement at a time.
- SampleRTT will vary.
  - Want estimated RTT smoother.
  - Average several recent measurements, not just current SampleRTT.

How to estimate RTT?

- EstimatedRTT = (1- α)*EstimatedRTT + α*SampleRTT.
- exponential weighted moving average (EWMA).
- Influence of past sample decreases exponentially fast
- Typical value: $\alpha = 1/8 = 0.125$.



How to find the correct timeout interval?

- Timeout interval: EstimatedRTT plus **safety margin.**
  - Large variation in EstimatedRTT: want a larger safety margin.
- TimeoutInterval = EstimatedRTT + 4*DevRTT.
- DevRTT: EWMA of SampleRTT deviation from EstimatedRTT.
  - DevRTT = (1-β)*DevRTT + β*|SampleRTT-EstimatedRTT|.
  - Typically, β = 0.25.

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How does a TCP sender recover from lost segments?

How does a TCP sender recover from lost segments?

- Event: data received from application
  - Create segment with sequence number.
  - Sequence number is a byte-stream number of first data byte in segment.
  - Start timer if not already running.
    - Think of timer as for oldest unACKed segment.
    - Expiration interval: TimeOutInterval.
- Event: timeout.
  - Retransmit segment that caused timeout.
  - Restart timer.
- Event: ACK received.
  - If ACK acknowledges previously unACKed segments.
    - Update what is known to be ACKed.
    - Start timer if there are still unACKed segments.

How is the TCP ACK generation?

How is the TCP ACK generation?

Event	TCP Receiver action
in-order segment arrival, no gaps, everything else already ACKed	delayed ACK. Wait up to 500ms for next segment. If no next segment, send ACK
in-order segment arrival, no gaps, one delayed ACK pending	immediately send single cumulative ACK
out-of-order segment arrival higher-than-expect seq. # gap detected	send duplicate ACK, indicating seq. # of next expected byte
arrival of segment that partially or completely fills gap	immediate ACK if segment starts at lower end of gap

Retransmission due to a lost acknowledgment

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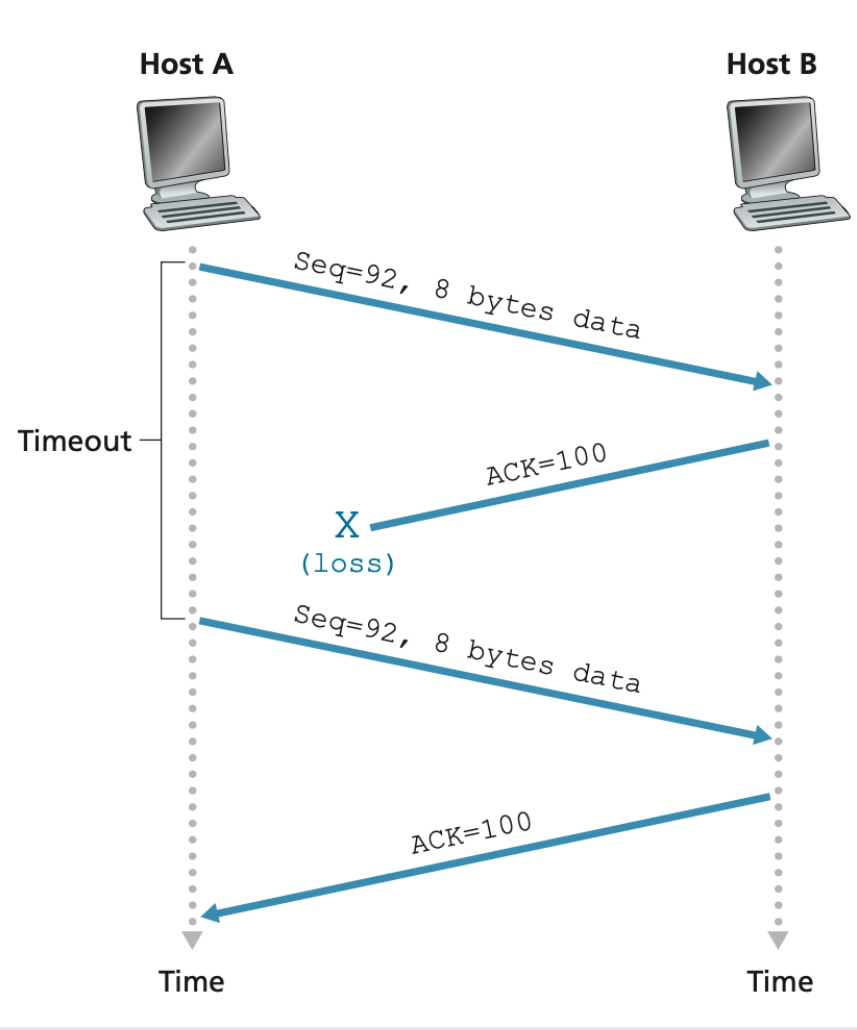

Segment 100 not retransmitted

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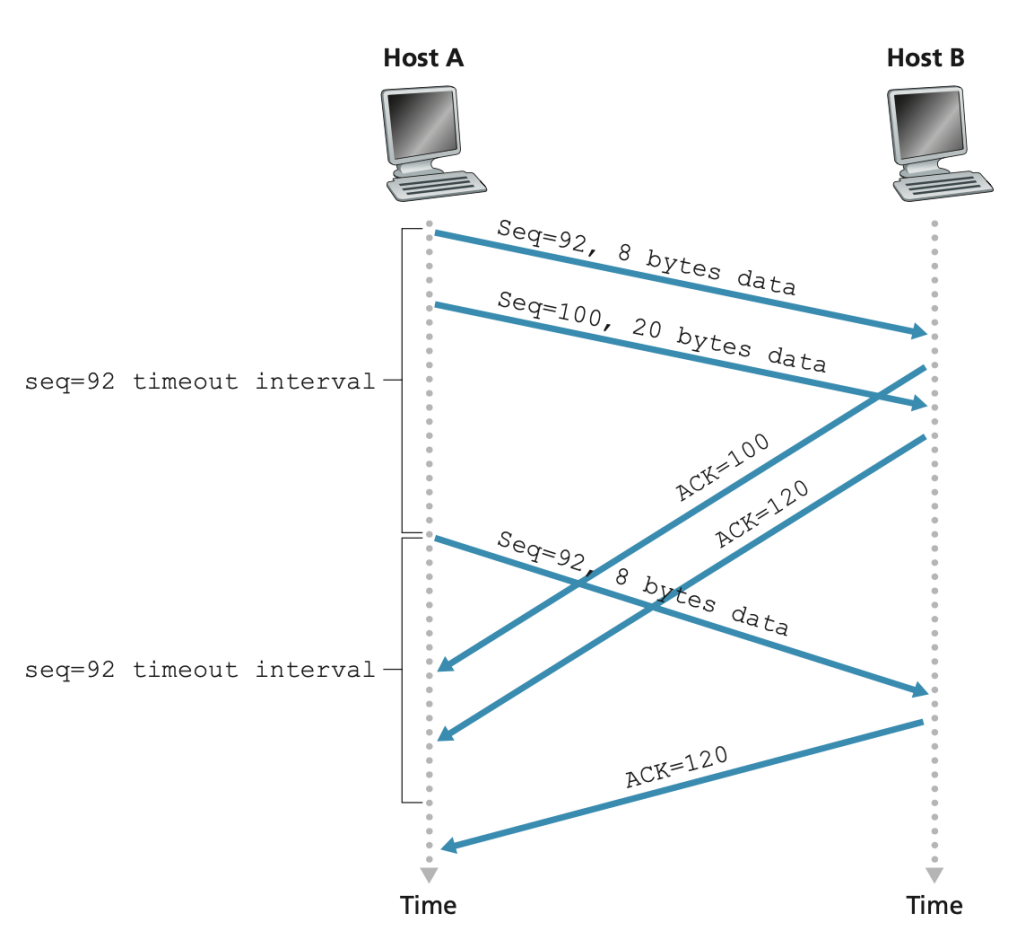

A cumulative acknowledgment avoids retransmission of the first segment

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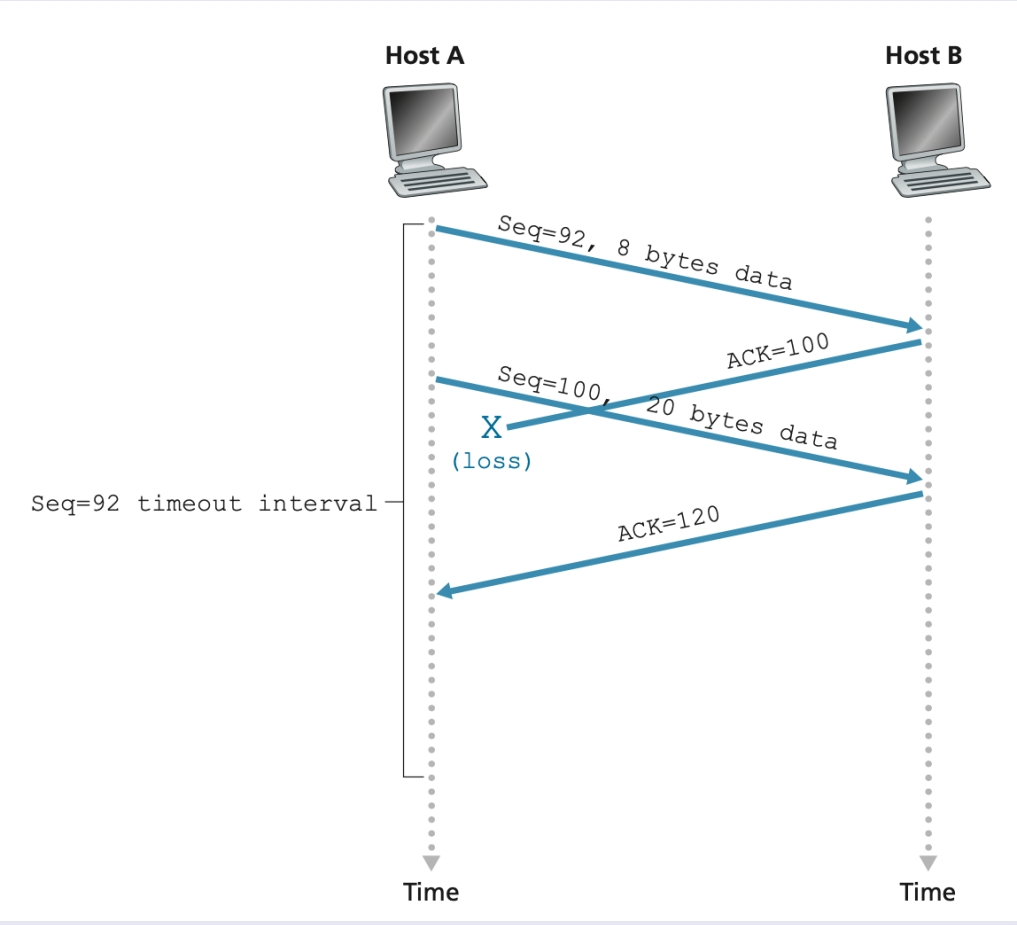

What are the problems of the timeout/retransmit mechanism?

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- In timeout-triggered retransmissions the timeout period can be relatively long.
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What can be done about it?

- Fast retransmit.
  - The sender can often detect packet loss well before the timeout event occurs by noting so-called duplicate ACKs.
  - A duplicate ACK is an ACK that reacknowledges a segment for which the sender has already received an earlier acknowledgment.

An example of fast retransmit

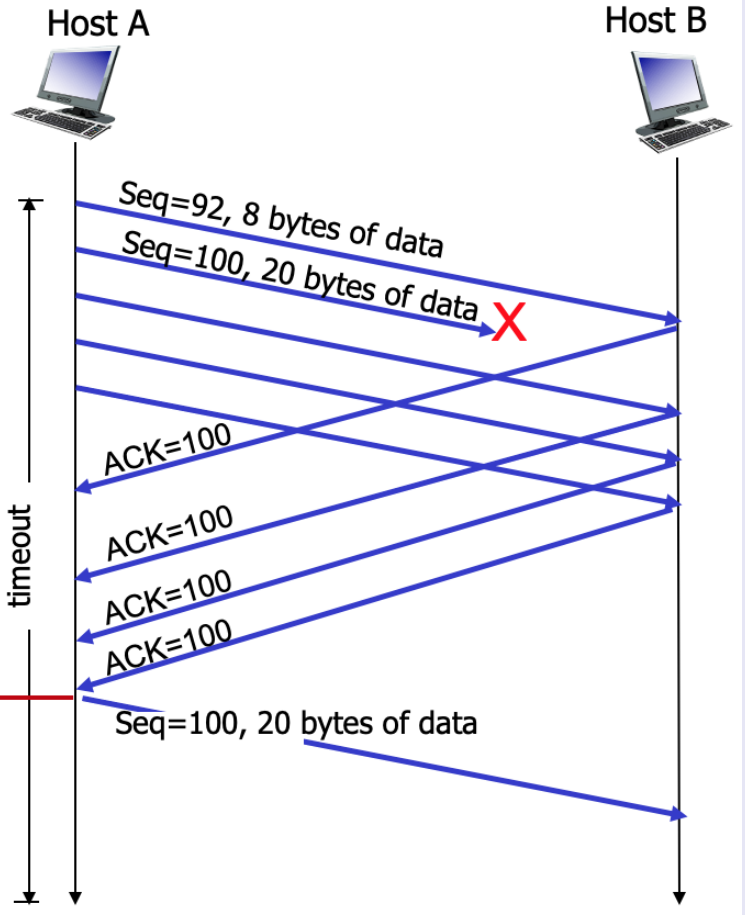
An example of fast retransmit

TCP fast retransmit

if sender receives 3 additional ACKs for same data ("triple duplicate ACKs"), resend unACKed segment with smallest seq #

- likely that unACKed segment lost, so don't wait for timeout

Receipt of three duplicate ACKs indicates 3 segments received after a missing segment – lost segment is likely. So retransmit!



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TCP Flow control

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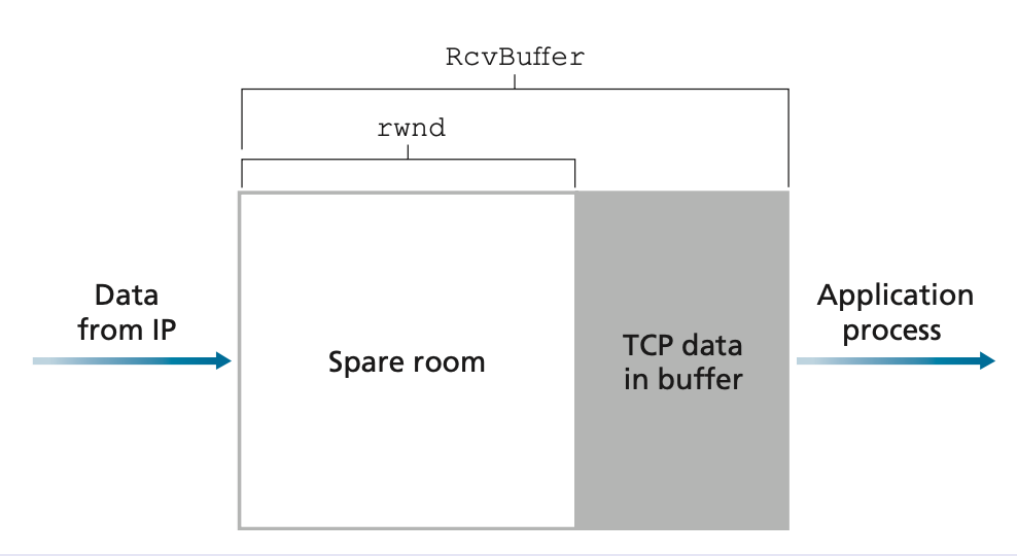

- The receive side of TCP connection has a receive buffer.
- App process may be slow at reading from buffer.
- Receiver controls sender, so sender won't overflow receiver's buffer by transmitting too much, too fast.
- TCP receiver advertises free buffer space in rwnd field in TCP header.
  - The receiver informs the sender how much free buffer space there is
  - The sender is limited to send no more than this amount of data.
  - This goes from receiver to the sender in the receiver window in the TCP header.
  - The value will change as the amount of free buffer space fluctuates over time.

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TCP Connection management

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How does TCP establish a connection?

- TCP sender, receiver establish connection before exchanging data segments.
  - Initialize TCP variables.
    - Sequence numbers.
    - Buffers, flow control info (e.g. RcvWindow).
  - Client: connection initiator.
    - Socket clientSocket = new Socket(hostname,portnumber);
  - Server: contacted by client.
    - Socket connectionSocket = welcomeSocket.accept();

TCP Connection management

How does the three way handshake work?

How does the three way handshake work?

Three way handshake:

Step 1: client host sends TCP SYN segment to server

- specifies initial seq #
- no data

Step 2: server host receives SYN, replies with SYNACK segment

- server allocates buffers
- specifies server initial seq. #

Step 3: client receives SYNACK, replies with ACK segment, which may contain data

How does TCP close a connection?

How does TCP close a connection?

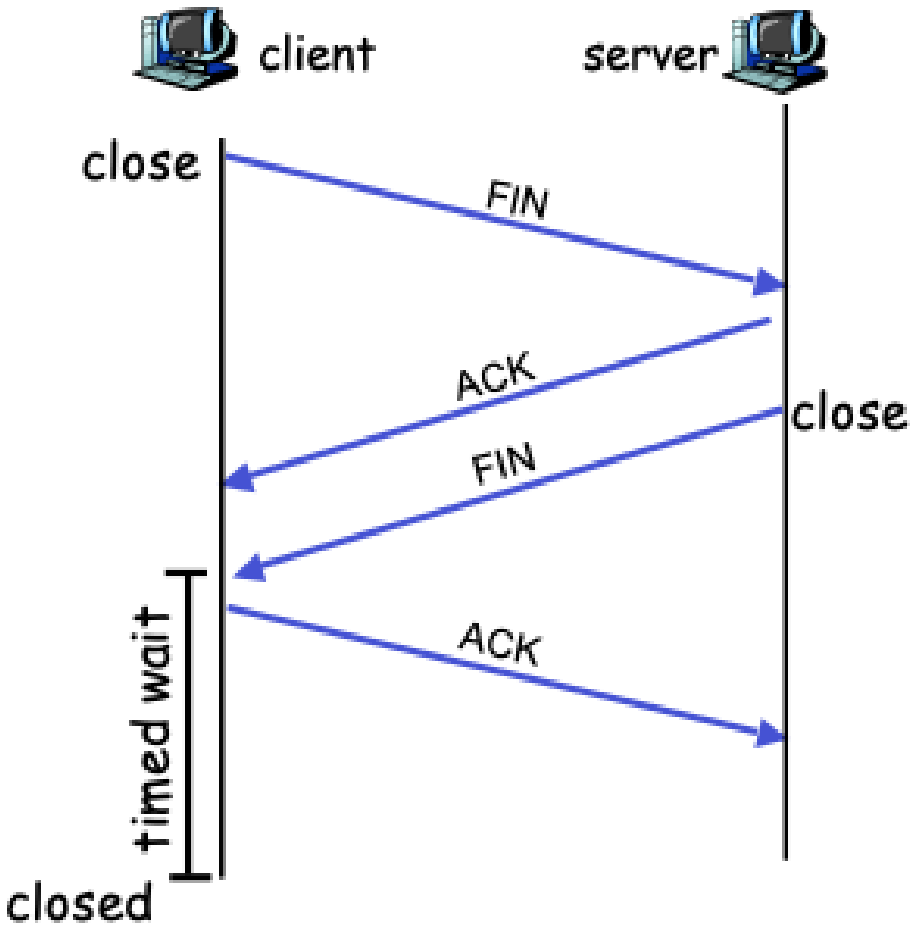
Closing a connection:

client closes socket:

```
clientSocket.close();
```

Step 1: client end system sends TCP FIN control segment to server

Step 2: server receives FIN, replies with ACK. Closes connection, sends FIN.



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How would the code for the client side of the application be?

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```java
import java.io.*;
import java.net.*;

class TCPClient {
  public static void main(String argv[]) throws Exception {
    String sentence;
    String modifiedSentence;
    BufferedReader inFromUser = new BufferedReader(new InputStreamReader(System.in));
    Socket clientSocket = new Socket("127.0.0.1", 6789);
    DataOutputStream outToServer = new DataOutputStream(clientSocket.getOutputStream());
    BufferedReader inFromServer = new BufferedReader(new InputStreamReader(clientSocket.getInputStream()));
    sentence = inFromUser.readLine();
    outToServer.writeBytes(sentence + '\n');
    modifiedSentence = inFromServer.readLine();
    System.out.println("FROM SERVER: " + modifiedSentence);
    clientSocket.close();
  }
}
```

How would the code for the server side of the application be?

How would the code for the server side of the application be?

```java
import java.io.*;
import java.net.*;

class TCPServer {
  public static void main(String argv[]) throws Exception {
    String clientSentence;
    String capitalizedSentence;
    ServerSocket welcomeSocket = new ServerSocket(6789);
    while(true) {
      Socket connectionSocket = welcomeSocket.accept();
      BufferedReader inFromClient = new BufferedReader(new InputStreamReader(connectionSocket.getInputStream()));
      DataOutputStream outToClient = new DataOutputStream(connectionSocket.getOutputStream());
      clientSentence = inFromClient.readLine();
      capitalizedSentence = clientSentence.toUpperCase() + '\n';
      outToClient.writeBytes(capitalizedSentence);
    }
  }
}
```

Exercises

1. Write a TCP client/server system in which the client program sends an integer number and the server program returns its square.
2. Write a Simple Calculator via TCP.