COSC264

Introduction to Computer Networks and the Internet

Transport Layer Protocols: UDP and TCP

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Outline

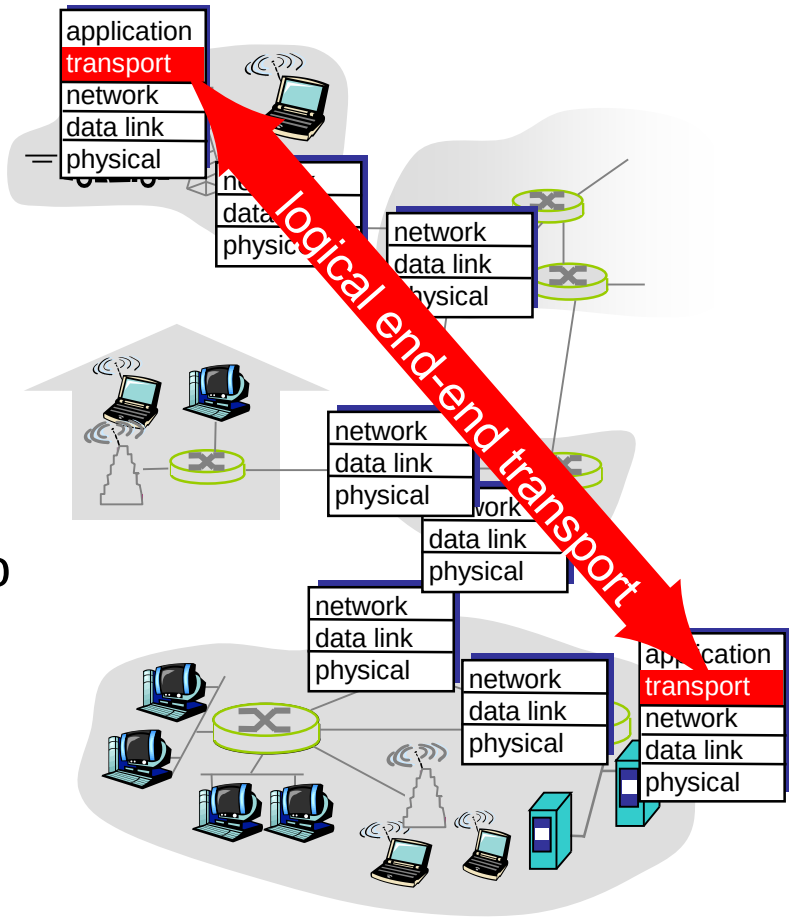
- Transport-layer services
- Multiplexing and demultiplexing
- Connectionless transport: UDP
- Connection-oriented transport: TCP

Popular Internet Applications and their underlying transport protocols

Application	Application-layer protocol	Underlying transport protocol
Email	SMTP	TCP
Web	HTTP	TCP
Routing protocol	BGP	TCP
Routing protocol	RIP	Typically UDP
Name translation	DNS	Typically UDP
Streaming multimedia	Typically proprietary	Typically UDP
Internet telephony	Typically proprietary	Typically UDP

Transport Protocols

- Provide *logical communication* between application processes running on different hosts
- Run on end hosts
  - Sender side: breaks application messages into segments, and passes to network layer
  - Receiver side: reassembles segments into messages, passes to application layer
- Multiple transport protocols available to applications
  - Internet: TCP and UDP
    - Other: RSVP (The Resource Reservation Protocol (RSVP))



Services provided by the Internet transport layer

- Extending host-to-host delivery to process-to-process delivery;
  - Transport-layer multiplexing and demultiplexing;
- Reliable data transfer;
- Flow control;
- Congestion control;

A host has many processes, communicating to many different processes at different remote hosts;
The Internet is a shared channel (with packet switching)!

Different destination hosts – network layer
Different processes -- transport layer
A shared channel – multiplexing and demultiplexing

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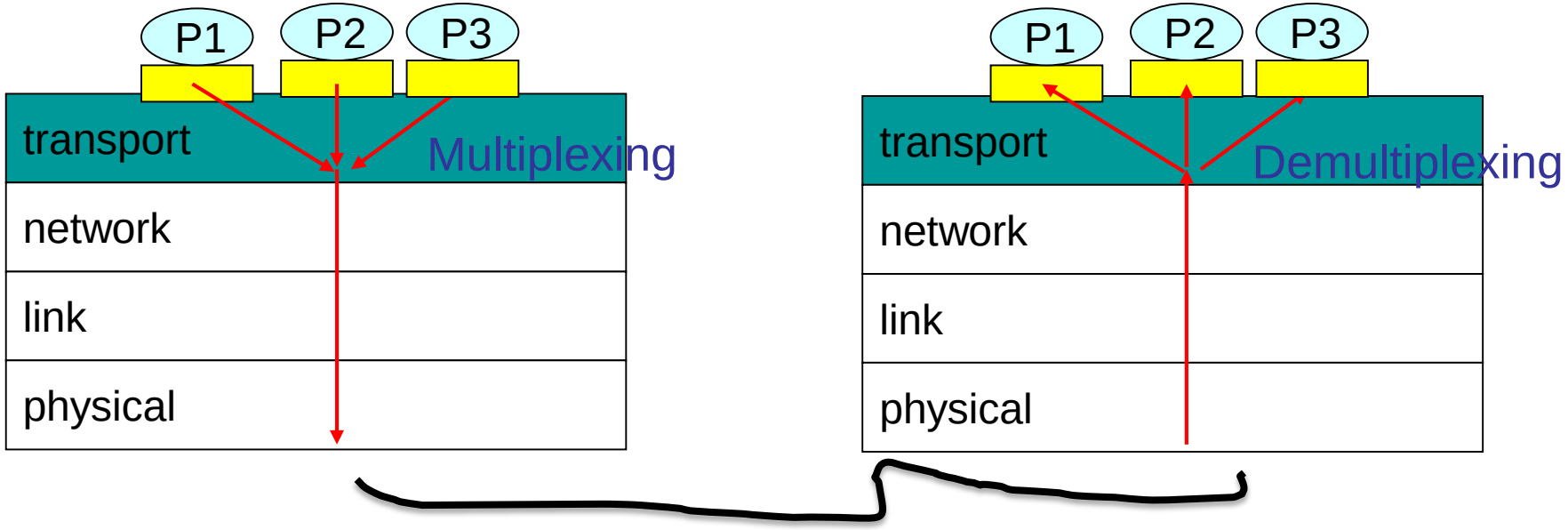
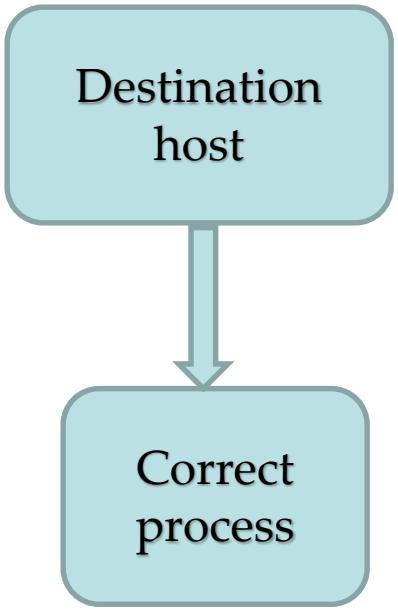
Multiplexing/demultiplexing – Definition

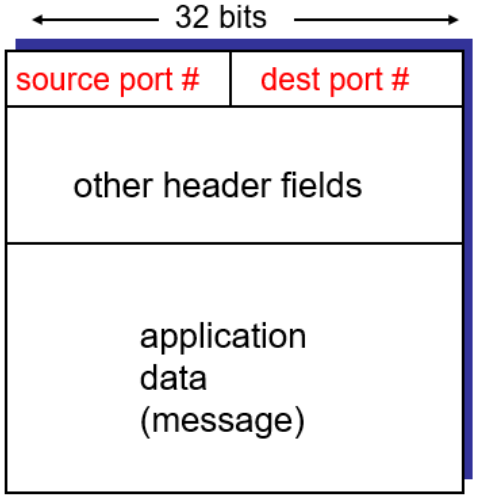
- Demultiplexing
  - To deliver the data in a transport-layer segment to the correct socket
- Multiplexing
  - To create segments and pass them to the network layer.



How demultiplexing works



- host receives IP datagrams
  - each datagram has source IP address, destination IP address
  - each datagram carries 1 transport-layer segment
- each segment has source, destination port number
- host uses IP addresses & port numbers to direct segment to appropriate socket



TCP/UDP segment format

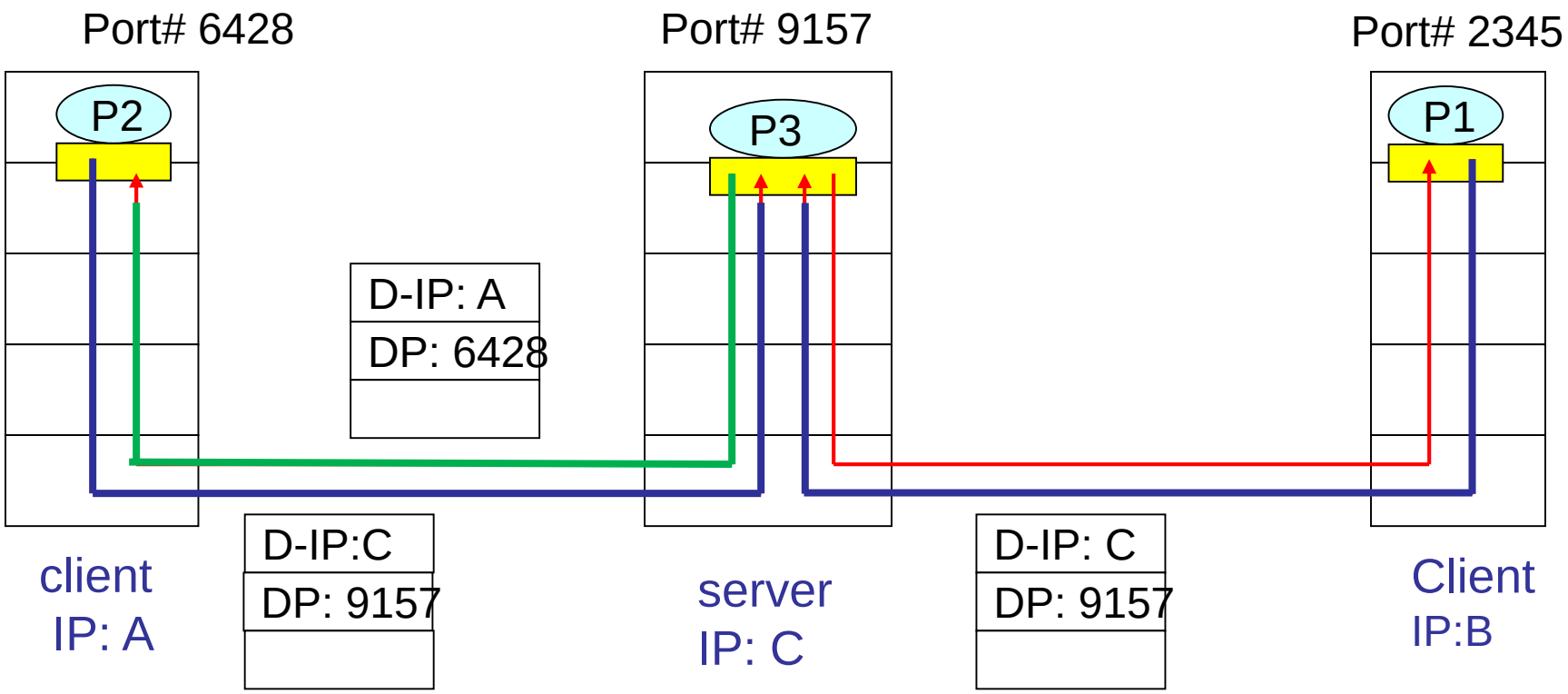
Connectionless demultiplexing

- UDP socket identified by two-tuple:

(dest IP address, dest port number)

- When host receives UDP segment:
  - checks destination port number in segment
  - directs UDP segment to socket with that port number
- Packets with different source IP addresses and/or source port numbers, but with the same destination IP and port number, will be directed to same socket.

Connectionless demux (cont)

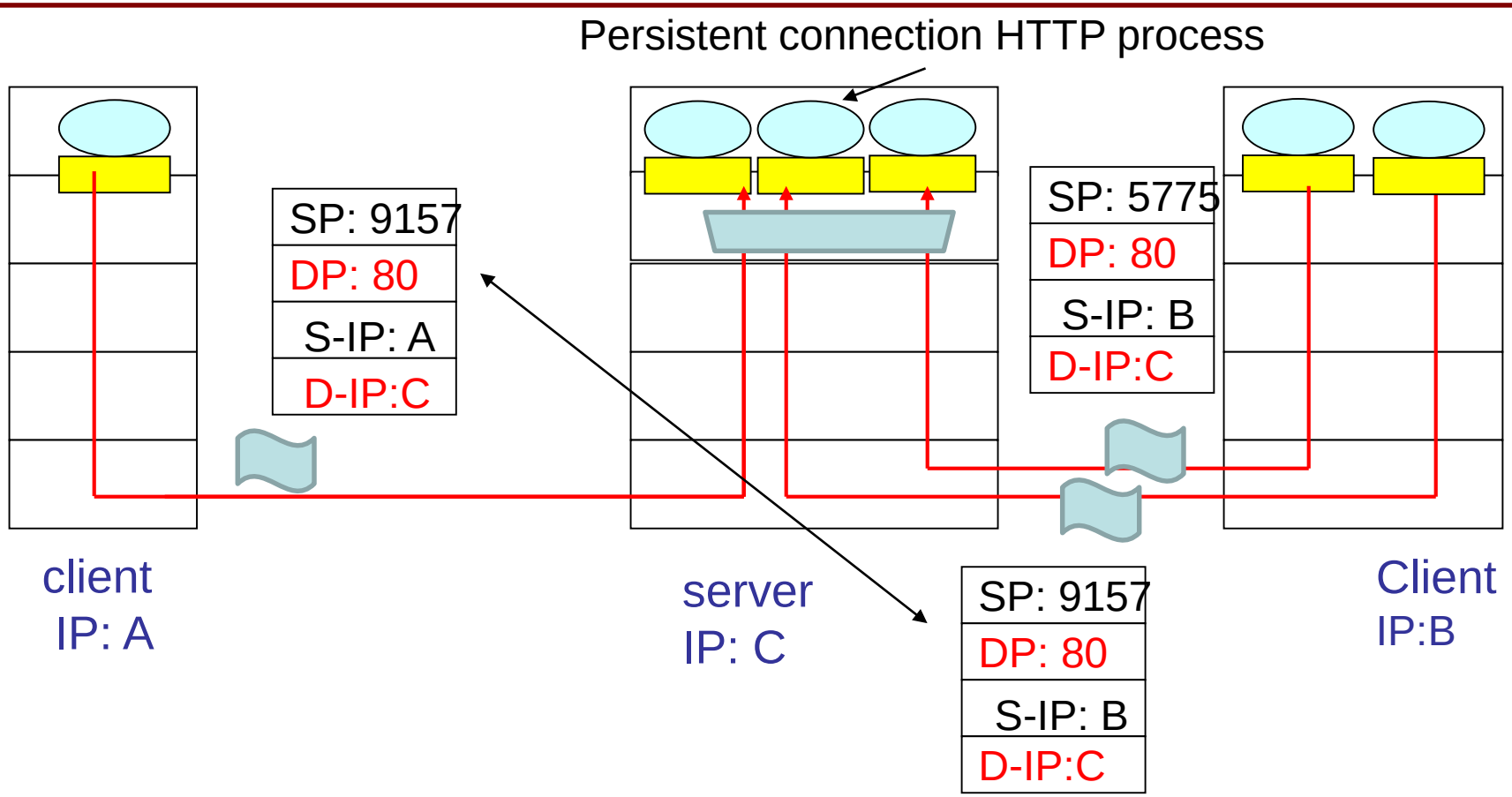


Source port provides “return address”

Connection-oriented demux

- TCP socket identified by 4-tuple:
  - source IP address
  - source port number
  - dest IP address
  - dest port number
- recv host uses *all four values* to direct segment to appropriate socket
- Server host may support many simultaneous TCP sockets:
  - each socket identified by its own 4-tuple
- Web servers have different sockets for each connecting client

Connection-oriented demux (cont)



The same Web server has different sockets for different processes at clients.

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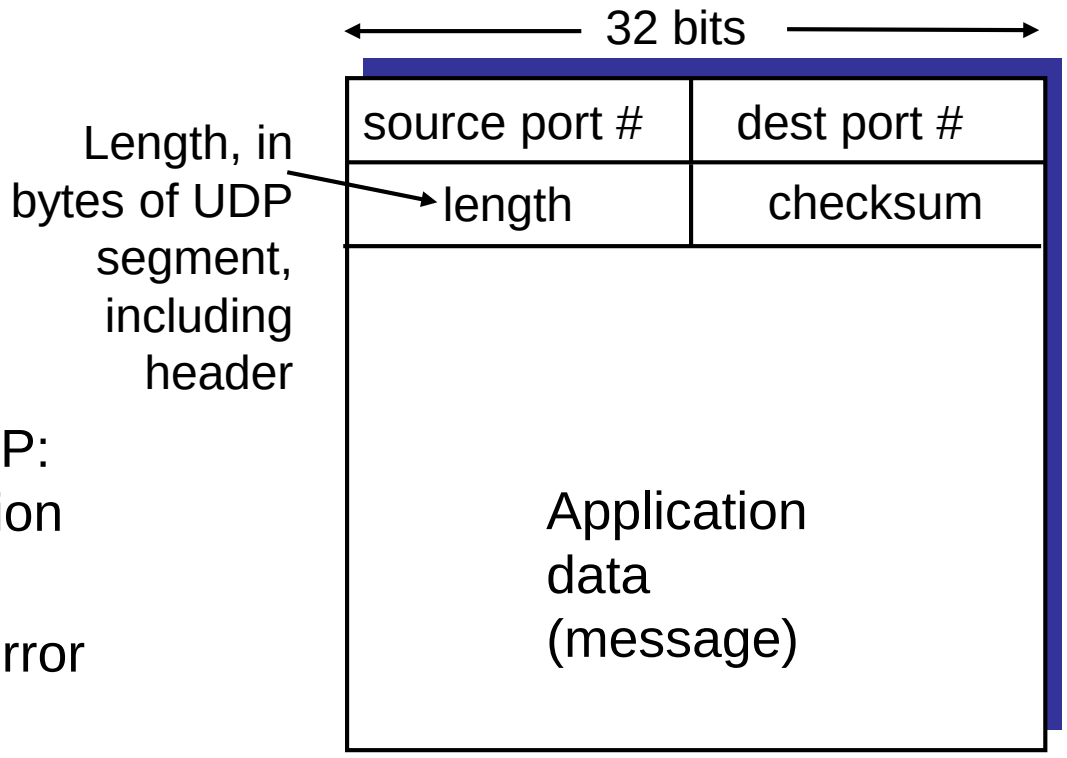
UDP: User Datagram Protocol [RFC 768]

- "no frills," "bare bones" Internet transport protocol
- "best effort" service, UDP segments may be:
  - lost
  - delivered out of order to app
- *connectionless:*
  - no handshaking between UDP sender, receiver
  - each UDP segment handled independently of others

UDP: more

- often used for streaming multimedia apps
  - loss tolerant
  - rate sensitive
- other UDP uses
  - RIP, DNS, SNMP
- reliable transfer over UDP: add reliability at application layer
  - application-specific error recovery!



UDP segment format

A UDP segment captured by Wireshark

12	0.508950	10.34.40.169	132.181.2.225	DNS
13	0.509041	132.181.2.225	10.34.40.169	DNS
14	0.509462	10.34.40.169	132.181.2.225	DNS
15	0.510280	132.181.2.225	10.34.40.169	DNS
16	0.510354	132.181.2.225	10.34.40.169	DNS
17	33.503303	10.34.40.169	132.181.2.225	DNS
18	33.504666	132.181.2.225	10.34.40.169	DNS
19	61.002465	10.34.40.169	132.181.2.225	DNS
20	61.004045	132.181.2.225	10.34.40.169	DNS
21	61.013117	10.34.40.169	132.181.2.225	DNS
22	61.014578	132.181.2.225	10.34.40.169	DNS

```
▷ Frame 12: 88 bytes on wire (704 bits), 88 bytes captured (704 bits) on interface 0
▷ Ethernet II, Src: IntelCor_b6:fe:63 (80:19:34:b6:fe:63), Dst: JuniperN_ef:61:00 (2c:21:31:ef:61:00)
▷ Internet Protocol Version 4, Src: 10.34.40.169, Dst: 132.181.2.225
◢ User Datagram Protocol, Src Port: 63507, Dst Port: 53
    Source Port: 63507
    Destination Port: 53
    Length: 54
    Checksum: 0xe576 [unverified]
    [Checksum Status: Unverified]
    [Stream index: 6]
▷ Domain Name System (query)
```

Why is there a UDP?

- no connection establishment (which can add delay)
- simple: no connection state at sender, receiver
- small segment header (8 bytes)
- no congestion control: UDP can blast away as fast as desired

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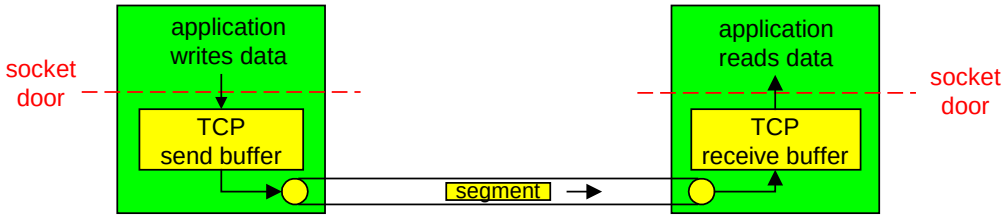
  - Overview and segment structure
  - Connection management

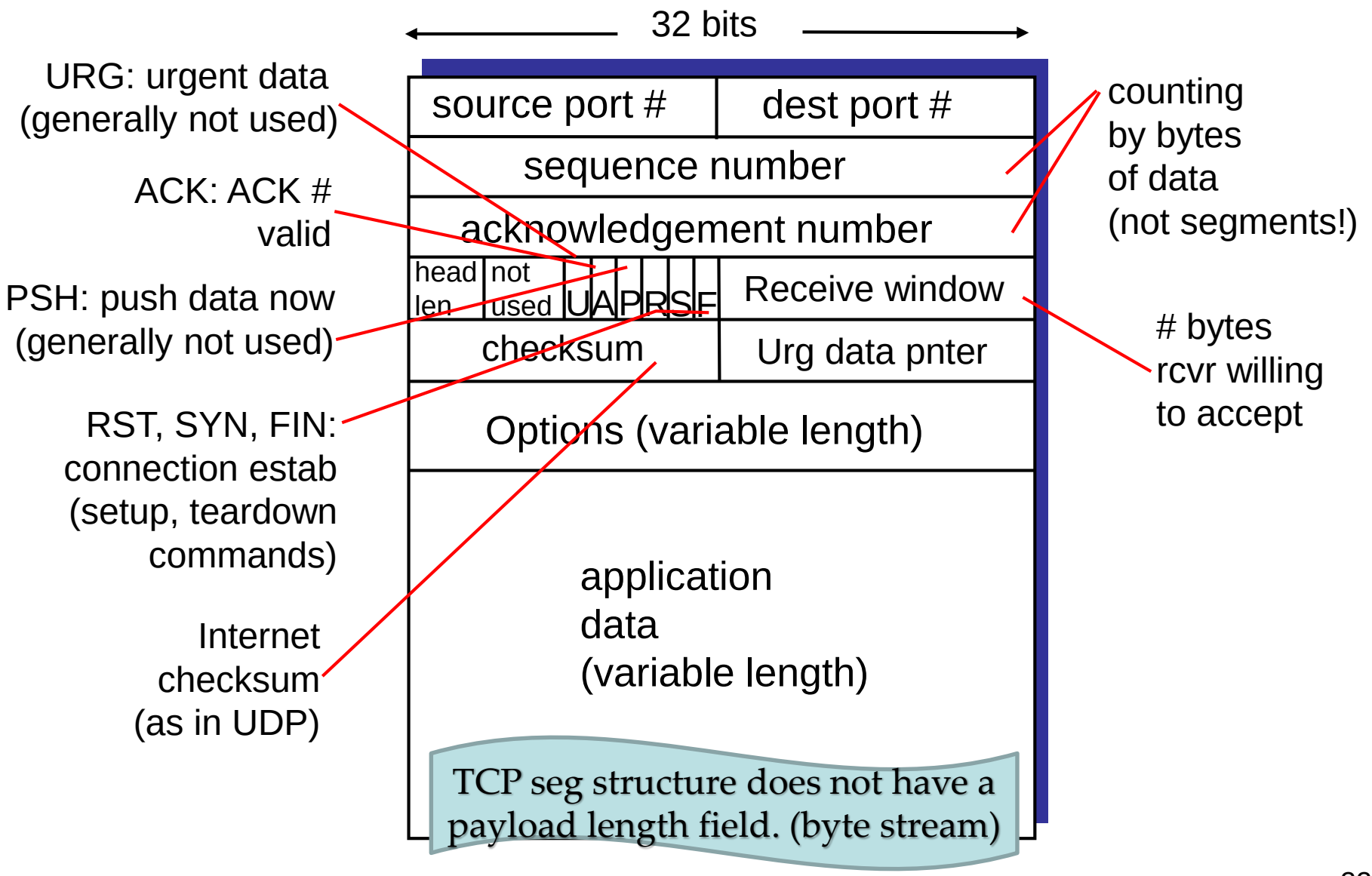
TCP: Overview RFCs: 793, 1122, 1323, 2018, 2581

- point-to-point:
  - one sender, one receiver
- reliable, in-order *byte steam:*
  - no (app. layer) “message boundaries”
- pipelined:
  - TCP congestion and flow control set window size



- full duplex data:
  - bi-directional data flow in same connection
  - MSS: maximum segment size
- connection-oriented:
  - handshaking (exchange of control msgs) init’s sender, receiver state before data exchange
- flow controlled:
  - sender will not overwhelm receiver

TCP segment structure



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	10.34.40.169	132.181.107.25	TCP	66	50769→25 [SYN] Seq=3883811340 Win=8192
2	0.001002	132.181.107.25	10.34.40.169	TCP	66	25→50769 [SYN, ACK] Seq=1828797403 Ack=
3	0.001049	10.34.40.169	132.181.107.25	TCP	54	50769→25 [ACK] Seq=3883811341 Ack=18287
4	0.002254	132.181.107.25	10.34.40.169	SMTP	161	S: 220 UCEXHUBCAS01-D.canterbury.ac.nz
5	0.199515	10.34.40.169	132.181.107.25	TCP	54	50769→25 [ACK] Seq=3883811341 Ack=18287
6	300.488449	132.181.107.25	10.34.40.169	SMTP	98	S: 451 4.7.0 Timeout waiting for client
7	300.488450	132.181.107.25	10.34.40.169	TCP	54	25→50769 [FIN, ACK] Seq=1828797555 Ack=
8	300.488515	10.34.40.169	132.181.107.25	TCP	54	50769→25 [ACK] Seq=3883811341 Ack=18287
9	300.489262	10.34.40.169	132.181.107.25	TCP	54	50769→25 [FIN, ACK] Seq=3883811341 Ack=
10	300.490656	132.181.107.25	10.34.40.169	TCP	54	25→50769 [ACK] Seq=1828797556 Ack=38838

```
▷ Frame 2: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface 0
▷ Ethernet II, Src: JuniperN_ef:61:00 (2c:21:31:ef:61:00), Dst: IntelCor_b6:fe:63 (80:19:34:b6:fe:63)
▷ Internet Protocol Version 4, Src: 132.181.107.25, Dst: 10.34.40.169
◢ Transmission Control Protocol, Src Port: 25, Dst Port: 50769, Seq: 1828797403, Ack: 3883811341, Len: 0
    Source Port: 25
    Destination Port: 50769
    [Stream index: 0]
    [TCP Segment Len: 0]
    Sequence number: 1828797403
    Acknowledgment number: 3883811341
    Header Length: 32 bytes
  ▷ Flags: 0x012 (SYN, ACK)
    Window size value: 8192
    [Calculated window size: 8192]
    Checksum: 0x9393 [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
  ◢ Options: (12 bytes), Maximum segment size, No-Operation (NOP), Window scale, No-Operation (NOP), No-Operation (NOP), SACK permitted
    ▷ Maximum segment size: 1460 bytes
    ▷ No-Operation (NOP)
    ▷ Window scale: 8 (multiply by 256)
    ▷ No-Operation (NOP)
    ▷ No-Operation (NOP)
    ▷ TCP SACK Permitted Option: True
```

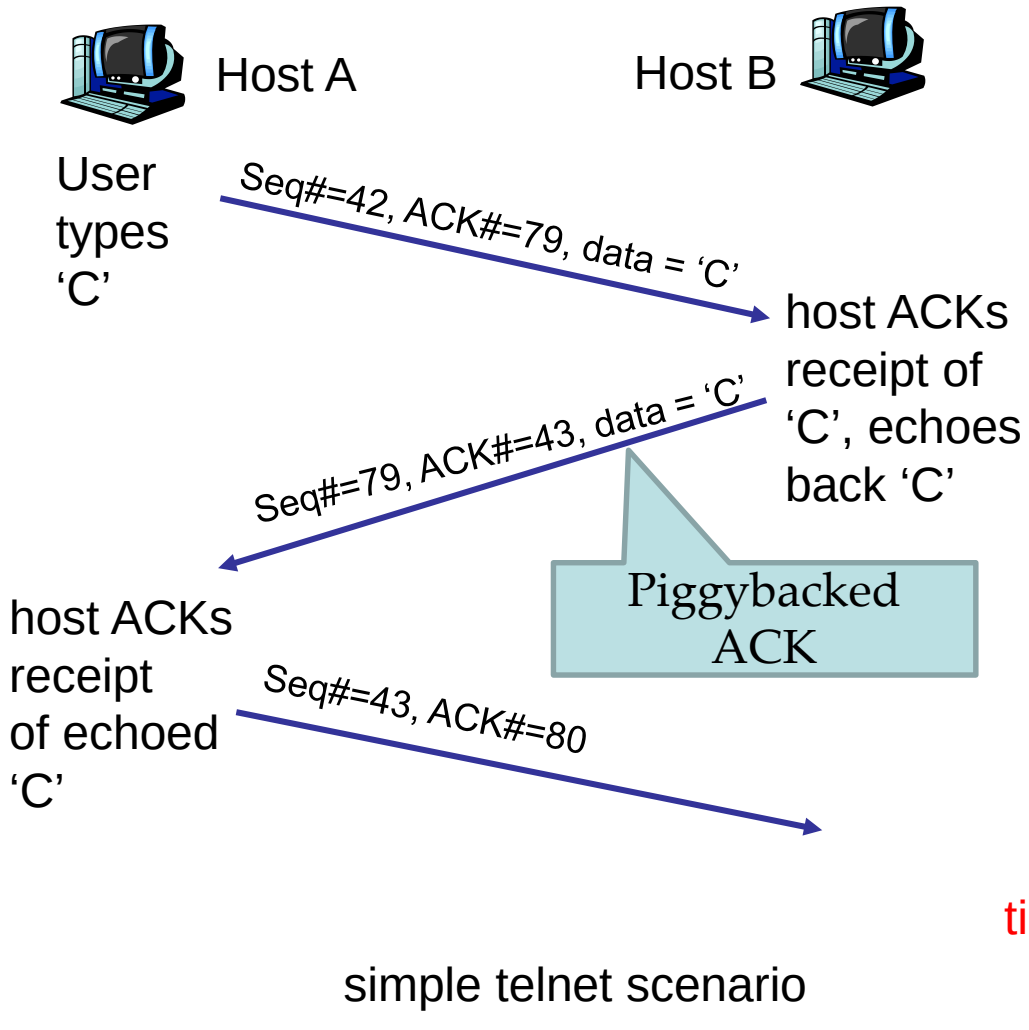
TCP seq. #'s and ACKs

Seq. #'s:

- byte stream "number" of first byte in segment's data

ACKs:

- seq # of next byte expected from other side
- cumulative ACK



simple telnet scenario

TCP Connection Management

Three way handshake:

Step 1: client host sends TCP SYN segment (*SYN bit is set to 1*) to server

- specifies initial seq # (*randomly chosen*), client_isn;
- no data

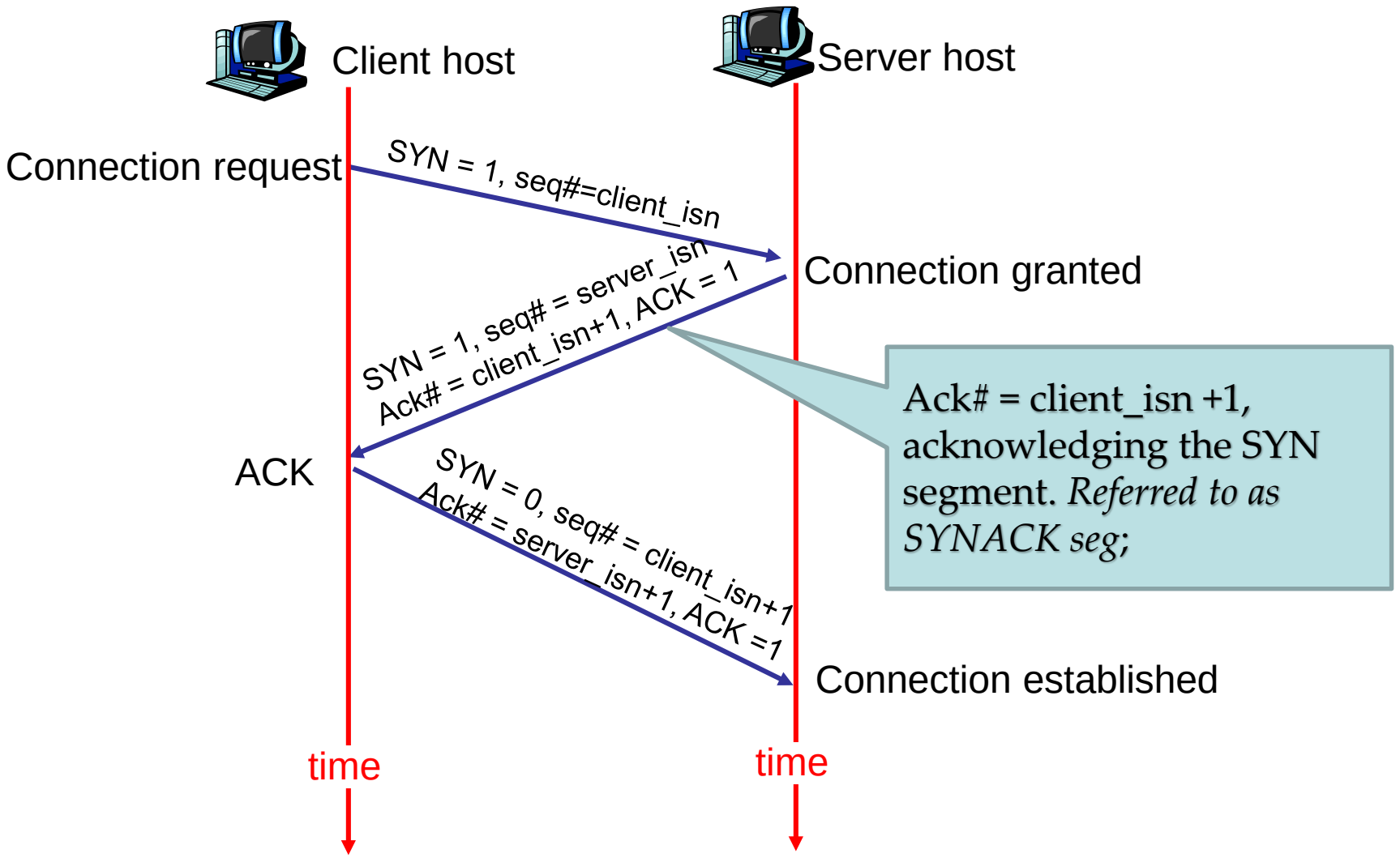
Step 2: server host receives SYN, replies with SYNACK segment

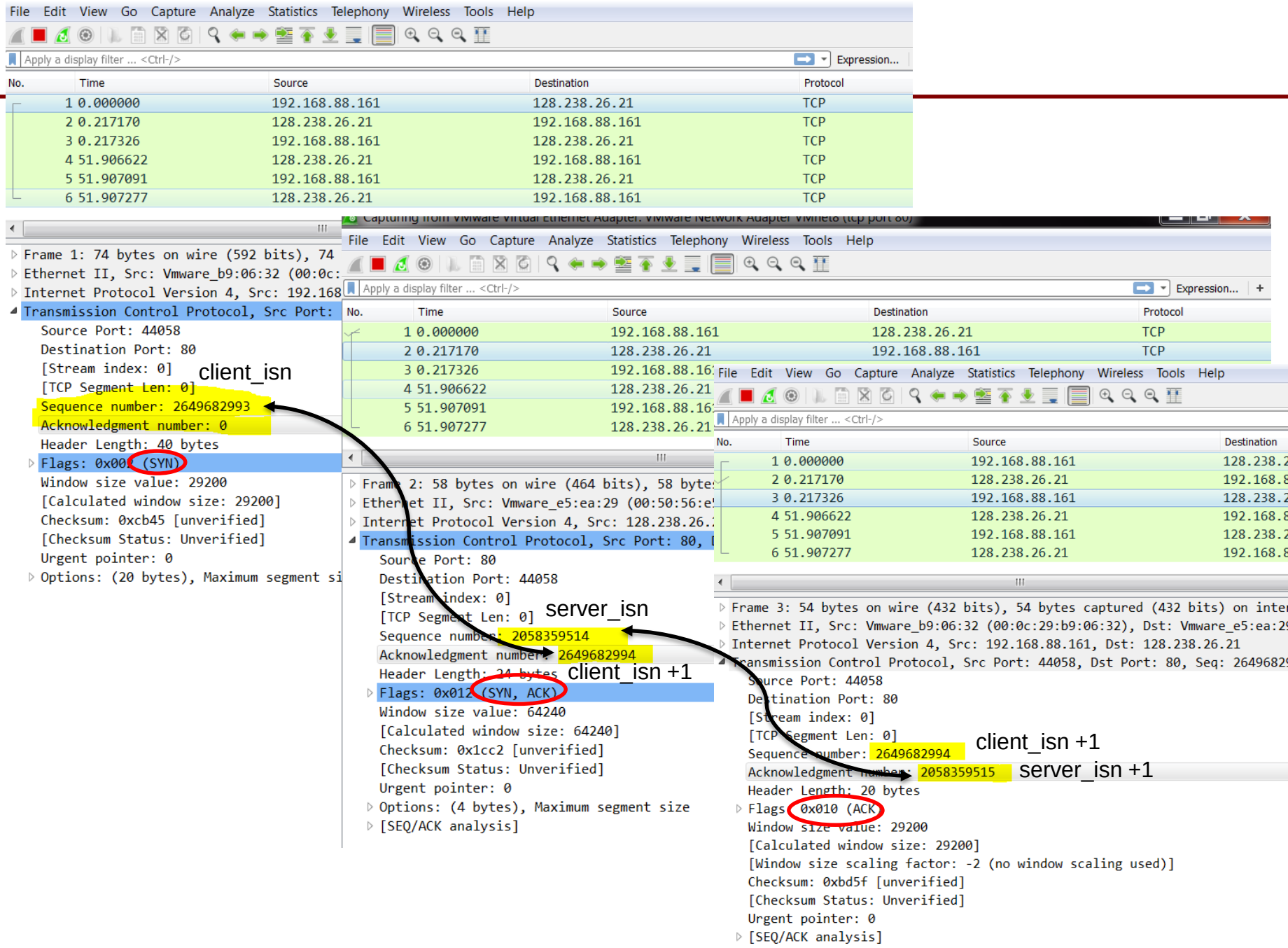
- server allocates buffers
- specifies server initial seq. #, server_isn;
- SYN = 1; ACK# = client_isn +1; ACK = 1; seq# = server_isn;

Step 3: client receives SYNACK, replies with ACK segment, which may contain data;

SYN = 0; ACK = 1; ACK# = server_isn + 1; seq# = client_isn + 1;

TCP 3-way handshaking




File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
Expression...
No. Time Source Destination Protocol
1 0.000000 192.168.88.161 128.238.26.21 TCP
2 0.217170 128.238.26.21 192.168.88.161 TCP
3 0.217326 192.168.88.161 128.238.26.21 TCP
4 51.906622 128.238.26.21 192.168.88.161 TCP
5 51.907091 192.168.88.161 128.238.26.21 TCP
6 51.907277 128.238.26.21 192.168.88.161 TCP
Frame 1: 74 bytes on wire (592 bits), 74
Ethernet II, Src: Vmware_b9:06:32 (00:0c:
Internet Protocol Version 4, Src: 192.168
Transmission Control Protocol, Src Port:
Source Port: 44058
Destination Port: 80
[Stream index: 0]
[TCP Segment Len: 0]
Sequence number: 2649682993
Acknowledgment number: 0
Header Length: 40 bytes
Flags: 0x002 (SYN)
Window size value: 29200
[Calculated window size: 29200]
Checksum: 0xcb45 [unverified]
[Checksum Status: Unverified]
Urgent pointer: 0
Options: (20 bytes), Maximum segment si
client_isn
Frame 2: 58 bytes on wire (464 bits), 58 bytes
Ethernet II, Src: Vmware_e5:ea:29 (00:50:56:e
Internet Protocol Version 4, Src: 128.238.26.
Transmission Control Protocol, Src Port: 80,
Source Port: 80
Destination Port: 44058
[Stream index: 0]
[TCP Segment Len: 0]
Sequence number: 2058359514
Acknowledgment number: 2649682994
Header Length: 24 bytes
Flags: 0x012 (SYN, ACK)
Window size value: 64240
[Calculated window size: 64240]
Checksum: 0x1cc2 [unverified]
[Checksum Status: Unverified]
Urgent pointer: 0
Options: (4 bytes), Maximum segment size
[SEQ/ACK analysis]
server_isn
client_isn +1
Frame 3: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interfac
Ethernet II, Src: Vmware_b9:06:32 (00:0c:29:b9:06:32), Dst: Vmware_e5:ea:29 (0
Internet Protocol Version 4, Src: 192.168.88.161, Dst: 128.238.26.21
Transmission Control Protocol, Src Port: 44058, Dst Port: 80, Seq: 2649682994,
Source Port: 44058
Destination Port: 80
[Stream index: 0]
[TCP Segment Len: 0]
Sequence number: 2649682994
Acknowledgment number: 2058359515
Header Length: 20 bytes
Flags: 0x010 (ACK)
Window size value: 29200
[Calculated window size: 29200]
[Window size scaling factor: -2 (no window scaling used)]
Checksum: 0xbd5f [unverified]
[Checksum Status: Unverified]
Urgent pointer: 0
[SEQ/ACK analysis]
client_isn +1
server_isn +1

TCP Connection Management (closing)

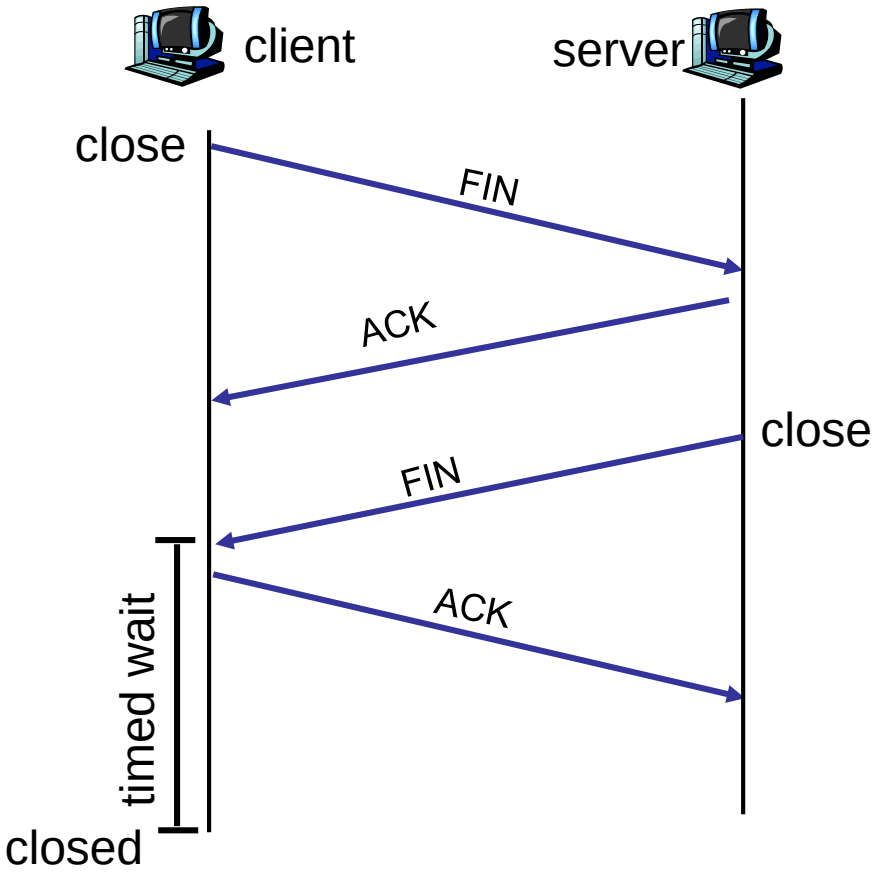
All good things must come to an end:

Step 1: client end system sends TCP FIN control segment to server

Step 2: server receives FIN, replies with ACK. Closes connection, sends FIN.

Step 3: client receives FIN, replies with ACK.

Step 4: server, receives ACK. Connection closed.



```
37 160.494102   10.34.40.169     132.181.107.25   TCP   54 57483→25 [FIN, ACK] Seq=3400705033 Ack=1545042735 Win=6…
38 160.495931   132.181.107.25   10.34.40.169     TCP   54 25→57483 [ACK] Seq=1545042735 Ack=3400705034 Win=131328…
39 160.496329   132.181.107.25   10.34.40.169     TCP   54 25→57483 [FIN, ACK] Seq=1545042735 Ack=3400705034 Win=1…
40 160.496413   10.34.40.169     132.181.107.25   TCP   54 57483→25 [ACK] Seq=3400705034 Ack=1545042736 Win=65536 …
```

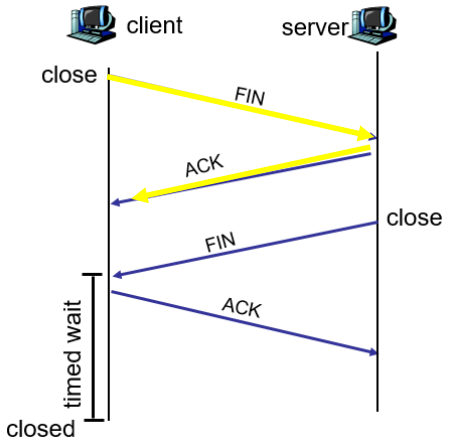
```
Internet Protocol Version 4, Src: 10.34.40.169, Dst: 132.181.107.25
Transmission Control Protocol, Src Port: 57483, Dst Port: 25, Seq: 3400705033, Ack: 1545042735, Len: 0
    Source Port: 57483
    Destination Port: 25
    [Stream index: 1]
    [TCP Segment Len: 0]
    Sequence number: 3400705033
    Acknowledgment number: 1545042735
    Header Length: 20 bytes
  ▲ Flags: 0x011 (FIN, ACK)
      000. .... .... = Reserved: Not set
      ...0 .... .... = Nonce: Not set
      .... 0... .... = Congestion Window Reduced
      .... .0.. .... = ECN-Echo: Not set
      .... ..0. .... = Urgent: Not set
      .... ...1 .... = Acknowledgment: Set
      .... .... 0... = Push: Not set
      .... .... .0.. = Reset: Not set
      .... .... ..0. = Syn: Not set
    ▷ .... .... ...1 = Fin: Set
      [TCP Flags: ·····A···F]
    Window size value: 256
    [Calculated window size: 65536]
    [Window size scaling factor: 256]
    Checksum: 0x6592 [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
```

```
    37 160.494102   10.34.40.169     132.181.107.25   TCP
    38 160.495931   132.181.107.25   10.34.40.169     TCP
    39 160.496329   132.181.107.25   10.34.40.169     TCP
    40 160.496413   10.34.40.169     132.181.107.25   TCP
```

```
▷ Frame 38: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interface 0
▷ Ethernet II, Src: JuniperN_ef:61:00 (2c:21:31:ef:61:00), Dst: IntelCor_b6:fe:63 (80:19:34:b6:fe:63)
▷ Internet Protocol Version 4, Src: 132.181.107.25, Dst: 10.34.40.169
▲ Transmission Control Protocol, Src Port: 25, Dst Port: 57483, Seq: 1545042735, Ack: 3400705034, Len: 0
    Source Port: 25
    Destination Port: 57483
    [Stream index: 1]
    [TCP Segment Len: 0]
    Sequence number: 1545042735
    Acknowledgment number: 3400705034
    Header Length: 20 bytes
  ▲ Flags: 0x010 (ACK)
      000. .... .... = Reserved: Not set
      ...0 .... .... = Nonce: Not set
      .... 0... .... = Congestion Window Reduced (CWR): Not set
      .... .0.. .... = ECN-Echo: Not set
      .... ..0. .... = Urgent: Not set
      .... ...1 .... = Acknowledgment: Set
      .... .... 0... = Push: Not set
      .... .... .0.. = Reset: Not set
      .... .... ..0. = Syn: Not set
      .... .... ...0 = Fin: Not set
      [TCP Flags: ·····A····]
    Window size value: 513
    [Calculated window size: 131328]
    [Window size scaling factor: 256]
    Checksum: 0x6491 [unverified]
```

FIN

ACK



37	160.494102	10.34.40.169	132.181.107.25	TCP
38	160.495931	132.181.107.25	10.34.40.169	TCP
39	160.496329	132.181.107.25	10.34.40.169	TCP
40	160.496413	10.34.40.169	132.181.107.25	TCP

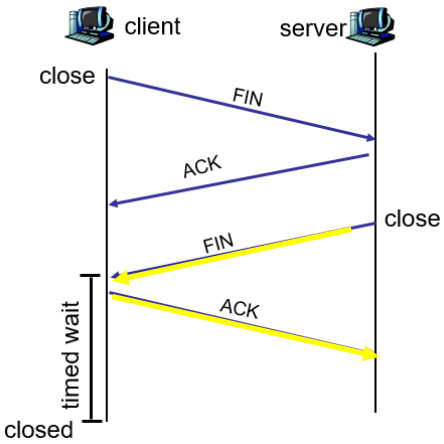
```
Frame 39: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interface 0
Ethernet II, Src: JuniperN_ef:61:00 (2c:21:31:ef:61:00), Dst: IntelCor_b6:fe:63 (80:19:34:b6:fe:63)
Internet Protocol Version 4, Src: 132.181.107.25, Dst: 10.34.40.169
Transmission Control Protocol, Src Port: 25, Dst Port: 57483, Seq: 1545042735, Ack: 3400705034, Len: 0
    Source Port: 25
    Destination Port: 57483
    [Stream index: 1]
    [TCP Segment Len: 0]
    Sequence number: 1545042735
    Acknowledgment number: 3400705034
    Header Length: 20 bytes
    Flags: 0x011 (FIN, ACK)
        000. .... .... = Reserved: Not set
        ...0 .... .... = Nonce: Not set
        .... 0... .... = Congestion Window Reduced (CWR): Not set
        .... .0.. .... = ECN-Echo: Not set
        .... ..0. .... = Urgent: Not set
        .... ...1 .... = Acknowledgment: Set
        .... .... 0... = Push: Not set
        .... .... .0.. = Reset: Not set
        .... .... ..0. = Syn: Not set
        .... .... ...1 = Fin: Set
        [TCP Flags: ·····A···F]
    Window size value: 513
    [Calculated window size: 131328]
    [Window size scaling factor: 256]
    Checksum: 0x6490 [unverified]
```

FIN

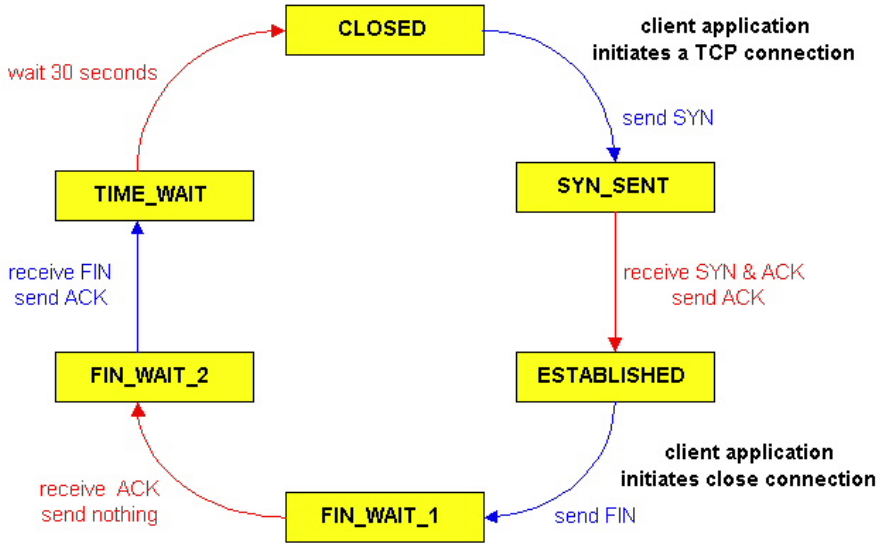
37	160.494102	10.34.40.169	132.181.107.25	TCP
38	160.495931	132.181.107.25	10.34.40.169	TCP
39	160.496329	132.181.107.25	10.34.40.169	TCP
40	160.496413	10.34.40.169	132.181.107.25	TCP

```
Frame 40: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interface 0
Ethernet II, Src: IntelCor_b6:fe:63 (80:19:34:b6:fe:63), Dst: JuniperN_ef:61:00 (2c:21:31:ef:61:00)
Internet Protocol Version 4, Src: 10.34.40.169, Dst: 132.181.107.25
Transmission Control Protocol, Src Port: 57483, Dst Port: 25, Seq: 3400705034, Ack: 1545042736, Len: 0
    Source Port: 57483
    Destination Port: 25
    [Stream index: 1]
    [TCP Segment Len: 0]
    Sequence number: 3400705034
    Acknowledgment number: 1545042736
    Header Length: 20 bytes
    Flags: 0x010 (ACK)
        000. .... .... = Reserved: Not set
        ...0 .... .... = Nonce: Not set
        .... 0... .... = Congestion Window Reduced (CWR): Not set
        .... .0.. .... = ECN-Echo: Not set
        .... ..0. .... = Urgent: Not set
        .... ...1 .... = Acknowledgment: Set
        .... .... 0... = Push: Not set
        .... .... .0.. = Reset: Not set
        .... .... ..0. = Syn: Not set
        .... .... ...0 = Fin: Not set
        [TCP Flags: ·····A····]
    Window size value: 256
    [Calculated window size: 65536]
    [Window size scaling factor: 256]
    Checksum: 0x6591 [unverified]
```

ACK



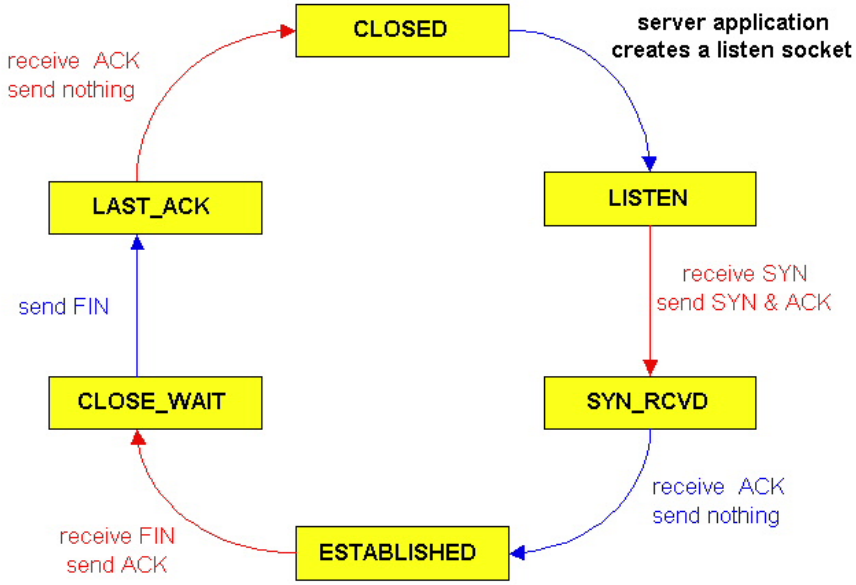
TCP Connection Management (cont)



TCP client lifecycle

This is the normal closing procedure; there are other cases.

TCP server lifecycle



Outline

- Transport-layer services
- Multiplexing and demultiplexing
- Connectionless transport: UDP
- Connection-oriented transport: TCP

References

- [KR3] James F. Kurose, Keith W. Ross, *Computer networking: a top-down approach featuring the Internet*, 3rd edition.
- [PD5] Larry L. Peterson, Bruce S. Davie, *Computer networks: a systems approach*, 5th edition
- [TW5] Andrew S. Tanenbaum, David J. Wetherall, *Computer network*, 5th edition
- [LHBi]Y-D. Lin, R-H. Hwang, F. Baker, *Computer network: an open source approach*, International edition

Acknowledgements

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  - Dr DongSeong Kim's slides for COSC264, University of Canterbury;
  - Prof Aleksandar Kuzmanovic's lecture notes for CS340,Northwestern University, https://users.cs.northwestern.edu/~akuzma/classes/CS340-w05/lecture_notes.htm