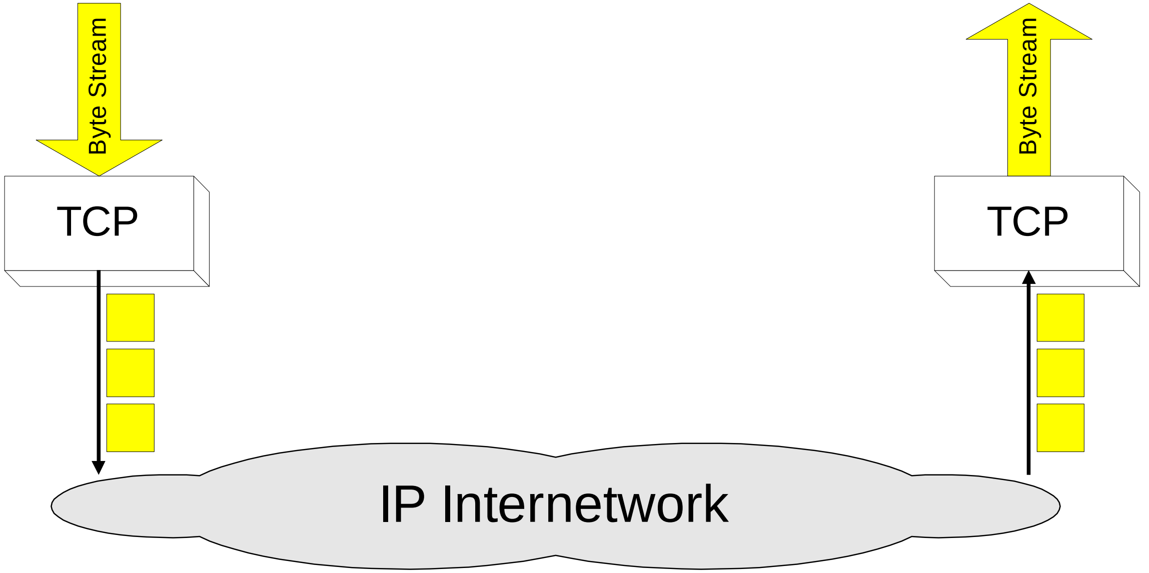
TCP - Part I

Relates to Lab 5. First module on TCP which covers packet format, data transfer, and connection management.

Overview

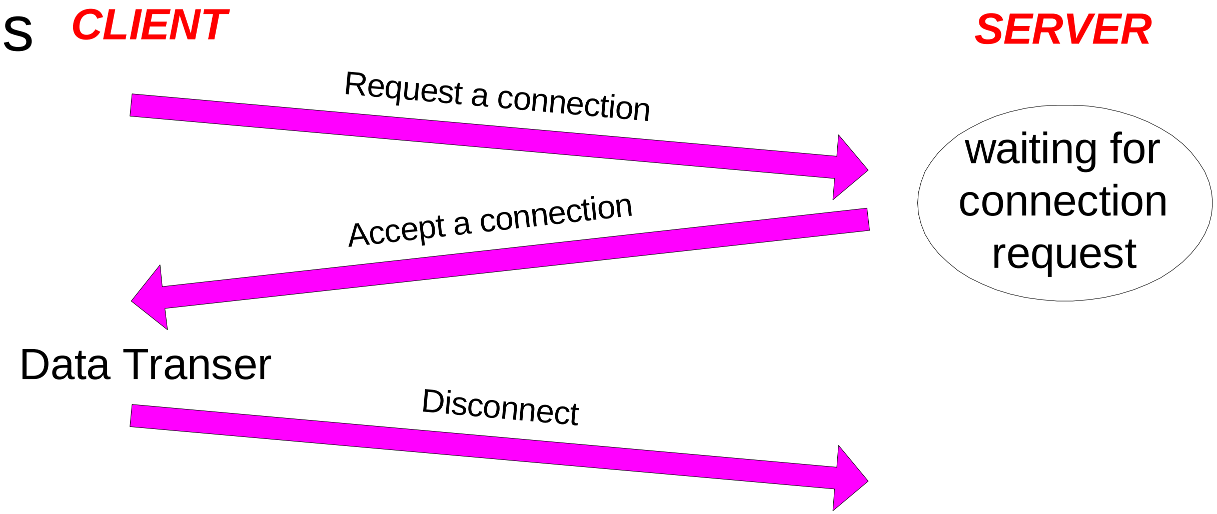
TCP = Transmission Control Protocol

- Connection-oriented protocol
- Provides a reliable unicast end-to-end byte stream over an unreliable internetwork.



Connection-Oriented

- Before any data transfer, TCP establishes a **connection**:
  - One TCP entity is waiting for a connection ("**server**")
  - The other TCP entity ("**client**") contacts the server
- The actual procedure for setting up connections is more complex.
- Each connection is full duplex

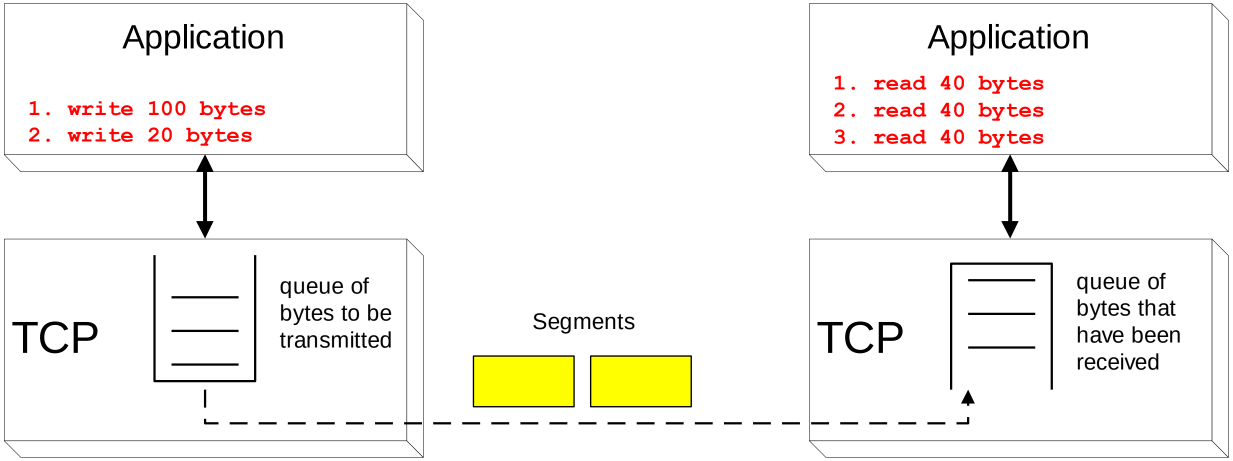


Reliable

- Byte stream is broken up into chunks which are called **segments**
    - Receiver sends acknowledgements (ACKs) for segments
    - TCP maintains a timer. If an ACK is not received in time, the segment is retransmitted
- **Detecting errors:**
    - TCP has checksums for header and data. Segments with invalid checksums are discarded
    - Each byte that is transmitted has a sequence number

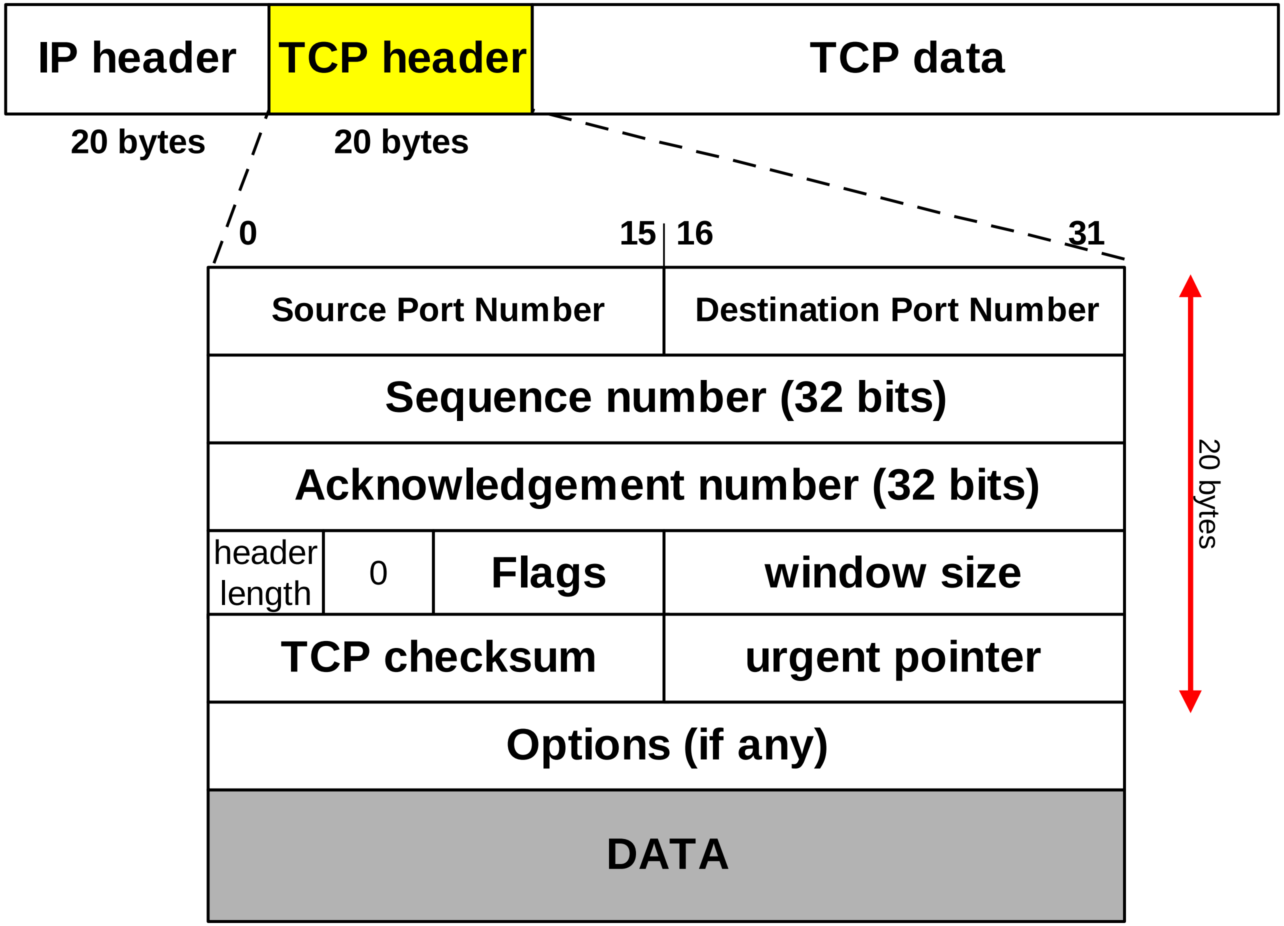
Byte Stream Service

- To the lower layers, TCP handles data in blocks, the segments.
- To the higher layers TCP handles data as a sequence of bytes and does not identify boundaries between bytes
- So: Higher layers do not know about the beginning and end of segments !



TCP Format

- TCP segments have a 20 byte header with >= 0 bytes of data.



IP header

TCP header

TCP data

20 bytes

20 bytes

0

15

16

31

Source Port Number

Destination Port Number

Sequence number (32 bits)

Acknowledgement number (32 bits)

header length

0

Flags

window size

TCP checksum

urgent pointer

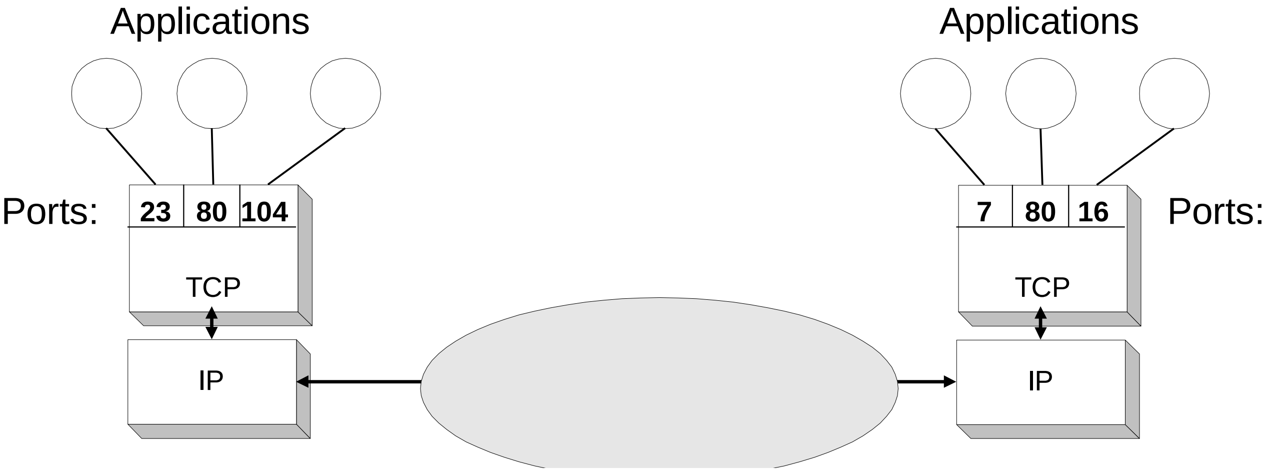
Options (if any)

DATA

20 bytes

TCP header fields

- **Port Number:**
  - A port number identifies the endpoint of a connection.
  - A pair `<IP address, port number>` identifies one endpoint of a connection.
  - Two pairs `<client IP address, server port number>` and `<server IP address, server port number>` identify a TCP connection.



TCP header fields

- **Sequence Number (SeqNo):**
  - Sequence number is 32 bits long.
  - So the range of SeqNo is

    $0 <= \text{SeqNo} <= 2^{32} - 1 \approx 4.3$ Gbyte
  - Each sequence number identifies a byte in the byte stream
  - Initial Sequence Number (ISN) of a connection is set during connection establishment

Q: What are possible requirements for ISN ?

TCP header fields

- **Acknowledgement Number (AckNo):**
  - Acknowledgements are piggybacked, I.e

    a segment from A -> B can contain an acknowledgement for a data sent in the B -> A direction

    Q: Why is piggybacking good ?

  - A hosts uses the AckNo field to send acknowledgements. (If a host sends an AckNo in a segment it sets the "**ACK flag**")
  - The AckNo contains the next SeqNo that a hosts wants to receive

    Example: The acknowledgement for a segment with sequence numbers 0-1500 is AckNo=1501

TCP header fields

- **Acknowledge Number (cont'd)**
  - TCP uses the sliding window flow protocol (see CS 457) to regulate the flow of traffic from sender to receiver
  - TCP uses the following variation of sliding window:
    - no NACKs (**N**egative **ACK**nowledgement)
    - only cumulative ACKs
- Example:

Assume: Sender sends two segments with "1..1500" and "1501..3000", but receiver only gets the second segment.

In this case, the receiver cannot acknowledge the second packet. It can only send AckNo=1

TCP header fields

- **Header Length (4bits):**
  - Length of header in 32-bit words
  - Note that TCP header has variable length (with minimum 20 bytes)

TCP header fields

- **Flag bits:**
  - **URG: Urgent pointer is valid**
    - If the bit is set, the following bytes contain an urgent message in the range:

      SeqNo <= urgent message <= SeqNo+urgent pointer
  - **ACK: Acknowledgement Number is valid**
  - **PSH: PUSH Flag**
    - Notification from sender to the receiver that the receiver should pass all data that it has to the application.
    - Normally set by sender when the sender's buffer is empty

TCP header fields

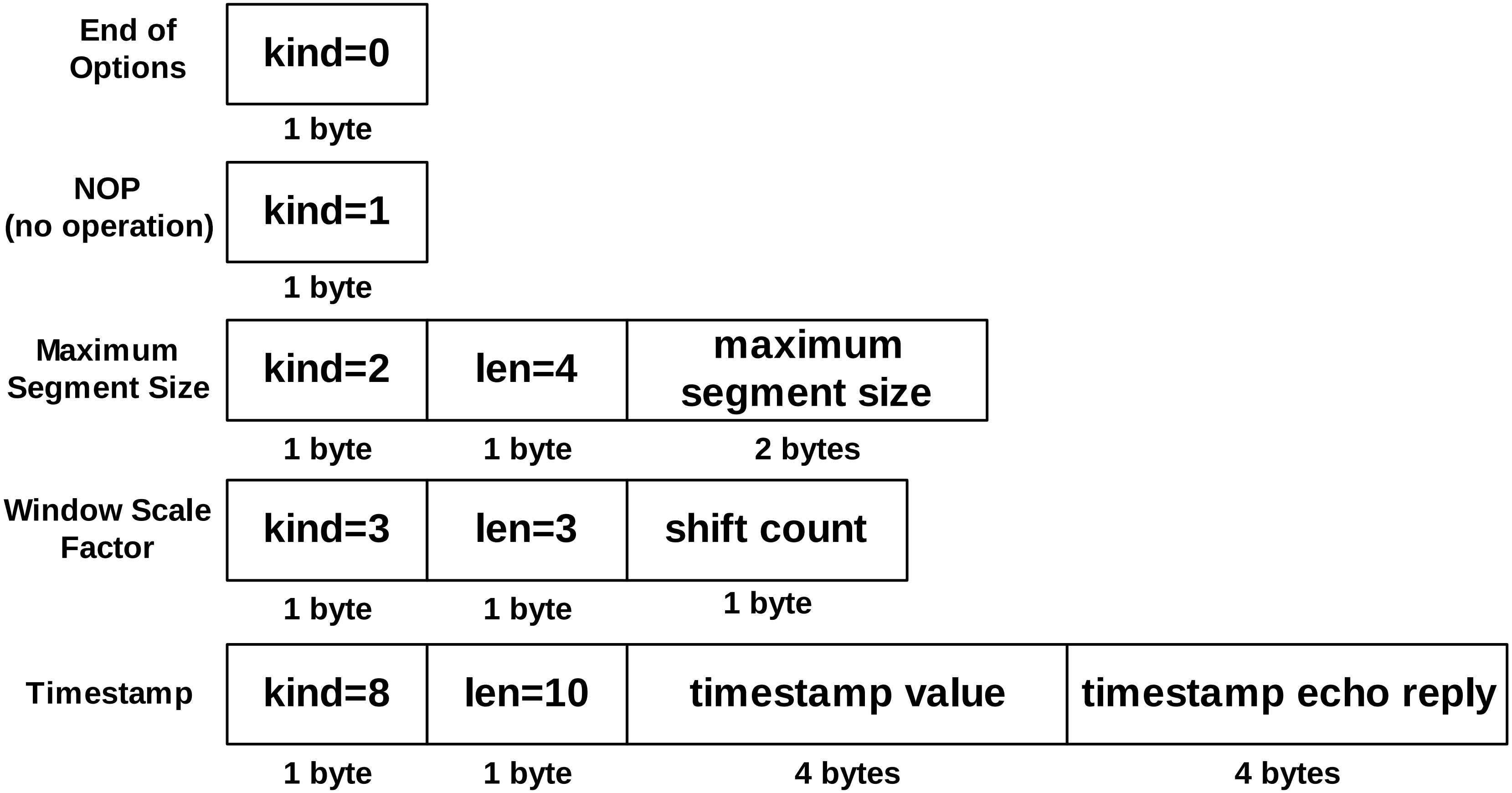
- **Flag bits:**
  - **RST: Reset the connection**
    - The flag causes the receiver to reset the connection
    - Receiver of a RST terminates the connection and indicates higher layer application about the reset
  - **SYN: Synchronize sequence numbers**
    - Sent in the first packet when initiating a connection
  - **FIN: Sender is finished with sending**
    - Used for closing a connection
    - Both sides of a connection must send a **FIN**

TCP header fields

- **Window Size:**
  - Each side of the connection advertises the window size
  - Window size is the maximum number of bytes that a receiver can accept.
  - Maximum window size is 2^{16}-1= 65535 bytes
- **TCP Checksum:**
  - TCP checksum covers over both TCP header **and** TCP data (also covers some parts of the IP header)
- **Urgent Pointer:**
  - Only valid if **URG** flag is set

TCP header fields

- **Options**:



End of Options
kind=0
1 byte

NOP (no operation)
kind=1
1 byte

Maximum Segment Size
kind=2 | len=4 | maximum segment size
1 byte | 1 byte | 2 bytes

Window Scale Factor
kind=3 | len=3 | shift count
1 byte | 1 byte | 1 byte

Timestamp
kind=8 | len=10 | timestamp value | timestamp echo reply
1 byte | 1 byte | 4 bytes | 4 bytes

TCP header fields

- **Options**:
  - **NOP** is used to pad TCP header to multiples of 4 bytes
  - **Maximum Segment Size**
  - **Window Scale Options**
    - » Increases the TCP window from 16 to 32 bits, I.e., the window size is interpreted differently

      Q: What is the different interpretation ?
    - » This option can only be used in the SYN segment (first segment) during connection establishment time
  - **Timestamp Option**
    - » Can be used for roundtrip measurements

Connection Management in TCP

- Opening a TCP Connection
- Closing a TCP Connection
- Special Scenarios
- State Diagram

TCP Connection Establishment

- TCP uses a **three-way handshake** to open a connection:

(1) ACTIVE OPEN: Client sends a segment with

  - SYN bit set *
  - port number of client
  - initial sequence number (ISN) of client

(2) PASSIVE OPEN: Server responds with a segment with

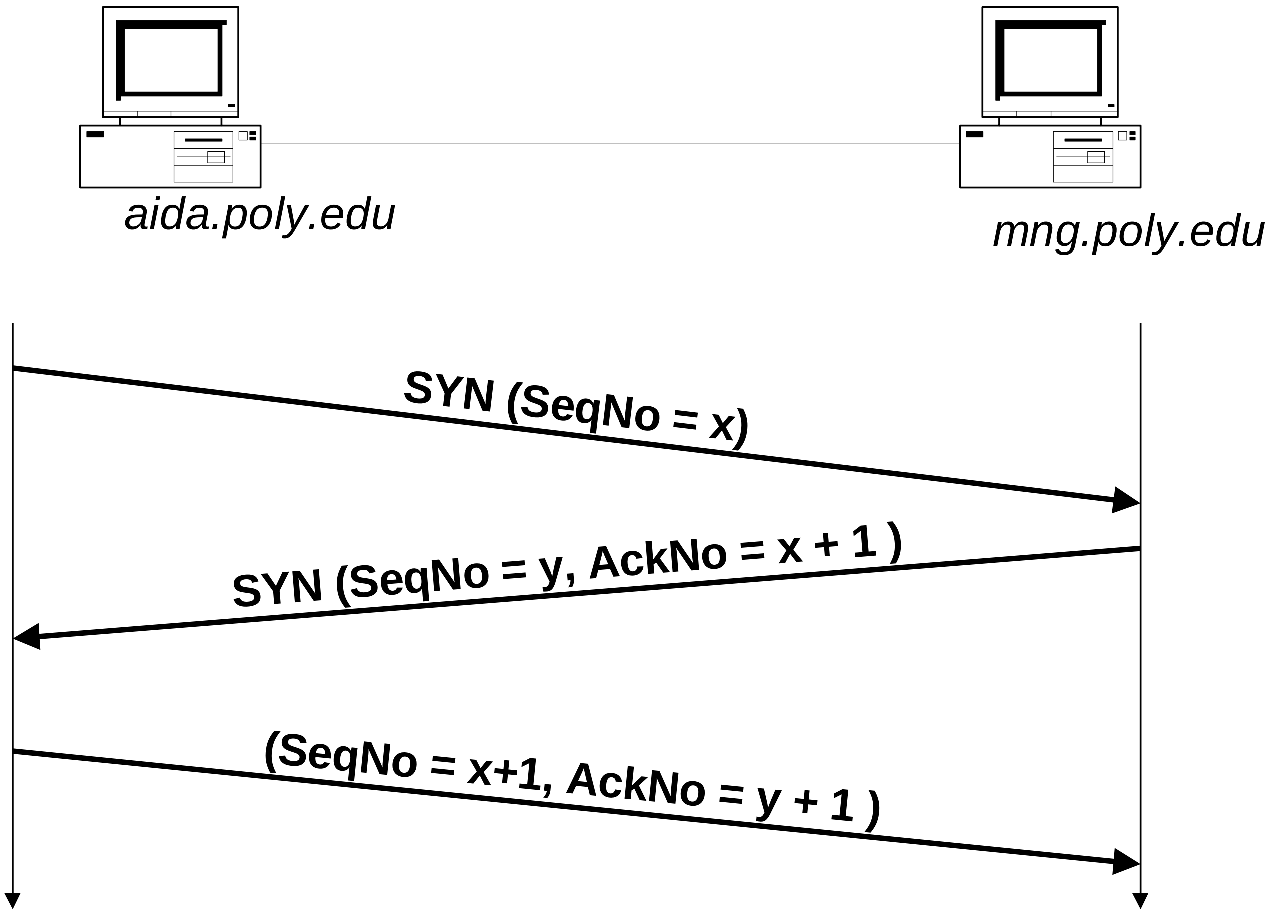
  - SYN bit set *
  - initial sequence number of server
  - ACK for ISN of client

(3) Client acknowledges by sending a segment with:

  - ACK ISN of server

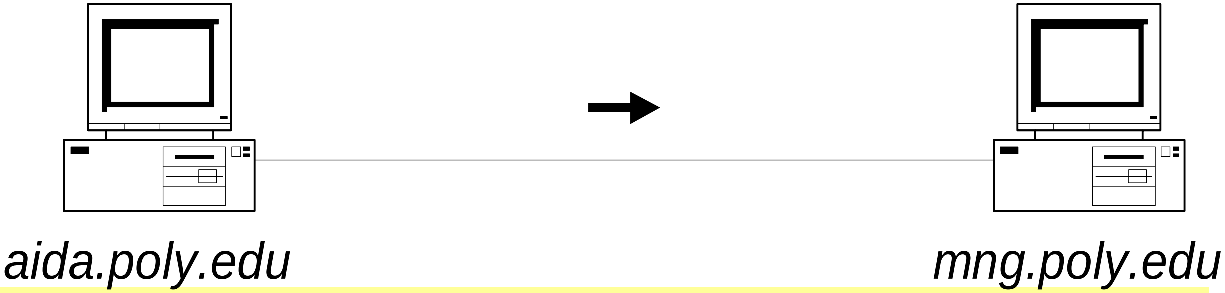
(* counts as one byte)

Three-Way Handshake


aida.poly.edu
mng.poly.edu
SYN (SeqNo = x)
SYN (SeqNo = y, AckNo = x + 1)
(SeqNo = x+1, AckNo = y + 1)

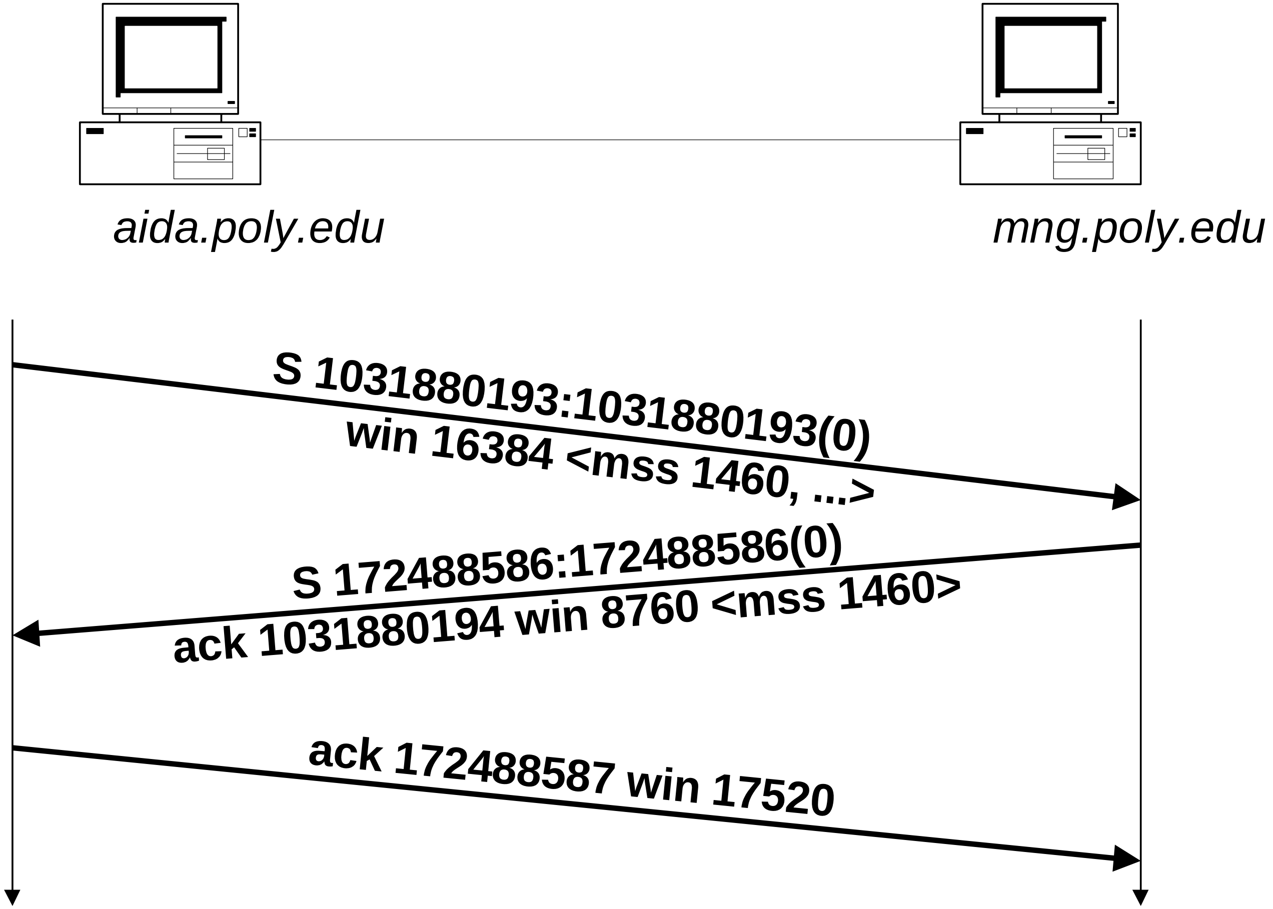
A Closer Look with tcpdump

aida issues
an "telnet mng"



```
1   aida.poly.edu.1121 > mng.poly.edu.telnet: S 1031880193:1031880193(0)
                              win 16384 <mss 1460,nop,wscale 0,nop,nop,timestamp>
2   mng.poly.edu.telnet > aida.poly.edu.1121: S 172488586:172488586(0)
                              ack 1031880194 win 8760 <mss 1460>
3   aida.poly.edu.1121 > mng.poly.edu.telnet: . ack 172488587 win 17520
4   aida.poly.edu.1121 > mng.poly.edu.telnet: P 1031880194:1031880218(24)
                              ack 172488587 win 17520
5   mng.poly.edu.telnet > aida.poly.edu.1121: P 172488587:172488590(3)
                              ack 1031880218 win 8736
6   aida.poly.edu.1121 > mng.poly.edu.telnet: P 1031880218:1031880221(3)
                              ack 172488590 win 17520
```

Three-Way Handshake



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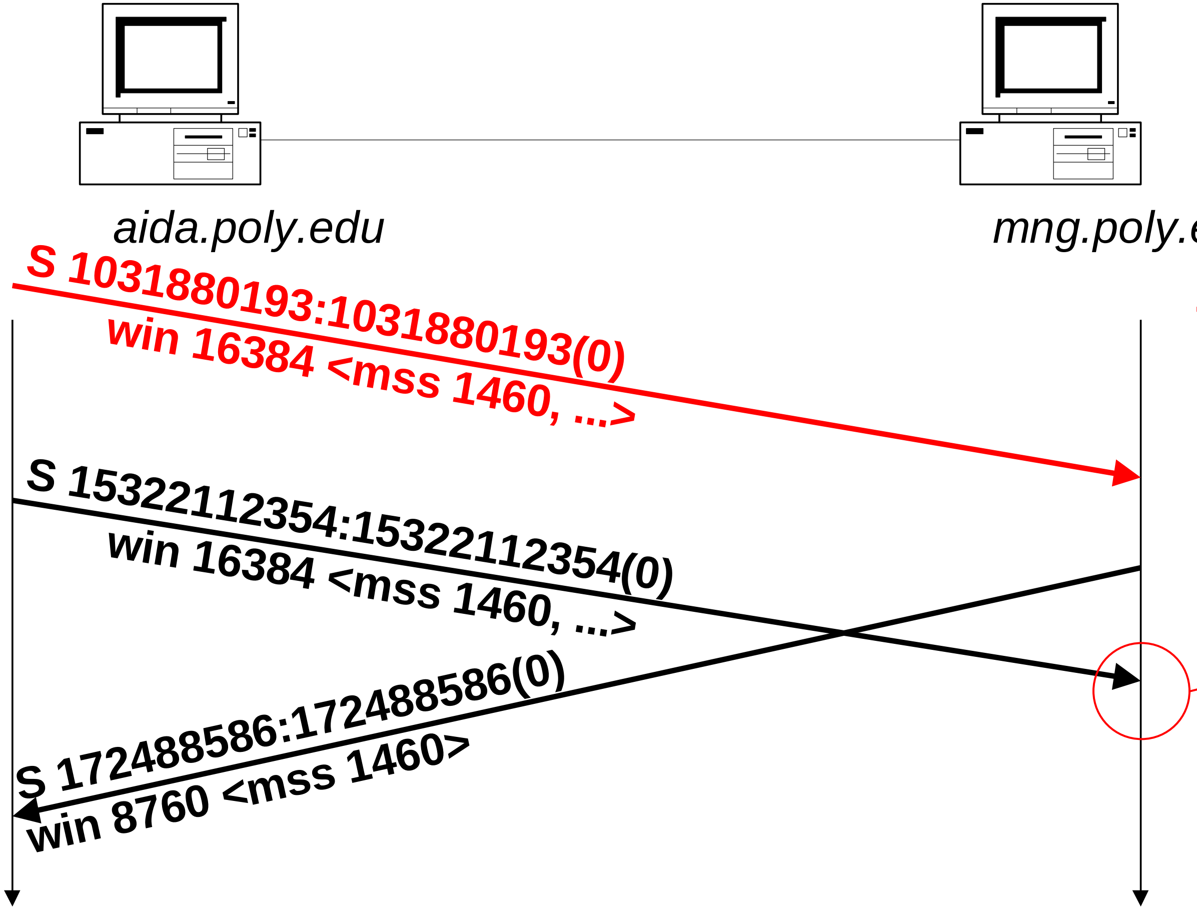
S 1031880193:1031880193(0)
win 16384 <mss 1460, ...>

S 172488586:172488586(0)
ack 1031880194 win 8760 <mss 1460>

ack 172488587 win 17520

Why is a Two-Way Handshake not enough?



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S 1031880193:1031880193(0)
win 16384 <mss 1460, ...>

S 15322112354:15322112354(0)
win 16384 <mss 1460, ...>

S 172488586:172488586(0)
win 8760 <mss 1460>

The red line is a delayed duplicate packet.

Will be discarded as a duplicate SYN

When aida initiates the data transfer (starting with SeqNo=15322112355), mng will reject all data.

TCP Connection Termination

- Each end of the data flow must be shut down independently **(“half-close”)**
- If one end is done it sends a FIN segment. This means that no more data will be sent

- Four steps involved:

  (1) X sends a FIN to Y **(active close)**

  (2) Y ACKs the FIN,

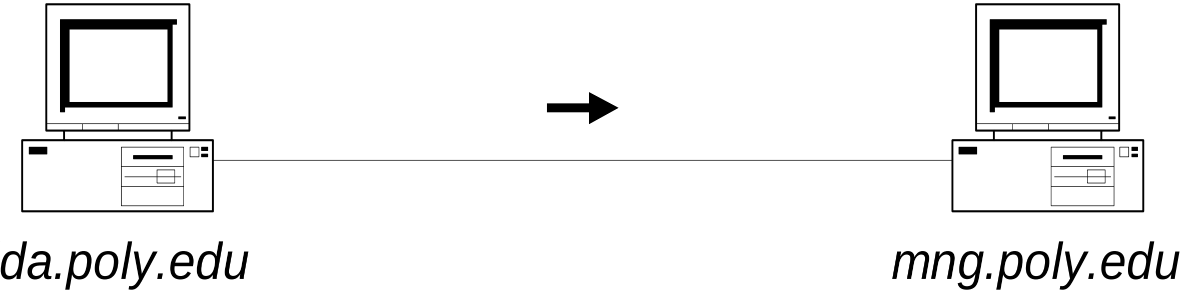
  (at this time: Y can still send data to X)

  (3) and Y sends a FIN to X **(passive close)**

  (4) X ACKs the FIN.

Connection termination with tcpdump

aida issues
an "telnet mng"

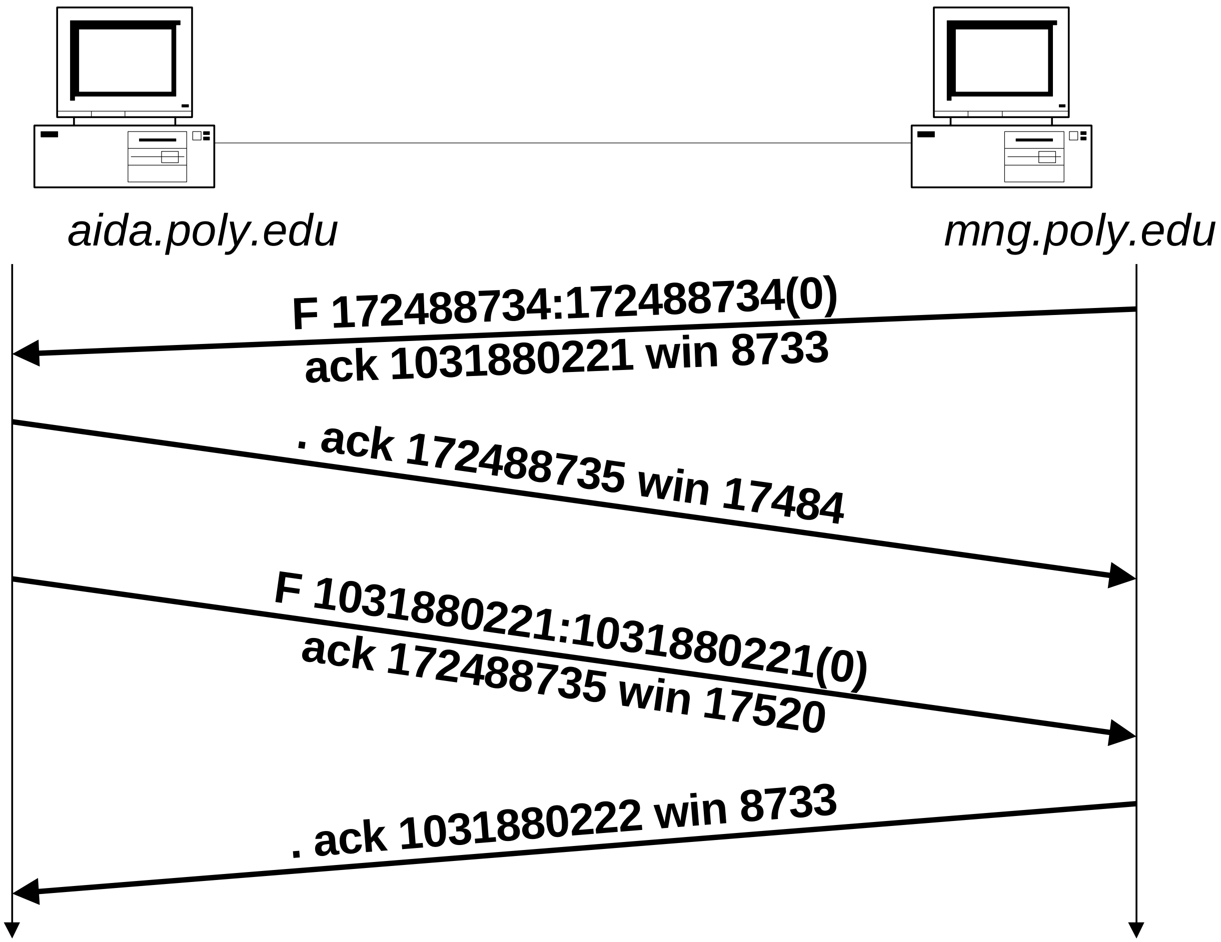


aida.poly.edu

mng.poly.edu

```
1   mng.poly.edu.telnet > aida.poly.edu.1121: F 172488734:172488734(0)
                                              ack 1031880221 win 8733
2   aida.poly.edu.1121 > mng.poly.edu.telnet: . ack 172488735 win 17484
3   aida.poly.edu.1121 > mng.poly.edu.telnet: F 1031880221:1031880221(0)
                                              ack 172488735 win 17520
4   mng.poly.edu.telnet > aida.poly.edu.1121: . ack 1031880222 win 8733
```

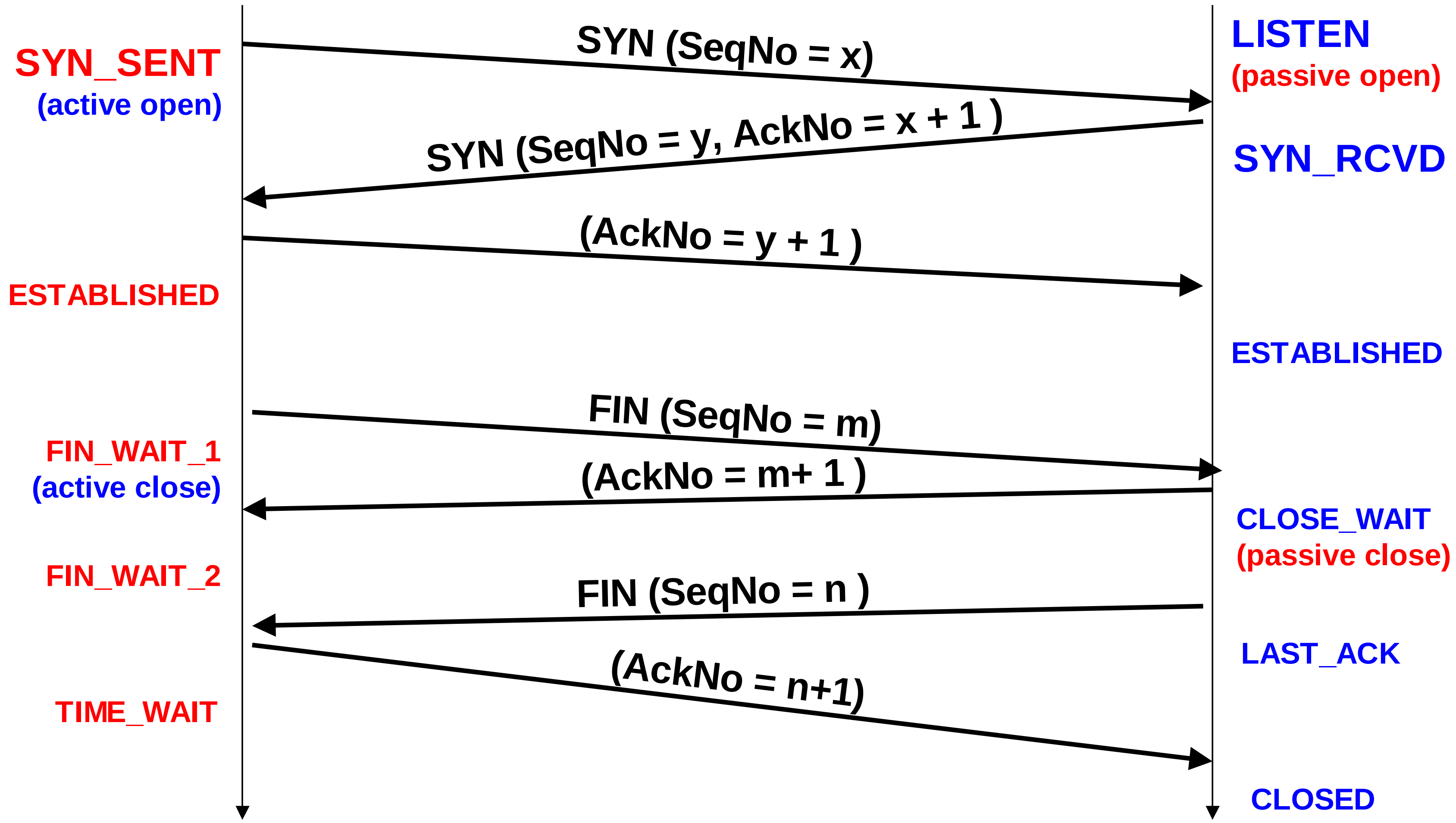
TCP Connection Termination



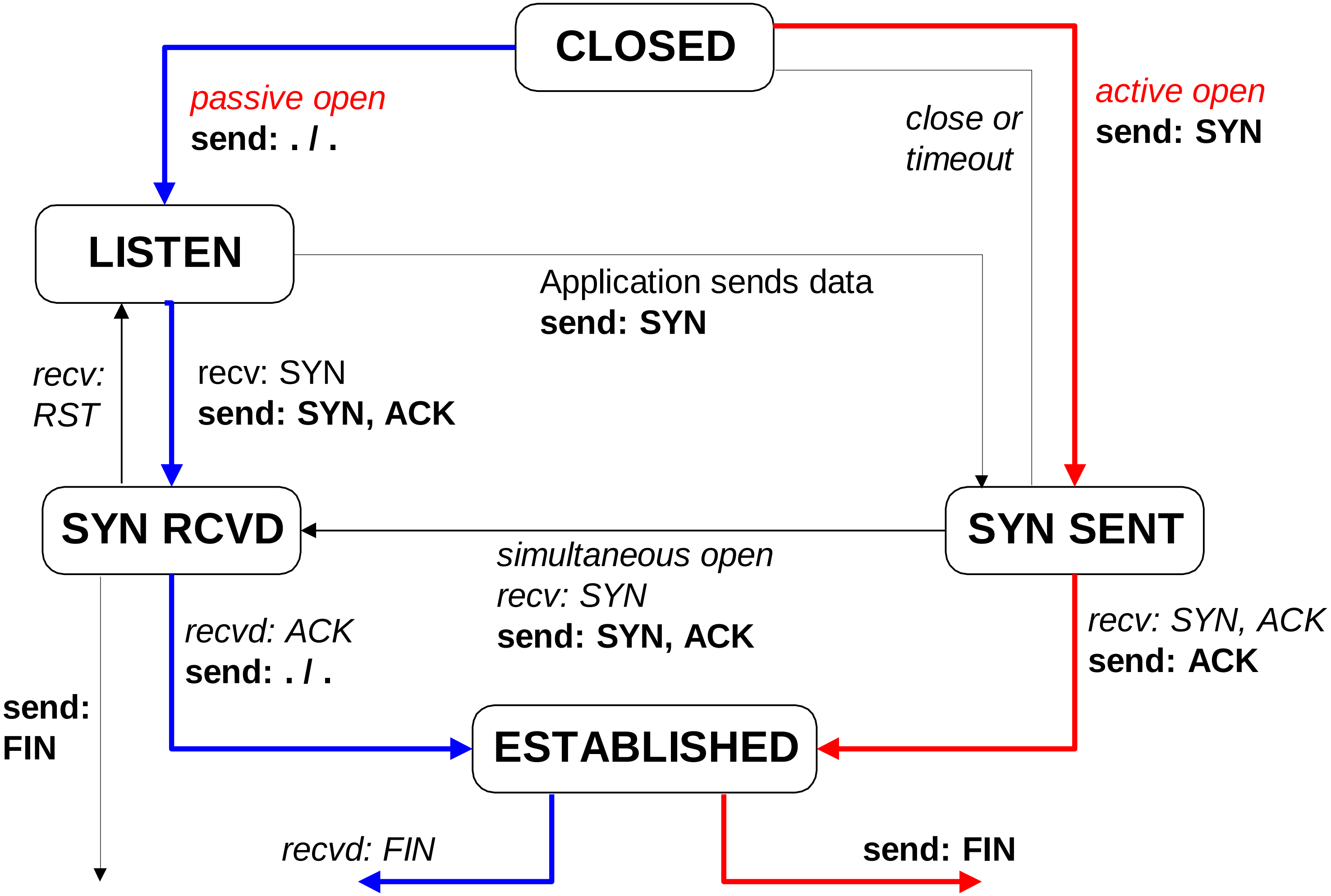
TCP States

State	Description
CLOSED	No connection is active or pending
LISTEN	The server is waiting for an incoming call
SYN RCVD	A connection request has arrived; wait for Ack
SYN SENT	The client has started to open a connection
ESTABLISHED	Normal data transfer state
FIN WAIT 1	Client has said it is finished
FIN WAIT 2	Server has agreed to release
TIMED WAIT	Wait for pending packets (“2MSL wait state”)
CLOSING	Both Sides have tried to close simultanesously
CLOSE WAIT	Server has initiated a release
LAST ACK	Wait for pending packets

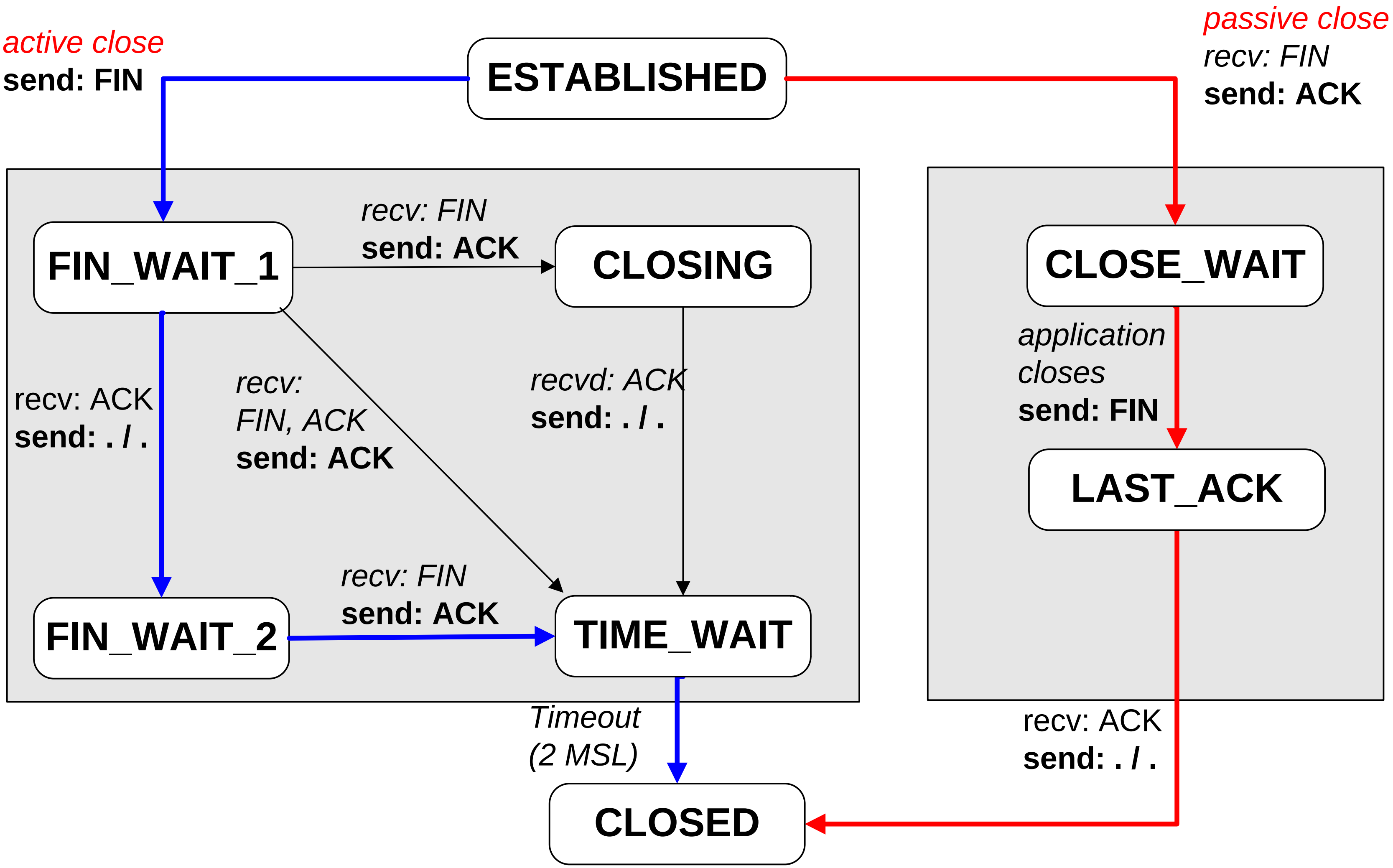
TCP States in “Normal” Connection Lifetime



TCP State Transition Diagram Opening A Connection



TCP State Transition Diagram
Closing A Connection



active close
send: FIN

ESTABLISHED

passive close
recv: FIN
send: ACK

FIN_WAIT_1

recv: FIN
send: ACK

CLOSING

CLOSE_WAIT

recv: ACK
send: . / .

recv:
FIN, ACK
send: ACK

recvd: ACK
send: . / .

application
closes
send: FIN

LAST_ACK

FIN_WAIT_2

recv: FIN
send: ACK

TIME_WAIT

Timeout
(2 MSL)

recv: ACK
send: . / .

CLOSED

2MSL Wait State

2MSL Wait State = TIME_WAIT

- When TCP does an active close, and sends the final ACK, the connection **must stay in in the TIME_WAIT state for twice the maximum segment lifetime**.

2MSL= 2 * Maximum Segment Lifetime

- Why?
  TCP is given a chance to resent the final ACK. (Server will timeout after sending the FIN segment and resend the FIN)
- The MSL is set to 2 minutes or 1 minute or 30 seconds.

Resetting Connections

- Resetting connections is done by setting the RST flag
- **When is the RST flag set?**
  - Connection request arrives and no server process is waiting on the destination port
  - Abort (Terminate) a connection
    Causes the receiver to throw away buffered data. Receiver does not acknowledge the RST segment