# TCP

•Transmission Control Protocol (TCP): defined in 1973 by Cerf and Kahn. RFC 793 specifies the protocol.

•Roadmap:

- •Lecture 1: the basics
  - •sliding window mechanism
  - •message formats
  - •TCP state machine
- •Lecture 2: operation
  - •congestion control algorithms
- •Lecture 3
  - •Performance
- •Other topics
  - •TCP enhancements
  - •TCP Friendly congestion control

# TCP

- Provides a **reliable** end-to-end delivery service
  - Sliding window protocol
- Properties of TCP:
  - Stream orientation
  - Virtual circuit connection
    - Transport vs network level
  - Buffered transport
    - for reliability and to handle speed mismatch
  - Unstructured stream
  - Full duplex connection

# TCP

•**Reliability:** objective is to deliver a stream from one machine to another without duplication or loss of data.
•Requires error detection and recovery algorithms.
•General approach: automatic repeat and request (ARQ)
•Example: Stop-and-Wait ARQ:

# TCP

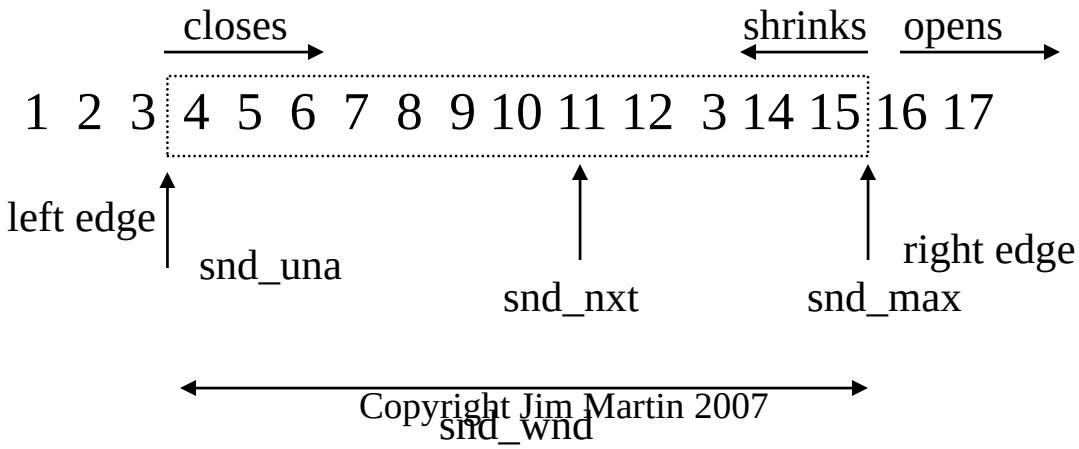
- Go-Back-n (or sliding window) ARQ protocols are more efficient

# TCP

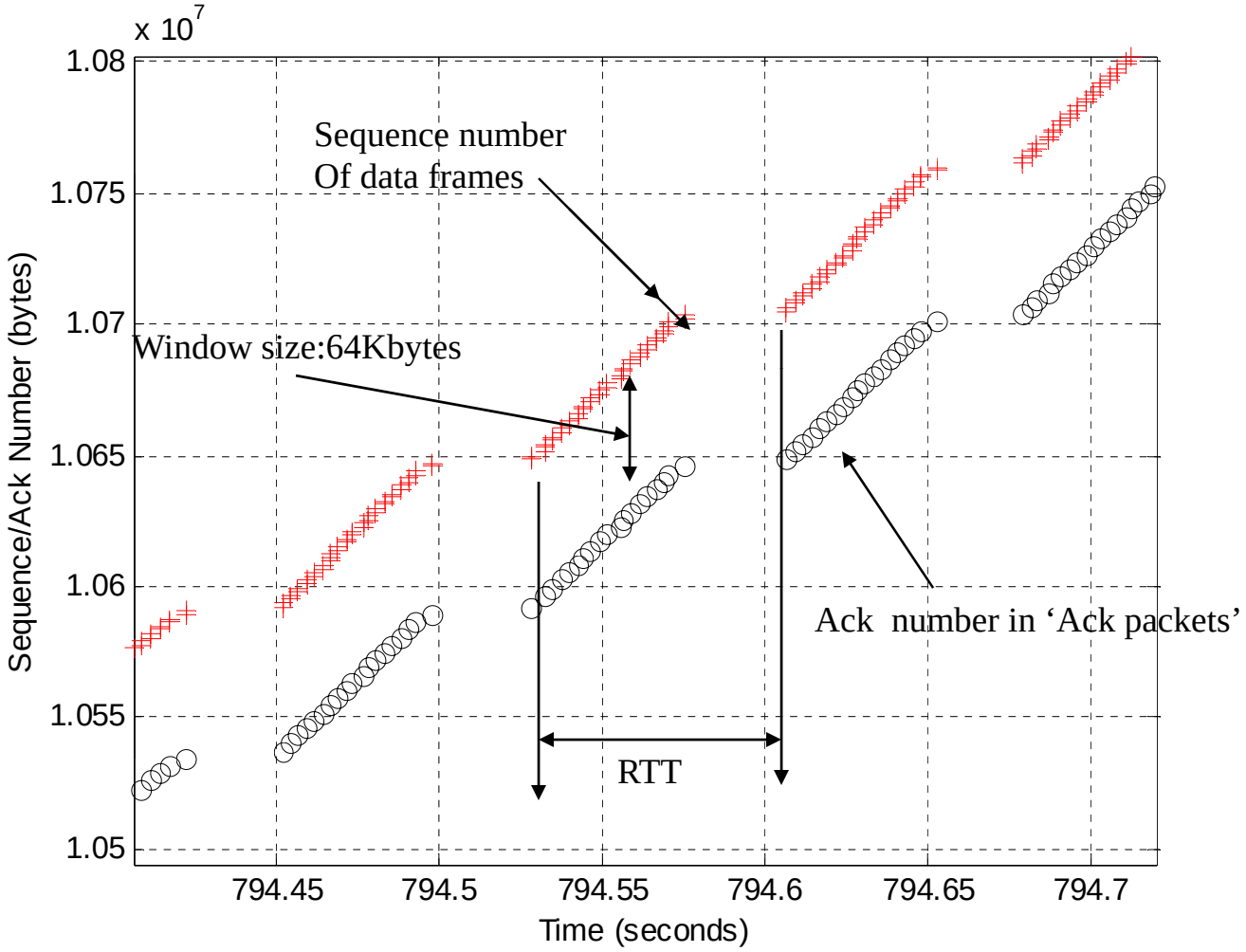
- Select  Repeat ARQ even more efficient

# TCP

- A sliding window algorithm has:
  - sequence numbers
  - acknowledgement numbers
  - a send window size
  - an ack strategy
- Go-back-n can substantially increase throughput compared with a stop and wait protocol.
- Selective repeat optimal for high loss networks.
- TCP's sliding window is a hybrid:
  - enhanced error recovery
  - a window size that changes over time



# ACK/SNUM plot: based on tcpdump at a sender




A "+" is a data packet transmission
A "o" is an Ack packet arrival

# TCP

- TCP is a protocol, not a piece of software.
- What does it do?
  - It specifies the format of the data and acknowledgements that two computers use to exchange data reliably.
  - It breaks application data into ***'segments'*** and presents the original stream to the receiver.
  - It specifies the rules for error recovery.
  - It specifies how a connection is started and closed.
- What does it not do?
  - It does not specify a programming interface.

# TCP

- TCP uses protocol numbers to demultiplex inbound traffic to applications.
- A UDP server will receive all packets destined for the server address/port.
- TCP uses a connection as the fundamental abstraction, not the port.
    - A connection is identified by a pair of endpoints.
    - Unlike UDP, a TCP server can multiplex multiple Cxs over a single port.

# TCP

•Both ends of a TCP application program must agree that the connection is desired.

- •The “initiator” does this with an explicit connect (an active open).
- •The “receiver” does this with a passive open (the listen and accept).

# TCP

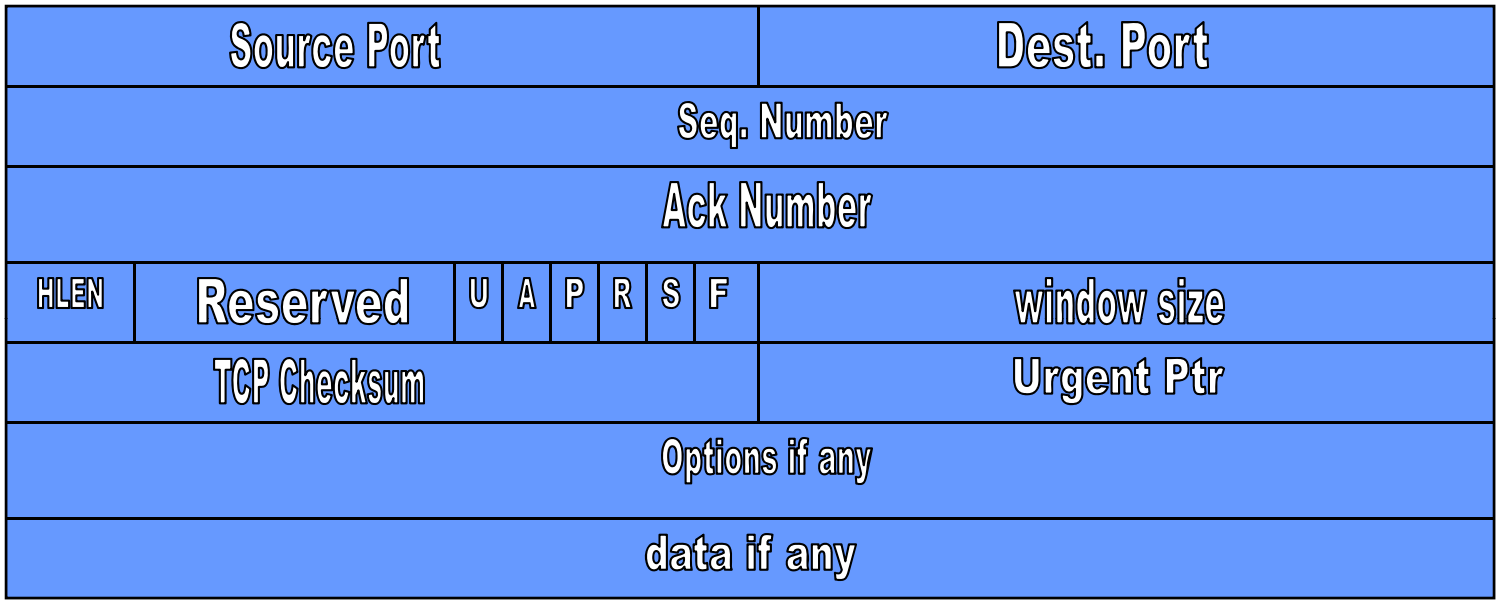
- UDP Datagram vs TCP Segment

# TCP

- TCP's window varies dynamically, determined by congestion control algorithms.
- Many forms of congestion control- one way to classify is by location:
- End to end flow control vs network level congestion.
    - End-to-end: sender and receiver participate.
        - A receiver can inform a sender when it runs out of buffers.
    - Network: routers participate in one of two ways:
        - implicit feedback indication such as dropped packets
        - explicit feedback indication such as source quench or setting a packet bit (a congestion indication bit).

# TCP

- TCP Segment header (minimum 20 byte header)




HLEN: header length in 32 bit multiples. Actual size depends on number of options.
Code bites:

URG: Urgent pointer field is valid
ACK: Ack field is valid (always except first syn packet)
PSH: Segment requests a push
RST: Reset the connection
SYN: Synchronize sequence numbers
FIN: Sender has reached end of its byte stream

Window size: Receiver's advertised window (flow control)

# TCP

Sequence and ack numbers:

- 32-bit unsigned long,  wraps around to 0 after reaching 2^32-1.
- Sequence number: identifies the byte in the stream of data that the first byte of data in the segment represents.
  - First segment contains the ‘initial sequence number’.
  - Subsequent Seq number’s relative to the ISN.
- Ack number: indicates the next sequence number that the receiver expects to receive.

- The ISN cycles, repeating roughly every 4-9 hours, why ?

# TCP

- Out of Band data: TCP allows a sender to specify data as urgent.
  - The receiver sends urgent data immediately to the receiver (regardless of its position in the stream).
  - When URG is set, the URG pointer field specifies the position in the segment where urgent data ends (I.e., it points to the last byte).
- But not a true out of band mechanism….
- Example: If a user aborts (CNT-C's) an FTP data transfer, urgent data (an ABORT message) is sent by the client instructing the server to cancel.

# TCP

- Push bit: A notification from the sender to the receiver for the receiver to pass all the data that it has to the receiving process.
  - BSD systems ignore it.
  - Most API's don't allow a program to set the push bit.
- TCP Options
  - Maximum Segment Sized: specifies the largest "chunk" of data that will be sent to the other end.
    - Option can only appear in a SYN segment
  - Timestamp
  - Window scale

# TCP

- TCP connection setup: 3 way handshake
  - guarantees that both sides are ready to transfer data (handles simultaneous opens)
  - Allows both sides to agree on initial sequence numbers (ISNs).

# TCP

- TCP connection termination:  modified  3 way handshake
- The TCP close requires 4 flows rather than 3
- A FIN leads to an EOF to a receiving application
- Handles simultaneous close
- Supports a half close:  one side terminates its output but still receives data from the other side.
    - Sockets supports this-  but most applications don't use it.

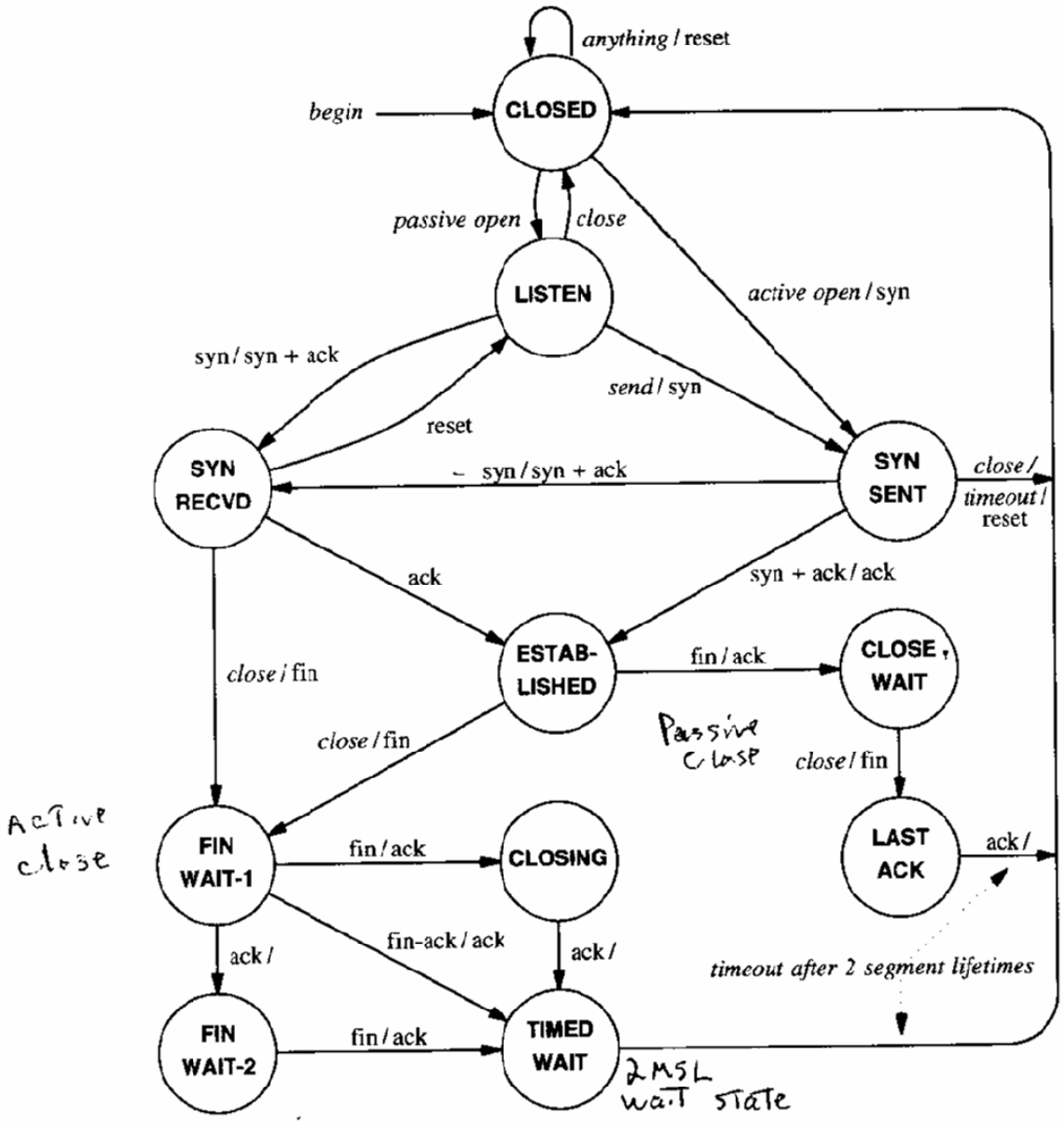



**Figure 13.15** The TCP finite state machine. Each endpoint begins in the *closed* state. Labels on transitions show the input that caused the transition followed by the output if any.

# TCP

- TCP Acks are cumulative
- Advantage:
  - Acks easy to generate and not amibiguous.
  - Lost Acks don’t necessarily force a retransmission.
- Disadvantage:
  - Receiver does not get all the information about successful retransmissions.

**982120155.354974 192.168.1.100.1279 > 212.208.230.29.45912: S 143851464:143851464(0) win 16384 <mss 1460> (DF)**
**982120155.567089 212.208.230.29.45912 > 192.168.1.100.1279: S 2709967313:2709967313(0) ack 143851465 win 32120 <mss 1460> (DF)**
**982120155.567271 192.168.1.100.1279 > 212.208.230.29.45912: . ack 1 win 17520 (DF)**
**982120156.248161 212.208.230.29.45912 > 192.168.1.100.1279: P 1:1461(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.258408 212.208.230.29.45912 > 192.168.1.100.1279: P 1461:2921(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.266857 192.168.1.100.1279 > 212.208.230.29.45912: . ack 2921 win 14600 (DF)**
**982120156.487286 212.208.230.29.45912 > 192.168.1.100.1279: P 2921:4381(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.496933 212.208.230.29.45912 > 192.168.1.100.1279: P 4381:5841(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.507092 212.208.230.29.45912 > 192.168.1.100.1279: P 5841:7301(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.666886 192.168.1.100.1279 > 212.208.230.29.45912: . ack 7301 win 10220 (DF)**
**982120156.936903 212.208.230.29.45912 > 192.168.1.100.1279: P 7301:8761(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.951005 212.208.230.29.45912 > 192.168.1.100.1279: P 8761:10221(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.963396 212.208.230.29.45912 > 192.168.1.100.1279: P 10221:11681(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120156.982527 212.208.230.29.45912 > 192.168.1.100.1279: P 11681:13141(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120157.066889 192.168.1.100.1279 > 212.208.230.29.45912: . ack 13141 win 4380 (DF)**
**982120157.299244 212.208.230.29.45912 > 192.168.1.100.1279: P 13141:14601(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120157.310435 212.208.230.29.45912 > 192.168.1.100.1279: P 14601:16061(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120157.321023 212.208.230.29.45912 > 192.168.1.100.1279: P 16061:17521(1460) ack 1 win 32120 (DF) [tos 0x10]**
**982120157.466886 192.168.1.100.1279 > 212.208.230.29.45912: . ack 17521 win 0 (DF)**
**982120158.988267 212.208.230.29.45912 > 192.168.1.100.1279: . ack 1 win 32120 (DF) [tos 0x10]**
**982120158.988477 192.168.1.100.1279 > 212.208.230.29.45912: . ack 17521 win 0 (DF)**
**982120161.846314 212.208.230.29.45912 > 192.168.1.100.1279: . ack 1 win 32120 (DF) [tos 0x10]**
**982120161.846590 192.168.1.100.1279 > 212.208.230.29.45912: . ack 17521 win 0 (DF)**
**982120162.258374 192.168.1.100.1279 > 212.208.230.29.45912: . ack 17521 win 10240 (DF)**
**982120162.266653 192.168.1.100.1279 > 212.208.230.29.45912: . ack 17521 win 17520 (DF)**