CS551
Basic TCP Mechanisms

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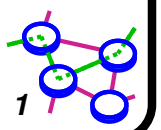
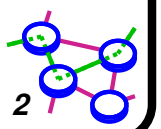
http://merlot.usc.edu/cs551-f12



What Does TCP Provide?

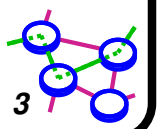
- Does TCP Provide...
  - Connection establishment?
  - Connectionless communication?
  - Congestion control?
  - Differentiated services?
  - Duplicate packet detection?
  - Flow control?
  - Loss recovery?
  - Message or record boundaries?
  - Ordered data delivery?
  - Out-of-order data delivery?
  - Quality of service guarantees?
  - Urgent data indication?



What Does TCP Provide?

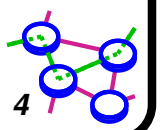
Does TCP Provide...

- Connection establishment? *Y*
- Connectionless communication? *N*
- Congestion control? *Y*
- Differentiated services? *Y (sort of)*
- Duplicate packet detection? *Y*
- Flow control? *Y*
- Loss recovery? *Y*
- Message or record boundaries? *N*
- Ordered data delivery? *Y*
- Out-of-order data delivery? *N*
- Quality of service guarantees? *N*
- Urgent data indication? *Y*



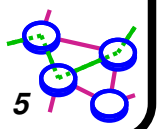
Where And Why Is TCP Used?

- Where: anywhere reliable communication is needed
  - everywhere (60-90% of traffic is TCP)
  - file transfer/ftp, http, p2p, DNS (zone transfers), BGP, SMTP, remote login/telnet
- Why?
  - connection oriented (reliability, ordering, ...)
  - has the right features (congestion control, flow control, ...)
  - widely deployed $\Rightarrow$ interoperability, understood, exhaustively studies, pretty good implementations
  - doing your own protocol is a lot of work

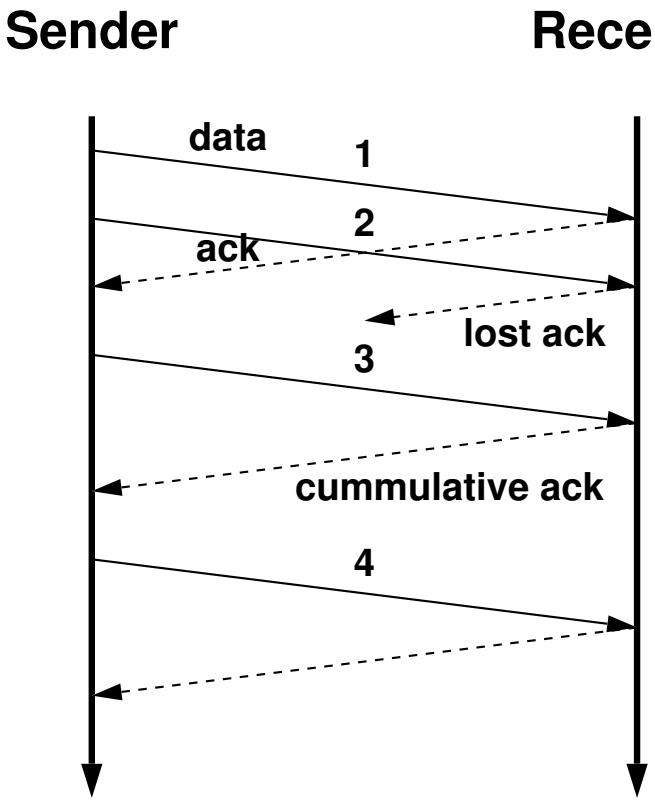


TCP Summary

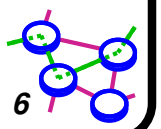
- Communication abstraction:
  - Reliable
  - Ordered
  - Point-to-point
  - Byte-stream
- Protocol implemented entirely at the ends
  - Assumes unreliable, non-sequenced delivery
  - Fate sharing
- Operations
  - OPEN/LISTEN, CONNECT, SEND, RECEIVE, ABORT



TCP Reliability Mechanism



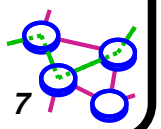
- Summary or mechanisms
  - window-based flow control
  - sequence numbers, 3-way handshake
  - reliability (ACK, retransmission policies)
  - congestion control
  - RTT estimation



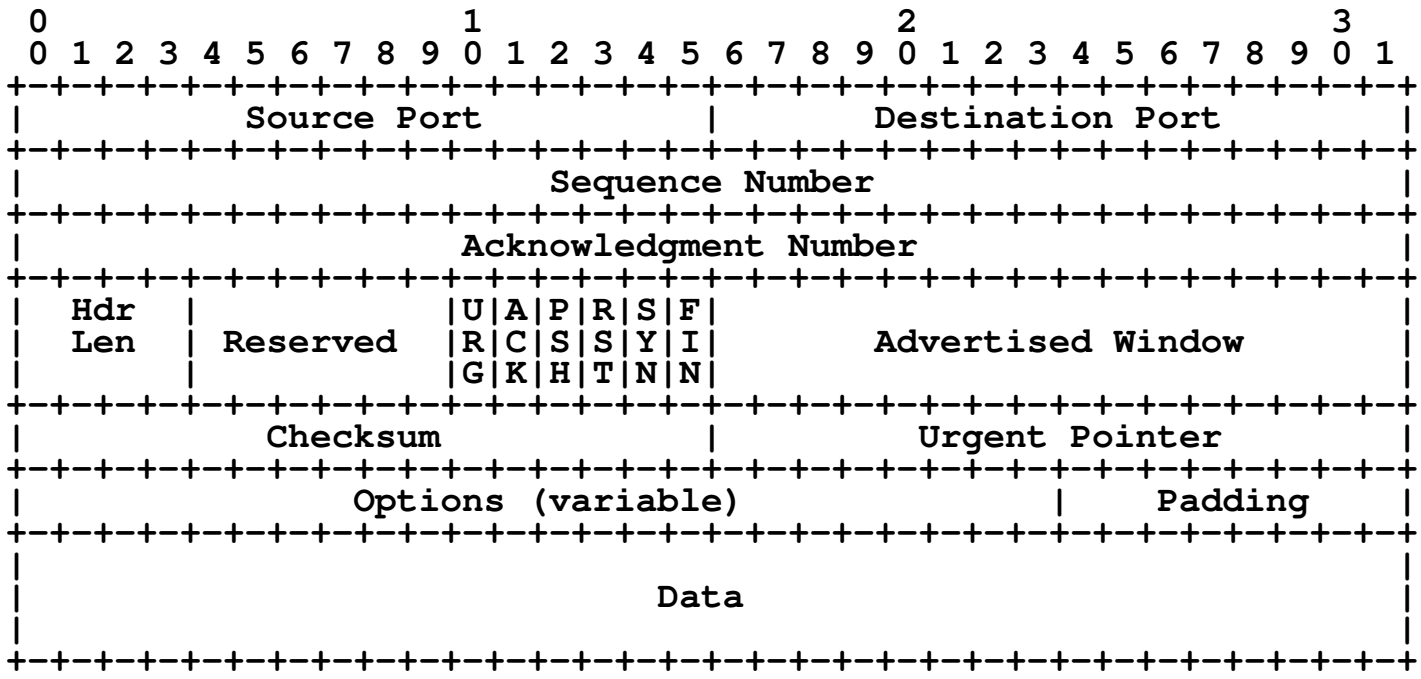
TCP Header

Source port			Destination port
Sequence number			
Acknowledgement			
Hdr len	0	Flags	Advertised window
Checksum			Urgent pointer
Options (variable)			
Data			

Flags: SYN
FIN
RESET
PUSH
URG
ACK

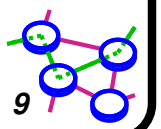


TCP Header



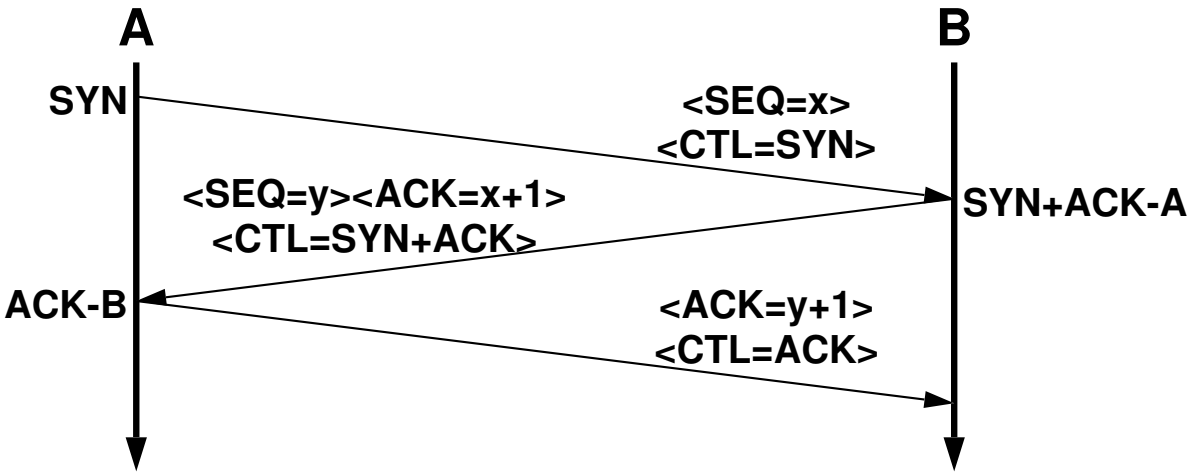
TCP Mechanisms

- Connection establishment
- Sequence number selection
- Connection tear-down
- Round-trip estimation
- Window flow control



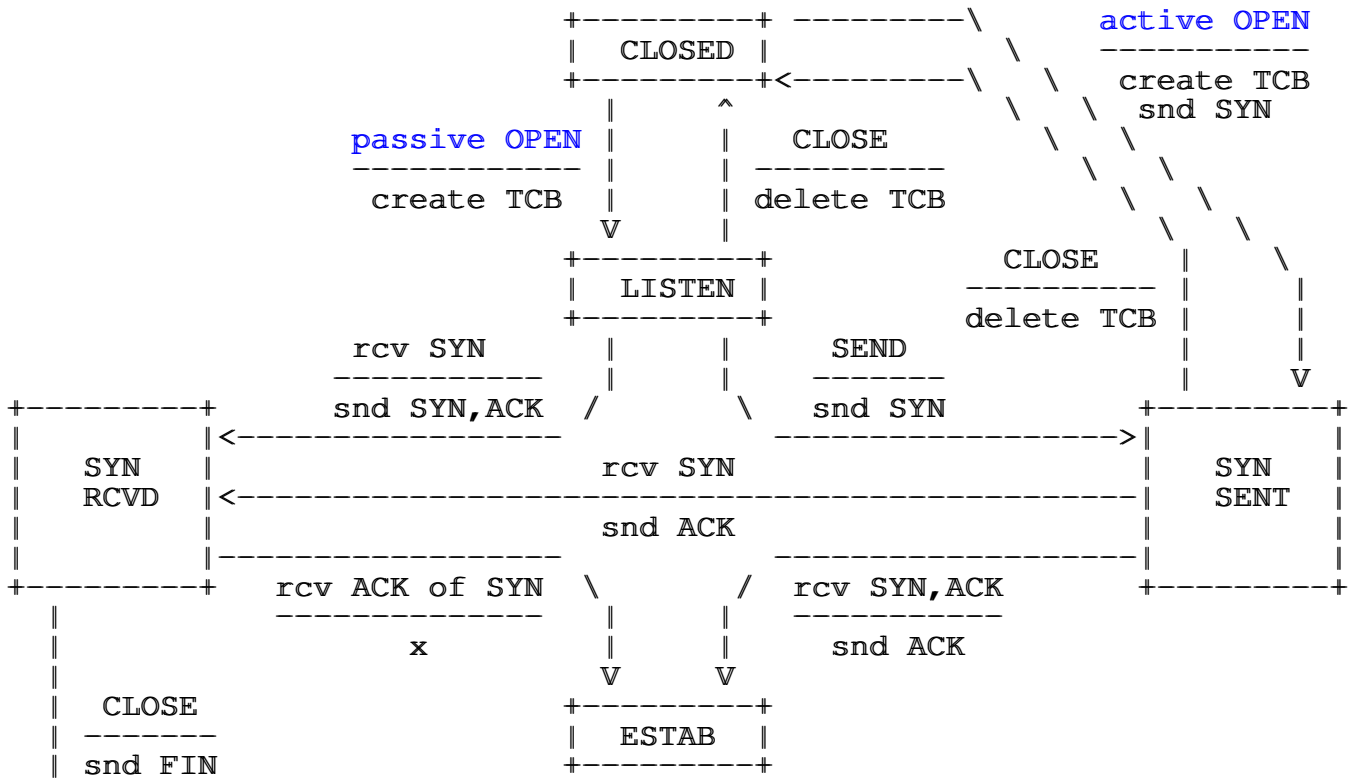
Connection Establishment

A and B must agree on initial sequence number selection:
Use *3-way handshake*

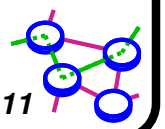


- Setup initial sequence number
- Make sure other side is listening
- Pass window sizes
- Setup options (such as timestamping)

Connection Setup

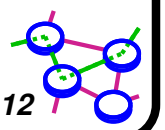


- Error recovery is not part of the spec



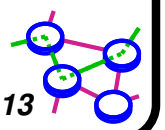
Detecting Half-open Connections

	TCP A			TCP B
1.	(CRASH)			(send 300, receive 100)
2.	CLOSED			ESTABLISHED
3.	SYN-SENT	→ <SEQ=400><CTL=SYN>	→	(??)
4.	(!!)	← <SEQ=300><ACK=100><CTL=ACK>	←	ESTABLISHED
5.	SYN-SENT	→ <SEQ=100><CTL=RST>	→	(Abort!!)
6.	SYN-SENT			CLOSED
7.	SYN-SENT	→ <SEQ=400><CTL=SYN>	→	



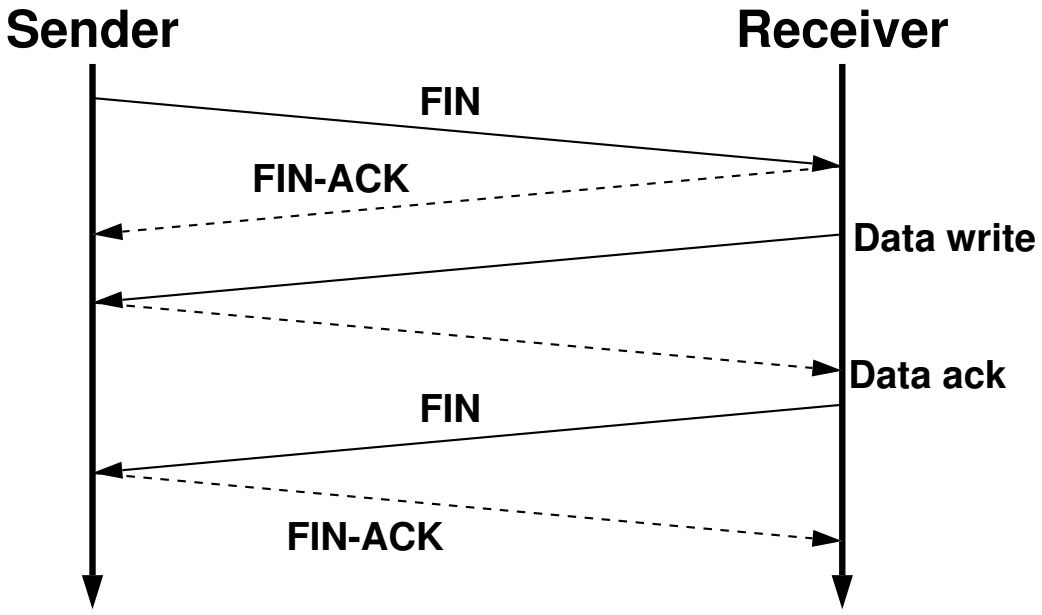
Sequence Number Selection

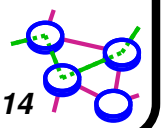
- Initial sequence number (ISN) selection
  - Why not simply chose 0?
  - Must avoid overlap with earlier incarnation
- Possible solutions
  - Assume non-volatile memory
  - Clock-based solutions
- Can still have sequence number overlap
  - If sequence number space not large enough for high-bandwidth connections



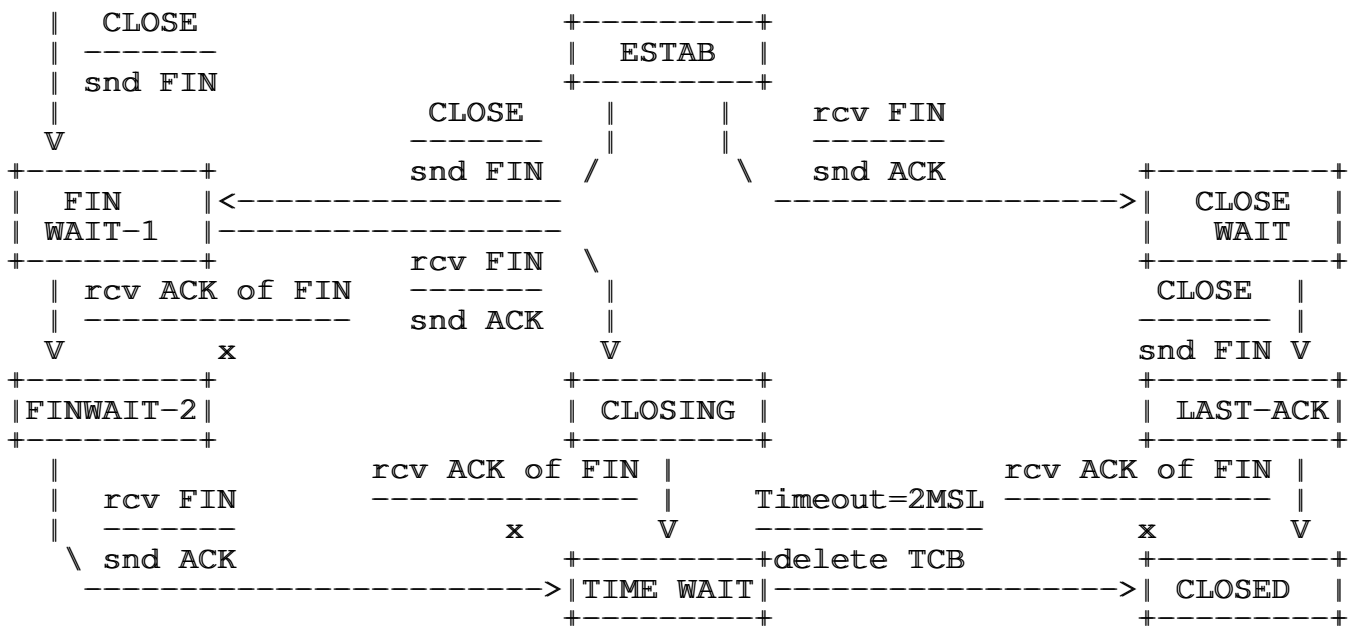
Connection Tear-down

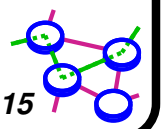
- Either side can close
  - Or one side is closed and the other stays open
- One side must maintain state (TIME_WAIT) for 2 minutes
  - Possible outstanding data in the network
  - Possible ACKs still needed



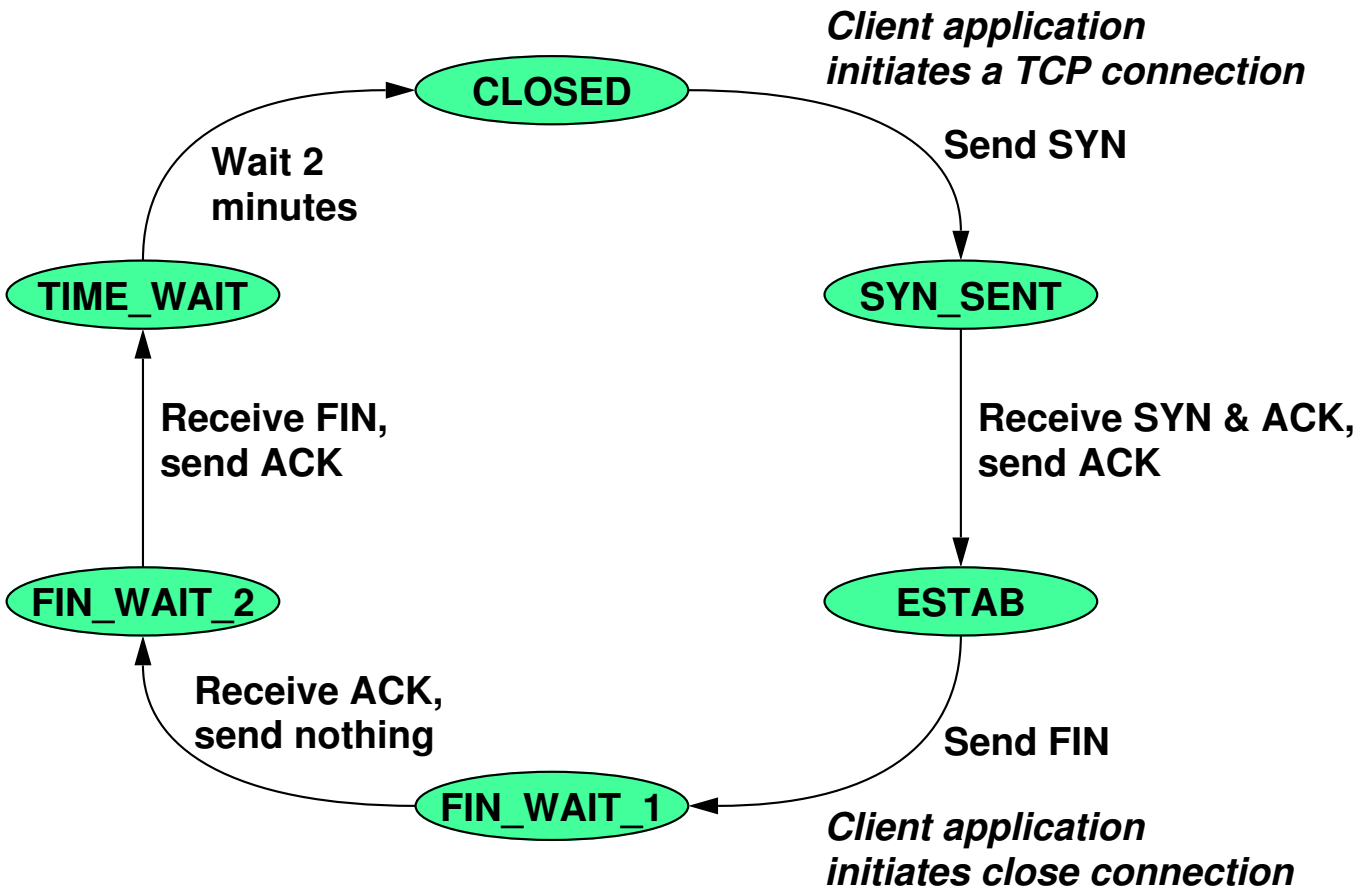


Connection Tear-down

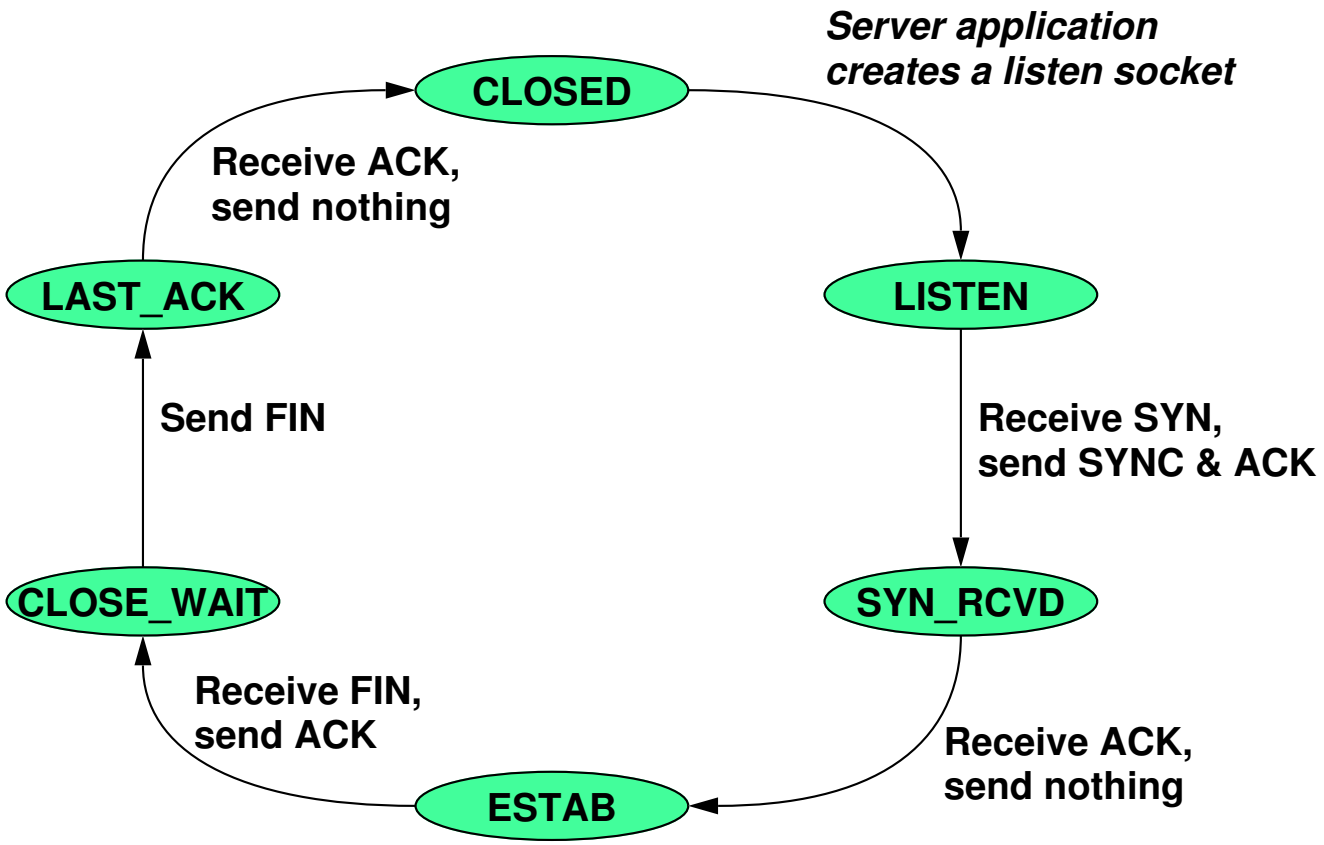


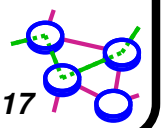


Typical Client TCP State Sequence



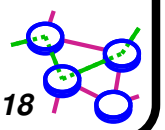
Typical Server TCP State Sequence





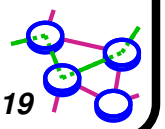
TIME-WAIT Assassination

	TCP A		TCP B
1.	ESTABLISHED (Close)		ESTABLISHED
2.	FIN-WAIT-1	<SEQ=100><ACK=300><CTL=FIN,ACK> →	CLOSE-WAIT
3.	FIN-WAIT-2	← <SEQ=300><ACK=101><CTL=ACK>	CLOSE-WAIT (close)
4.	TIME-WAIT	← <SEQ=300><ACK=101><CTL=FIN,ACK>	LAST-ACK
5.	TIME-WAIT	<SEQ=101><ACK=301><CTL=ACK> →	CLOSED
5.1.	TIME-WAIT	← <SEQ=255><ACK=33> ... old duplicate	
5.2.	TIME-WAIT	<SEQ=101><ACK=301><CTL=ACK> →	????
5.3.	CLOSED (prematurely)	← <SEQ=301><CTL=RST>	????

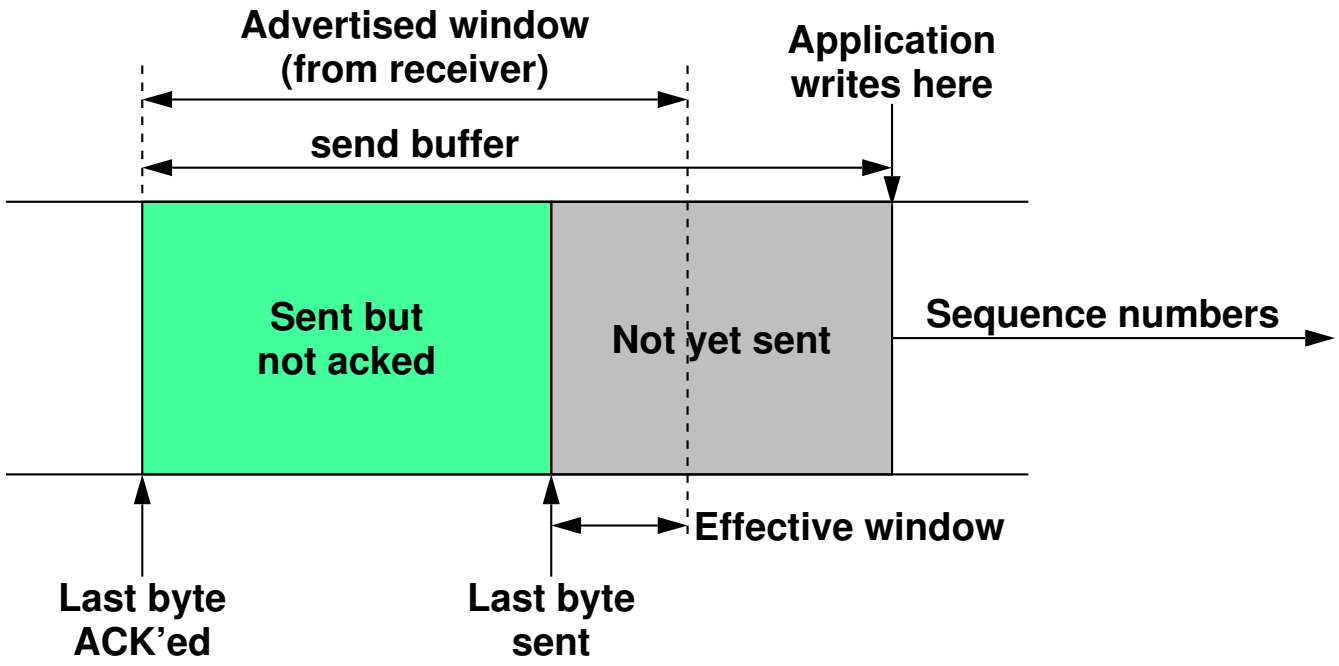


Flow Control

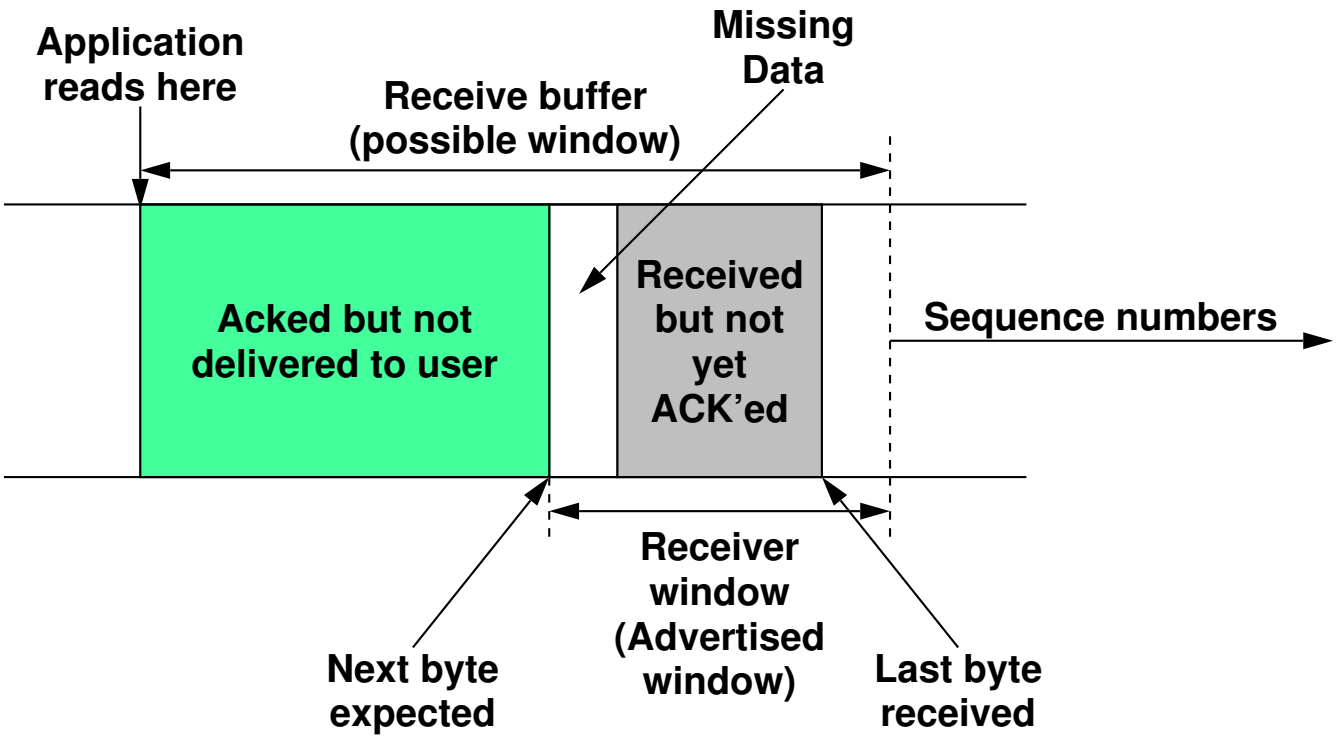
- Problem: Fast sender can overrun receiver
  - Packet loss, unnecessary retransmissions
- TCP's solution:
  - Window sizes are passed in every packet to avoid sender overrunning the receiver
  - Sender transmits at pre-negotiated rate
  - Sender limited to a window's worth of unacknowledged data
- Flow control different from congestion control



Window Flow Control: Sender

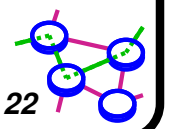


Window Flow Control: Receiver



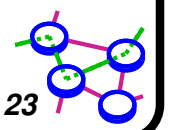
Window Advancement Issues

- Advancing a full window
  - Slow receiver: receive buffer fills up (all data ACK'ed), last advertised window size is 0, sender is not allowed to send, how does it know the window has opened up?
    - solution: sender sends one data byte (probe) when advertised window size is 0
- Silly window syndrome
  - Fast sender, slow receiver: receiver with small buffer advertise it, sender quickly fills it with small amount of data
    - solution: delay ACK at receiver, Nagle's algorithm at sender
    - Nagle's algorithm -- send 1st partial packet, but not more until it is ACK'ed or have a full packet (basically, stop & wait for small packets)



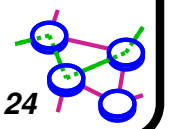
TCP Extensions

- Needed for high-bandwidth delay connections
  - Accurate round-trip time estimation
  - Window size limitations
  - Impact of loss
- Implemented using TCP options
  - Timestamp
  - Protection from sequence number wraparound
  - Large windows



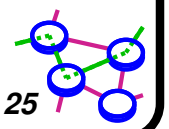
Timestamp Extension

- Used to improve timeout mechanism by more accurate measurement of RTT
- When sending a packet, insert current timestamp into option
- Receiver echoes timestamp in ACK



Protection From Wraparound

- Wraparound time vs. link speed:
  - 1.5Mbps (T1): 6.4 hours
  - 10Mbps (Ethernet): 57 minutes
  - 45Mbps (T3): 13 minutes
  - 100Mbps (FDDI): 6 minutes
  - 155Mbps (STS-3): 4 minutes
  - 622Mbps (STS-12): 55 seconds
  - 1.2Gbps (STS-24): 28 seconds
- Recall that MSL is 2 minutes in TCP
- Use timestamp (32-bit) to distinguish sequence number wraparound



Large Windows

- Recall that the AdvertisedWindow field is 16-bit long
- Delay $\times$ Bandwidth vs. link speed, assuming 100ms RTT
  - 1.5Mbps (T1): 18KB
  - 10Mbps (Ethernet): 122KB
  - 45Mbps (T3): 549KB
  - 100Mbps (FDDI): 1.2MB
  - 155Mbps (STS-3): 1.8MB
  - 622Mbps (STS-12): 7.4MB
  - 1.2Gbps (STS-24): 14.8MB
- Apply scaling factor to advertised window
  - Specifies how many bits window must be shifted to the left
- Scaling factor exchanged during connection setup