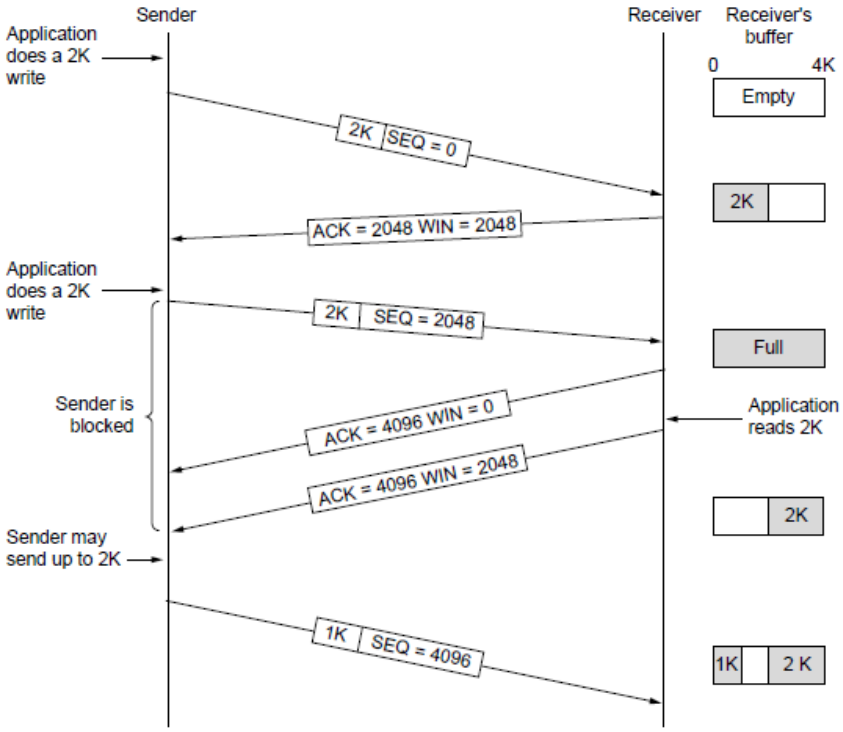
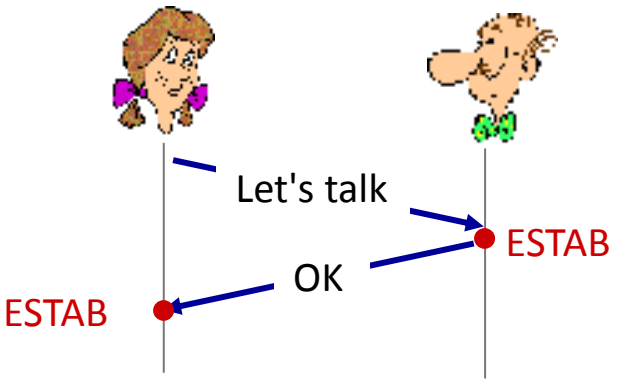
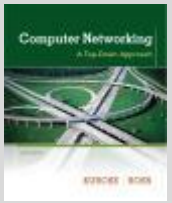
TCP flow control and connection setup





Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley



Chapter 3 outline

3.1 Transport-layer services

3.2 Multiplexing and demultiplexing

3.3 Connectionless transport: UDP

3.4 Principles of reliable data transfer

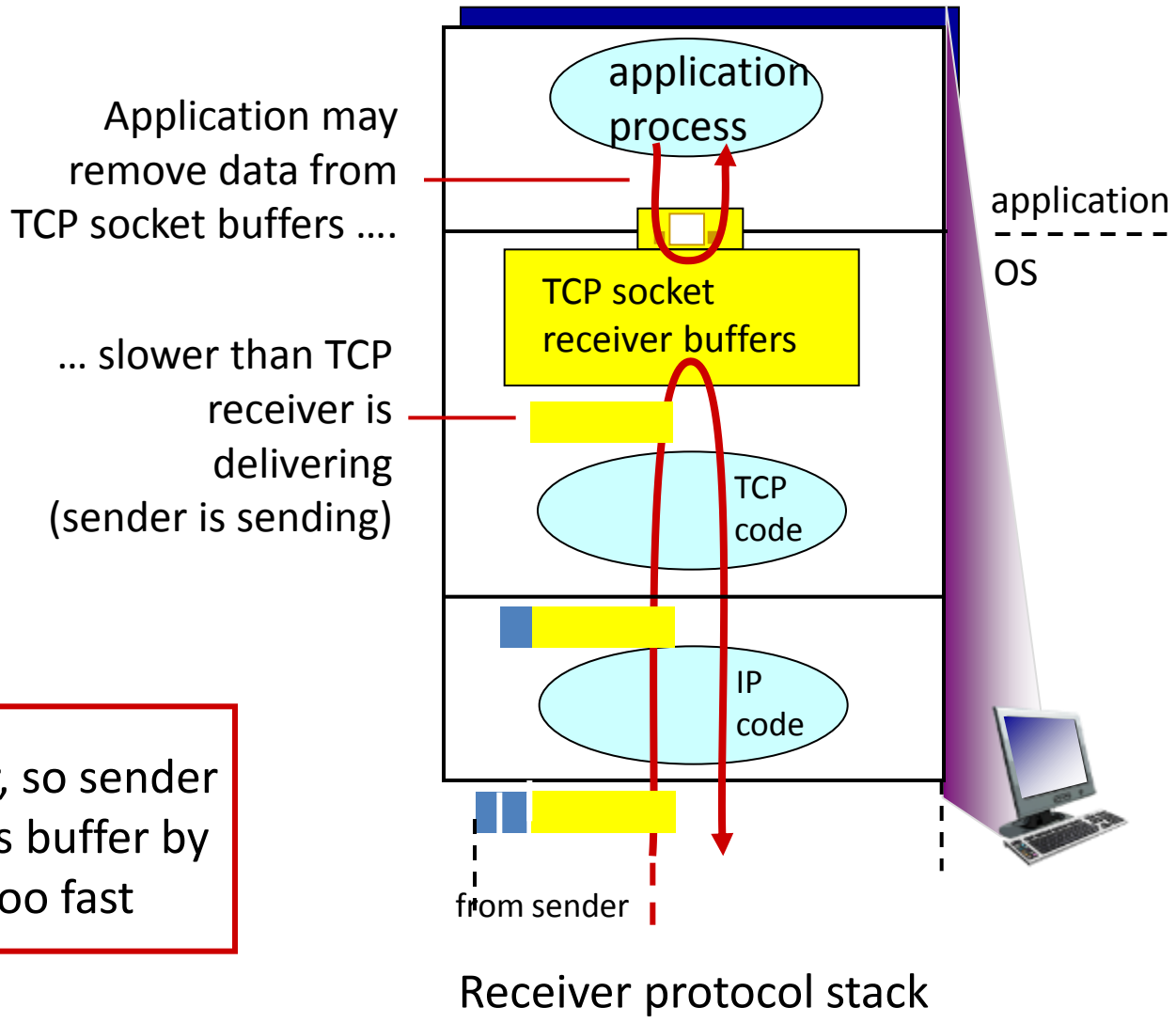
3.5 Connection-oriented transport: TCP

- Segment structure
- Reliable data transfer
- Flow control
- Connection management

3.6 Principles of congestion control

3.7 TCP congestion control

TCP flow control

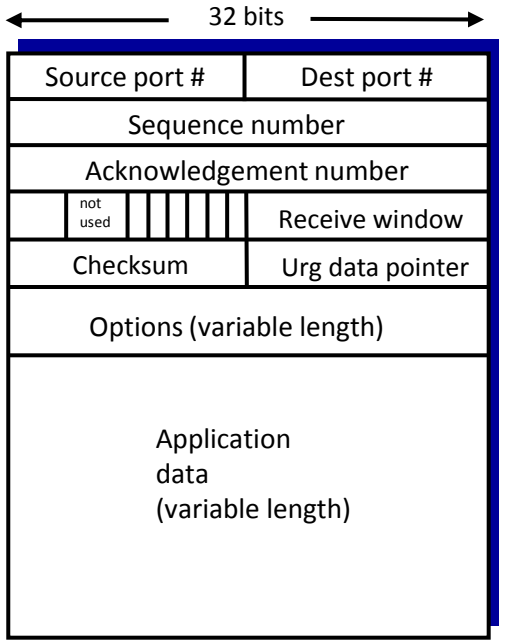


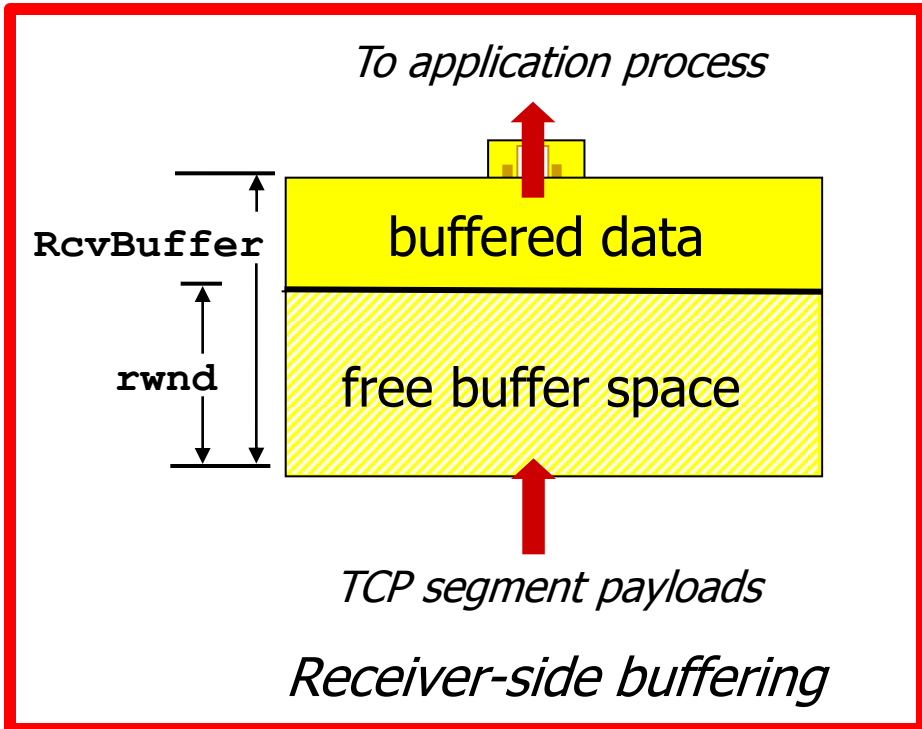
Flow control

Receiver controls sender, so sender won't overflow receiver's buffer by transmitting too much, too fast

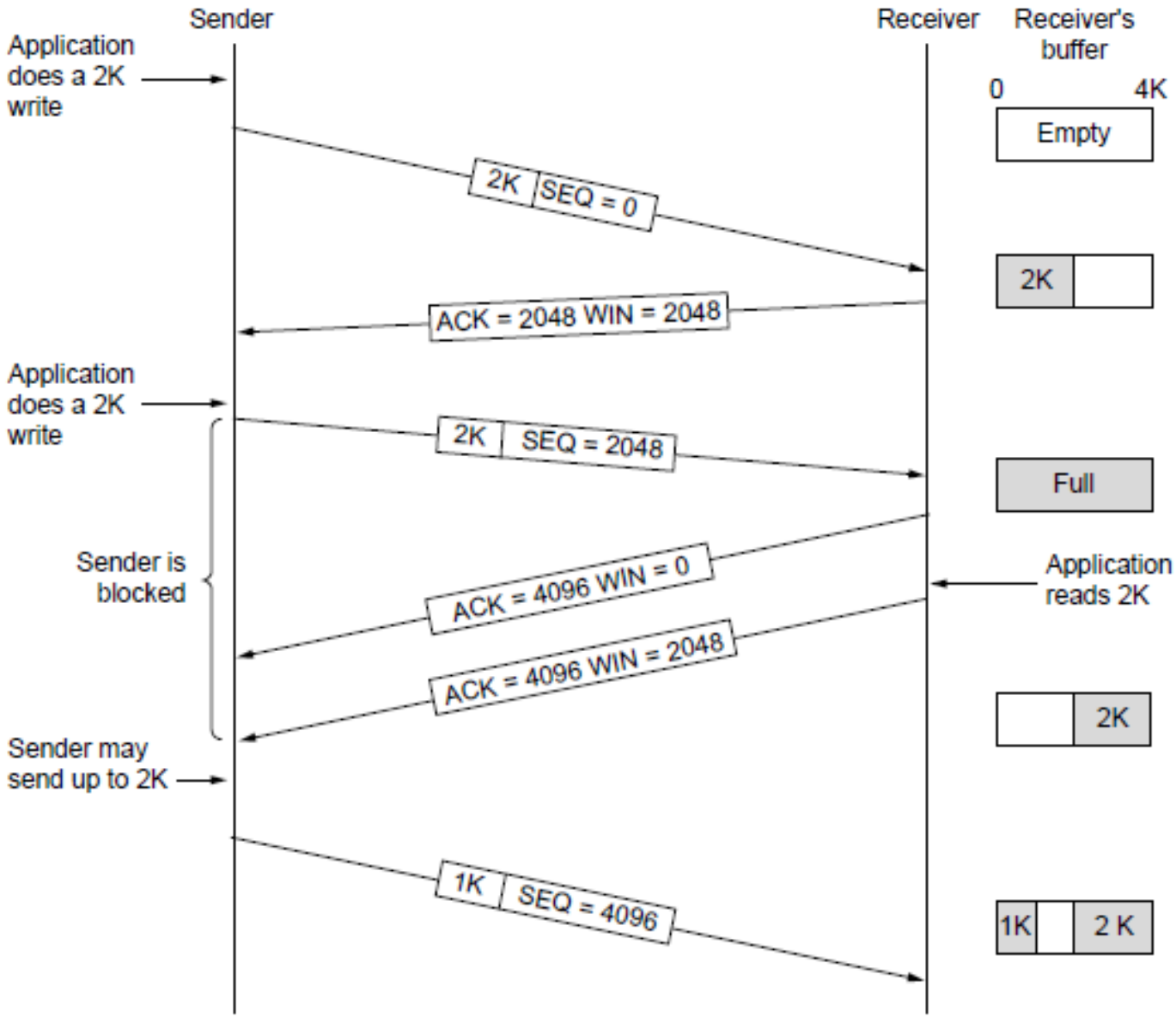
TCP flow control

- Receiver advertises free buffer space by including `rwnd` value in TCP header
  - `RcvBuffer` size set via socket options (typical default is 4096 bytes)
  - Many operating systems autoadjust `RcvBuffer`
- Sender limits amount of unACKed in-flight data to receiver's `rwnd` value
- Guarantees receive buffer will not overflow





TCP sliding window



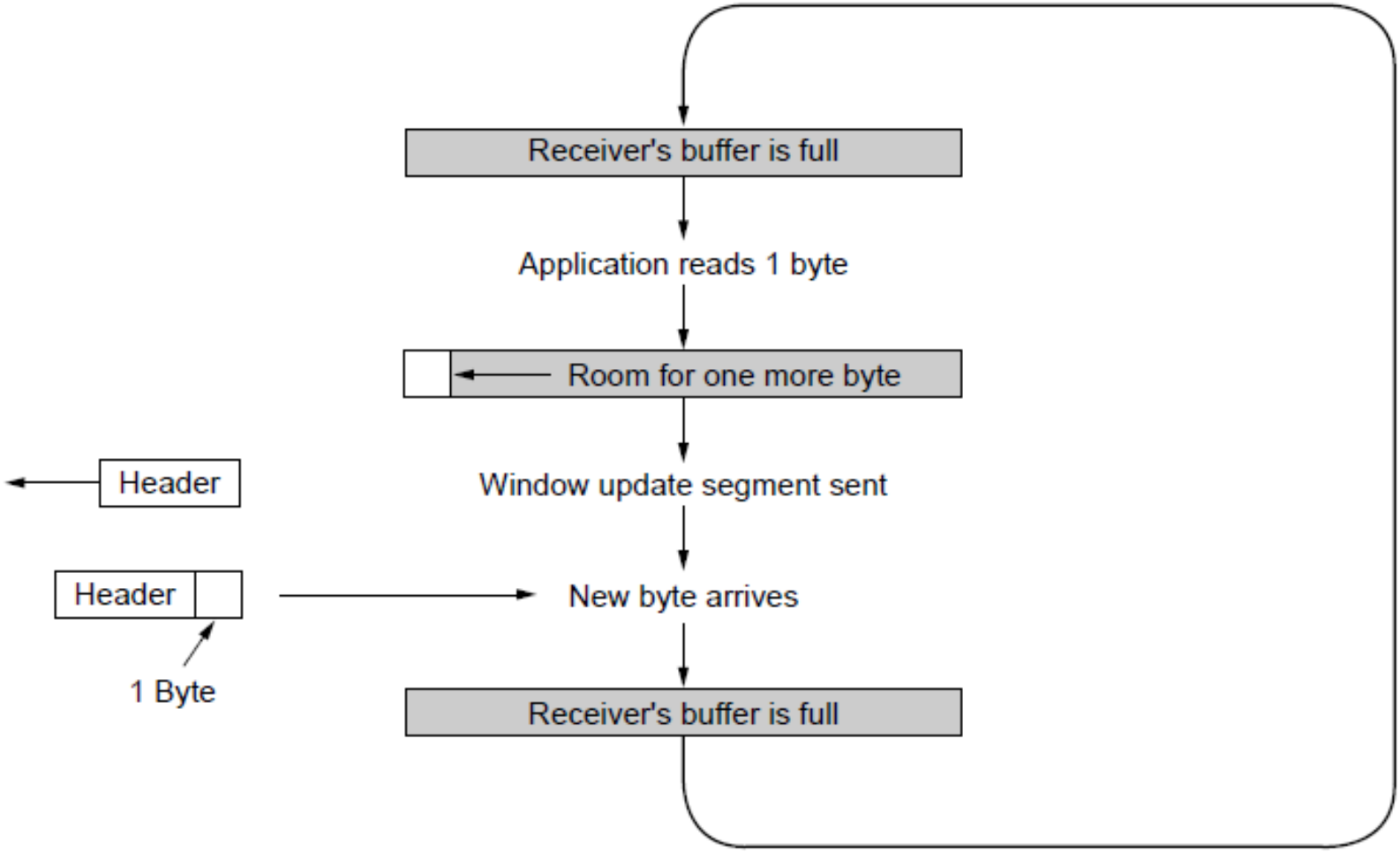
TCP sliding window

- Windows size = 0
  - Bytes up to an including ACK # - 1 have been received
  - Receiver has not consumed data so don't send more
  - When ready, receiver issues same ACK # and non-zero window size
  - Provides the flow-control in TCP
- Sender can still send:
  - Urgent requests (e.g. kill the process)
  - Periodic window probe frames, see if window has opened
    - Prevents deadlock should the receiver's windows update get lost
    - Persistence timer

http://media.pearsoncmg.com/aw/aw_kurose_network_4/applets/flow/FlowControl.htm

http://www.ccs-labs.org/teaching/rn-2012s/animations/flow/index.htm

Silly Window Syndrome



Nagle's Algorithm

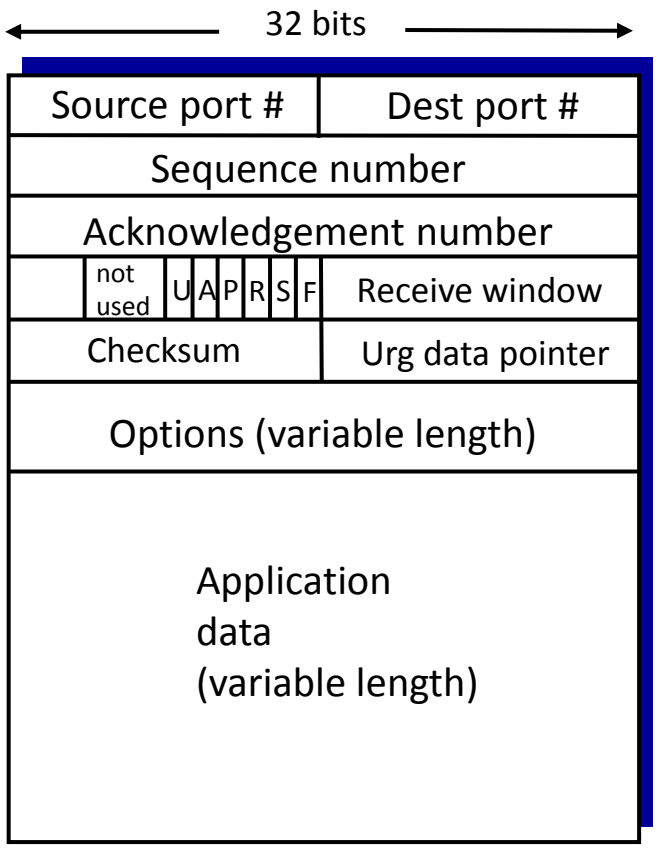
- Sender-side silly window avoidance
- Application produces data to send
  - If >= MSS, send segment
  - If no segments in flight, send the segment
  - Otherwise queue the data
- Limits to one small segment in network
  - But bad for interactive apps like gaming
  - Especially bad if combined with delayed ACKs
    - write byte, write byte, read byte
  - Can be disabled, TCP_NODELAY option

Clark's solution

- Receiver-side silly window avoidance
- Do not send window size update unless:
  - It can handle full MSS size
  - Half of its buffer is empty

Limits in the TCP header

- Sequence number
  - 32 bits longs
- Receive window
  - 16 bits long
  - TCP has satisfied the requirement of the sliding window algorithm that the sequence number space be twice as big as the window size
  - $2^{32} >> 2 \times 2^{16}$



Protecting against wraparound

- Relevance of the 32-bit sequence number space
  - Sequence number may wraparound
  - A byte with sequence *x* could be sent, then later time a second byte with the same sequence *x* could be sent
  - Packets cannot survive in the Internet for longer than the maximum segment lifetime: **MSL = 120s**
  - Sequence number must not wrap around within MSL

Bandwidth	Time until Wraparound
T1 (1.5 Mbps)	6.4 hours
Ethernet (10 Mbps)	57 minutes
T3 (45 Mbps)	13 minutes
Fast Ethernet (100 Mbps)	6 minutes
OC-3 (155 Mbps)	4 minutes
OC-12 (622 Mbps)	55 seconds
OC-48 (2.5 Gbps)	14 seconds

Keeping the pipe full

- 16-bit receive window must allow sender to keep the pipe full
- If the receiver has enough buffer space
  - Window can be opened to allow a full delay × bandwidth product's worth of data

Bandwidth	Delay × Bandwidth Product
T1 (1.5 Mbps)	18 KB
Ethernet (10 Mbps)	122 KB
T3 (45 Mbps)	549 KB
Fast Ethernet (100 Mbps)	1.2 MB
OC-3 (155 Mbps)	1.8 MB
OC-12 (622 Mbps)	7.4 MB
OC-48 (2.5 Gbps)	29.6 MB

Required window size for 100 ms RTT

TCP extensions

- Timestamp option
  - Timestamp added to segment by the sender
  - Echoed by the received
  - Sender can then compute RTT
  - Also can be combined with sequence number
    - Protects against wraparound
- Large window option
  - Use a scale factor
  - Left shift window size field by up to 14 bits
  - Windows of up to 2^{30} bytes

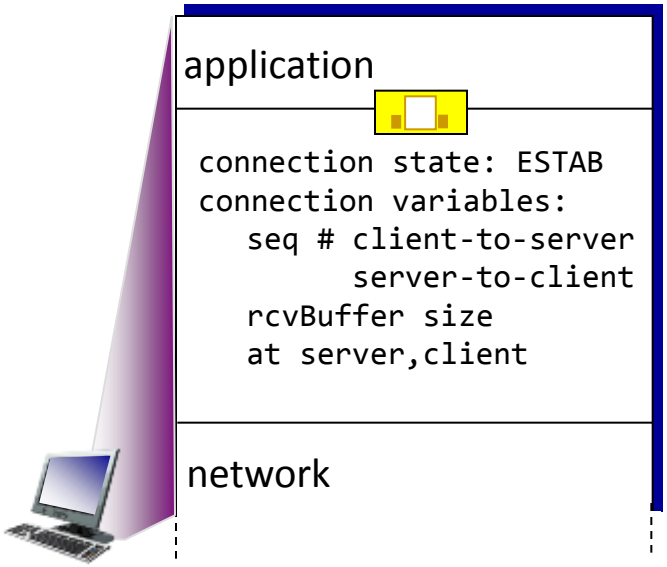
TCP extensions

- Selective acknowledgements (SACK)
  - Optional header fields used to acknowledge additional blocks
  - Sender can then resubmit only missing blocks
- Maximum Segment Size (MSS)
  - Only valid extension during connection setup
  - Set a non-default value for maximum segment size

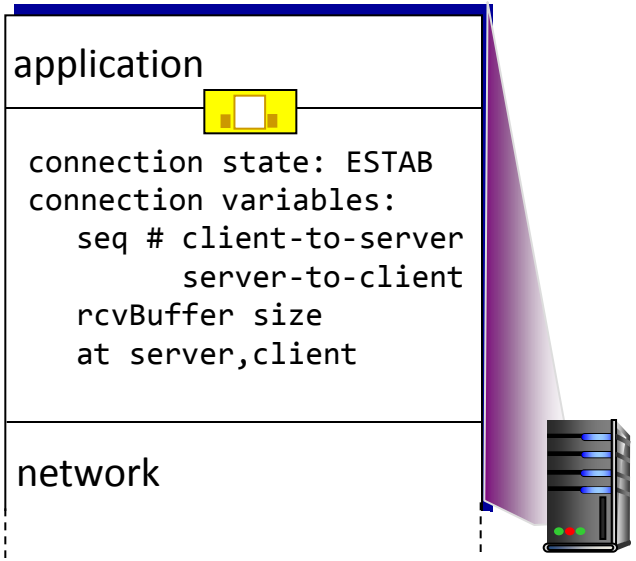
Connection management

Before exchanging data, sender/receiver handshake:

- Agree to establish connection
- Agree on connection parameters



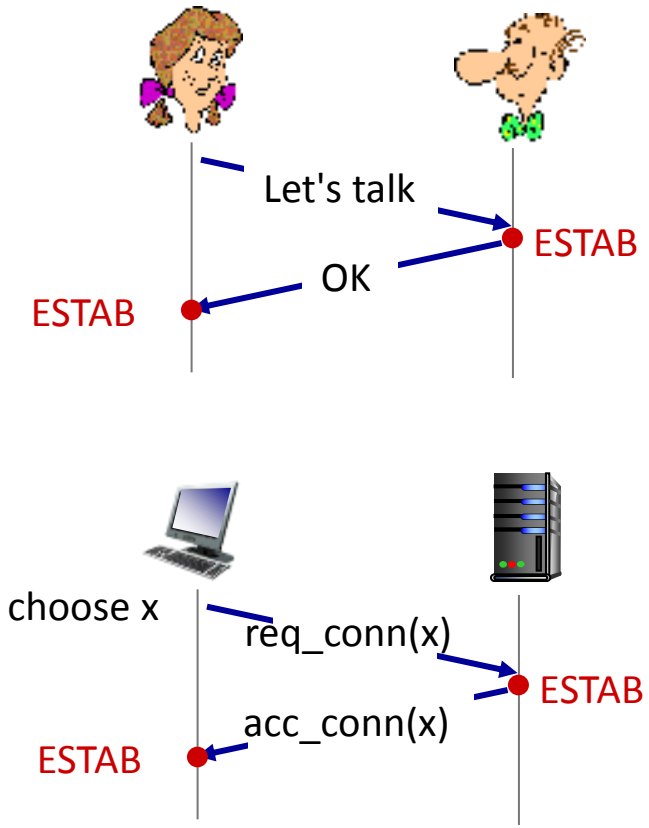
Socket clientSocket =
newSocket("hostname", port);



Socket connectionSocket =
welcomeSocket.accept();

Agreeing to establish a connection

2-way handshake:

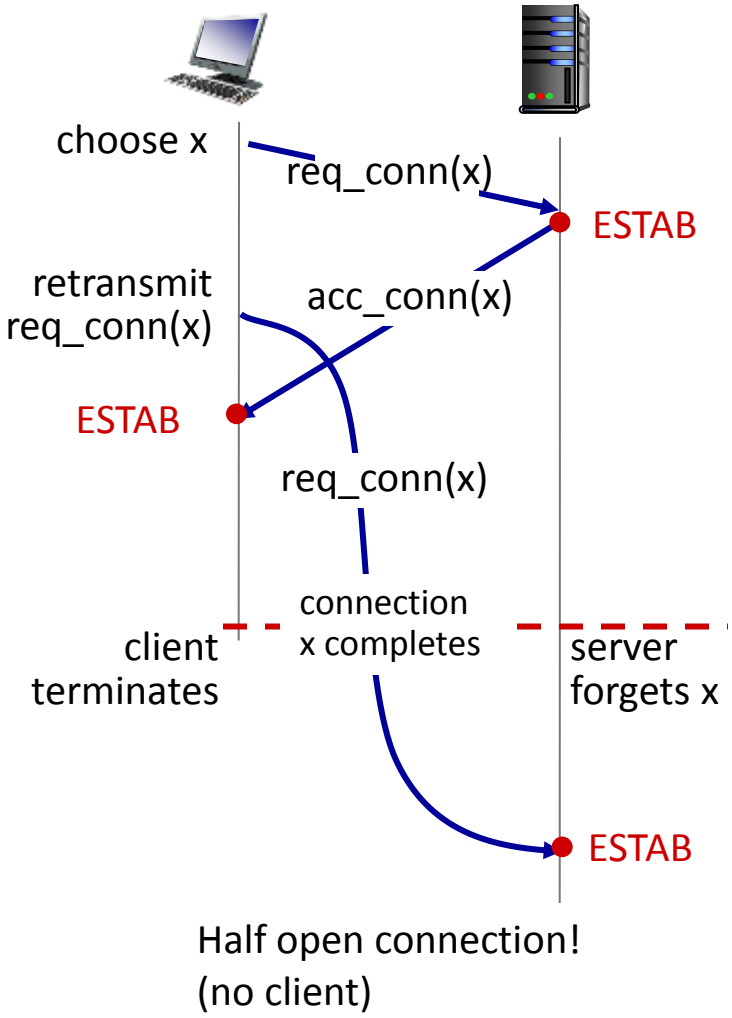


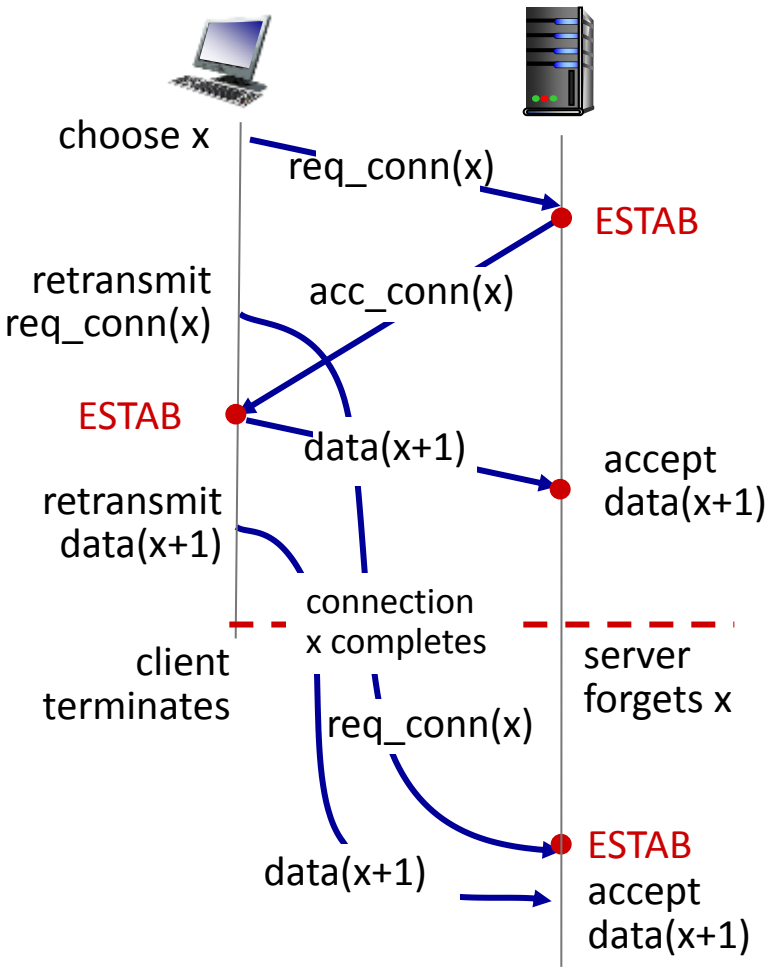
Q: Will 2-way handshake always work in network?

- Variable delays
- Retransmitted messages (e.g. req_conn(x)) due to message loss
- Message reordering
- One side can't see other side

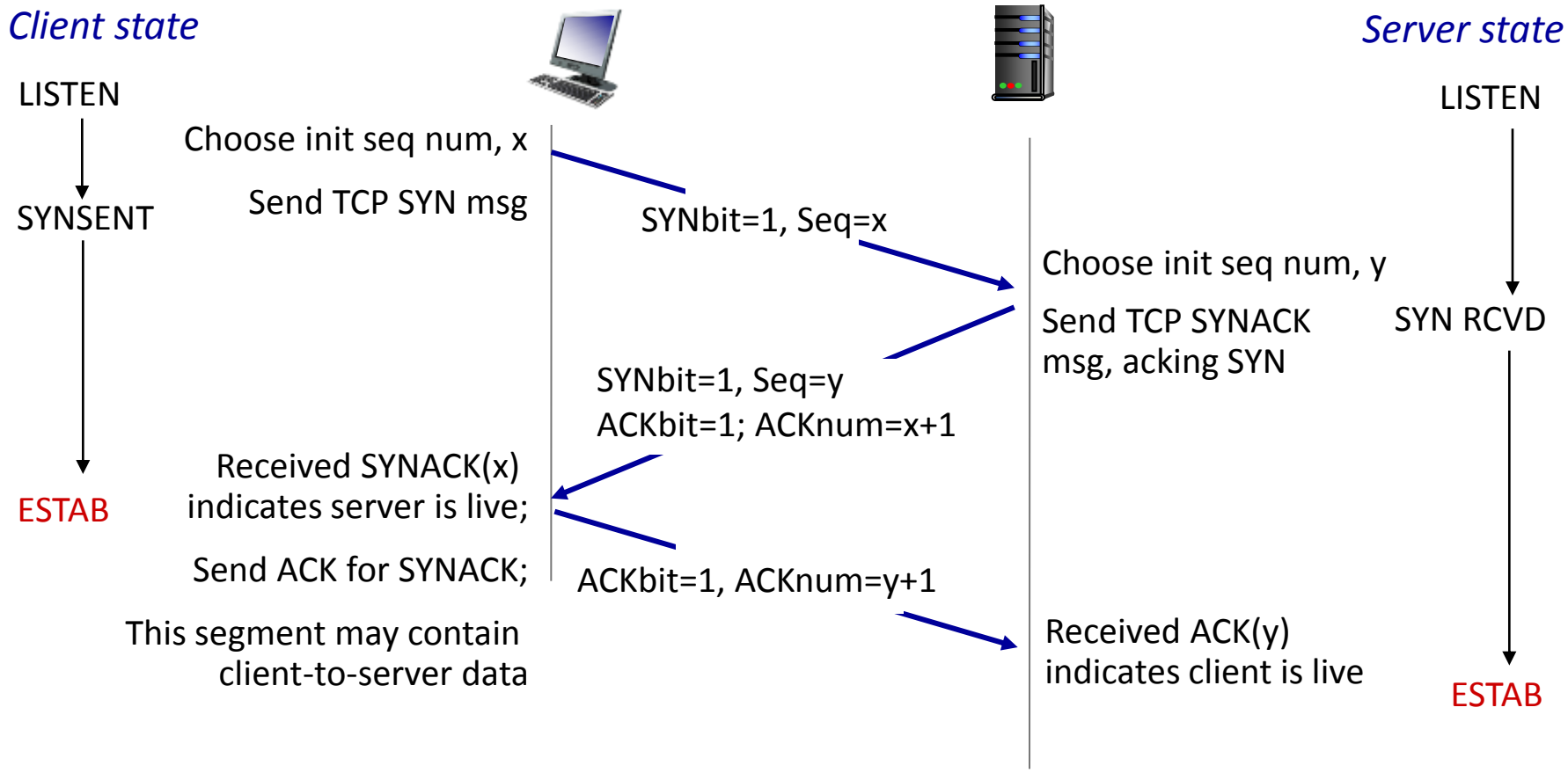
Agreeing to establish a connection

2-way handshake failure scenarios:

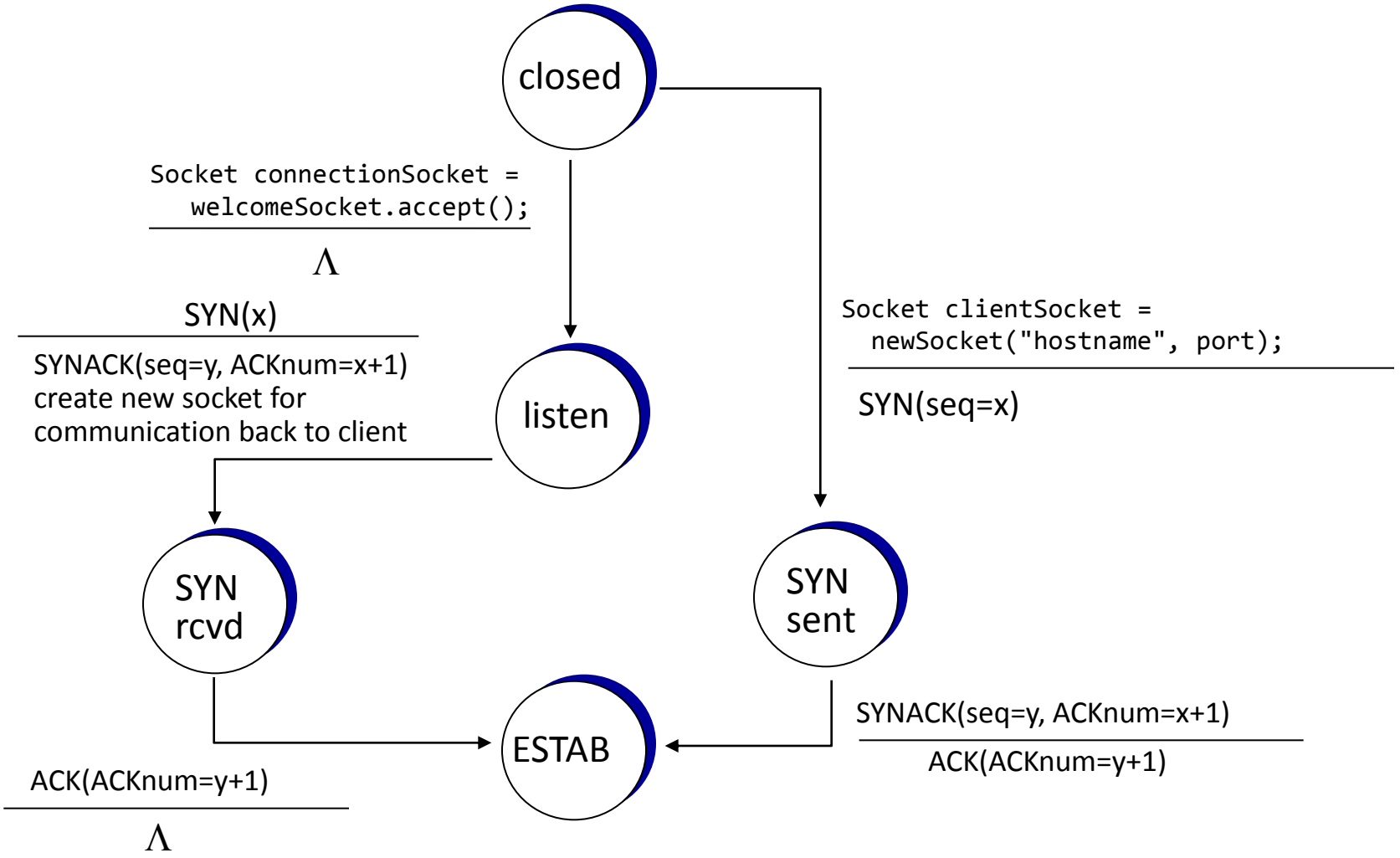




TCP 3-way handshake

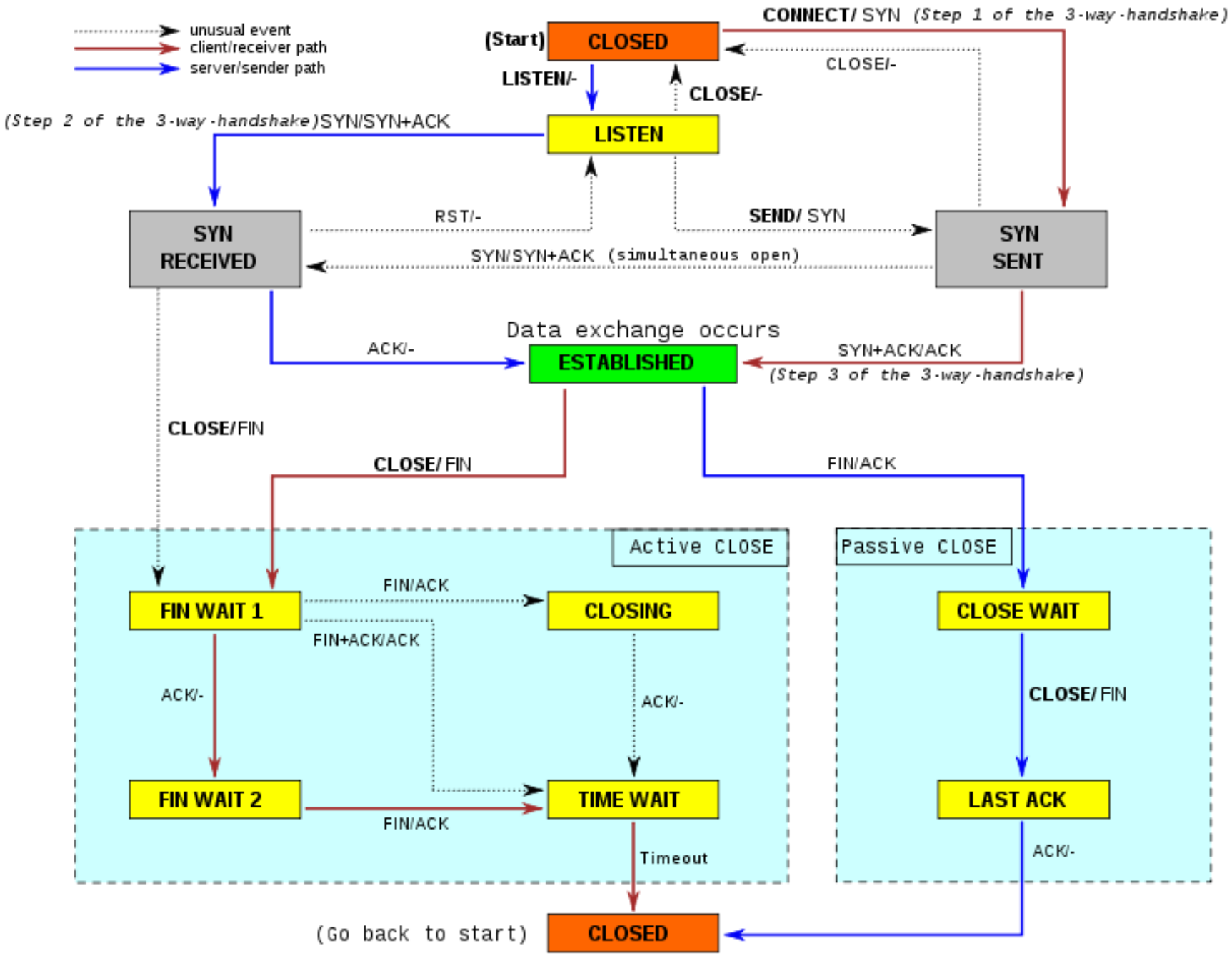


TCP 3-way handshake: FSM

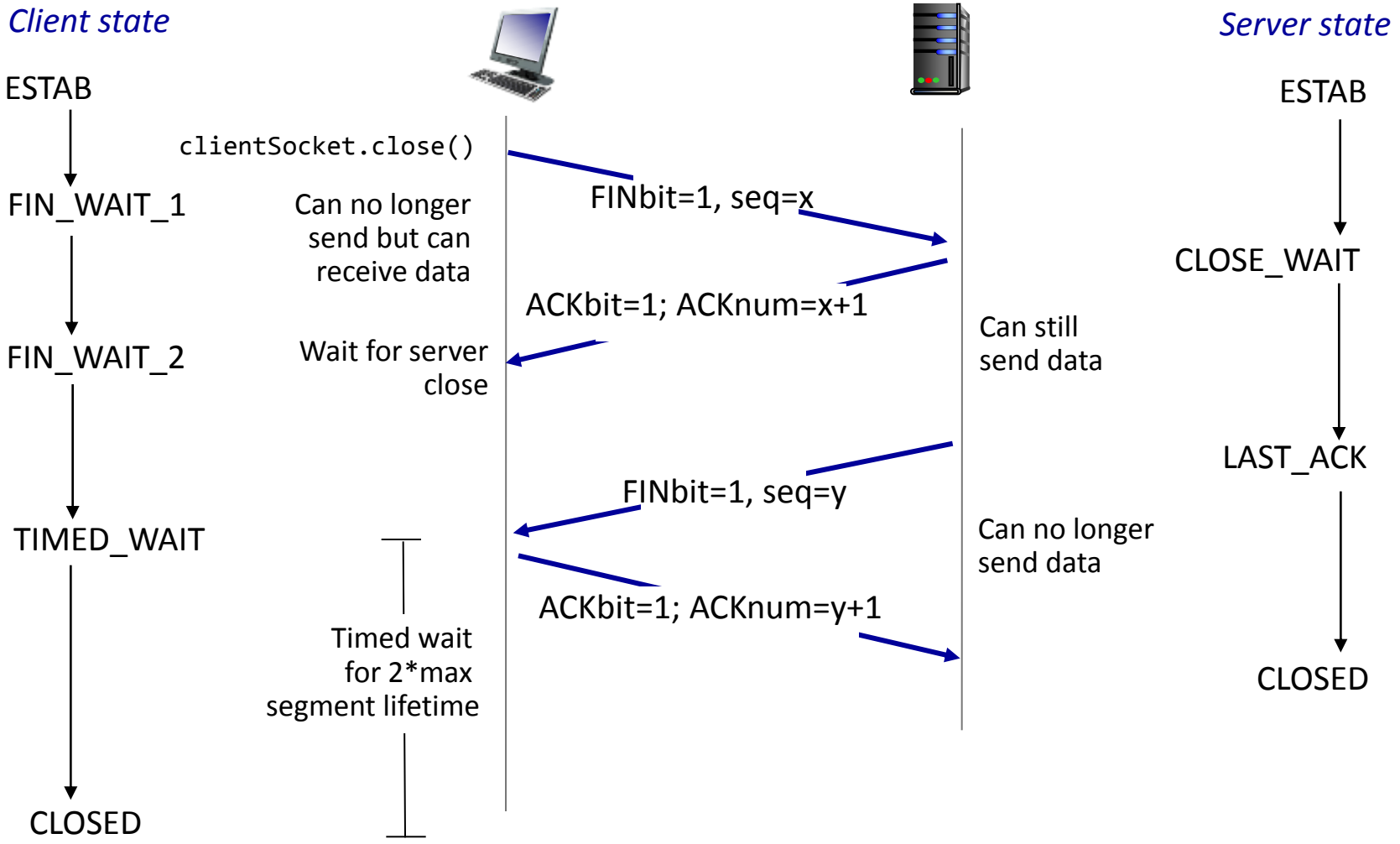


TCP: closing a connection

- Client, server each close their side of connection
  - Send TCP segment with FIN bit = 1
- Respond to received FIN with ACK
  - On receiving FIN, ACK can be combined with own FIN
- Simultaneous FIN exchanges can be handled

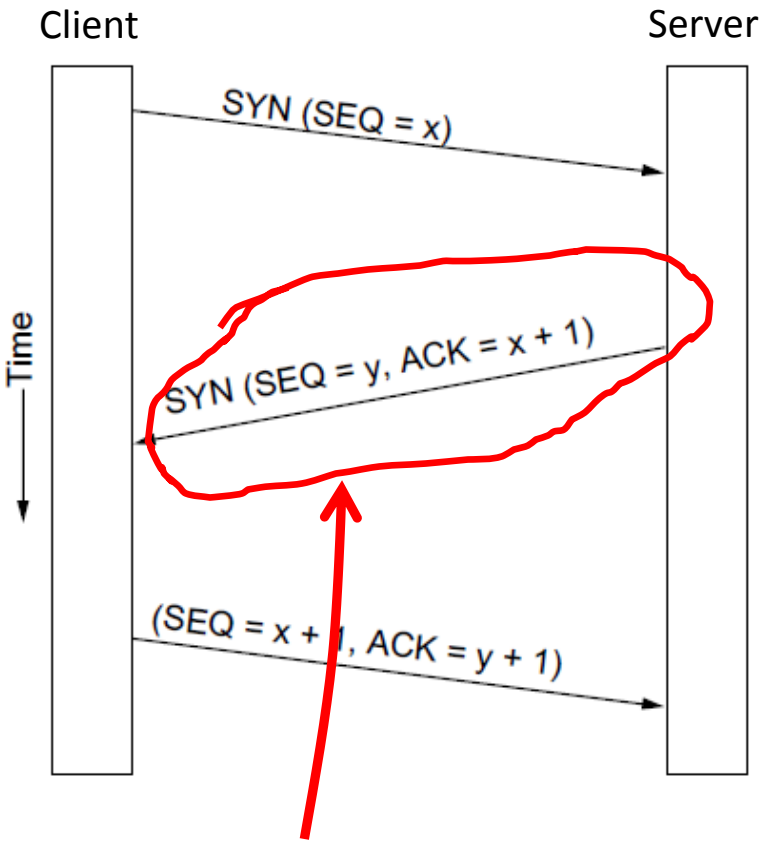

unusual event
client/receiver path
server/sender path
(Start)
CLOSED
CONNECT/ SYN (Step 1 of the 3-way-handshake)
CLOSE/-
LISTEN/-
CLOSE/-
(Step 2 of the 3-way-handshake)SYN/SYN+ACK
LISTEN
SYN RECEIVED
RST/-
SEND/ SYN
SYN/SYN+ACK (simultaneous open)
SYN SENT
Data exchange occurs
ACK/-
ESTABLISHED
SYN+ACK/ACK
(Step 3 of the 3-way-handshake)
CLOSE/ FIN
CLOSE/ FIN
FIN/ACK
Active CLOSE
Passive CLOSE
FIN WAIT 1
FIN/ACK
CLOSING
CLOSE WAIT
FIN+ACK/ACK
ACK/-
ACK/-
CLOSE/ FIN
FIN WAIT 2
TIME WAIT
LAST ACK
FIN/ACK
Timeout
ACK/-
(Go back to start)
CLOSED

TCP: closing a connection



Connection: three-way handshake

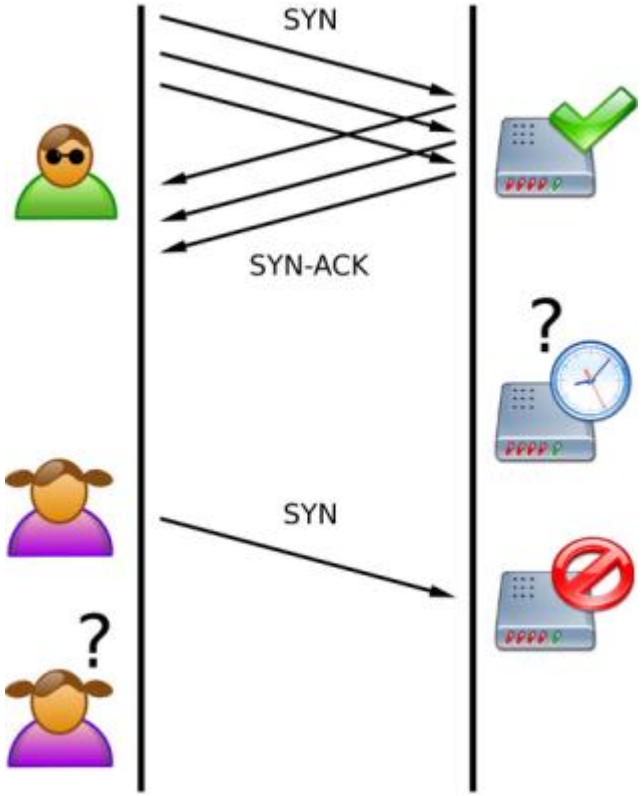
Client	Server
	LISTEN, ACCEPT Passively waits for incoming connection
CONNECT Sends TCP segment to (IP, port) with SYN bit on, ACK bit off	
	Receives segment. OS hands off to process that has done LISTEN on port. If process accepts, send TCP with SYN and ACK bit set.



Server has to remember it's sequence number in step 2

SYN flooding

- SYN flooding
  - Denial-of-service attack
    - Attacker sends large number of SYN requests
    - Never responds or spoofs source IP address
  - Server runs out of resources
    - Server has to track assigned sequence number
    - Fills with half-open connections



SYN cookies

- Server generates sequence number
  - Uses cryptographic process
  - Combine counter, MSS requested, and secret generated from client/server IP and ports
- Fires off response, forgetting number
- Recover original sequence number if client responds

http://cr.yp.to/syncookies.html

http://nmap.org/nmap_doc.html

nmap versus Tokyo

```
$ nmap -v -A 106.187.54.31 -p 1-65535
...
Scanned at 2012-10-16 16:31:38 MDT for 1391s
Not shown: 65526 closed ports
PORT     STATE    SERVICE    VERSION
22/tcp   open     ssh        OpenSSH 5.9p1 Debian 5ubuntu1 (protocol 2.0)
| ssh-hostkey: 1024 c5:ea:eb:88:a3:f1:d1:2d:5f:ed:63:c2:a8:54:bf:33 (DSA)
|_2048 d1:b3:75:95:ed:2a:13:90:27:89:1b:f4:f5:2b:b8:7c (RSA)
25/tcp   filtered smtp
53/tcp   filtered domain
67/tcp   filtered dhcps
68/tcp   filtered dhcpc
80/tcp   open     http       Apache httpd 2.2.22 ((Ubuntu))
|_http-methods: No Allow or Public header in OPTIONS response (status code 200)
|_http-title: Site doesn't have a title (text/html).
1433/tcp filtered ms-sql-s
1434/tcp filtered ms-sql-m
8080/tcp open     http-proxy Squid http proxy 3.1.19
|_http-methods: No Allow or Public header in OPTIONS response (status code 400)
Service Info: OS: Linux; CPE: cpe:/o:linux:kernel
Final times for host: srtt: 188947 rttvar: 3251  to: 201951
...
```

Summary

- TCP flow control
  - Each side informs other of available buffer space
  - Other side never has more than that unACKed in-flight
- TCP connection setup
  - Three-way handshake
  - Each size chooses random sequence number
  - Can be exploited:
    - SYN flood attack
    - Port scanning (NMAP)