Transmission Control Protocol (TCP)

Antonio Carzaniga

Faculty of Informatics
Università della Svizzera italiana

November 10, 2017

Outline

- Introduction to TCP
- Sequence numbers and acknowledgment numbers
- Timeouts and RTT estimation
- Reliable data transfer in TCP
- Connection management

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- Full-duplex service
  - both endpoints can both send and receive, at the same time

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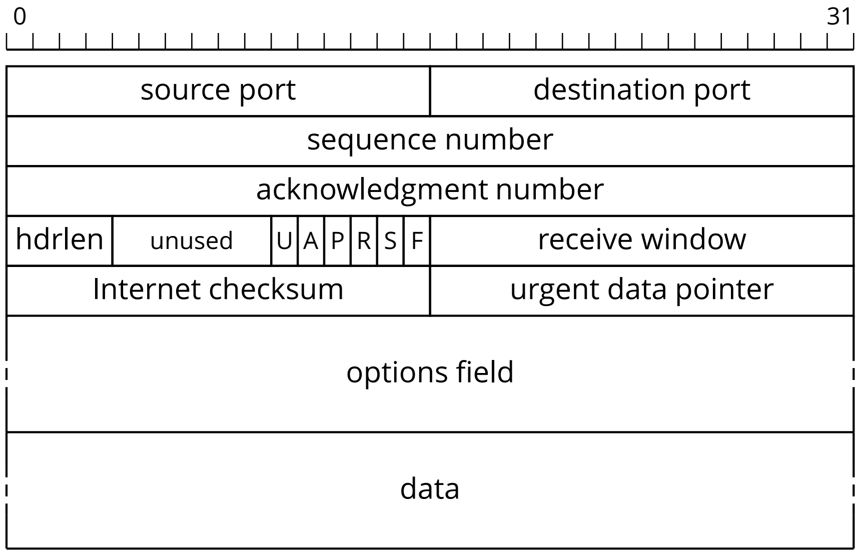
- ***Maximum transmission unit (MTU):*** largest link-layer frame available to the sender host
  - *path MTU:* largest link-layer frame that can be sent on all links from the sender host to the receiver host

TCP Segment Format



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- *Optional and variable-length options field:* may be used to negotiate protocol parameters

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- *Checksum:* (16-bit) used to detect transmission errors

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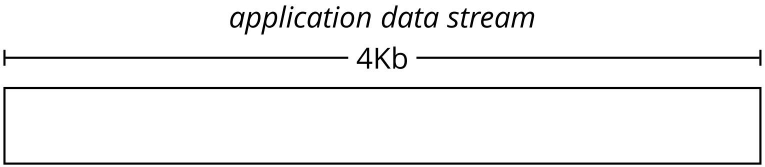

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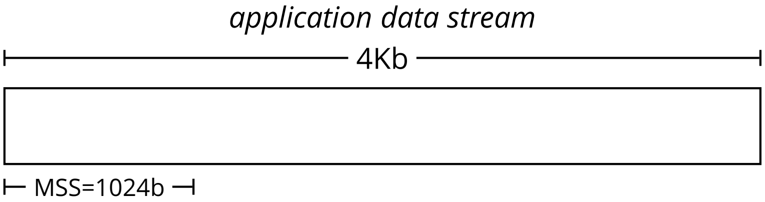

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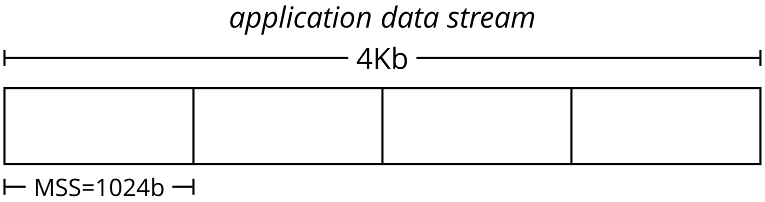

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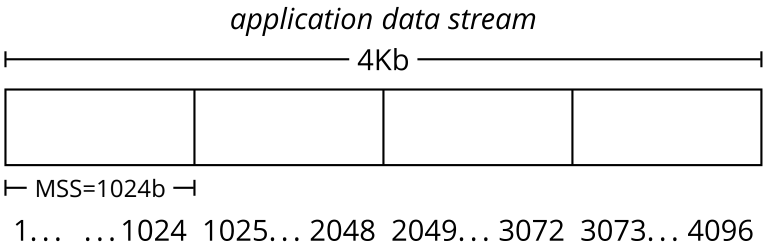

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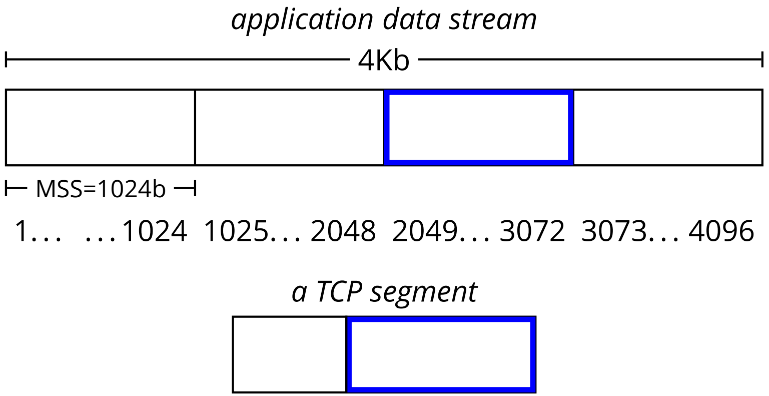

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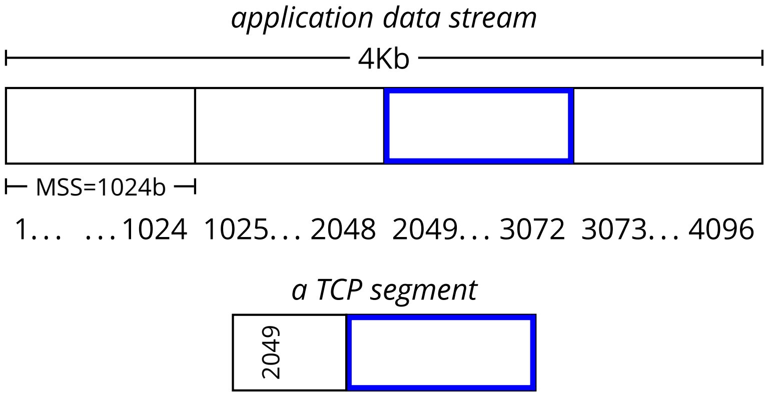

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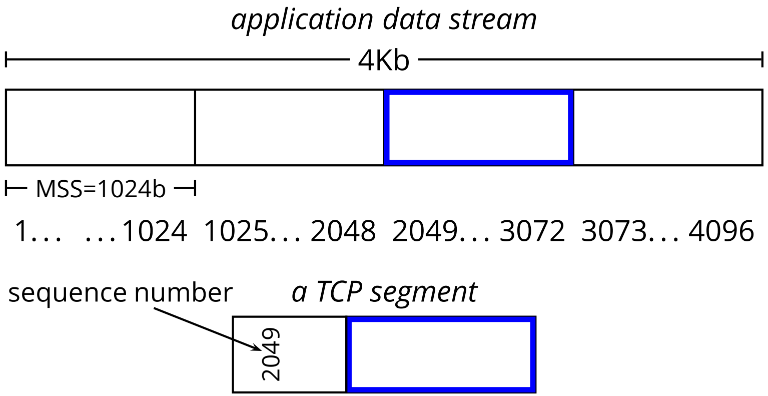

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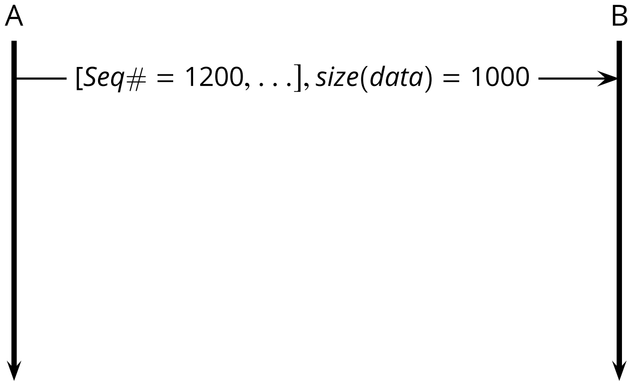

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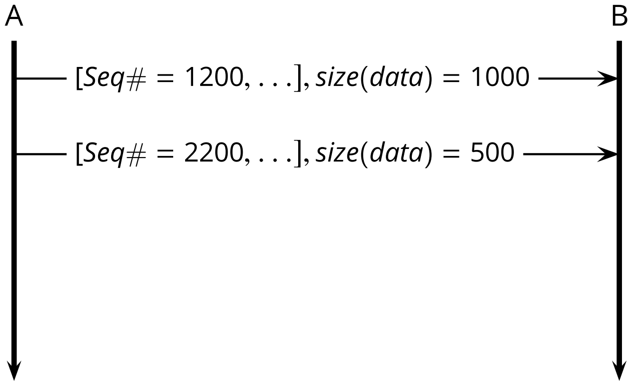
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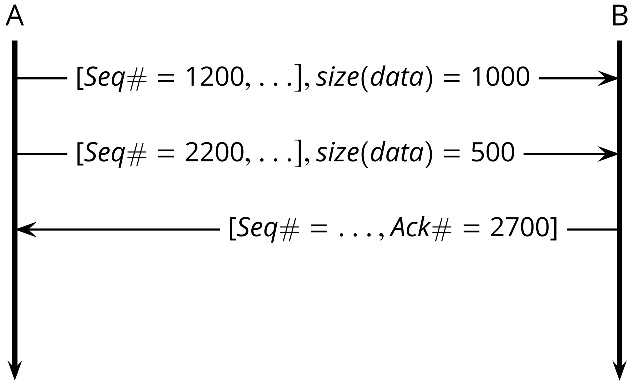
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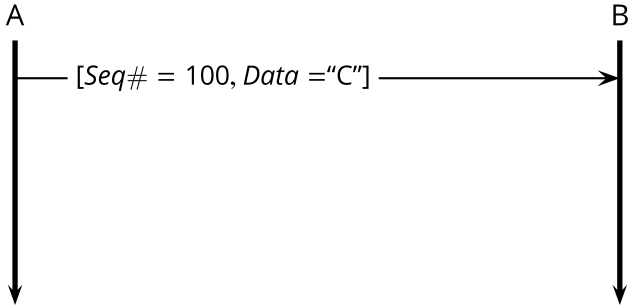

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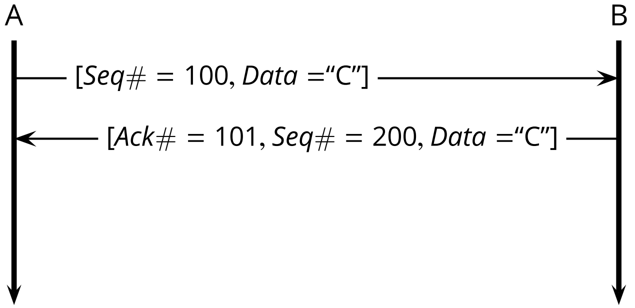
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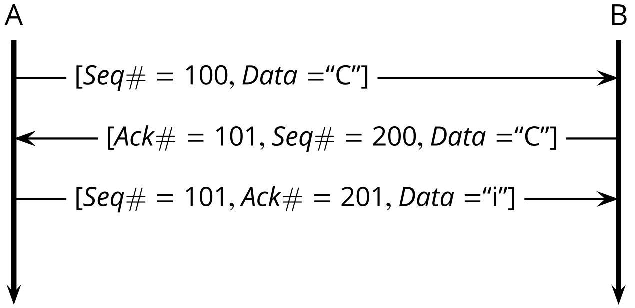
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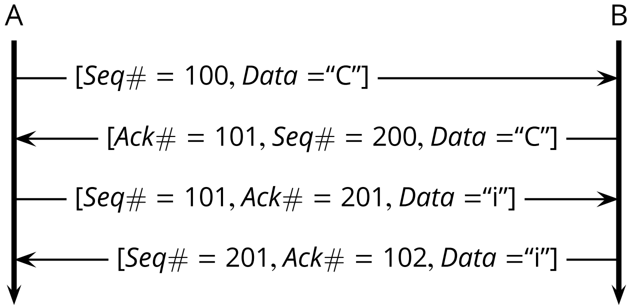
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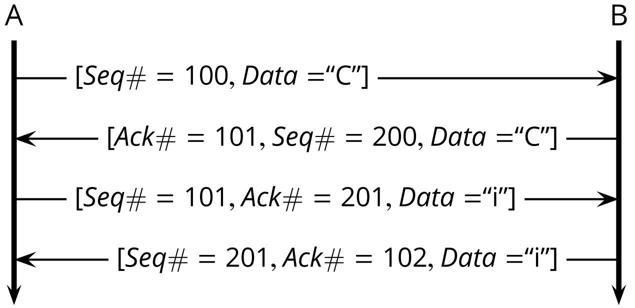
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- Acknowledgments are "piggybacked" on data segments

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  - as close as possible to the RTT
- TCP controls its timeout by continuously *estimating the current RTT*

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- RTT is measured using ACKs
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- Given a single sample S at any given time
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- TCP sets its timeouts using the estimated RTT ($\overline{RTT}$) and the variability estimate $\overline{DevRTT}$:

$$T = \overline{RTT} + 4\overline{DevRTT}$$

Reliable Data Transfer (Sender)

A simplified TCP sender

- r_send(*data*)

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if (timer not running)
    start_timer()
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- u_recv([ACK,*y*])

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if ($y > base$)
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else ...
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    if ($ack\_counter[y] = 3$)
        u_send(segment with sequence number $y$)
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client
server

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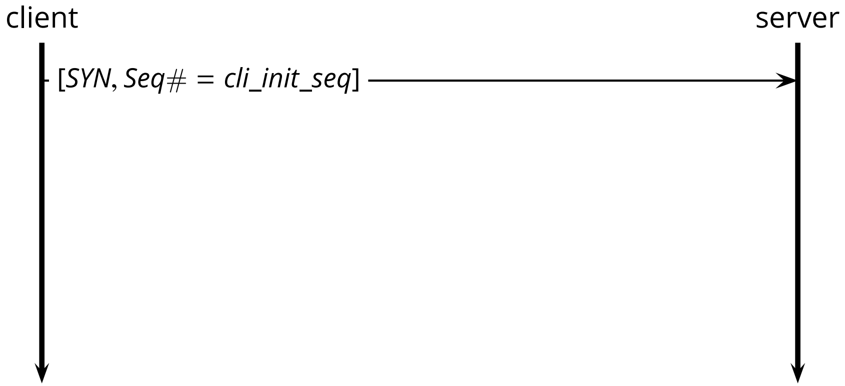

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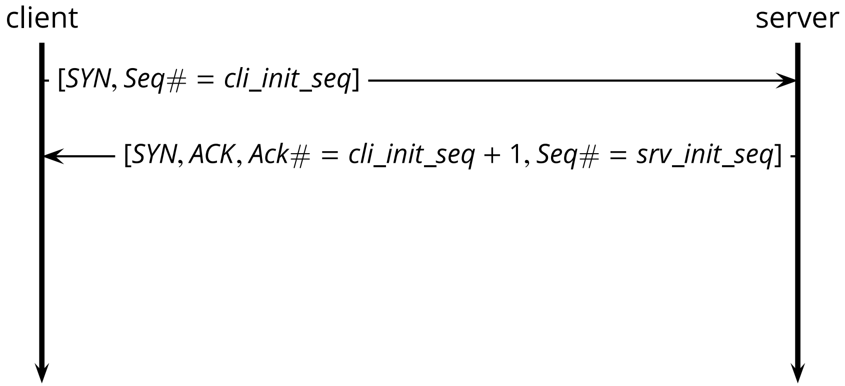
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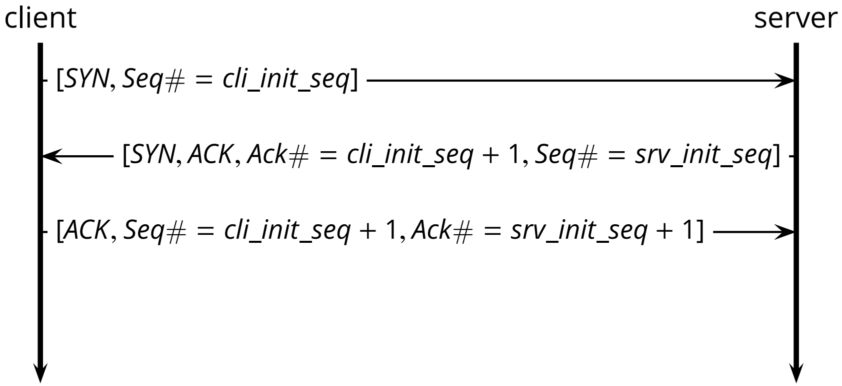
client
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[SYN, ACK, $Ack\#$ = $cli\_init\_seq + 1$, $Seq\#$ = srv_init_seq]
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"Okay, Bye now."
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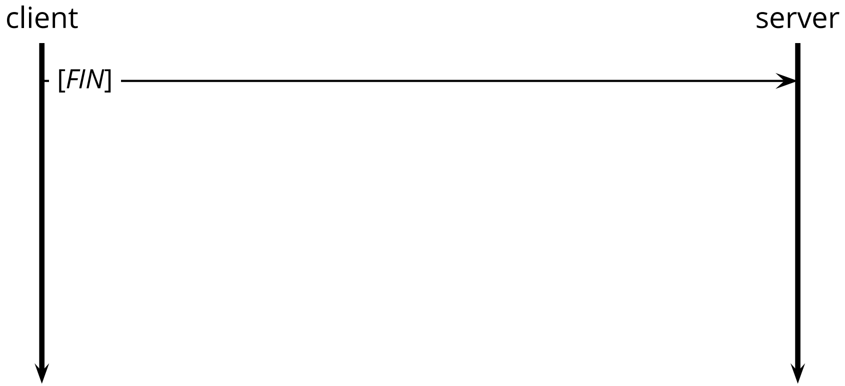

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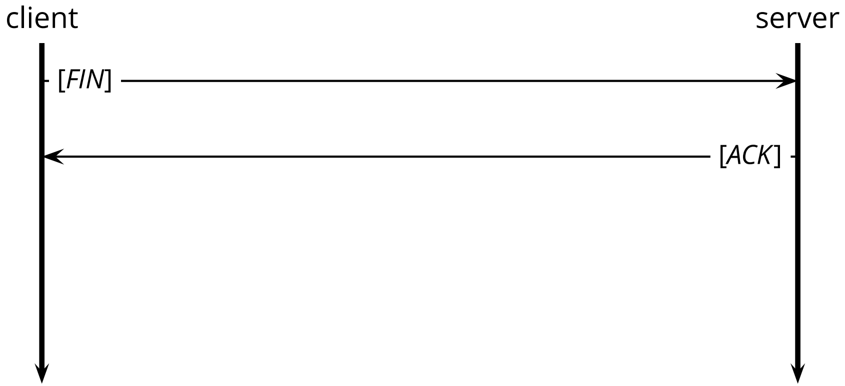
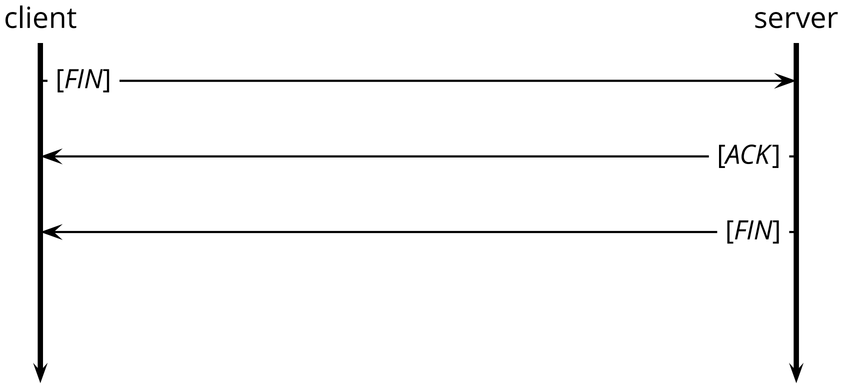


Connection Shutdown

“This is it.”
“Okay, Bye now.”
“Bye.”



Connection Shutdown

“This is it.”
“Okay, Bye now.”
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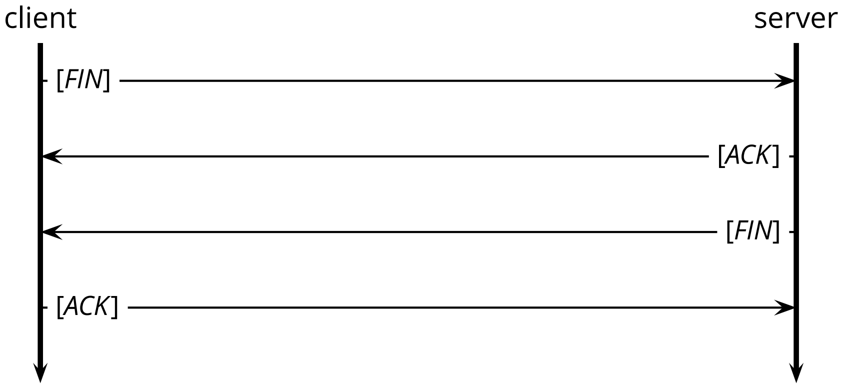
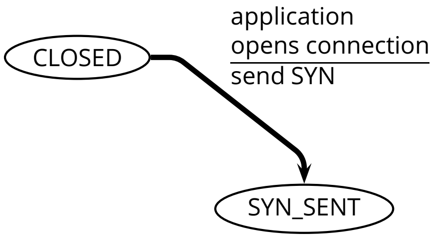
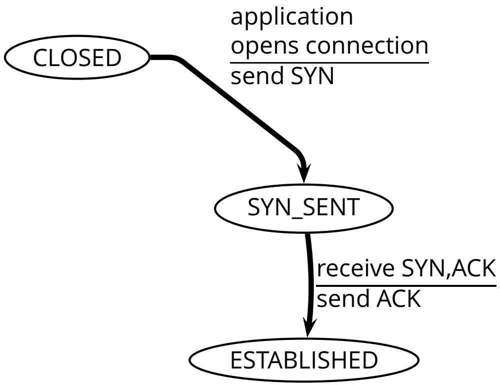


The TCP State Machine (Client)

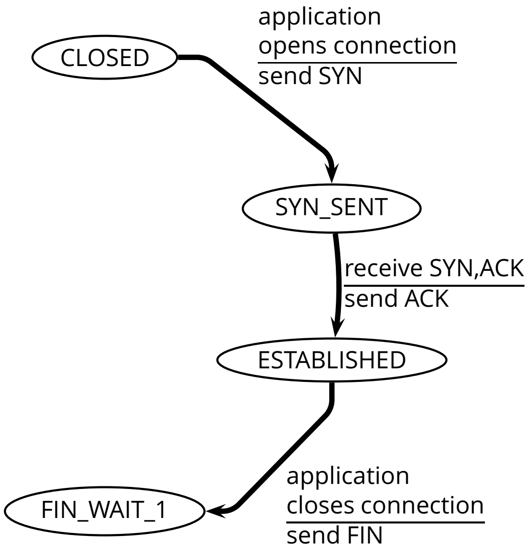
The TCP State Machine (Client)



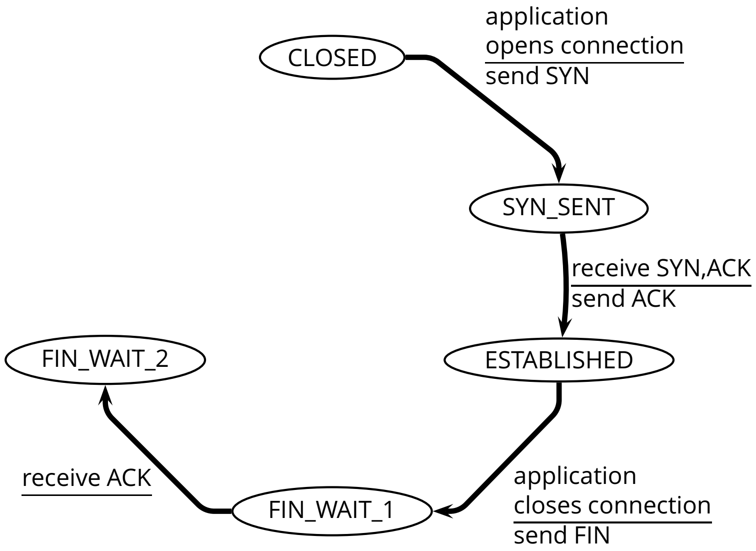
The TCP State Machine (Client)



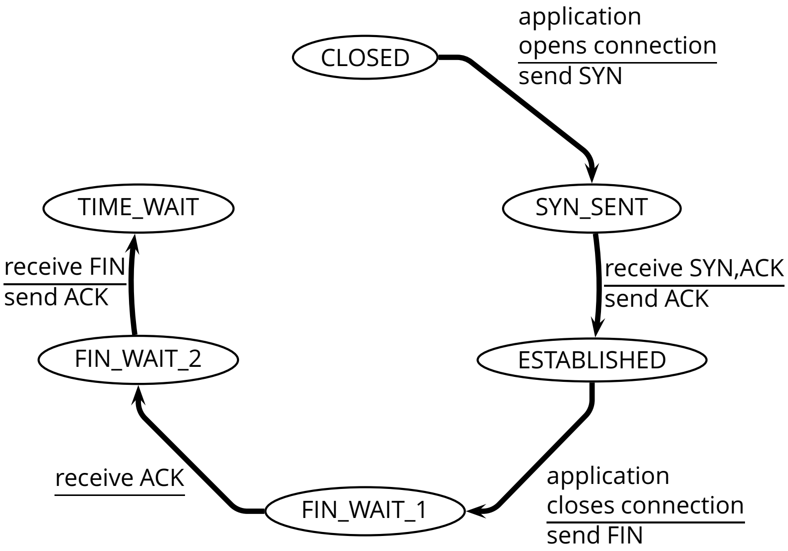
The TCP State Machine (Client)



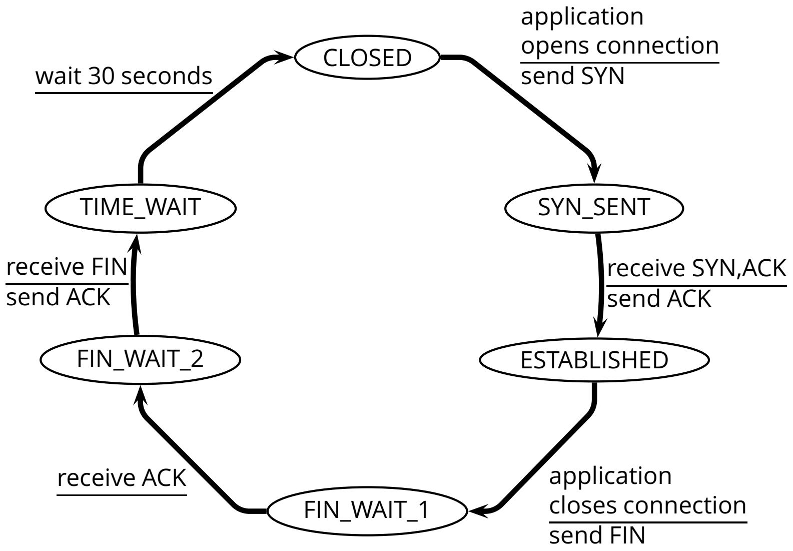
The TCP State Machine (Client)



The TCP State Machine (Client)

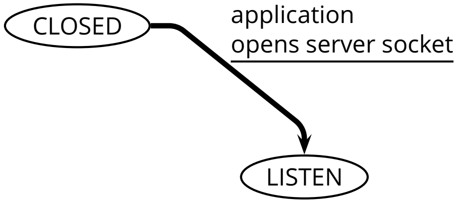


The TCP State Machine (Client)

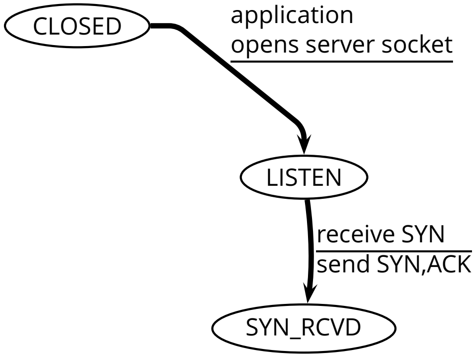


The TCP State Machine (Server)

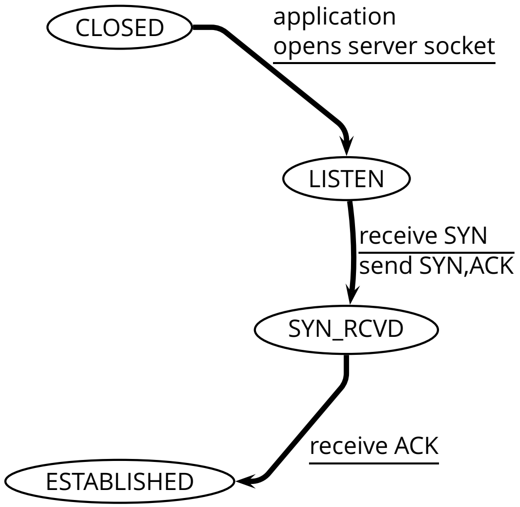
The TCP State Machine (Server)



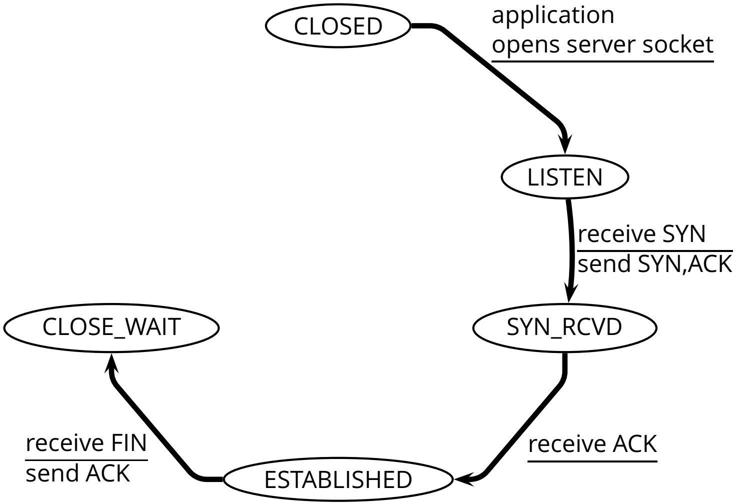
The TCP State Machine (Server)



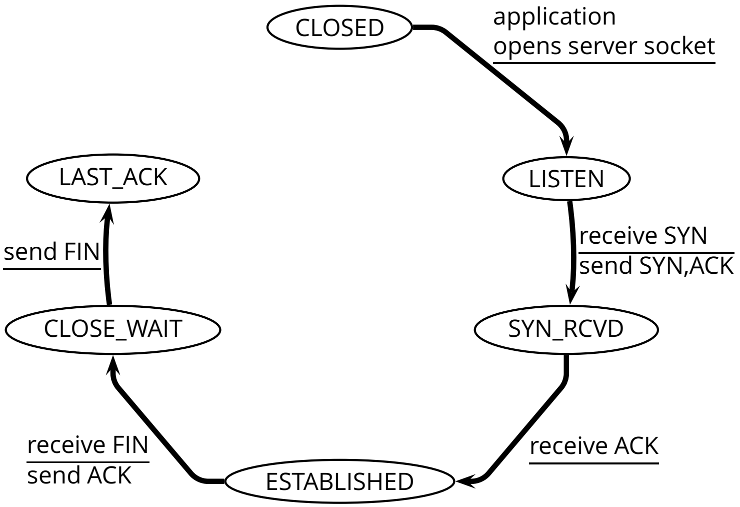
The TCP State Machine (Server)



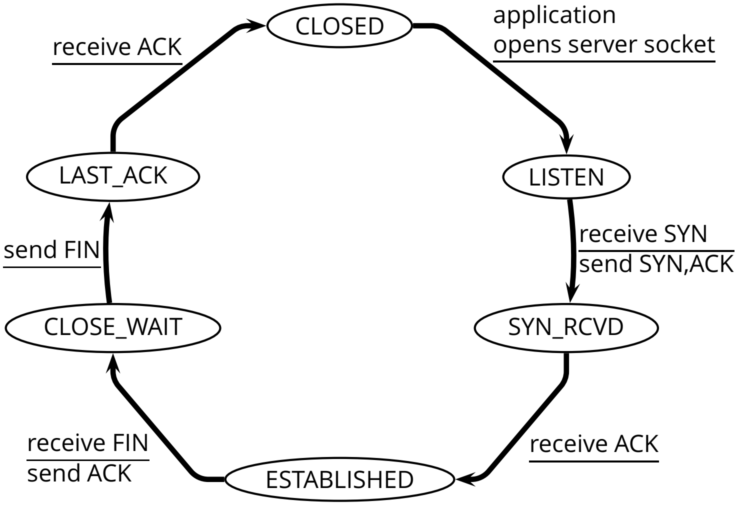
The TCP State Machine (Server)



The TCP State Machine (Server)



The TCP State Machine (Server)


CLOSED
application
opens server socket
LISTEN
receive SYN
send SYN,ACK
SYN_RCVD
receive ACK
ESTABLISHED
receive FIN
send ACK
CLOSE_WAIT
send FIN
LAST_ACK
receive ACK